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Special Issue on Research Findings in Software Technology and Applications

Guest Editorial

In present era, information has become an important factor in productivity and strategic resources for social development. Information technology is the world's most advanced productive forces. Because of information technology development over the past 50 years, the transformation of society is enormous. Information technology will continue to change human society in the 21st century. As with previous industrial revolution, information revolution stems from major innovation in science and technology, promotes the tremendous progress to productive forces, and promotes the new stage of civilization. The information technology progresses swiftly and violently, and is leading the entire economic system rapid renewal, all-round upsurge. Information technology and its applications are developing rapidly, and has become main essential engines for the world's scientific and technological progress and human society advance. IT (Information Technology) is the general term for various technologies used to manage and process information. It mainly applied the computer science and communications technology to design, development, installation and implementation of information systems and application software. It is also often referred to as Information and Communications Technology (ICT). Its rapid development is supported by two big supporting-heaven pillars that are the computer science technology and the communication engineering technology.

In order to expand and promote information technology and its application, academic exchange and mutual cooperation among researchers, developers, applications, administrators, educators and learners in the field of worldwide. The International Association of Information Technology and Applications (IITAA) have been successfully held the 2009 International Forum on Information Technology and Applications (IFITA 2009), and the 2009 International Forum on Computer Science-Technology and Applications (IFITA 2009). Many scholars participated actively in the academic exchange activities, and presented their research results. Some researches and findings in Software Technology and Applications are selected here:

- **”Research on RFID Integration Middleware for Enterprise Information System”** Considering the requirements of RFID middleware and business process integration with enterprise information systems, an integration framework for RFID middleware based on business process rule and data stream technologies are introduced.

- **”Test Sequence Generation for Distributed Software System”** considers the test case generation for distributed software (a test case contains one or more test sequences).

In **”Research on Algorithm and Model for Indefinite Multi-objective Decision Making”**, Firstly construct a range pole plan and introduce the policy-maker risk-preference weight. Then with three tuples (Limit low similarity, Risk degree, Risk-preference value) reflect the risk-degree existing in the decision-making process. At last, construct the risk-weighted similarity measure operator (RWSMO) to measure the risk balance similarity's size between each of decision schemes and the range pole plan.

- **”Study on Pricing Model of Online Auction under Competitive Strategy”** Firstly gives the overview of the online auction pricing mechanism and introduces the e-commerce auction market and its characteristics on the one hand. On the other hand, it discusses the factors affecting the price of online auctions from three aspects, the information flow, the business objectives and the risk factors.

- **”Constrained Optimal Controller Design of Aerial Robotics Based on Invariant Sets”** An explicit optimal controller for hybrid systems based on multi-parametric quadratic programming (mp-QP) is proposed.

- **”The Application of Fuzzy Neural Network in Fault Self-diagnosis System of Automatic Transmission”** According to the design procedure of fault self-diagnosis system and features of automatic transmission system, the list of relation and mapping between fault symptoms and fault causes are made in this paper. Applying the approach of fault self-diagnosis based on fuzzy neural network, fault diagnosis of the automatic transmission electronic control system is realized. The structure of fuzzy neural network and its corresponding learning method and pretreating strategy about the training samples are introduced in this paper.

- **”Fuzzy Random Dependent-Chance Programming Models of Loan Portfolio”** Proposes two fuzzy random dependent-chance programming models of loan portfolio, one is minimize the mean chance of a bad outcome under the certain expected return rate, one is maximize the mean chance of the prospective return rate under the certain expected return rate. Hybrid intelligent algorithms are employed to solve the models.

- **”Research on Target Detection and Automatic Extraction of Region of Interest in Infrared Serial Images”** A new stepwise approaching and recurring threshold search algorithm based on two-dimensional maximum entropy principle was proposed by studying recurring formulation optimized of two-dimensional maximum entropy in order to realize to detect target and extract ROI of serial images under complex background. The algorithm above realizes automatic extraction of ROI in Infrared serial images.

- **”Approximation Algorithm and Scheme for RNA Maximum Weighted Stacking”** the general problem of pseudoknotted RNA structure prediction, maximum weighted stacking problem is presented based on stacking actions, and its polynomial time approximation algorithm with $O(n \log n)$ time and $O(n)$ space and polynomial time approximation scheme are given.
“Research on Spatial Data Line Generalization Algorithm in Map Generalization” introduced the curve fit algorithm about line generalization in map generalization, then analysed it in detail.

“Personality's Influence on the Relationship between Online Word-of-mouth and Consumers’ Trust in Shopping Website”, did a survey on 162 college students, with an aim to find out the role of consumers’ personality in their trust in the website as far as the online word-of-mouth is concerned. All the data collected are analyzed by SPSS 15.0 and LISREL. It shows that there is a significant difference between the introverted consumers and the extroverted consumers viewing their attitude towards online word-of-mouth.

It is our hope that the readers of this Special Issue could find and would enjoy something, such as the academic ideas, methods and enlightening from the papers in this Special Issue.

Guest Editors:

Zhou Qihai
President, “International Information Technology and Applications Association, IITAA”, Hong Kong
Full Professor (Grade 2, in China), Southwestern University of Finance and Economics, China
General Chair, “International Forum on Information Technology and Applications, IFITA”
General Chair, “International Forum on Computer Science-Technology and Applications, IFCSTA”
General Chair, “International Forum on Communication Technology and Applications, IFCTA”

LI Yan
Information Technology Application Research Institute, Southwestern University Of Finance and Economics, Chengdu, Sichuan, China

Zhou Qihai (1947-) is a Full Professor (from 1995), Doctor’s (and Master’s) tutor and a head of Information Technology Application Research Institute, School of Economic Information Engineering, Southwestern University of Finance and Economics (SWUFE), China. He graduated in 1982 from Lanzhou University, China; has been working in SWUFE since 1982, successively hold posts from teaching assistant (1982-1987), lecturer (1987-1991), vice professor (1991-1995, promoted anomaly in 1991), professor (1995-today, promoted anomaly in 1995); and got the titles of both “Outstanding experts (enjoyed government subsidies) with outstanding contributions of Sichuan province, China” (summa cum laude of Sichuan province government, 1996) and “One hundred academic and managerial leading heads of China informationalization” (summa cum laude about this domain in China, 2006). He has published 46 academic books and over 212 academic papers; and is President of IITAA (International Information Technology & Applications Association), Chair or Organizing Chair of some important international conferences. His research interests are in algorithm research, computational geometry, isomorphic information processing, economics & management computation, eBusiness, and so on. More about Prof. Zhou Qihai is shown here: http://www.iitaa.com/member-ZhouQihai.doc

LI Yan (1983- ) Ph.D. student, is studying in School of Economic Information Engineering, Southwestern University of Finance and Economics, Chengdu, Sichuan, China. He has published 15 papers. His research areas are in Non-definite decision-making, intelligence information processing.
Research on RFID Integration Middleware for Enterprise Information System

Li Minbo  
Software school, Fudan University, Shanghai, 201203, China  
Email: limb@fudan.edu.cn

Li Hua  
Software school, Fudan University, Shanghai, 201203, China  
Email: 082053018@fudan.edu.cn

Abstract: Radio Frequency Identification (RFID) is a promising technology for automated non-line-of-sight object identification. Traditional research of RFID middleware does not concern RFID related integration with enterprise information systems. Considering the requirements of RFID middleware and business process integration with enterprise information systems, an integration framework for RFID middleware based on business process rule and data stream technologies are introduced. Main modules of the RFID integration middleware, such as devices monitoring, data management, XML business documents exchange, business process control and RFID event management, are designed and discussed in detail. The semantic definition of the complex RFID event and RFID event classification are presented. A real-time scheduling strategy of RFID event which is based on the buffer and priority queue, can process the concurrent RFID events. Application system based on RFID is realized to control the business process through RFID events.

Keywords: RFID; RFID Integration Middleware; Data Stream; Business Process Rule

I. INTRODUCTION

Enterprise applications such as Supply Chain Management (SCM) Systems, Enterprise Resource Plan (ERP) Systems, and Manufacturing Execution Systems (MES) help enterprises to achieve efficiency, reduce costs and increase productivity in their operations. Automatic Identification and Data Capture (AIDC) is a methodology of assigning an identity to a business object and automatically capturing the identity of the business object as it moves within and across an enterprise. Some enterprise applications can generate and aggregate information about raw materials, products, equipment through their identity by supporting AIDC to improve efficiency [1].

Radio Frequency Identification (RFID) is a non-contact technology of AIDC, which identifies objects attached with tags. RFID has been widely applied to various areas such as railway transport monitoring, highway fees and charges, tracking of agriculture product, food, medicine [2] animal identification, anti-counterfeiting, logistics transportation, etc. Nowadays, low-cost RFID has attracted more and more interests from industry and academic institutes [3]. In supply chain management, RFID tags are used throughout the supply chain to track products, from supplier, deliver, to warehouse stock and retail. Compared with bar-code, which is another popular technology of AIDC, RFID has several advantages, including non-line-of sight reading, the ability of handling serial number, automatic real-time reading, more sensor networks or monitoring systems that flavor to it and so on [4].

ERP system may not be designed to handle the serial-number information from RFID data. It may cost a lot for enterprise applications with multiple identification technologies used but no explicit RFID interface to be rebuilt for RFID Integration. Such limitations of enterprise applications make it a challenging task to integrate RFID to enterprise applications. A graceful way to address this challenge is to introduce a layer between RFID readers and enterprise applications, which has come to be known as RFID middleware.

RFID middleware should meet requirements such as dissemination, filtering and aggregation of RFID data, reading from and writing to a tag, privacy [5]. Besides, some RFID middleware may be able to manage RFID events and to response to data subscriptions from external applications. In traditional RFID applications, there is little need for an RFID middleware because the RFID readers are not connected in a network and the RFID data is only used by a single application. However, it is not the same when RFID should be integrated with enterprise applications, such as supply chain management system. Under that situation, many readers which are distributed across enterprise and warehouse capture RFID data that will be disseminated to a variety of applications [6], and an RFID middleware is needed to manage RFID readers and data from these readers. At present, IBM, Microsoft, Oracle, Sun, SAP, BEA, Sybase and other companies had released their respective RFID middleware which are more platform-dependent and less scalability. Most of these RFID middleware solutions focused on RFID data
filtering and ignored the integration between RFID application system and real-time enterprise business handling.

This paper puts forward a RFID Integration middleware (called Rdspor) for enterprise information systems. Rdspor is driven by XML documents from enterprise information systems, uses a rule engine to control data process, and emphasizes on how to integrate RFID with enterprise information systems. Meanwhile, a data stream engine is used by Rdspor to filter and aggregate RFID data. The paper is organized as follows: the related work is described in section II. An overview of Rdspor is presented in section III. Section IV explains the details of the design and implementation. In the last section, we present our conclusions.

II. RELATED WORK

RFID middleware plays a key role to the application of RFID technology. So far, there are many achievements in the aspects of technology research and product development of RFID middleware. For products, as mentioned above, IBM, Oracle, Sun, BEA and other software companies have introduced RFID middleware or RFID solutions. These products or solutions which are developed mainly on existing web application servers or middleware products of the companies are tightly coupled and are heavyweights among the RFID middleware products, and only applies to large and complex RFID application systems because of their lower expandability and high costs. The MIT University, USA together with ETH had proposed an open-source middleware platform (called Accada) for RFID applications. They also conducted some thoroughly studies aimed at issues such as data distribution, data integration, data filtering, the external sensor-driven reader, events packaging, coding management and so on.

The major domestic RFID middleware products include RFID middleware SRM from Shanghai Jiaotong University, GDIX-RFID middleware from South China University of Technology, ezRFID middleware from Tsinghua Tongfang, etc. These products are designed for restructuring, and some of them are based on service oriented architecture (SOA). The research of RFID middleware technology mainly focused on topics such as hardware device integration, RFID event management, RFID information services, architecture of RFID middleware, etc. Zhang Jiehao analyzed the integration technology of RFID devices for middleware such as SNMP, EPC global Reader Protocol and Reader Management Protocol. On this basis, he had implemented RFID hardware device management module which based on the J2EE platform for the RFID middleware SRM of Shanghai Jiaotong University [7]; Yun Guoqing had implemented the multi-protocol RFID reader adaptor under TCP/IP communication protocol by configuring an XML file [8]; Zhao Li studied and designed the RFID middleware event management systems. First, he encoded the valid RFID events under Manchester Encoding, and then post-matches them with business rules after pattern recognition and content filtering. After that, according to the results of post-match, he called the pre-defined SOAP Service in the warehouse system. It is a successful interaction between RFID middleware event management systems and warehouse systems. However, it needs great reconstruction of the warehouse system [9]; Xu Qiang, borrowing the Java event model, had designed and implemented the real-time event management mechanism for RFID middleware [10]; Yang Xiaofeng did some research on reader network management, labels data smoothing, RFID data encryption and compression, RFID event filtering, aggregation, reporting and sharing [11]; Christian Floerkemerier used Java Message Service (JMS) as the way of information exchange between RFID middleware and enterprise information systems when designing RFID middleware [5].

According to the specification of architecture of RFID middleware which was proposed by EPC global, an RFID middleware should implement particular interfaces, such as Application Level Event (ALE) interface and Electronic Product Code Information Service (EPCIS) interface, to be compatible with the EPC Architecture and Protocol (shown in Fig.1).

![Figure 1. The EPC Architecture and Protocol](image)

ALE is an RFID data oriented processing and integration specification that defines how to accumulate, filter, and group EPC data and how to send result in the form of ALE report to the client which subscribes data to ALE, such as enterprise information systems. ALE interface allows applications to access to RFID data at the tag level in a read cycle or an event cycle; meanwhile the EPCIS interface allows applications query RFID events, in order to achieve logistics track and trace. ALE now
serves as the standards for EPC data integration interface. However, the goal of integrating RFID with enterprise information systems is to achieve not only data integration but also business integration. In the management of enterprise information systems, there is always a spectrum of purposeful actions, ranging from planning to control. Generally, these purposeful actions are executed within the enterprise information system, but sometimes we need to execute some of them externally. For example, when we are using RFID to receive goods, but the received goods are invalid according to the arrival notice generated by a warehouse system, it may requires the RFID system (or RFID middleware) to determine what to do next, reject the goods directly or just send the invalid data back to the warehouse system and notify it to handle the mess. Some enterprise information systems may not be designed for RFID integration, and it is not easy to solve the issue mentioned above without RFID middleware. For that reason, we proposed a lightweight way of integrating RFID technology with enterprise information system, which focused on both data integration and business integration.

III. SYSTEM ARCHITECTURE

As shown in Fig.2, Rdspor (RFID integration middleware) is consisted of the following five modules:

a) Devices Monitoring and Control Module
   - Manages and integrates different RFID devices in a registration way;
   - Configures a registered RFID device dynamically according to the business process which is defined in the middleware context;
   - Provides Rdspor with a unified interface to manipulate RFID data by sending reading or writing commands;
   - Monitors registered devices and if an error or fault is detected, invokes a particular handler to deal with the error or fault.

b) Data Processing Module
   - Processes the great number of received redundant data in the front-end of readers;
   - Given the RFID data’s characteristics such as real-time and continuing, combines data stream management technology with top business demands, which include redundant data clean-up, filter and aggregation of data;
   - Encapsulates raw data from a reader adapter (will be introduced later);
   - Generates fault-tolerant, filtered and aggregated data or events for the follow-up action.

c) Business Process Control Module
   - Driven by business documents from enterprise information systems;
   - Validates whether the data from readers matches the business documents, proofing the consistency of information flow, and then executes a predefined action, for example, automatically generates a business document which is planned by the enterprise information system and writes it back to the system;

   - Captures EPC events and sends them to EPCIS server for data sharing and querying or logistic tracking and tracing.

d) Business Documents Exchange and Interpretation
   - Exports or imports business documents from enterprise information systems;
   - Sets up the encoding scheme for interpretation of heterogeneous documents from different enterprise information systems since business documents are usually rely on the IDs which are encoded quite differently in different systems;
   - Interprets business documents in a set-up encoding scheme, persists the interpreted documents into databases and post them to business process control module.

e) Database Management Module
   - Manages internal or external databases, such as database to persist business documents information and database for EPCIS;
   - Accepts EPC events from business process control module, and defines the strategy how to manage these events and upload them to EPCIS server.

\[\text{Figure 2. RFID integration middleware architecture}\]

Rdspor is a business document driven RFID middleware and aims to achieve a more effective and loosely coupled way of integrating RFID to enterprise information systems. It accepts a business document and generates another planned document, and tries to float some business processes from enterprise information systems to RFID systems, such as product inbound or outbound in the inventory management of ERP system.

IV. DESIGN AND IMPLEMENTATION

A. Device Management and Monitoring

As shown in Fig.3, Device Monitor provides reader adapters to access to physical readers. When deploying a physical reader, Device Monitor will configure the reader’s communication mode and assign it a unique
number as identification. A reader adapter may have several physical readers attached to it by maintaining a mapping from the adapter to unique number of physical readers. Meanwhile, a physical reader may be mapped to more than one reader adapter. The reader-adaptor mechanism makes it possible for multiple physical readers that are not deployed together to cooperate with each other.

**RFID Reader Service Interface**

![Diagram](image)

**Figure 3. The architecture of Device Monitor**

With a reader adapter, a programmer can read and write to a RFID tag without knowing physical readers and RFID protocols such as Tag Air Interface Protocol, which improves reusability. Fig.4 shows a part of the class diagram of reader adapter.

**B. RFID Data Process**

The real time RFID data is collected by readers at a high speed, which means that RFID data will arrive in great volume. Database operation involves frequent disk I/O operations, such as inserting or deleting data, and they have a significant effect on performance of the database management system. As a result, a traditional database may not work very well when dealing with RFID data. On that basis, we use data stream technologies instead of database methods to process RFID data. There are a lot of researches and products in the area of data stream technologies, and it is far beyond the paper to discuss these researches and products. We used an open source data stream engine called Esper to process RFID data in a data stream way.

Fig.5 shows the framework of RFID data process. The business process control module sends reading commands to device monitor, requiring the specific reader adapters to read RFID tags. After the device monitor has completed reading of physical readers attached to the specific reader adapters, it sends RFID data to data process module. In the form of data stream, RFID data will be represented by the data stream event model which has attributes such as EPC to represent the tag’s EPC in the RFID data, reader adapter identification to identify the reader adapter that read the RFID data represented by the data stream event, timestamp to imply when this RFID data was generated and a task identification for business process control.

![Diagram](image)

**Figure 4. Partial class diagram of reader adapter**

![Diagram](image)

**Figure 5. Data process framework**

Esper needs to initialize the context before it begins to process RFID data stream. Firstly, it creates an service instance of class EPServiceProviderManager by invoking the class’s static method GetProvider (providerURI, configuration), and then it creates queries represented by class EPStatement through calling a factory method named CreateEPL on the service instance.

```java
Configuration configuration = new Configuration();
configuration.addType("RfidDataEvent", "Rdspor.Model.RfidDataEvent");
EPServiceProviderManager epService = EPServiceProviderManager.GetProvider("DataFilterEngine", configuration);
EPStatement statement = epService.CreateEPL(Create EPL);
```

Finally, Esper accepts RFID data stream events as input through the service instance’s method sendEvent. In addition, Esper defines an interface named UpdateListener to handle the query result, and an instance of classes that implement UpdateListener should be added to a query.

```java
statement.addListener(updateListener);
epService.sendEvent (object);
```
The sequences above can be demonstrated by Fig.6.

Figure 6. Sequence diagram of Esper context initialization

C. Business Documents Exchange

Enterprise information systems can provide data integration interfaces, through which external applications can interact with these information systems, such as data exchange of business documents in XML file format. However, documents from different systems are not compatible with each other in document schema and encoding scheme.

XPath is an effective way to extract information with XML file format, and it bases on the XML document’s explicit schema. Since documents from different systems are defined in quite different schemas, a program which designed to process documents of an enterprise information system may not be able to handle documents from another system. Rdspor is a RFID integration middleware for many kinds of enterprise information systems, aims to deal with business documents of various enterprise information systems. It requires a lot of work to write a program for documents from each kind of system, and it also costs a lot to maintain these programs. In order to resolve this problem, we defined several document models, and each model has common attributes to represent a particular kind of documents such as StockIn in ERP system and warehouse system. It also maintained a mapping relationship of each model with every document it represents. A mapping relationship is configured in a XML formatted file, and tells us how an attribute of a model is mapped to the XML node in its represented document. With the relationship configuration file, a program language with reflect mechanism can initialize these model from the documents they represent in a unified way.

The next step of modeling a document is to interpret it. Since the document is rely on IDs in a specific encoding scheme, an attribute of a model mapped to an ID node in the document may be unreadable without the document’s encoding scheme or the fundamental data, which is the meta-data in an enterprise information system, such as raw material, department, person and so on in an ERP system. To solve this problem, instead of directly reading data from the database of enterprise information systems, which may cause security issues, we create a local mirror of the fundamental data in enterprise information system, and maintain a one-way synchronization from the fundamental data to its mirror. Such synchronization can be achieved though deploying data-sync software such as OneBridge Mobile Data Suit.

D. Business Process Control

Business processes in enterprise information systems are configurable, and may be changed with business environment. The business process control module is designed for changeable business processes based on an open source rule engine called NxBRE. In the NxBRE rule file, we can define rules to define how to collect RFID from device monitor, including which reader adapters to use and how many times each reader adapter should read; how to filter and encapsulate the collected data; how to handle the result. A rule is a component that implements the interface ExecuteRuleInterface in NxBRE and configured in tag node Evaluate of the rule file.

Fig.7 shows an example of NxBRE rule file. This rule file contains four rules which are represented by xml node Evaluate, and some of them are configured with arguments in the context. Take the evaluate node CollectRfidData for example, there are three arguments configured within it. This rule means that NxBRE will collect RFID tag data using reader adapter Reader “urn:epc:1.4.16.36” and use a data filter named dataFilterEngine to complete the data process in a time span of sixty seconds. In addition, the IF-DO-ELSE logic is supported in the NxBRE engine context, which is useful for business control in some cases.

Figure 7. An example of NxBRE rule file

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The framework of business process control module is shown in Fig.8. When a business document from XML documents exchange module reaches, it will be added to the job queue, waiting for processing. The job dispatcher selects an appropriate job and rules in the queue under an explicit strategy, initializes NbXRE context. For example, a resource is allocated, and then start NbXRE engine in a new thread. Once the NbXRE engine begins to process, it will execute the rules defined in the rule file in sequence. When using the Inject Object Container of Spring.NET, the program can be easily to maintain.

![Figure 8. The framework of business process control module](image)

**E. RFID Event Semantic Definition**

RFID is always used to record and track the product logistics. In order to set up the relationship between product tracking and corresponding logistics information, it need to define the mapping from physical entity identification to corresponding logical data in management system. The traceable unit which can be traced through all or part of its production and supply chain is the item of products, semi-finished products, boxes, trays, containers, etc. The traceable information contains identification definition and recording information. RFID tag is used to identify its uniqueness in the tracking and tracing process. With the recording of RFID identification and logistics information, we can realize the transition from the physical tracing to the information tracing.

The tuple (R, S, T, Step, Rela(S), Order(S)) is used to represent that RFID reader R identify RFID tag S at time T and record the logistics state of the traceable unit. Step of the tuple represents the business type of the traceable unit in supply chain, such as the producing, packing, storage, unpacking, distribution, query, etc. Rela(S) of the tuple is used to identify the relationship between S and the packaging or transport units, such as products associated with the package, packages associated with the tray, and packages associated with the container. Order(S) of the tuple is used to identify the bill number of the corresponding business documents, such as Goods Receipt Notification (GRN), sale bill, transport documents, etc.

In Rdspor, we refer to the EPCIS interface, and use XML schema to describe RFID events in logistics business. Fig.9 shows the five types of RFID complex business events and their elements.

According to the status of product in the supply chain, RFID events are divided into five types which are object event, aggregation event, quantity event, transaction event and query event. The semantic definition of RFID event is shown as the following:

1) Object event represents an event that happened to one or more entities denoted by EPCs.
2) Aggregation event represents an event that happened to one or more entities denoted by EPCs that are physically aggregated together.
3) Quantity Event represents an event concerned with a specific quantity of entities.
4) Transaction Event represents an event in which one or more entities denoted by EPC become associated or disassociated with one or more identified business transactions.
5) Query Event represents an event in which one or more entities enquired by users.

Each of the core event types has fields that represent four key dimensions of any EPCIS event. These four dimensions are: (a) the object(s) or other entities that are the subject of the event; (b) the date and time; (c) the location at which the event occurred; (d) the business context. These four dimensions may be conveniently remembered as “what, when, where, and why” respectively.

![Figure 9. RFID Event types and elements](image)

**F. Process mechanism of RFID complex event**

As shown in Fig.10, the data process module filters duplicated RFID data, and the business process control module encapsulates filtered RFID data into RFID events according to the business type and transfer them to the buffer pool. Event scheduling module generates the priority event queue from the pending events according to the business rules. The processing component of RFID complex event is responsible for matching the RFID data.
complex events and business documents in order to complete the business operational steps or alarm. Meanwhile, RFID event based on XML format, which contains logistics information, will be uploaded into the EPCIS server. EPCIS server is used to provide the capture interface and query interface for product tracing in the supply chain.

![Dataflow process of RFID complex event](image)

In enterprise application environment, there are many RFID readers to collect the logistics information of product. Several RFID events will create simultaneity by different RFID readers. RFID events should be stored in different priority buffer according to their importance, so buffer pool contains a lot of pending events. Real-time scheduling module of RFID event uses pending events to generate the priority queue based on business rules. In the priority queue, all events will be process according to the time. Real-time scheduling strategy includes three methods which are buffer priority processing, business rules scheduling and time sequence order to handling.

The modules of buffer priority processing are as follows:

1. **Buffer Initialization.** We should set the capacity of each buffer, the upper limit threshold, the level of priority and the maximum blocking time;

2. **Buffer Size Monitor Module.** When the buffer reached or exceeded the upper limit capacity, the module will change the priority of this buffer to highest dynamically and also will notify the data processing module;

3. **Buffer Blocking Time Monitoring Module.** When the blocking time exceeds the threshold, the module will change the priority of this buffer to highest dynamically and also will notify the data processing module;

4. **Buffer Data Processing Module.** The module process the buffer according to their priority. After that, the default priority value of each buffer has to be reset.

The buffer with higher priority will be processed first. The buffer priority is decided by the importance of the RFID reader which detected the RFID tag and sent it the buffer.

Business rules are used to process the RFID event according to the predefined business rules. Time sequence processing adopts the FIFS (First In, First Serve) mechanism.

### G. Tracing Inquiry

The tracing information of unit S can be expressed as:

\[
\text{Inf}(S) = (\sum_{i=1}^{num1} \text{Mat}_i(S) \cdot \sum_{j=1}^{num2} \text{Attr}_j(S) \cdot R, S, T, \text{Step}, \text{Rela}(S), \text{Order}(S))
\]

Equation (1) includes this unit’s raw materials, attributes, transaction time T in its business flow, location R, business process Step, relative objects Rela(S) and business bills Order(S).

According to the tracing method above, manufacturer is responsible to maintain raw materials and product attributes in its database. EPCIS event database is responsible to provide the logistics movement information about product manufacturing and circulating. RFID application system is provided the service to query RFID tags in both real-time querying pattern and publish/subscribe pattern. Users can use fixed RFID terminal, web site and NFC mobile with RFID reader to read the RFID tag on the product. Users can also use web service and SMS to visit the product tracing platform and achieve products’ logistic tracing information.

### V. CONCLUSION

Because of some limitations of enterprise information systems and the characteristics of RFID, real –time integrating of RFID data with enterprise information systems is a challenge task. The integration of RFID is not only data integration but also business integration. Many RFID middleware are designed for RFID device management or RFID data collection, but not for business process integration. RFID middleware products of companies, such as Oracle, BEA etc, are powerful but not scalable since these products are dependent on these companies’ technology platform.

In this paper, some researches on RFID middleware are discussed. A RFID integration middleware framework named Rdspor is introduced. This middleware focuses on business process integration between RFID and enterprise information systems. The RFID integration middleware named Rdspor is consisted of five modules which are devices monitoring, data processing, business process control, database management and business documents exchange. The main mechanisms of these modules are discussed in detail.

The semantic definition of the complex RFID event and RFID event classification are introduced. A real-time scheduling strategy of RFID event which is based on the buffer and priority queue, can handle the complexity of concurrent RFID events. RFID application system controls the business process through RFID events. Users identify RFID tag to query product tracing information in different modes.
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Li Hua received his B.S. degree in Software Engineering from Shanghai Jiaotong University, Shanghai, China, in 2008, and is currently a master candidate in the department of Software Scholl at Fudan University, China. His research interests data management of RFID event and data stream, integration technologies between RFID and enterprise information systems, and RFID middleware.

Li Min-bo is an Associate Professor in the Software Scholl of Fudan University, China. He is also employed part-time as a research fellow of UFIDA software institute since 2006. He received his Ph.D. from the University of Tsinghua University in January, 2001. He did a postdoctoral research work at National University of Singapore from 2001 to 2002. He worked at central research institute of Kingdee Software Company from 2003 to 2004. Currently, he is an associate professor of Software Scholl of Fudan University from 2006. His current research interests are RFID application research and management information system.
Test Sequence Generation for Distributed Software System

Shuai Wang
1. Department of Automation, Tsinghua University
2. Tsinghua National Laboratory for Information Science and Technology, Tsinghua University, Beijing, China
wangshuai81@gmail.com

Yindong Ji
1. Department of Automation, Tsinghua University
2. Tsinghua National Laboratory for Information Science and Technology, Tsinghua University, Beijing, China
jyd@tsinghua.edu.cn

Shiyuan Yang
Department of Automation, Tsinghua University
ysy-dau@tsinghua.edu.cn

Abstract—This paper considers the test case generation for distributed software (a test case contains one or more test sequences). Applying the single finite state machine (FSM) test approach to distributed software, we will suffer from some problems: 1) the state combinatorial explosion problem; 2) some unexecutable test cases may be generated; 3) some fault may be masked and cannot be isolated accurately. This paper proposed a new test case generation method based on the FSM net model. Instead of testing the global transitions of product machine, the generated test cases are used to verify the local transitions. We discuss the detailed methods of verifying the outputs and the tail states of the local transitions. Moreover, we prove that if all the local transitions are right, the transition structure of the distributed software is right. The tests are generated on the local transition structure of components, so we will not meet the state combinatorial explosion problem. All the outputs of the local transitions are checked, so the fault isolation results may be more accurate.

Index Terms—Distributed software, finite state machine net, output identifying sequence, extended unique input/output sequence, test case generation

I. INTRODUCTION

Distributed software system is usually composed of several components. These components are distributed in different computers and connected through network. As a result, testing becomes an important work for the validity and reliability of distributed software.

The presence of a formal model or specification, which defines the required behaviors of the software, introduces the possibility of automating or semi-automating much of the testing process, especially the generation of test case. This can lead to more effective and efficient testing.

There are many approaches to formally modeling or specifying a software system. Some formal methods have been used in software testing [1-7]. The formal methods based on finite state machine (FSM) model are widely studied and applied [2-14].

In this paper, we will study how to extend the FSM model on the test generation for distributed software. The distributed software may be more naturally and simply modeled by a set of FSMs, rather than a single FSM, which operate concurrently and may interact by changing messages. Then the behaviors of the software can be described by a product machine which is the equivalent single FSM constructed from the set of FSMs through product operation [15].

Tests can be generated from the product machine using standard FSM test techniques. It is assumed that the model of certain distributed software consists of FSMs $A_1, \ldots, A_n$. Then the number of the product machine states is $|A_1| \ldots |A_n|$, where $|A_i|$ means the number of states of FSM $A_i$. Thus we may suffer from the state combinatorial explosion problem when computing the product machine.

Take the software in Fig. 1 for example. We suppose that the software is composed of two components, and each is modeled as a FSM, $A_1, A_2$. The transitions and

![Figure 1. Combining the FSMs of the software components](image-url)
states for each FSM are shown in Fig. 1.A1 and Fig. 1.A2. The product machine get through product operation is shown in Fig. 1.A too. Each component FSM contains three states, and the product machine contains nine states. From this example, we can see that if the software has many components or each component contains many states, the state number of product machine may be too large to handle.

When applied to complex distributed system, the traditional test approach for single FSM mainly has the following problems:

1) State combinatorial explosion problem[16].
2) Unexecutable test sequence: The test sequence combining the local transitions may be unexecutable. If the specification of software constrains that the component $A_i$ can trigger transition $t_{ij}$ only after it receives the output of transition $t_{i1}$, then the transition path $t_{i1}, t_{12}, t_{21}, t_{22}$ cannot be carried out. Generally, the unexecutable test sequences are caused by the unreachable state of the product machine.
3) Fault isolation between synchronous transitions: In Fig. 1, it is assumed that the output of $t_{11}$ is sent to $t_{21}$ and triggers it executing. Then the two transitions are defined as synchronous transitions. Only the output of $t_{21}$ can be observed by the tester and the two transitions compose a global transition, thus the output of $t_{11}$ is not checked. The fault isolation therefore may be a problem. Sometime the fault may be masked.

To solve these problems, Hierons proposed a method in [16]. His main idea is verifying the local transitions instead of the global transitions. But when we generate the verifying sequences, some parts of the product machine still need to be computed. Meanwhile, how to check the output of the transition when the output is sent to other component was not discussed in his study.

In this paper, we proposed a novel test case generation method for distributed software. By extending the FSM model, we set up the FSM net model as the formal test model for distributed software. We proved that if all the local transitions are right, the transition structure of the software is right. In order to verify the output of the local transition that will be sent to other component, a construction method of the output identifying sequence is proposed. We extend the unique input/output sequence to multiple components to verify the tail state of local transition.

Because we do not need to compute the product machine, we will not meet the state combinatorial explosion problem. All the test sequences are generated from the transition structure of software component, so they are all executable. Since all the outputs of the local transitions are checked, the fault isolation may be more accurate.

The rest of this paper is organized as follows. The basic idea of testing with FSM is introduced in Section 2 and the FSM net model are also presented in this section. How to check the local transition is introduced in Section 3. The verification of distributed software is discussed in Section 4. An example is given in Section 5. Finally, conclusion is presented in Section 6.

II. BASIC PRINCIPLES

For the sake of convenience, in this section we will recall the basic idea of testing with finite state machine (FSM), and then introduce the formal model which we will use to model the distributed software. At the end of this chapter, the concept of product machine will be introduced.

A. Testing with FSM

Usually the software under test can be modeled by a FSM or a set of FSMs that produce the outputs on its state transitions after receiving the inputs. When the software is modeled as a FSM, the testing of software can be taken as checking the output value of several sequences of input values. Usually, an input is given at an input port, and the outputs associated with the input can be observed at the output ports. The outputs will then be compared with the expected outputs corresponding with the inputs.

Definition 1: A finite state machine is a six-tuple[17]

$$FSM = (Q, q_0, \Sigma, \Lambda, \delta, \lambda)$$

where:

1) $Q$ is the finite set of states;
2) $\Sigma$ is the finite set of inputs;
3) $\Lambda$ contains all outputs;
4) $\delta: Q \times \Sigma \rightarrow Q$ is the set of state transition functions;
5) $q_0$ is the initial state;
6) $\lambda: Q \times \Sigma \rightarrow \Lambda$ is the set of output functions.

A FSM can be represented by a directed graph $G = (V, E)$, where the set $V = \{v_1, \ldots, v_n\}$ of vertices represents the set of specified states $Q$ of the machine and directed edges represents transitions from one state to another in it. An edge in $G$ is fully specified by a triple $(v_i, v_j; L)$, where $L = i_o / o_i, L^{\text{in}} = i_o$ and $L^{\text{out}} = o_i$. In this paper, it is assumed that $G$ is strongly connected.

The verification of software is implemented through checking the output and the tail state of every transition. The procedure for testing a specified transition from state $q_i$ to state $q_j$ with input/output $i_k / o_l$ takes place in three steps:

1) The implementation is leaded into state $q_i$;
2) Input $i_k$ is applied and the output is checked to see whether it is $o_l$ as expected, or not.
3) The new state of implementation is checked to verify that if the tail state of the specified transition is $q_j$, as expected, or not.

It is assumed that there exist a reset action which is applied to make the software return to its initial state. This ensures that each test is applied in the same state of the implementation. The reset action might be a certain
sequences of the inputs or a single action such as a reset, or the system being closed off and then powered on again.

We also suppose that this implementation has a status message. For each state \( q_i \in Q \), this message denotes the state uniquely, such as the unique input/output (UIO) sequence [6]. The tail state is verified by checking this message.

The test case for transition \((q_i, q_j, i_i, o_o)\) is constructed based on the U-method introduced in [14] as follows:
1) Constructing the reset action \( r \) to implementation \( I \) so that \( I \) can be reset to its initial state.
2) Generating the shortest transition sequence that can lead the implementation from state \( q_0 \) to state \( q_i \), namely preamble sequence.
3) Applying the input \( i_i \) which can enable the transition to be tested.
4) Generating the verifying sequence of tail state \( q_j \), namely postamble sequence.

### B. FSM Net Model

The distributed software usually consists of several components and has multi-thread, distributed and parallel properties. Thus we should model such software as a set of FSMs, and each of components behaves as a FSM that may interact with other components. We call this set of FSMs a FSM net.

**Definition 2:** An finite state machine net is formally defined by a two-tuple \( FSMnet = (A, C) \).

1) \( A = \{A_1, A_2, \ldots, A_n\} \) is the finite set of component finite state machines;
2) \( C = \{c_{ij} : i, j \leq n \land i \neq j\} \) is the set of finite channel finite state machine, and \( c_{ij} \) is the channel FSM between software component \( A_i \) and component \( A_j \).

A component FSM \( A_i \in A \) is a classical FSM that is defined in the definition 1. Its states are called local states and its transitions are named local transitions, which are in contrast to global transition and global state that are defined on the product machine of component FSMs.

We define channel FSMs to describe the message transporting behaviors between FSMs. The behaviors of \( e_i \) are decided by the channel properties.

**Definition 3:** A channel FSM is a four-tuple \( c_{ij} = (Q, \delta, q_0, M) \), where:
1) \( Q \) is the set of finite channel states, its number is decided by the properties and the buffer limit of communication channel;
2) \( \delta \) is the state transition function set of communication channel;
3) \( q_0 \) is the initial state of communication channel;
4) \( M \) is the set of finite messages transporting through channel \( c_{ij} \). \( m \in M \) is one of the messages sent from \( A_i \) to \( A_j \).

Since this paper focuses on the testing of the transition to verify the correctness of software, the properties of channel will not be discussed here.

According to its properties, the local transition of component FSM can be divided into three types:
1) Non-communication transition: the input of this type transition will be applied at the input port of this component and output can be observed at the output port. It is formally defined as \((q_i, q_j; i_i / o_o)\).
2) Sending message transition: the input of this type transition will be applied at the input port of this component, but the output will be sent to other components. This output is called internal output and cannot be observed by the tester. It is formally defined as \((q_i, q_j; i_i / A_i o_o)\).
3) Receiving message transition: the input of this type transition is received from output of other component, but output can be observed at the output port of this component. When testing, the input of this type transition can be applied by both the tester and other component. It is defined as \((q_i, q_j; A_j o_o / o_o)\).

Where \( A_i o_o \) means sending message \( o_o \) to component \( A_j \), and \( A_j o_o \) means receiving message \( o_o \) from \( A_i \).

**Example 1:** A distributed software system is modeled as FSM net \( FSMnet = (A, C) \) shown in Fig. 2, where
\[
A = \{A_1, A_2, A_3, A_4\}; C = \{c_{12}, c_{13}, c_{23}, c_{24}, c_{34}\};
M_{12} = \{c, e\}; M_{13} = \{x, e\}; M_{23} = \{f, h\};
M_{24} = \{d, g\}; M_{34} = \{f\}.
\]

**C. The Product Machine**

This paper deals with the problem of generating tests for the transition structure and thus shall only consider testing transitions from stable states. If input values will only be received in stable states, the full behavior of software is equivalent to a product machine [15].

We use \( P(A) \) to denote the product machine generated from \( A \), and we use \( X \) and \( Y \) to denote the input and output sets of \( P(A) \). \( S = Q_1 \times Q_2 \times \cdots \times Q_n \) is used to
denote the set of stable global states. \( S(k) \) denotes the state of the \( k \)th component when global state is \( S \). Clearly some elements in \( S \) may be unreachable. We therefore use \( S_\circ \) to denote the reachable state in \( S \). The initial state of \( P(A) \) is \( s_\circ = (q_1^\circ, q_2^\circ, \cdots, q_s^\circ) \). The state transition functions and the output functions are also denoted as \( \delta \) and \( \lambda \). Thus \( P(A) \) is defined by

\[
P(A) = (S_\circ, s_\circ, X, Y, \delta, \lambda).
\]

Given an input \( \sigma \in \Sigma_a \) and the current global state \( s \in S \), next state and functions \( \delta \) and \( \lambda \) for the product machine are defined by the following ways.

If \( \lambda(s(k), \sigma) \notin \bigcup \Sigma_\circ \), the next state is

\[
s_{i+1} = \delta(s, \lambda(s(k), \sigma))
\]

where \( \forall m \neq k, \ s_s(m) = s_{i+1}(m) \) and \( s_{i+1}(k) = \delta(s(k), \sigma) \).

The output is

\[
\lambda(s, \sigma) = \lambda(s(k), \sigma)
\]

And this is called the first class global transition.

If \( \lambda(s(k), \sigma) \in \bigcup \Sigma_\circ \), and the output will be sent to component \( A_k \), such that the next state is

\[
s_{i+1} = \delta(s, \lambda(s(k), \sigma))
\]

where \( \forall m \neq k, \ s_s(m) = s(m) \) and \( s_s(k) = \delta(s(k), \sigma) \).

The output is

\[
\lambda(s, \sigma) = \lambda(s(k), \sigma)
\]

And this is called the second class global transition.

The first case defines the behavior when the input triggers a non-communication transition and thus this transition forms a global transition. The second case defines the behavior when a sending message transition \( r \) is triggered (this is simply the behavior produced if \( r \) is executed and the output from \( r \) is fed back into \( A \) as an input). This process will be executed until a non-communication transition is triggered.

In the second case, the global transition is composed of the local transitions through the synchronous operation between sending message transition and receiving message transition.

**Definition 6 synchronous operation:** it defined as a transition will send a message to another transition. And we use \( \cup \) to denote this operation.

Before execute synchronous operation, we apply an admissible preamble sub-sequence to the component that will receive message. Then this component can be leaded to the state that certain massage can be accepted.

**Example 2:** If we compute the product machine of the distributed software in example 1, its state number is 400. Although some of these states are unreachable, the reachable state number will be very large. The attempt of drawing the state transition graph is impossible. This state combinatorial explosion problem causes the traditional test approaches for single FSM fail for complex distributed software system. In this example, \( (q_1^\circ, q_2^\circ, q_3^\circ, q_4^\circ) \) is the global initial state. \( I_i(a)/O_j(c) \) is a first class global transition and

\[
I_i(a)/O_j(c)(I_i(a)/O_j(A_k\circ c)) \cup (I_i(A_k\circ c)/O_j(d))
\]

is a second class global transition by the synchronous operation between transition \( I_i(a)/O_j(A_k\circ c) \) and transition \( I_i(A_k\circ c)/O_j(d) \).

### III. Verification of Local Transition

This section shall consider the problem of verification of local transitions. For the sake of convenience, we first introduce the fault model of transition. A general survey on a variety of fault models in testing was given in [18]. We use \( A = (Q, q_0, \Sigma, A, \delta, \lambda) \) to represent the required behaviors of component \( i \) and \( I_i = (Q', q_0', \Sigma, A', \delta', \lambda') \) to represent the implementation behaviors of this component. We define the following two faulty types as the major faults that may be encountered when testing a transition:

1) **Output fault:** We say that a transition in \( I_i \) has an output fault if for \( \forall q \in Q, q' \in Q', \ a \in \Sigma \), following equation holds,

\[
q = q' \land \delta_i(q, a) = \delta_i(q', a) \land \lambda_i(q, a) \neq \lambda_i(q', a).
\]

(7)

2) **Transfer fault:** We say that \( I_i \) has a transfer fault if for \( \forall q \in Q, q' \in Q', \ a \in \Sigma \), following equation holds,

\[
q = q' \land \delta_i(q, a) = \delta_i(q', a) \land \lambda_i(q, a) = \lambda_i(q', a).
\]

(8)

Certainly, the two type faults can happen simultaneously.

A local transition is said to be a correct implementation when its output and tail state are all right. The verification of local transition is carried out based on the following hypothesis:

**Hypothesis 1:** The inputs will be applied at the stable state. This means that the inputs are applied when no internal events can occur.

**Hypothesis 2:** We assume that message transporting time is zero, then \( s_{i+1}(m) = s(m) \) and \( s_{i+1}(m) = s(m) \) are synchronous. This means that the behaviors of channel between two components are modeled as empty channel.

**Hypothesis 3:** It is assumed that when testing a transition, all the other transitions are correct.

**Hypothesis 4:** We suppose that the ports of different components can be distinguished by tester, so the same inputs applied to different components and same outputs observed from different components can be distinguished by tester and were seen as different inputs and outputs.

#### A. Verification of Local Transition

The verification of local transition is implemented through checking its output and its tail state. Then the procedure for testing a specified local transition of \( A \) from state \( q_n \) to state \( q_n' \) with input/output \( i_i/o_i \) takes place in three steps:

1) The implementation of software component \( A \) is leaded to state \( q_n' \);

2) Input \( i_i \) is applied and the output is checked to see whether it is \( o_i \) as expected, or not.
3) The new state of implementation is checked to verify
that if the tail state of the specified transition is \(q_n^*\) as
expected, or not.
This procedure is the same as that for transition of single
FSM verification, but its operations in each step are
different. We also assume that there exist a reset action
which is applied to make the software return to its initial
state.

The local transition sequence that can lead \(A_i\) from the
state \(q_{n_i}^*\) to the state \(q_{n_i}^*\) is named the local preamble
sequence. If the test cost is assigned to every transition,
the least test cost preamble sequence can be obtained
from the sub-graph of FSM \(A_i\). Especially, the required
inputs for the receiving message transitions are applied
by tester not the corresponding component. Taking the
testing of transition \(I_3(a)/O_3(A_i x f)\) in \(A_i\) for instance,
the local preamble sequence \(I_3(c)/O_3(d)\) is constructed
for its verification. After the input \(i_1\) is applied, the
output and tail state will be checked. The construction of
the output checking sequence and the tail state verifying
sequence will be discussed in following two sections
respectively.

B. Checking the Output

The checking for the output of a local transition can be
divided into two cases based on the type of transition.
The outputs of the receiving message transitions and the
non-communication transitions can be observed by the
tester and it is seen as a global output of system. Then
the check of them is easy to be implemented through
comparing them with required outputs.

The outputs of the sending message transition will be
applied to other components and cannot be observed by the
tester. We have assumed that when checking a
transition all the other transitions are correct. Then we
can observe that if the output of sending message
transition is right, it will trigger another local transition
belonging to other FSM \(A_j\). This output can be denoted
uniquely by the flowing input/output sequence. For example,
the output of local transition \(I_3(b)/O_3(A_i x e)\)
can be denoted by the sequence \(u(t) = I_3(A_i ? e)/O_3(d),I_3(x)/O_3(y)\). When we input \(b\) to
\(A_i\), \(d\) is observed at \(A_i\) (\(A_i\) has been leaded to \(q_{n_i}^*\)) and
when we input \(x\) to \(A_j\), \(y\) is observed at \(A_i\). These
observations mean the output of transition \(I_3(b)/O_3(A_i x e)\)
must \(e\), because when other output is generated by this
transition, sequence \(O_3(e),I_3(x)/O_3(y)\) cannot be
observed by tester. \(u(t)\) is an output identifying sequence (OIS)
for local transition, if the following holds:
\[
\{x(\{q_{n_i}^*,\cdots,u(i)\} \cap \lambda(\{q_{n_i}^*,\cdots,u(i)\}) \neq \emptyset) = \emptyset \}
\]
where \(u(i)\) is the input sequence of \(u(t); u(i)\) is first
input of this sequence which is the output of transition
belonging to \(A_i\).

So the verification of output of a sending message
transition can be carried out through checking the OIS.
The OIS is constructed as possible as by the transitions
belonging to \(A_i\). If the transition sequence belonging to
\(A_i\) cannot denote the output uniquely, we can combine
the transitions belonging to other components, such as the
sequence \(I_3(A_i ? h)/O_3(c),I_3(h)/O_3(A_i x d)\) \(I_3(A_i ? d)/O_3(f)\)
for output \(O_3(A_i x h)\) verifying of transition \(I_3(x)/O_3(A_i x h)\).

C. Checking the Tail State

This section shall consider the problem of checking the
tail state of a local transition.
The UIO sequence method was proposed in [6] to
check the tail state of the transition in the single FSM.
It is possible to extend it for the verification of the tail state
of local transition in this paper. An local input sequence
\(u(i)\) in \(A_i\) is capable of verifying a local state \(q_{n_i}^*\), if the
following holds:
\[
\{x(\{q_{n_i}^*,\cdots,u(i)\} \cap \lambda(\{q_{n_i}^*,\cdots,u(i)\}) \neq \emptyset) = \emptyset \}
\]
Unfortunately, not every state in component \(A_i\) has a
status message that is composed of the local transitions
belonging to \(A_i\). We extend the UIO sequence to multiple components, and then the UIO sequence can be
composed of the local transitions belonging to different
components. We noted this sequence extended unique
input/output sequence (EUIO). It is the “status message”
for local state.

An extended input sequence \(u(i)\) is capable of
verifying a local state \(q_{n_i}^*\), if the following holds:
\[
\{x(\{q_{n_i}^*,\cdots,u(i)\} \cap \lambda(\{q_{n_i}^*,\cdots,u(i)\}) \neq \emptyset) = \emptyset \}
\]
Let us see the software in example 1. The local state
\(q_{n_i}^*\) in \(A_j\) does not have UIO sequence composed of
the local transitions belonging to \(A_i\), but EUIO sequence
\(I_3(a)/O_3(b),I_3(c)/O_3(A_i x x)\) \(I_3(A_i ? x)/O_3(h)\)
can denote the state \(q_{n_i}^*\) uniquely. This means \(q_{n_i}^*\)
is the unique state after \(I_3(a),I_3(e)\) is applied \(O_3(b),O_3(h)\) is
observed by tester.

D. Test Sequences for Local Transition

Based on previous discussions, the test case for local
transition \((q_{n_i}^*,q_{n_i}^*;i/o)\) contains two test sequences, and
is constructed in following ways:
The test sequence for the output checking (required
only when the outputs are sent to other component and
cannot be observed by tester):
1) Constructing the reset action \(r\) to implementation \(I\)
so that the software under test can be reset to its
initial state;
2) Generating the least test cost preamble sequence for
local transition to be tested;
3) Generating the preamble sequence for the
synchronous transition of the transition to be tested
which has the least test cost;
4) Applying the input \(i\) which can enable the local
transition to be tested;

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5) Generating the OIS for output $o_i$. (if it contains some synchronous operations in it, the admissible preamble sequences for all operations are needed)

The test sequence for the tail state verifying:
1) Constructing the reset action $r$ to implementation $I$ so that $I$ can be reset to its initial state.
2) Generating the shortest transition sequence that can lead the machine from state $q_i$ to state $q_j$, namely preamble sequence.
3) Applying the input $i_k$ which can enable the transition to be tested.
4) Generating the verifying sequence of tail state $q_j$.
For the $I$ with the extended status message feature, the test case for local transition in $A_i$ is of the form
$$ts_{\text{pre}}: r, ts_{\text{post}}: I.$$
(12)
where $r$ is the reset action; $ts_{\text{pre}}$ is the preamble sequence for the transition $t: t = (q_i, q_j, i_k / o_i)$ is the local transition to be tested; $ts_{\text{post}}$ is the postamble sequence to check the tail state of transition $t$; $ts_{\text{post}}$ is the postamble sequence for synchronous operation; $ts_{\text{post}}$ is the postamble sequence to check the output of transition $t$.

IV. VERIFICATION OF DISTRIBUTED SOFTWARE

As discussed in [6], the verification of software can be implemented through verifying all transitions. Therefore, the verification of distributed software can be carried out through checking of outputs and tail states of all global transitions.

In this section, we will prove that the checking of all local transitions has the same ability to validate the correctness of software by checking of all the global transitions.

**Lemma 1:** If all the local transitions are right, all the global transitions are right.

**Proof.**

Given a global transition $s_j = \delta(s_i, \sigma)$, and we let
$$\sigma \in \Sigma_i \in X$$
$$s_i \in S | s_i = (q_1, q_2, \ldots, q_{n-1}) s_i = (q_1', q_2', \ldots, q_{n-1}')$$
We consider the two class global transitions.

1) For the first class, a non-sending message transition forms a global transition. Given a local transition $(q_i, q_j, i_k / o_i)$ of $A_i$, then the global transition is $s_i = (s_1, s_2, \ldots, s_{n-1})$, where $\forall k \in (1, n), k \neq m, s(k) = s_j(k)$ and $s(m) = q_i$, $s(m) = q_j$.

Now, we prove that for this class, if the local transition is right, the global transition is right. We will use apagope to prove it.

When the local transition has an output fault, $o_j' \neq o_i$, the global output is $o_j'$. So there is an output fault of global transition. When the local transition has a tail state fault, $(q_i', q_j')$, the global transition is right only if the two local transitions are all right.

2) For the second class, more than one communication transitions form the global transition through synchronous operation. We only need to prove the situation in which the global transition is composed of two transitions. The situation having more two transitions can be proved recursively by the situation of two transitions.

Given a sending message transition $(q_i, q_j; i_k / A_i!o_{m})$ in $A_i$ and a receiving message transition $(q_i, q_j; A_i?o_{m} / o_i)$ in $A_i$ then the global transition is $(s_i, s_j; i_k / o_i)$, where $s(m) = q_i$, $s(m) = q_j$, $s_j(n) = q_j$, $s_j(n) = q_j$, and $\forall k \in (1, n), k \neq m, k \neq n, s_j(k) = s_j(k)$. We only use apagope to prove it.

First, we prove that if the two local transitions are all right, the global transition is right. We also use apagope to prove it.

When any of the local transitions has an output fault, the global output is not $o_i$. So there is an output fault of global transition. When any of the local transitions has a tail state fault, $(q_i, q_j')$, the global state transition is $(s_i, s_j')$, $s_j' \neq s_j$. So there is a tail state fault of the global transition. Thus a global transition is right only if the local transition is right.

Then we show that the faults of global transition can be detected by checking the local transition.

Obviously, the output fault can be checked through checking the output of the local transition which forms this global transition. If the tail state fault is $(s_i, s_j')$, $s_j' \neq s_j$, $s_j'(m) \neq s_j(m)$, this fault can be detected through checking the tail state of the local transition which forms this global transition. If the tail state fault is $s_j' \neq s_j$, $s_j'(n) = s_j(n), n \neq m$, this means a transition of other component has been triggered. This must be caused by an output fault of local transition. The non-communication local transition might send a message to component $A_i$. This can be detected by checking the output of local transition.

Up to here, we prove that for the first class global transition, the verification of global transition can be implemented through checking corresponding local transition.

Generating the OIS for output $o_i$, the test state $s_i$, and the pretest state $s_i$ and the preamble sequence $ts_{\text{pre}}$ for all operations are needed.)


\[ s_i \neq s_j \mid s_j(n) \neq q_j \], the fault can be detected through checking the tail state of local transition \((q^n, q^j)\). If the tail state fault is \( s_i \neq s_j \mid s_j(k) \neq s_i(k) \mid k \neq m, k \neq n \), this means a transition of other component has been triggered. This must be caused by the output fault of the local transition. The destination of sending message transition in \( A_n \) is then wrong or the receiving message transition in \( A_n \) sends a message to other component. This can be detected by checking the outputs of the two local transitions, too.

In short, we prove that for the second class global transition, the verification of global transition can be implemented through checking all the corresponding local transitions.

Based on the above discussions, we can conclude that the verification of global transition can be implemented by checking of local transitions. In other words, if all the local transitions belonging to software system are all right, the implementation of the distributed software system is right.

V. EXPERIMENTS

In this section, we will discuss the test case generation for the software in Example 1 to examine our approach.

A. Test Cases

Using the proposed test case generation method, we first identify the EUIO sequences for all the local states and the results are shown in Table I. More than one EUIO can denote the state uniquely and we only list the shortest one in the table. The OISs for all communication outputs are listed in Table II. Then the generated test cases for all local transitions are shown in Table III.

<table>
<thead>
<tr>
<th>Internal output</th>
<th>OIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>( O_i(A_n ? c) )</td>
<td>( I_j(A_n ? c) / O_i(d) )</td>
</tr>
<tr>
<td>( O_i(A_n ? e) )</td>
<td>( I_j(A_n ? e) / O_i(c) )</td>
</tr>
<tr>
<td>( O_i(A_n ? e) )</td>
<td>( I_j(A_n ? e) / O_i(d), I_j(x) / O_i(y) )</td>
</tr>
<tr>
<td>( O_i(A_n ? f) )</td>
<td>( I_j(A_n ? f) / O_i(e) )</td>
</tr>
<tr>
<td>( O_i(A_n ? d) )</td>
<td>( I_j(A_n ? d) / O_i(f) )</td>
</tr>
<tr>
<td>( O_i(A_n ? x) )</td>
<td>( I_j(A_n ? x) / O_i(y) )</td>
</tr>
<tr>
<td>( O_i(A_n ? f) )</td>
<td>( I_j(A_n ? f) / O_i(b) )</td>
</tr>
<tr>
<td>( O_i(A_n ? h) )</td>
<td>( I_j(A_n ? h) / O_i(c) )</td>
</tr>
<tr>
<td>( O_i(A_n ? e) )</td>
<td>( I_j(A_n ? e) / O_i(h) )</td>
</tr>
<tr>
<td>( O_i(A_n ? g) )</td>
<td>( I_j(A_n ? g) / O_i(k) )</td>
</tr>
</tbody>
</table>

TABLE I. EXTENDED UNIQUE INPUT/OUTPUT

<table>
<thead>
<tr>
<th>State</th>
<th>EOUI</th>
</tr>
</thead>
<tbody>
<tr>
<td>( q_0^A )</td>
<td>((I_1(a) / O_1(c)) \subseteq (I_1(A_n ? c) / O_1(d)))</td>
</tr>
<tr>
<td>( q_1^A )</td>
<td>((I_1(e) / O_1(d)) \subseteq (I_1(A_n ? e) / O_1(c)))</td>
</tr>
<tr>
<td>( q_2^A )</td>
<td>((I_1(x) / O_1(y)) \subseteq (I_1(A_n ? y) / O_1(x)))</td>
</tr>
<tr>
<td>( q_3^A )</td>
<td>((I_1(c) / O_1(c)) \subseteq (I_1(A_n ? c) / O_1(c)))</td>
</tr>
<tr>
<td>( q_4^A )</td>
<td>((I_1(h) / O_1(e)) \subseteq (I_1(A_n ? h) / O_1(f)))</td>
</tr>
<tr>
<td>( q_5^A )</td>
<td>((I_1(g) / O_1(k)) \subseteq (I_1(A_n ? g) / O_1(k)))</td>
</tr>
</tbody>
</table>

TABLE II. OUTPUT VERIFYING SEQUENCE

B. Discussions

In the introduction chapter, we have pointed out the potential problems when the traditional test method for single FSM is applied to the complex distributed software system. In this section we will discuss if our method can benefit these problems.

1) State combinatorial explosion problem: it is not necessary to compute the product machine using our method when generating test cases, so we will not meet the state combinatorial explosion problem.

2) Unexecutable test sequence: all the test sequences are generated based on the transition structure of the local component and synchronous operation, so all of them are executable.

3) Test cost: a local transition can form more than one global transitions, such as:

\[ ((q^n_0, q^n_0, q^n_0, q^n_0); (q^n_0, q^n_0, q^n_0, q^n_0); a / A_n ! c) \] and

\[ ((q^n_1, q^n_1, q^n_1, q^n_1, q^n_1, q^n_1); (q^n_1, q^n_1, q^n_1, q^n_1); a / A_n ! c) \]

are both formed by local transition \( a / A_n ! c \). With our method, only one local transition needs to be verified, but using traditional methods for single product machine, more than one global transition need to be verified. So the test cost of our method may be less than traditional methods.

4) Fault isolation between synchronous transitions: the outputs of sending message transitions can be checked by the OIS, but this cannot be implemented by the product machine method.

In summary, our method is an efficient method to solve the problems that encountered by the single product machine method.

VI. CONCLUSION

When we use traditional test methods for distributed software testing through computing the product machine, we will suffer from the state combinatorial explosion problem and some generated test sequences may be unexecutable. Besides, some outputs of the sending
message transition cannot be checked. In this paper, we propose a new test generation method based on sequences we extend it to multiple components. Then the HCS sequence can be composed of the local transitions identifying sequence is used to verify the output of the applying to different components, and this makes more

<table>
<thead>
<tr>
<th>Case</th>
<th>Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>2</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>3</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>4</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>5</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>6</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>7</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>8</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>9</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>10</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>11</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>12</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>13</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>14</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>15</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>16</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>17</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>18</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>19</td>
<td>10(0,4)(1,0)</td>
</tr>
<tr>
<td>20</td>
<td>10(0,4)(1,0)</td>
</tr>
</tbody>
</table>

Table III: Test Cases
local states have status messages.

The tests are generated on the local transition structure of components, so we will not meet the state combinatorial explosion problem. By applying the admissible preamble sub-sequence of all synchronous operations, all the test sequences are executable. All the outputs of the local transitions can be checked by OIS, so the fault isolation may be more accurate.

The experiment in section 5 shows that this method has better properties than single product machine method. It is a promising way for distributed software testing.

ACKNOWLEDGMENT

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Shuai Wang was born in Changchun, Jilin Province, China, on April 3, 1981. He received his B.S. degree in control science and engineering from Beijing Institute of Technology University, Beijing, China in 2004. Currently, he is a PH.D candidate working in fields of control science and engineering at Tsinghua University. His major research interests include system test, fault diagnosis and reliability analysis.

Yindong Ji was born in Beijing, China in 1962. He received his B.S. and M.S. all from the Department of Automation, at Tsinghua University, in 1985 and 1989, respectively. His main research areas are digital signal process, fault diagnosis, modeling & simulations. He is a member of IEEE.

Prof. Ji is with the Department of Automation, and Tsinghua National Laboratory for Information Science and Technology, Tsinghua University, Beijing, China. He has published over 60 papers in journals. His current research interest is in the area of train control system of high speed railway.

Shiyuan Yang was born in Shanghai, China, in 1945. He received his B.S. and M.S degree from Tsinghua University in 1970 and 1981, respectively. Currently, he is a Professor in automation of department in Tsinghua University. He is an Associate Director of the FTC committee, China. His main research interests are home automation network, test technology, electronic technology application, system fault diagnosing.
Research on Algorithm and Model for Indefinite Multi-objective Decision Making

ZHOU Qihai
Information Technology Application Research Institute, Southwestern University Of Finance and Economics, Chengdu, Sichuan, China; School of Economic Information Engineering, Southwestern University Of Finance and Economics, Chengdu, Sichuan, China
Email: zhouqh@swufe.edu.cn

LI Yan
Information Technology Application Research Institute, Southwestern University Of Finance and Economics, Chengdu, Sichuan, China; School of Economic Information Engineering, Southwestern University Of Finance and Economics, Chengdu, Sichuan, China
Email: Liyan77@163.com

Abstract—Decision Support System is playing an important role in computer science, technology and engineering. Intelligent decision-making is one of the current hotspots in the decision support system research. Intelligent decision-making methods and algorithms are one of the most important basics and key cores in intelligent information processing, intelligent pervasive computing and so on. In this paper, conduct the research to two kinds of indefinite multi-objective decision making question: the indefinite sector and the indefinite language. (1) In view of multi-attribute decision-making under linguistic setting, propose one new decision method. Firstly construct a range pole plan and introduce the policy-maker risk-preference weight. Then with three tuples (Limit low similarity, Risk degree, Risk-preference value) reflect the risk-degree existing in the decision-making process. At last, construct the risk-weighted similarity measure operator (RWSMO) to measure the risk balance similarity's size between each of decision schemes and the range pole plan. (2) In view of multi-attribute decision-making under the indefinite sector, propose one new decision method based on the multiple-valued intuitive fuzzy sets.

Index Terms—Intelligent Method, Range pole plan, Risk balance similarity, Multiple-valued intuitive fuzzy sets, Isomorphism, Indefinite multi-objective decision-making

I. CONSTRUCTING POLICY-MAKING ALGORITHM FOR THE LINGUISTIC SETTING VALUE MULTI-ATTRIBUTES DECISION-MAKING BASED ON RISK-WEIGHTED

The multi-objective decision making question is the current hotspots in decision-making science, systems engineering, management science and so on, also has a very extensive and important using in the practical application. The multi-objective decision making under that the policy-making attribute take the single real value has been already studied quite thoroughly. But in the practical application, because of incomplete information about attributes or attributes characteristics, we often cannot evaluate one plan on some attributes with precise values, for example: Automobile's performance, personnel's quality, equipment performance and so on. When carry on evaluating to plans on those attributes, we often use the linguistic value for example: worst, worse, bad, good, better, best and so on. Literature [1] ~ [4] has conducted the research to this kind of language decision-making. Often we can not use a precise linguistic value to evaluate plans on some attributes, but can only use a Linguistic Setting value to estimate approximately. This kind of multi-objective decision making is the indefinite multi-objective decision making. Recent years this kind of policy-making question receives some scholar's attention gradually, and has obtained a series of research results [5]~[11]. As a result of attribute evaluation value is indefinite, therefore has uncertainty in the decision-making process. Making decision in the indefinite condition, people will face with the risk. Because of the different degree of risk preferences, the different policy-maker may have the different evaluation value to the identical plan. The existing indefinite multi-objective decision making methods have not considered the policy-maker's risk-preference. In this part, the innovation is that the policy-maker's risk-preference will be considered in the decision-making process by constructing three tuples (Limit similarity, Risk degree, Risk preference value) to reflect the risk-degree existing in the decision-making process. Then construct risk-weighting similar measure operator (RWSMO) to measure similarity between the decision plan and the range pole plan. The risk-weighted similarity is closest to 1, the decision scheme is the optimalizing plan.

A. Preparation Knowledge

Suppose \( A = \{A_1, A_2, \cdots, A_n\} \) as the decision plan set and \( U = \{u_1, u_2, \cdots, u_m\} \) as the attribute set. When carry on the qualitative measurement to attributes, generally need suitable language evaluation scale.
Therefore, we should establish language evaluation scale
\[ S = \{ s_{a} | a = \{-t, \cdots, t\} \} \]
where \( s_{a} \) express language varity. Specially, with \( s_{-t}, s_{t} \) separately express the scale's low limit, the up limit. The commonly used language evaluation scale may be: Third-level evaluation scale \( S1= \{ \text{bad, general, good} \} \); Seven-level evaluation scale \( S2= \{ \text{worst, worse, bad, general, good, better, best} \} \) or \{\text{smallest, smaller, small, general, big, bigger, biggest}\} and so on. Introduce symbol \( \prec \) to express relation in various linguistic values. Define “bad \( \prec \) general \( \prec \) good”, in this formula, rank-number of a linguistic value setting the left of “\( \prec \)” is smaller \( \langle 1 \rangle \) to that of a linguistic value setting the right of “\( \prec \)”, and the rank-number can be accumulated. For example: In this third-level evaluation scale “bad \( \prec \) general \( \prec \) good” may promote the rank-number of the linguistic value “good” is bigger \( 2 \) to that of the linguistic value “bad”. But cannot promote “bad \( \prec \) good”, because “bad” is smaller two ranks to “good”, but is not one rank. Similarly define in seven-level evaluation scales \( S2 \) worst \( \prec \) worse \( \prec \) bad \( \prec \) general \( \prec \) good \( \prec \) better \( \prec \) best or “smallest \( \prec \) smaller \( \prec \) small \( \prec \) general \( \prec \) big \( \prec \) bigger \( \prec \) biggest”. When carry on the evaluation on each attribute, we may select appropriate evaluation scale according to the characteristics of attributes as well as the policy-maker's knowledge, we may use the different evaluation scale to carry on the evaluation to the different attributes.

Symbol “\( \tilde{v}_{ki} \)” represent linguistic sector value. Evaluate the plan \( A_k \) \( (k = 1, 2, \cdots, n) \) on the attribute \( u_i \) \( (i = 1, 2, \cdots, m) \), then get a linguistic sector value, recording \( \tilde{v}_{ki} = [v_{1i}^{k}, v_{2i}^{k}, \cdots, v_{pi}^{k}] \), where \( v_{ji}^{k} \) \( (j = 1, 2, \cdots, p[k,i]) \) represent the linguistic value whose rank-number is “\( j \)” in the linguistic sector value “\( \tilde{v}_{ki} \)”. Linguistic values' ordering rule is: When for cost attribute, linguistic values carry on sorting according to the rank-number's descending sequence. When for efficient attribute, carry on sorting according to the rank-number's rising sequence. The symbol “\( p[k,i] \)” expresses the number of linguistic values in the linguistic sector value “\( \tilde{v}_{ki} \)”. Thus may obtain the linguistic sector value decision-making matrix. The symbol “\( v_{L}^{ki} \)” represents the left limit value in the language sector value “\( \tilde{v}_{ki} \)”; \( v_{R}^{ki} \)” represents the right limit value in language sector value “\( \tilde{v}_{ki} \)”. \( v_{L}^{ki} \)” represents the left limit value in language evaluation scale which policy-maker use to evaluate each plan on the attribute “\( u_i \)”. \( v_{R}^{ki} \)” represents the right limit value in language evaluation scale that we use to evaluate each plan on the attribute “\( u_i \).” Suppos the expert weight value of the attribute \( u_i \) is \( \omega_i \) \( (i = 1, 2, \cdots, m) \) .

Definition 1. Suppose \( v_{0i} \) to be the best value of attribute \( u_i \) \( (i = 1, 2, \cdots, m) \) (when only considering the attribute \( u_i \), linguistic value \( v_{0i} \) is the optimalizing value in view of policy-making goal), then say that the plan \( (v_{01}, v_{02}, \cdots, v_{0m}) \) is the range pole plan, recording \( A_0 \).

### TABLE I.

<table>
<thead>
<tr>
<th>Risk evaluation scale</th>
<th>Risk-preference degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_2 = { r_{12}^{2}, r_{22}^{2} } )</td>
<td>( W = { \lambda_{12}^{2}, \lambda_{22}^{2} } ), where ( \lambda_{12}^{2} + \lambda_{22}^{2} = 1 ), ( 0 \leq \lambda_{12}^{2}, \lambda_{22}^{2} \leq 1 )</td>
</tr>
<tr>
<td>( R_3 = { r_{13}^{3}, r_{23}^{3}, r_{33}^{3} } )</td>
<td>( W = { \lambda_{13}^{3}, \lambda_{23}^{3}, \lambda_{33}^{3} } ), where ( \lambda_{13}^{3} + \lambda_{23}^{3} + \lambda_{33}^{3} = 1 ), ( 0 \leq \lambda_{13}^{3}, \lambda_{23}^{3}, \lambda_{33}^{3} \leq 1 )</td>
</tr>
<tr>
<td>( R_p = { r_{1p}, \cdots, r_{np} } )</td>
<td>( W = { \lambda_{1p}, \cdots, \lambda_{np} } ), where ( \lambda_{1p} + \lambda_{2p} + \cdots + \lambda_{np} = 1 ), ( 0 \leq \lambda_{1p}, \lambda_{2p}, \cdots, \lambda_{np} \leq 1 )</td>
</tr>
</tbody>
</table>

Often one specific policy-maker displays certain risk-preference (risk-preference degree possibly base on policy-maker's individuality, objective environment or both). Therefore before carrying on the decision-making, the policy-makers may make the evaluation to their risk-preference degree and construct the policy-maker risk-preference degree table shown as Figure 1. Notice: On this table, in every risk evaluation scale, the risk degree along with the subscript increases. The value \( \lambda \) expresses risk-preference degree of policy-maker. The value of \( \lambda \) is more big, the policy-maker is more like to the corresponding risk degree. \( p = \max( p[k,i], (i = 1, 2, \cdots, m), (k = 1, 2, \cdots, n) \) .

Define the following four operators:

1. \( \| u_i - v_{0i} \|_{L} \) is equal to grading rank-number between the linguistic value \( v_{0i} \) and the linguistic value \( v_{L}^{i} \) \( (i = 1, 2, \cdots, m) \).
2. \( \| u_i - v_{0i} \|_{R} \) is equal to grading rank-number between the linguistic value \( v_{0i} \) and the linguistic value \( v_{R}^{i} \) \( (i = 1, 2, \cdots, m) \).
(3) \[ \| \mathbf{u}_i \| = \max \left( \| \mathbf{u}_i - \mathbf{v}_o \|_E, \| \mathbf{u}_i - \mathbf{v}_{0i} \|_E \right), \] 
\text{call } \| \mathbf{u}_i \| \text{ as the biggest deviation of the attribute } \mathbf{u}_i (i = 1, 2, \ldots, m). \]

(4) \[ \| v_j^v - \mathbf{v}_o \|_E \text{ is equal to grading rank-number between the linguistic value } \mathbf{v}_o \text{ and the linguistic value } v_j^v, (i = 1, 2, \ldots, m) (j = 1, 2, \ldots, p[k, i]). \]

**Definition 2.** Call \[ 1 - \frac{\| v_j^v - \mathbf{v}_o \|_E}{\| \mathbf{u}_i \|} \text{ as low limit} \]

similarity between the plan \( A_k \) and the range pole plan \( A_0 \) about the attribute “ \( u_i \) “, recording \( \ell_{ki}^L (i = 1, 2, \ldots, m), (k = 1, 2, \ldots, n). \)

**Definition 3.** Call \[ 1 - \frac{\| v_j^v_r - \mathbf{v}_o \|_E}{\| \mathbf{u}_i \|} \text{ as up limit} \]

similarity between the plan \( A_k \) and the range pole plan \( A_0 \) about the attribute “ \( u_i \) “, recording \( \ell_{ki}^R (i = 1, 2, \ldots, m), (k = 1, 2, \ldots, n). \)

Obviously similarity between the plan \( A_k (k = 1, 2, \ldots, n) \) and the range pole plan \( A_0 \) about the attribute \( u_i (i = 1, 2, \ldots, m) \) situates between \( \ell_{ki}^L \) and \( \ell_{ki}^R \). The policy-maker is unable to determine the position precisely with the existing information. This means that when carrying on the decision-making, the policy-maker must undertake the corresponding risk. People already constructed some methods to solve this kind of policy-making problem, for example: With the probability method, the fuzzy set method and so on. In this paper, the author will study this kind of policy-making issue from new angle: the policy-maker risk preference. Introduce three tuples (Limit low similarity, Risk degree, Risk preference value) to precisely quantify the risk-degree existing in the decision-making process and policy-maker’s risk-preference degree to corresponding risk degree. These three tuples express the following meaning: When thinking that the similarity is not smaller than a value (Limit low similarity), the policy-maker needs to undertake the corresponding risk degree (Risk degree) and the policy-maker’s risk-preference degree (Risk-preference degree) to the corresponding risk degree. Recording “Limit low similarity” in the three tuples as \( \ell_{ki}^L \), \( \ell_{ki}^R \) \( = 1 - \frac{\| v_j^v - \mathbf{v}_o \|_E}{\| \mathbf{u}_i \|} \) \( (j = 1, 2, \ldots, p[k, i]). \)

For example: suppose the attribute “ \( u_i \) ” is an efficient attribute and the evaluation scale is “worst < worse < bad < general < good < better < best”. Use this evaluation scale to measure attribute “ \( u_i \) ”. When \( \mathbf{v}_{ki} = [\text{good}, \text{better}, \text{best}] \), therefore in view of this risk (as evaluation value’s of plan \( A_k \) on attribute \( u_i \) is uncertainty), the policy-maker can use the following risk evaluation scale \( R_k = \{ r_1^3, r_2^3, r_3^3 \} \) in the policy-maker risk-preference degree table to measure this risk degree. Then obtain the following three tuples: \( (4/6, r_1^3, \lambda_1^3), (5/6, r_2^3, \lambda_2^3) \) and \( (1, r_3^3, \lambda_3^3) \).

**Definition 4.** Call \[ \sum_{j=1}^{m} \omega_j \ell_{ki}^j \text{ as risk-weighted similarity between the plan } A_k \text{ and the range pole plan } A_0 \text{ about the attribute “ } u_i \text{ “, recording “ } \ell_{ki} \text{ “, obviously } 0 \leq \ell_{ki} \leq 1 \ (i = 1, 2, \ldots, m), (k = 1, 2, \ldots, n). \)

When \( \ell_{ki} = 1 \), the risk-weighted similarity attracts the biggest value. When \( \ell_{ki} = 1 \), the risk-weighted similarity attests the smallest value.

**B. Constructing Policy-making Algorithm**

**Risk-weighted similar measure operator (RWSMO)**

RWSMO: \( \tilde{S}^m \rightarrow R, \widetilde{S}^m \) is a set which constructed by m-dimension vectors.

\[ \ell_k = \text{RWSMO}_{W,B}(\mathbf{v}_{k1}, \mathbf{v}_{k2}, \ldots, \mathbf{v}_{km}) = \sum_{i=1}^{m} \omega_i \ell_{ki} = \sum_{i=1}^{m} \omega_i \sum_{j=1}^{p[k,i]} \lambda_j^{p[k,i]} \ell_{ki}^j = \sum_{i=1}^{m} \omega_i \sum_{j=1}^{p[k,i]} \lambda_j^{p[k,i]} \left( 1 - \frac{\| v_j^v - \mathbf{v}_o \|_E}{\| \mathbf{u}_i \|} \right) \]

\( (k = 1, 2, \ldots, n) \)

Where \( W = (\lambda_1^{p[k,i]}, \lambda_2^{p[k,i]}, \ldots, \lambda_m^{p[k,i]}) \) is \( \ell_{ki}^L, \ell_{ki}^R \) policy-maker risk-preference weight vector. \( B = (\omega_1, \omega_2, \ldots, \omega_m) \) is the expert weight vector to the attributes \( u_1, u_2, \ldots, u_m \). \( \omega_i \) is the weight value of attribute \( u_i (i = 1, 2, \ldots, m) \). The symbol \( \mathbf{v}_{ki} \) represents a linguistic sector value. Measure the
plan $A_k$ ($k = 1, 2, \cdots, n$) on the attribute $u_i$ ($i = 1, 2, \cdots, m$) and get a linguistic sector value, recording $\tilde{v}_{ki} = [v_{ki}, v_{k2}, \cdots, v_{km}]$. $v_{oi}$ expresses the attribute $u_i$ ($i = 1, 2, \cdots, m$) value to the range pole plan $A_0$. The symbol $p[k, i]$ expresses the number of linguistic value in the linguistic sector value $“ \tilde{v}_{ki} ”$.

Policy-making algorithm

Before constructing the algorithm make the following work: determine each attribute is the cost attribute or the efficient attribute, as the following method: If the value of attribute $u_i$ ($i = 1, 2, \cdots, n$) and policy-making goal are respectively changing, the attribute $u_i$ is an cost attribute and $u_i = 0$; Otherwise attribute $u_i$ is an efficient attribute, and $u_i = 1$.

Multi-attribute Decision-making Algorithm

Input: 
(1) attributes' value $\tilde{v}_k = (\tilde{v}_{k1}, \tilde{v}_{k2}, \cdots, \tilde{v}_{kn})$, $k = (1, 2, \cdots, n)$, where $m$ is the number of attributes, $n$ is the number of plans. Total $m \times n$ the linguistic sector values, The symbol “$v_{ki}^L$” represents the left limit value in the linguistic sector value “$\tilde{v}_{ki}$”, “$v_{ki}^R$” represents the right limit value in linguistic sector value “$\tilde{v}_{ki}$”.

(2) $(u_1, u_2, \cdots, u_n)$

(3) $\{\lambda_1, \lambda_2, \lambda_3, \cdots, \lambda_p\}$, m, n.

(4) Expert weight vector ($\omega_1, \omega_2, \cdots, \omega_m$)

Output: The optimalizing plan.

Begin

Step1: Separately extract the right limit value and left limit value of the linguistic value set $\tilde{v}_k$ $\cup$ $\tilde{v}_2$ $\cup$ $\cdots$ $\cup$ $\tilde{v}_m$, respectively recording $v_{i}^R$ and $v_{i}^L$ ($i = 1, 2, \cdots, n$).

Step2: $v_{oi} = v_{i}^L$ ($i = 1, 2, \cdots, n$), then may extract the range pole plan $A_0 = (v_{o1}, v_{o2}, \cdots, v_{on})$.

Step3: According to the formula $\|v_i\| = \max (\|v_i - v_{01}\|, \|v_i - v_{02}\|, \cdots, \|v_i - v_{0m}\|)$ ($i = 1, 2, \cdots, m$), extract the biggest deviation of each attribute value.

Step4: Extract the value $p[k, i]$ according to the following method: $p[k, i]$ equals the number of linguistic value in the linguistic sector value “$\tilde{v}_{ki}$”. According to the formula $p = \max(p[k, i], (i = 1, 2, \cdots, m), (k = 1, 2, \cdots, n))$, get the value “P”. Then policy-makers construct their risk-preference degree table according to their risk-preference.

Step5: According to the formula $\ell_{kj} = 1 - \frac{v_{j}^L - v_{0j}}{\|v_i - v_{0j}\|}$ ($j = 1, 2, \cdots, p[k, i]$), get all possible limit similarity between the plan $A_k$ and the range pole plan $A_0$ about the attribute $u_j$. According to the number of linguistic value in the linguistic sector value “$\tilde{v}_{ki}$”, determine the corresponding risk evaluation scale (method: select the risk evaluation scale in which the number of risk-degree value is equal to $p[k, i]$). Then can construct the corresponding three tuples ($\ell_{kj}$, Risk-degree, Risk preference value), ($i = 1, 2, \cdots, m$) ($k = 1, 2, \cdots, n$) ($j = 1, 2, \cdots, p[k, i]$).

Step6: According to the formula $\ell_{ki} = \sum_{j=1}^{p[k, i]} \lambda_j \rho_{kj} \ell_{kj}$, get risk-weighted similarity between the plan $A_k$ and the range pole plan $A_0$.

Step7: According to the formula $\ell_k = \sum_{i=1}^{m} \omega_i \ell_{ki}$ ($k = 1, 2, \cdots, n$), get risk-weighted similarity between the plan $A_k$ and the range pole plan $A_0$.

Step8: $A_k$ ($k = 1, 2, \cdots, n$) carry on sorting according to the corresponding the descending sequence of value $\ell_k$. The first plan is the best plan.

End

II. CONSTRUCTING POLICY-MAKING ALGORITHM FOR THE SECTOR VALUE MULTI-ATTRIBUTE DECISION-MAKING BASED ON THE MULTIPLE-VALUED INTUITIVE FUZZY SETS

In decision-making process, as the decision information is unprecise, incomplete and so on, in addition the policy-maker’s information-handling capacity is limit. So sometimes gain the precise attribute’s evaluation value is very difficult, even was impossible. Conducting the research to this kind of multi-objective decision making containing the incomplete information is further expansion to the research of the traditional multi-objective decision making question. For the fundamental research and solving actual problems, the sector multi-objective decision making question gains more and more people’s attention. In this part, for the two major difficulties (As the information about attributes is indefinite, how to express the indefinite information; as the information has multi-channels, how to fuse the information into synthetic information.) in the multi-objective decision making process, introduce the multiple-valued intuitive fuzzy sets into the multi-objective decision making question, and construct one
new algorithm for interval value multi-objective decision making based on the multiple-valued intuitive fuzzy sets.

A. Multiple-valued intuitive fuzzy sets information fusion

**Definition6.** (multiple-valued intuitive fuzzy sets [12]) Suppose \( X \) as the given domain, then a multiple-valued intuitive fuzzy sets in \( X \) is:

\[
A = \{x, [\mu^A_1(x), \mu^A_2(x), \ldots, \mu^A_n(x)]
\]

\[
, [\gamma^A_1(x), \gamma^A_2(x), \ldots, \gamma^A_n(x)] > [x \in X]
\]

Where, \( \mu^A_i(x) : X \rightarrow [0,1] \), \( \gamma^A_i(x) : X \rightarrow [0,1] \)

Represent the first “\( i \)” membership function \( \mu^A_i(x) \) and the non-membership function \( \gamma^A_i(x) \), and \( \forall x \in X \), \( 0 \leq \mu^A_i(x) + \gamma^A_i(x) \leq 1, (i = 1, 2, \ldots, n) \) is establishment.

Represent the multiple-valued intuitive fuzzy sets \( A \) as:

When given domain \( X \) is the continual space:

\[
A = \int < [\mu^A_1(x), \mu^A_2(x), \ldots, \mu^A_n(x)]
\]

\[
, [\gamma^A_1(x), \gamma^A_2(x), \ldots, \gamma^A_n(x)] > [x, x \in X]
\]

When given domain \( X \) is the discrete space, suppose \( X = \{x_1, x_2, \ldots, x_n\} \):

\[
A = \sum_{j=1}^{m} < [\mu^A_1(x_j), \mu^A_2(x_j), \ldots, \mu^A_n(x_j)]
\]

\[
, [\gamma^A_1(x_j), \gamma^A_2(x_j), \ldots, \gamma^A_n(x_j)] > [x_j, x_j \in X],
\]

\( j = 1, 2, \ldots, m \).

B. Degree of membership or non-degree of membership of multiple-valued intuitive fuzzy set information fusion

The degree of membership or non-degree of membership of multiple-valued intuitive fuzzy sets information fusion refers to fusing the degree of membership or non-degree of membership into one degree of membership or non-degree of membership, thus multiple-valued intuitive fuzzy sets will be transformed into a general intuitive fuzzy sets. Suppose \( A \) as a multiple-valued intuitive fuzzy set:

\[
A = \{x, [\mu^A_1(x), \mu^A_2(x), \ldots, \mu^A_n(x)]
\]

\[
, [\gamma^A_1(x), \gamma^A_2(x), \ldots, \gamma^A_n(x)] > [x \in X]
\]

Following, construct several methods to fuse this multiple-valued intuitive fuzzy sets into a general intuitive fuzzy sets

\[
B = \{x, \mu_B(x), \gamma_B(x) > [x \in X]
\]

(1) Median method

(1.1) The median of the material not grouped

Firstly group various degrees of membership or the non-degree of membership’s value by ascending. Then, compute median:

When \( n \) is an even number:

\[
\mu_B(x) = \frac{\mu^A_{n/2}(x) + \mu^A_{n+1/2}(x)}{2}
\]

\[
\gamma_B(x) = \frac{\gamma^A_{n/2}(x) + \gamma^A_{n+1/2}(x)}{2}
\]

(1.2) The median of the material grouped

If the material has grouped, and establishes distribution list, then calculate the median using the distribution list, its formula is:

\[
\mu_B(x) = L_{\mu} + \frac{i_{\mu}}{f_{\mu}} (n - c_{\mu})
\]

\[
\gamma_B(x) = L_{\gamma} + \frac{i_{\gamma}}{f_{\gamma}} (n - c_{\gamma})
\]

In the formula: \( L_{\mu}, L_{\gamma} \) — lower limit; \( i_{\mu}, i_{\gamma} \) — interval; \( f_{\mu}, f_{\gamma} \) — number of times; \( n \) — total degree;

\( c_{\mu}, c_{\gamma} \) — number of times smaller than the median.

(2) Simple weighted arithmetic average method

(3) Harmonic mean method

(3.1) Simple harmonic mean method

\[
\mu_B(x) = \frac{1}{\sum_{i=1}^{n} \frac{1}{\mu^A_i(x)}} = \frac{n}{\sum_{i=1}^{n} \mu^A_i(x)}
\]

\[
\gamma_B(x) = \frac{1}{\sum_{i=1}^{n} \frac{1}{\gamma^A_i(x)}} = \frac{n}{\sum_{i=1}^{n} \gamma^A_i(x)}
\]

(3.2) Weighting harmonic mean method

\[
\mu_B(x) = \frac{1}{\sum_{i=1}^{n} \frac{\lambda_i}{\mu^A_i(x)}} = \frac{1}{\sum_{i=1}^{n} \lambda_i \mu^A_i(x)}
\]

\[
\gamma_B(x) = \frac{1}{\sum_{i=1}^{n} \frac{\lambda_i}{\gamma^A_i(x)}} = \frac{1}{\sum_{i=1}^{n} \lambda_i \gamma^A_i(x)}
\]

Where \( \lambda_1, \lambda_2, \ldots, \lambda_n \) satisfy the following conditions:

\[
\sum_{i=1}^{n} \lambda_i = 1, 1 \geq \lambda_i \geq 0 (i = 1, 2, \ldots, n)
\]

(4) Combination of mean values [13]

The combination mean value defers that many kinds of traditional mean values carry on the weighted average. Therefore, its formula is:

\[
p_0 = \sum_{i=1}^{n} \omega_i p_i
\]

In the formula: \( P_0 \) — combination mean value; \( p_i \) — different type mean value, where \( i = 1, 2, \ldots, n \) (similarly
hereinafter, omitted); $\omega_i$ — weight of various mean values, they satisfy $\sum_{i=1}^{n} \omega_i = 1$. Combination mean value may collect each kind of mean value the superiority, reflects more accurately the information in the general level of data.

(5) Mathematics optimization method

Regarding each pair $< \mu_i^A, \gamma_j^A >$ $(i = 1, 2, \cdots, n)$ in the multiple-valued intuition fuzzy set. Each of them expresses information which obtains from the different attributes. When carry on the information fusion, a very natural idea is: In the information fusion process, as far as possible to make the modification to the existing information to a minimum. We may establish the following mathematical programming model according to this principle:

When is X a continual space:

$$\min \left[ \int \left( \sum_{i=1}^{n} \left( \mu_i^A(x) - \mu_B(x) \right)^2 + \sum_{i=1}^{n} \left( \gamma_j^A(x) - \gamma_B(x) \right)^2 \right) dx \right]$$

s.t. $0 \leq \mu_B(x) + \gamma_B(x) \leq 1$

$$0 \leq \mu_B(x) \leq 1$$

$$0 \leq \gamma_B(x) \leq 1$$

$x \in X$

(A1)

Through solving the optimize question (A1), may obtain the various parameters' estimated value in the function $\mu_B(x)$ and $\gamma_B(x), (x \in X)$.

When is $X$ the discrete space:

$$\min \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} \left( \mu_i^A(x_j) - \mu_B(x_j) \right)^2 + \sum_{i=1}^{n} \sum_{j=1}^{m} \left( \gamma_j^A(x_j) - \gamma_B(x_j) \right)^2 \right]$$

s.t. $0 \leq \mu_B(x_j) + \gamma_B(x_j) \leq 1$

$$0 \leq \mu_B(x_j) \leq 1$$

$$0 \leq \gamma_B(x_j) \leq 1$$

$(j = 1, 2, \cdots, m)$

(A2)

Through solving the optimize question (A2), may obtain the following values: $\mu_i^A(x_j), \gamma_j^A(x_j), x_j \in X$ $(j = 1, 2, \cdots, m)$ $(i = 1, 2, \cdots, n)$.

C. Constructing decision method

Suppose $A = \{ A_1, A_2, \cdots, A_n \}$ to the decision plan set and $U = \{ u_1, u_2, \cdots, u_m \}$ to the attribute set. When carry on the qualitative measure to attributes, generally need suitable language evaluation scale. Therefore, we should establish language evaluation scale $S = \{ s_a \mid a = -t, \cdots, t \}$ where $s_a$ express language Variables. Specially $s_0$ and $s_t$ separately express the scale's low limit and the up limit. The commonly used language evaluation scale may be: Third-level evaluation scale $S_1 = \{ \text{bad, general, good} \}$, seven-level evaluation scale $S_2 = \{ \text{worst, worse, bad, general, good, better, best} \}$ or $\{ \text{smallest, smaller, small, general, big, bigger, biggest} \}$ and so on. Introduce mark $ \prec $ to express relation in various linguistic values. Define “bad $ \prec $ general $ \prec $ good”, in this format rank-number of a linguistic value setting the left of “$ \prec $” is smaller “1” to that of a linguistic value setting the right of “$ \prec $”, and the rank-number can be accumulated. For example: In this third-level evaluation scale “bad $ \prec $ general $ \prec $ good” may promote the rank-number of the linguistic value “good” is bigger 2 to that of the linguistic value “bad”. But can not promote “bad $ \prec $ good”, because “bad” is smaller two ranks to “good”, but is not one rank. May similarly definite in seven-level of evaluation scales $S_2$, “worst $ \prec $ worse $ \prec $ bad $ \prec $ general $ \prec $ good $ \prec $ better $ \prec $ best” or “smallest $ \prec $ smaller $ \prec $ small $ \prec $ general $ \prec $ big $ \prec $ bigger $ \prec $ biggest”. Symbol $ \tilde{v}_{ki} $ represent a value by measuring the attribute $ u_i $ $(i = 1, 2, \cdots, m)$ of plan $ A_k $ $(k = 1, 2, \cdots, n)$.

Supposes $ \tilde{v}_i = \bigcup_{k=1}^{n} \tilde{v}_{ki} $, the right margin value which records is. Records the right margin value of $ \tilde{v}_i $ as $ \tilde{v}_i^R $, the left margin value of $ \tilde{v}_i $ as $ \tilde{v}_i^L $.

Definition 7. Policy-maker takes a value in an indefinite value, and supposes that attribute’s value is not smaller than this value. Then calls this spot as the vacillation decision point. Obviously as the vacillation decision point toward the right migration, the plan's performance is better in this attribute. When carries on the decision-making at this kind of suppose, policy-maker must withstand the bigger risk. Therefore the vacillation decision point's integer and policy-maker's risk manner has the relation.

Policy-makers risk preferences
People carry on the decision-making at the definite condition, because policy-maker risk preferences is different. With a programme, to a certain decision-makers policy makers it is a certain optimal programme, but in terms of other policy-makers it is’s necessarily optimal programme. Therefore in the indefinite multi-objective decision making, considers policy-maker’s risk preferences is very essential.

**TABLE II.**

<table>
<thead>
<tr>
<th>Risk scale</th>
<th>Risk-income balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_2 = { r^2_1, r^2_2 }$</td>
<td>$W_2 = { \lambda^2_1, \lambda^2_2 }$, where $\lambda^2_1 + \lambda^2_2 = 1$ $0 \leq \lambda^2_1, \lambda^2_2 \leq 1$</td>
</tr>
<tr>
<td>$R_3 = { r^3_1, r^3_2, r^3_3 }$</td>
<td>$W_3 = { \lambda^3_1, \lambda^3_2, \lambda^3_3 }, \lambda^3_1 + \lambda^3_2 + \lambda^3_3 = 1$ $0 \leq \lambda^3_1, \lambda^3_2, \lambda^3_3 \leq 1$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$R_n = { r^n_1, r^n_2, \cdots, r^n_p }$</td>
<td>$W_p = { \lambda^n_1, \lambda^n_2, \cdots, \lambda^n_p }, \lambda^n_1 + \lambda^n_2 + \cdots + \lambda^n_p = 1$ $0 \leq \lambda^n_1, \lambda^n_2, \cdots, \lambda^n_p \leq 1$</td>
</tr>
</tbody>
</table>

**Note:** On this table, in every risk evaluation scale, the risk degree along with the subscript increases. The value $\lambda$ expresses risk-preference degree of policy-maker. The more the value of $\lambda$ is big, the more policy-maker is like to the corresponding risk degree, $p = \max( p[k,i]$, $(i = 1,2,\cdots,m)$, $(k = 1,2,\cdots,n)$ )

Sector value discretization: Suppose $M$ as the most district of span in all sector value (Before asks district of span, carry on standardized processing. Approach is that the right margin value and the left margin value respectively divide maximum value of this attribute).

Supposes $g = \frac{M}{p - 2}$, divide the various standardized sectors with $g$, then obtain a series of break points (including the right margin value and the left margin value), separately record as $v^{ki}_L, v^{ki}_R, \cdots, v^{ki}_{p[k,i]}$, and take these break points as vacillation decision point.

**Using the intuitive fuzzy sets to express the indefinite information**

In 3.1. We can express the uncertainty information of the value of $\tilde{v}_{ki}$ as a series of intuitive fuzzy values owing different degrees of risk, respectively records as $< \mu_{ki}, \gamma_{ki} >, \lambda^j_{p[k,i]}$ $j = 1,2,\cdots,p[k,i]$.

Transformation method:

$$
\mu_{ki}^{j} = \frac{v_{kj}^L - \tilde{v}_i^L}{\tilde{v}_i^L - v_{kj}^L}
$$

$$
\gamma_{ki}^{j} = \frac{\tilde{v}_i^R - v_{ki}^R}{\tilde{v}_i^R - \tilde{v}_{ki}^R}
$$

Where symbolic $\| x - y \|$ represent distance or grading number between value $x$ and value $y$.

With the information fusion methods which are constructed in the previous section, can transform these multiple-valued intuitive fuzzy sets into an ordinary intuitive fuzzy sets, record as:

$$
\hat{B} = \{ \mu_1, \gamma_1 > / A_1, \mu_2, \gamma_2 > / A_2, \cdots, \mu_n, \gamma_n > / A_n \}
$$

According to the indefinite multi-objective decision making’s characteristic, the weighted average method is a good fusion method:

$$
\mu_k (A_k) = \sum_{j=1}^{p[k,i]} \lambda^j_{p[k,i]} \mu_{kj} (A_k)
$$

$$
\gamma_k (A_k) = \sum_{j=1}^{p[k,i]} \lambda^j_{p[k,i]} \gamma_{kj} (A_k) \quad \text{ (B)}
$$

Speaking of each decision scheme, the most ideal result is $< 1,0 >$.

Intuitive fuzzy value similar measure method:

The massive literature has conducted the research to the intuitive fuzzy value similarity measure method (Vague similarity measure method). The intuitive fuzzy value’s similar measure method may profit from the fuzzy similar measure method. In the literature [14] construct a method, as follows:

Suppose $x = [\mu_x, \gamma_x]$ and $y = [\mu_y, \gamma_y]$ as two intuitive fuzzy value in the given domain, the similar measure formula as follows:

$$
S(x, y) = 1 - \sqrt{\frac{(\mu_x - \mu_y)^2 + (\gamma_x - \gamma_y)^2}{2}} \quad \text{ (C)}
$$

**Policy-making algorithm:**

**Step 1:** Respectively appraisal each decision scheme according to each attributes and carries on standardized processing to each appraisal result.

**Step 2:** The policy-maker determines the policymaker risk-income balance table according to the subjective and objective condition. Based on this carries on discretization processing to each sector value, and determines vacillation decision point of each indefinite value.

**Step 3:** With formula (A), can express the uncertainty information of the value of $\tilde{v}_{ki}$ as a series of intuitive fuzzy values owing different degrees of risk.

**Step 4:** With the information fusion methods which are constructed in the Part 2, can transform these multiple-valued intuitive fuzzy sets into an ordinary intuitive fuzzy sets.

**Step 5:** With formula (C), extract similarity between $< A_i, \mu_i, \gamma_i > (i = 1,2,\cdots,n)$ and $< 1,0 >$, record as $\ell_i$.
Step 6: $A_k (k = 1,2, \cdots ,n)$ carry on sorting according to the corresponding the descending sequence of value $\ell_k $. The first plan is the best plan.

III. EXAMPLE

Consider one venture capital company which carries on the high tech project investment. Five alternative enterprises (plan) $A_k (k = 1,2, \cdots ,5)$ can be chosen. Carry on the appraisals from the angle of those enterprises ability's, firstly formulate seven appraisal targets (attribute) [15]: The marketing capacity ($u_1$), the managed capacity ($u_2$), productivity ($u_3$), technical ability ($u_4$), fund ability ($u_5$), risk exposure ability ($u_6$), the uniformity of enterprise strategy ($u_7$). Obviously, these seven attributes are the efficient attribute. Use the seven-level evaluation scale to measure these seven attributes, which is “worst < worse < bad < general < good < better < best” or “smallest < smaller < small < general < big < bigger < biggest”. Might as well use the mark “$S_1 < S_2 < S_3 < S_4 < S_5 < S_6 < S_7$” to express the corresponding linguistic value. Then obtain the policy-making matrix (shown as Table 2). Try to determine the best enterprise.

<table>
<thead>
<tr>
<th>$u_1$</th>
<th>$u_2$</th>
<th>$u_3$</th>
<th>$u_4$</th>
<th>$u_5$</th>
<th>$u_6$</th>
<th>$u_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>$[s_5,s_3]$</td>
<td>$[s_3,s_4]$</td>
<td>$[s_3,}$</td>
<td>$[s_6,s_4]$</td>
<td>$[s_6,s_5]$</td>
<td>$[s_5,s_6]$</td>
</tr>
<tr>
<td>$A_2$</td>
<td>$[s_5,s_6]$</td>
<td>$[s_4,s_5]$</td>
<td>$[s_6,}$</td>
<td>$[s_6,s_4]$</td>
<td>$[s_6,s_5]$</td>
<td>$[s_5,s_6]$</td>
</tr>
<tr>
<td>$A_3$</td>
<td>$[s_5,s_3]$</td>
<td>$[s_3,s_4]$</td>
<td>$[s_5,}$</td>
<td>$[s_6,s_4]$</td>
<td>$[s_6,s_5]$</td>
<td>$[s_5,s_6]$</td>
</tr>
<tr>
<td>$A_4$</td>
<td>$[s_5,s_3]$</td>
<td>$[s_4,s_5]$</td>
<td>$[s_5,}$</td>
<td>$[s_5,s_6]$</td>
<td>$[s_6,s_4]$</td>
<td>$[s_5,s_6]$</td>
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<tr>
<td>$A_5$</td>
<td>$[s_5,s_6]$</td>
<td>$[s_4,s_5]$</td>
<td>$[s_5,}$</td>
<td>$[s_5,s_6]$</td>
<td>$[s_6,s_4]$</td>
<td>$[s_5,s_6]$</td>
</tr>
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</table>

Obviously the above 7 attributes are the efficient attribute, then $(u_1,u_2$, $\cdots ,u_7) = (1,1,1,1)$ . Policy-makers carry on measuring their risk preference, Obtain the following policy-maker risk-preference degree table (shown as Table 3).

Carry on the above algorithm to this multi-objective decision making. Obtain the following result (shown as Table 4):

Obviously, $\ell_2 > \ell_4 > \ell_3 > \ell_5 > \ell_1$. Therefore, the enterprise is the best enterprise.

<table>
<thead>
<tr>
<th>Table IV. POLICY-MAKER RISK-PREFERENCE DEGREE TABLE</th>
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</thead>
<tbody>
<tr>
<td>Risk evaluation scale</td>
</tr>
<tr>
<td>$R_2 = {r_1^2, r_2^2}$</td>
</tr>
<tr>
<td>$R_3 = {r_1^3, r_2^3, r_3^3}$</td>
</tr>
<tr>
<td>$R_4 = {r_1^4, r_2^4, r_3^4, r_4^4}$</td>
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<table>
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<tr>
<th>Table V. MULTI-OBJECTIVE DECISION MAKING RESULT</th>
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<tbody>
<tr>
<td>$\ell_k$</td>
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<tr>
<td>0.6133</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

As society developing, the questions which the people face in the actual decision-making are getting more and more complex. Thus in many situations, as the existing information is insufficient, people often can’t carry on precisely quantitative assessment to the prelection plans. So the very major part of policy-making questions are the linguistic setting or sector multi-objective decision making. In view of practical needs, these multi-objective decision-making gradually receive the numerous researcher's attention.

In the first partion, conduct the research on the linguistic setting multi-objective decision making question, constructe risk-weighted similar measure operator (RWSMO) to measure similar degree size between the prelection plans and the range pole plan, and introduce the risk preferences of the policy-maker to the decision marking. At last, construct one new decision method based on these. This decision method's merit: On the one hand, calculate easily; the final result has the explicit significance—similar degree, It’s advantageous for the policy-maker to understand the model result. On the other hand, consider risk-preference of policy-maker in the decision-making process. So that decision-makers can independently decide some parameters in the decision-making model according to their own characteristics and decision-making environmental changing. The dialogue between decision-making model and decision-makers can make the result of decision-making meeting with specific decision-making environment. Thus let the policy-maker be satisfied to the policy-making result. Innovation in the second partion is that: for the two major difficulties in the multi-objective decision making process, introduce the multiple-valued intuitive fuzzy sets into the multi-objective decision making question, then study the multiple-valued intuitive fuzzy set's information fusion and construct some methods to fuse the information included in the degree of memberships or non-degree of memberships of multiple-valued intuitive
fuzzy set. At last, use the isomorphism mind to research the interval multi-objective decision making and construct one new algorithm for interval value multi-objective decision making based on isomorphism information fusion.

REFERENCES


Zhou Qihai (1947-) is a Full Professor (from 1995), Doctor’s (and Master’s) tutor and a head of Information Technology Application Research Institute, School of Economic Information Engineering, Southwestern University of Finance and Economics (SWUFE), China. He graduated in 1982 from Lanzhou University, China; has been working in SWUFE since 1982, successively hold posts from teaching assistant (1982-1987), lecturer (1987-1991), vice professor (1991-1995, promoted anomaly in 1991), professor (1995-today, promoted anomaly in 1995); and got the titles of both “Outstanding experts (enjoyed government subsidies) with outstanding contributions of Sichuan province, China” (summa cum laude of Sichuan province government, 1996) and “One hundred academic and managerial leading heads of China informationalization” (summa cum laude about this domain in China, 2006). He has published 46 academic books and over 212 academic papers; and is President of IITAA (International Information Technology & Applications Association), Chair or Organizing Chair of some important international conferences. His research interests are in algorithm research, computational geometry, isomorphic information processing, economics & management computation, eBusiness, and so on. More (in Chinese) about Prof. Zhou Qihai is shown here: http://www.iitaa.com/member-ZhouQiHai.doc

LI Yan (1983- ) Ph.D. Graduate students, is studying in School of Economic Information Engineering, Southwestern University of Finance and Economics, Chengdu, Sichuan, China. He has published 13 papers. His research areas are in Non-definite decision-making, intelligence information processing.
Constrained Optimal Controller Design of Aerial Robotics Based on Invariant Sets

Jianqiang Li
College of Computer Science and Software Engineering, Shenzhen University, Shenzhen 518060, China
Email: lijq@szu.edu.cn

Yahui Lu
College of Computer Science and Software Engineering, Shenzhen University, Shenzhen 518060, China.
Email: luyahui@163.com

Zhen Ji
College of Computer Science and Software Engineering, Shenzhen University, Shenzhen 518060, China.
Email: jizhen@szu.edu.cn

Hailong Pei
Department of Automation, South China University of Technology, Guangzhou 510641, China.
Email: auhlpei@scut.edu.cn

Abstract—Constrained optimal control problem of unmanned aerial vehicle (UAV) which is also called aerial robotics is studied in this paper. The nonlinear system of small unmanned helicopter with bounded disturbance is abstracted and modeled by PWA hybrid systems model. As the complexity on-line computation for a class of large hybrid systems, an explicit optimal controller for hybrid systems based on multi-parametric quadratic programming (mp-QP) is proposed. The feasible domain which is the maximal controlled invariant sets for hybrid systems is partitioned in backward dynamic programming by mp-QP method. At each step, one step reachable sets are computed, optimal control laws are constructed to the corresponding regions, and the explicit optimal controller is obtained. Finally simulation results verify the effectiveness of the proposed control method.

Index Terms—aerial robotics, hybrid systems, invariant sets, mp-qp, explicit controller

I. INTRODUCTION

Aerial Robotics (Unmanned helicopter) which is also called unmanned aerial vehicles (UAV), plays important roles in the application of monitor, rescue and aerial photograph. There has been a great deal of interests in the study of unmanned helicopter in the last decade [1].

As the UAV model is a complex high order nonlinear system and the variety of flying environment, the controller is difficult to design. It is common to design double closed loops controller for autonomous helicopter, inner loop for the attitude and outer loop for the trajectory [1]. A linear quadratic regulator is design in the study of Hu and Yue [2-5]. After modeled by hybrid system, Li designed a model predictive controller of UAV [6]. However, the study of optimal performance and the real time control are still the important points for the UAV.

In this paper, based on the study before, the nonlinear unmanned helicopter is modeled by hybrid systems on the states of hover and forward flying. In the flying envelop of the UAV system, maximal invariant set is computed for the attitude as the feasible domain [1]. In the security area, an explicit optimal algorithm is designed for the UAV controller by back-step dynamic program, the performance of real time is guaranteed. In the optimal control, on step multi-parametric program method is extended to hybrid system. Optimal control problem is resolved by multi efficient domains and sub-systems multi-parametric program, one back-step reachable sets is computed, and the explicit relation of optimal control and systems states is constructed. Different from the paper[7], bounded disturbance is considered in the invariant set computing and controller design.

The rest of this paper is organized as follow: the hybrid model of unmanned helicopter with bounded disturbance is described in Section 2, then the invariant set is introduced in Section3, the optimal controller is designed in Section 4, followed by some simulation in the next Section. Conclusions and further discussion are given in Section 6.

II. HYBRID SYSTEMS MODEL OF UAV

A. Nonlinear model of UAV
The system of unmanned helicopter is shown in Fig.1, which contains 11 states and 4 control inputs, the nonlinear dynamic is given as follow[2]:

$$\dot{x} = f(x, u, t) + h$$

$$x = [u \ v \ w \ p \ q \ r \ \phi \ \theta \ \psi \ a_1 \ b_1]^T$$

$$u = [\delta_{col} \ \delta_{lon} \ \delta_{lat} \ \delta_1]^T, h \in \mathcal{I}$$

In equation (1), \( h \) is the bounded disturbance of \( \mathcal{I} \), the column vector \( x \) is the states of the small unmanned helicopter, \( u, v, w \) denote the velocity with respect to the body-coordinate frame, \( \phi, \theta, \psi \) denote roll, pitch and yaw, and \( p, q, r \) are their rates. The longitudinal and latitudinal swing angle of rotary wing are \( \delta_{lon}, \delta_{lat} \), and the tail blade pitch angle \( \delta_1 \).

\( f \) is a nonlinear function which describes the relationship of unmanned helicopter with input control and external disturbance, it can be given as follow:

$$\dot{u} = vr - wq - g \sin \theta + (X_{mr} + X_{fus})/m$$

$$\dot{v} = wp - ur + g \sin \phi \cos \theta + (Y_{mr} + Y_{fus} + Y_{v})/n$$

$$\dot{w} = uq - vp + g \cos \phi \cos \theta + (Z_{mr} + Z_{fus} + Z_{lat})/m$$

$$\dot{p} = qr(I_{yy} - I_{zz})/I_{xx} + (L_{mr} + L_{fus} + L_{v})/I_{xx}$$

$$\dot{q} = pr(I_{zz} - I_{xx})/I_{yy} + (M_{mr} + M_{fus} + M_{v})/I_{yy}$$

$$\dot{r} = pq(I_{xx} - I_{yy})/I_{zz} + (-Q_{mr} + N_{fus} + N_{v})/I_{zz}$$

$$\dot{\phi} = p + q \cdot \sin \phi \cdot \tan \theta + r \cdot \cos \phi \cdot \tan \theta$$

$$\dot{\theta} = q \cdot \cos \phi - r \cdot \sin \phi$$

$$\dot{\psi} = q \cdot \sin \phi / \cos \theta + r \cdot \cos \phi / \cos \theta$$

$$\dot{a}_1 = -q / \tau_e + 1 / \tau_e \left( \frac{\partial a_1}{\partial \mu} \frac{u - u_m}{\Omega R} + \frac{\partial a_1}{\partial \mu_v} \frac{w - w_m}{\Omega R} \right) + A_{bmn} / \tau_e \delta_{lon}$$

$$\dot{b}_1 = -p / \tau_e - 1 / \tau_e \left( \frac{\partial b_1}{\partial \mu_v} \frac{v - v_m}{\Omega R} + B_{blat} / \tau_e \delta_{lat} \right)$$

In equation (2), \( m \) is the mass of UAV, \( X, Y, Z, L, M, N \) denote the forces and torques acting on the helicopter, \( I_{xx}, I_{yy}, I_{zz} \) are moments of inertia of the helicopter, \( Q_{mr} \) is torque of motor, the rotational speed of main motor is \( \Omega, I_{rot} \) is the rotation inertia of main rotor blade, \( A_{lom} \) and \( B_{lat} \) are longitudinal and latitudinal gains, the subscript \( mr \) stands for main blade, \( fus \) stands for helicopter, \( tr \) stands for tail rotor, \( vf \) stands for vertically tail, \( ht \) stands for level tail. The nonlinear model detail of small unmanned helicopter can be found in [2].

B. Trimming calculation of UAV

It is difficult to design the controller of UAV, as high order nonlinear model of unmanned helicopter. At an equivalent point, the nonlinear model is approximate linearized, controller is design based on the linear model. This paper mainly studies the states of hover and the forward speed of 3m/s. The equivalent points is trimming calculated first, the control input and attitudes are computed at trim state as given the fly condition. The constant linear flight is discussed, so the force and torque are at balance condition. Acceleration, angular velocity, and angular acceleration are equal to zero, then the trimming equations can be constructed, the trimming value also can be calculated.

C. Hybrid systems model

For UAV, several mode can be constructed as Fig.2, states of hover and 3m/s forward speed is considered in this paper. At the equivalent points of hover and 3m/s forward speed, the nonlinear model is linearized first.

For the nonlinear system (1), the output is given as (3):

$$y = [1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0] x$$

1 outputs can be selected for the nonlinear system, and the corresponding equivalent points are calculated. By Jacobi linearization, linear model can be obtained at the equivalent points [2]. At the equivalent points \((x, u, y)\),
the form of linear model $\sigma_i$ can be described as follow [8]:

$$\dot{x} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial u} \end{bmatrix}_{x=x_0} x + \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial u} \end{bmatrix}_{x=x_0} u + h$$

\text{t. } y_i - \varepsilon_i \leq y \leq y_i + \varepsilon_i \tag{4}

Suppose $A_i = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial u} \end{bmatrix}_{x=x_0}$, $B = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial u} \end{bmatrix}_{x=x_0}$, rigid body assumption is considered to resolve the problem that the swing angle can not be measured. The differential equation of swing angle is replaced by stable relation. As the horizontal plane of unmanned helicopter is studied in this paper, the six degrees of freedom can abstracted to three degrees of freedom model. The longitudinal variables of model are set to zero [4]:

$$w = 0, \quad p = 0, \quad q = 0, \quad \phi = 0, \quad \theta = 0$$

the linear model can be obtained by reduced order:

$$\dot{x} = A_i x(t) + B_i u(t) + h$$ \tag{5}

The column vector $x$ is the system states of abstract model, containing 9 states: two dimensions speed, the angle and attitude of yaw:

$$x = [u \quad v \quad r \quad \psi]^T$$ \tag{6}

$$u = [\delta_{\text{col}} \quad \delta_{\text{lon}} \quad \delta_{\text{lat}} \quad \delta_i]^T$$ \tag{7}

$$y = [1 \quad 0 \quad 0 \quad 0]^T x$$ \tag{8}

The nonlinear system can be described by the subsystem of hybrid systems (5). The transition condition between the modes should be determined according to the system condition. Invariant sets is computed as safety in section

III. INVARIANT SETS

An (positive) invariant set of a dynamic system is a subset of the state space that once the state enters this set it will remain in it for all future times in it [15]. i.e

$$x(0) \in X \rightarrow x(t) \in X \quad \text{for all } t>0.$$  

Where $x(t)$ is the subset of the dynamic at time of $t$ and $X$ is a subset of the state space.

Consider the continuous dynamic system

$$\dot{x}(t) = f(x(t))$$ \tag{9}

Where $f : \mathbb{R}^n \rightarrow \mathbb{R}^n$ is a continuous Lipschitz function. An sufficient and necessary for $X$ is the invariant set is that the differential equation is directed into the set at each point on the boundary: $\partial X$.

**Definition 2** (Bouligand, 1932).Let a closed set $\kappa \subset \mathbb{R}^n$. The tangent cone to $\kappa$ in $x$ is the set

$$\kappa_{\nu} = \left\{ z \in \mathbb{R}^n : \lim_{h \rightarrow 0} \frac{\text{dist}(x_0 + hz, \kappa)}{h} = 0 \right\} \tag{10}$$

The definition is due to Bouligand as Fig. 3. Note that if $x_0 \in \text{int}\{\kappa\}$, the interior of $\kappa$, then $\kappa_{\nu} = \mathbb{R}^n$. if $x_0 \notin \text{int}\{\kappa\}$, then $\kappa_{\nu} = \phi$ and $x_0 \in \partial \kappa$, the tangent cone is a cone which contains all the vectors which direct from $x_0$ into the set $\kappa$.

**Theorem 1** (Nagumo, 1942) Assume the system (9) admits a unique solution for $x_0 \in \mathbb{R}^n$. The closed set $\kappa$ is positively set for the system (9) if and only if for all $x \in \kappa$.

$$f(x) \in \kappa_{\nu}$$ \tag{11}

From the theorem, a necessary and sufficient condition for system (9) is every point on the boundary $\partial \kappa$ is directed into the set. This can be expressed as below:

$$n_x(x) \in \gamma_x(x) \leq 0 \quad \forall x \in \kappa$$ \tag{12}

Where $n_x(x)$ denotes a normal to $\partial \kappa$ at $x$. The invariant set is described by an inequality

$$\kappa = \{ x \in \mathbb{R}^n | V(x) \leq b \} \tag{13}$$

$V(x)$ which defines the invariant set is a function of $x$.

There are two important families of invariant sets. These are the classes of ellipsoidal sets and polyhedral sets. Mode transition dynamic system or continuous systems have these types of invariant sets.

**A Ellipsoidal sets**

Ellipsoidal sets are used widely as invariant sets in continuous system. From the existence of a quadratic Lyapunov function for such system and that level sets of Lyapunov functions are invariant sets [15]. A corollary can be deduced from it:

**Corollary 1** A system $\dot{x} = A(x), x \in \mathbb{R}^n, A \in \mathbb{R}^{nxn}$, if A has all non-positive real-part eigenvalues , then the system has ellipsoidal invariant set.

Ellipsoidal sets are popular invariant sets. An ellipsoidal invariant set can be expressed as follow:

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\[ \delta = \{ x \in \mathbb{R}^n \mid x^T Px \leq 1 \} \quad (14) \]

Or

\[ \delta = \{ x \in \mathbb{R}^n \mid (x - x_a)^T P(x - x_a) \leq 1 \} \quad (15) \]

\[ P > 0 \text{ is symmetry matrix, and } x_a \text{ is the center of the ellipsoidal invariant.} \]

The invariant sets can be computed as convex optimization problems as follows:

Minimize \( \log \det P^{-1} \)
Subject to \( P > 0 \), \( \tau \)
\[ \text{LMI}(P,q) \quad (16) \]

Where \( P^T = P \in \mathbb{R}^{n \times n} \) and \( P \) is positive definite. This is convex optimization problem and can be solved by LMI tools [16]. As an ellipsoidal invariant problem, this set can be computed as follows:

Minimize \( \log \det P^{-1} \)
Subject to \( A^T P + PA \preceq 0 \), \( \tau \)
\[ P > 0 \quad (17) \]

Given a set of initial states \( \delta_0 \), the condition \( \delta_0 \subseteq \delta \) can be formulated as a linear matrix inequality using the so called S-procedure[14]. It can be described as follow: \( \tau > 0 \),

\[
\begin{bmatrix}
P & 0 \\
0 & -1 \\
\end{bmatrix}^{-\tau}
\begin{bmatrix}
P_0 & -P_0x_0 \\
x_0^TP & x_0^TPx_0 - 1 \\
\end{bmatrix} \preceq 0 \quad (18)
\]

\( P \) and \( \tau \) are the variables of the linear matrix inequality. The last \( p \) inequalities in (11) can be substituted. A convex optimization problem for computing the smallest invariant sets that contains \( \delta_0 \). The LMI is change as follow by a slight variation.

\[
\begin{bmatrix}
C_N & C^Td \\
0 & 1 \\
\end{bmatrix}^T Q(\tau)
\begin{bmatrix}
C_N & C^Td \\
0 & 1 \\
\end{bmatrix} \preceq 0 \quad (19)
\]

\( C^d \) is the pseudo inverse of \( C \), the columns of \( C_N \) is a basis of the nullspace of \( C \), and \( Q(\tau) \) is the left side of the LMI in (19) [17].

For the system \( \dot{x} = Ax + Bu \) with control, consider the follow equation for the invariant set \( \delta \) is contractive.

\[ (A + BK)^T P + P(A + BK) \prec 0 \quad (20) \]

As \( P \) and \( K \) are bilinear in the equation, thus it is not easy to handle. But the both side of the in-equation can be multiply by \( Q \preceq P^{-1} \), and parameterized \( K \) as \( K = YP \) to achieve the linear matrix inequality as follow.

\[ QA^T + AQ + Y^T B^T + BY \prec 0, Q > 0 \quad (21) \]

The linear matrix inequality is easy to handle. It can be computed by LMI toolbox of MATLAB, and \( \delta \) is contractive with linear control as follow form:

\[ u(t) = -\gamma B^T Px(t), \quad \gamma > 0 \quad (22) \]

The above property can be easily extended to the case of an uncertain pair \((A, B)\).

\[ B \text{ Polyhedral sets} \]

In fact, polyhedral sets are often natural expressions of physical constraints on states and control variable to the invariant sets. However, the shape of the polyhedral sets is more flexible than that of the ellipsoid, this leads to better approximation to the invariant sets and domain of dynamic systems. This flexible property makes polyhedral sets more representation in the computation.

A polyhedral set can be represented in the following form[15]:

\[ \delta = \{ x : Fx \leq \tilde{I} \} \quad (23) \]

where \( F \) is a \( r \times n \) matrix, and \( \tilde{I} \in \mathbb{R}^r \) denotes a vector of the form

\[ \tilde{I} = [1 \ 1 \ \ldots \ 1]^T \]

The computation of polyhedral invariant sets is difficult than the computation of an ellipsoidal sets. There are mainly two methods to constructive the polyhedral invariant sets: iterative methods which use a backward procedure to compute the invariant sets [15] and eigenstructure analysis/assignment methods.

Invariant set can be computed by the iterative methods as follow algorithm.

**Algorithm 1**

Initialization: \( k=0 \) and \( \delta_0 = \delta \)
Repeat

\[ \delta_{k+1} = \{ x \in \delta : \exists u(x) \in U : Ax + Bu(x) + Ew \in \delta_k, \forall w \in W \} \]

\[ \delta_{\infty} = \bigcap_{i=0}^{\infty} \delta_i \]

Until \( \delta_{k+1} = \delta_{k} \) then \( \delta_{k+1} = \delta_{\infty} \)
At each step, the algorithm compute the set of states for which all solution of the system stay in the \( \delta_{k+1} \). The sequence \( \delta_i \) is then the subset of those states for which if a transition is possible, the state after the transition is also in the \( \delta_i \).

Eigenstructure analysis/assignment method is another efficient method. Some contributions show how to determine invariant sets included in polyhedra of the form

\[ \delta(G, \rho) = \{ X : -\rho \leq Gx \leq \rho \} \quad (23) \]

A stabilizing control law \( u = Kx \) is assigned [17].
Invariant sets for hybrid systems can also be computed by iterative method.

IV. MP-QP OF HYBRID SYSTEMS

A Optimal control of hybrid systems

Consider piecewise affine hybrid systems (5), where
\[ \begin{bmatrix} x(t) \\ u(t) \end{bmatrix} \in \Omega, \]
the finite-time optimal control problem of constraint hybrid systems can be defined as follows:
\[ J^*_f(x(0)) = \min_{U_0^{T-1}} J(x(0), U_0^{T-1}) \]  (24a)

Subj. to:
\[ \begin{align*}
L_t x(t) + E_t u(t) & \leq W_t, \quad \text{if} \quad [x(t), u(t)] \in \Omega, \\
x(t+1) & = f_{PW}(x, u) = A_x x(t) + B_x u(t) + h
\end{align*} \]  (24b)

\[ J(x(0), U_0^{T-1}) = \|P x(T)\|_2 + \sum_{i=0}^{T-1} \|Q x(t)\|_2 + \|R u(t)\|_2 \]  (25)

In optimal control problem (25), \( x_f \) defines the terminal constraints, \( T \) is the optimal time, \( U_0^{T-1} = [u(0), \cdots, u(T-1)] \in R^{mT} \) is the optimal control, \( \|Q x\|_2 = x^T Q x \) and \( R = R^T > 0 \), \( Q = Q^T \), \( P = P^T > 0 \). \( \{\Omega_i\}_{i=1} \) is the sub-system domain of hybrid systems.

As model predictive control method in [9], the optimal control vector \( U_0^*(x(0)) \) is determined by \( x(0) \) in (24). Once \( x(0) \) is changed, the control input should be calculated again, so it is an on-line optimal control problem. Consider problem (24) as a multi-parametric quadratic problem, \( x(0) \) is considered as parametric vector, the explicit function of \( U_0^{T-1} \) and \( x(0) \) is built. The optimal control can be obtained in real-time control as the states in explicit function is replaced by the currently states. The problem of multi time on-line computing problem can be solved by this method.

A method of multi-parametric quadratic program method is proposed in this paper, the explicit piece affine function of \( U_0^{T-1} \) and \( x \) is constructed by state domain partitions and optimal control design.

B Explicit controller design

State polyhedron partitions are obtained by multi-parametric program in [13], the piece-affine property of control law and value function is also proved. This method is extended to hybrid systems in this section, and explicit controller of hybrid systems is designed by dynamic program.

**Theorem 2**: Consider the hybrid systems optimal control problem (24), the optimal control vector can be described as piece-affine control law (26):
\[ u^*(x(t)) = f^*_i x(t) + c^*_i \]  (26)
The performance index is defined as follow:
\[ J^*(x(t)) = x(t)^T Q^*_i x(t) + L_i x(t) + C^*_i \]  (27)
In (26) and (27),
\[ x(k) \in CR^k_i \triangleq \{x : x(t)^T L_i x(t) + M_i x(t)^T x(t) \leq N_i^k\}, \]
\( t = 0, \cdots, T-1 \)

\( CR^k_i \) are convex partitions of \( D^k \) which is feasibility set in \( x(k) \).

In theorem 2, optimal control vector and value function are computed according to control input by multi-parametric quadratic program method. \( x(0) \) is selected to proved \( u(x(0)) \) as follow, \( u(x(t)) \) can also be proved.

**Proof**: Given initialization state \( x(0) \) and corresponding \( U = [u(0), \cdots, u(k-1)] \), on the function of states and control series, \( x(k) \in \chi_i \), let \( x^{T+1} \) is the amount of partitions where \( x(0), \cdots, x(T) \) may be in, support \( v_i, i = 1, \cdots, s^{T+1} \) are transition series of time T, \( v_i^k \) is the \( k \) element of \( v_i \), then:
\[ v_i^k = j \quad \text{if} \quad x(k) \in \chi_j \]  (29)

Select \( v_i \) and its transition, the optimal problem (24) can be transform to (30):
\[ J^*_{v_i}(x(0)) = \min_{U_0^{T-1}} J(x(0), U_0^{T-1}) \]  (30a)

Subj.to:
\[ \begin{align*}
L_t x_t + E_t u_t & \leq W_t, \quad \text{if} \quad [x(t), u(t)] \in \chi_j, \\
x(t+1) & = A_x x(t) + B_x u(t) + h \\
x(k) & \in \chi_{v_i^k}, \quad x_T \in x_f, \quad k = 0, \cdots, T \\
x(0) & \in x_f, \quad x_T \in x_f
\end{align*} \]  (30b)

If there is a problem that the constraints in optimal control (30) is time varying, piecewise affine feedback control law can be obtained by multi-parametric quadratic method.

As the equivalence between mixed logic dynamic (MLD) model and piecewise affine model for the optimal control problem (30), multi-parametric mixed integer quadratic method based on MLD model is used in [10]. In order to improve computation efficiency, one step back multi-parametric dynamic program [7] is extended to hybrid systems optimal control. The back reachable set is computed to design optimal controller.

Consider the optimal control problem (24) by dynamic program:
\[ J^*_j(x_j) = \min_u \|Qx(t)\|_2 + \|Ru(t)\|_2 + J^*_j(x_{j+1}) \]

(31a)

Subject to:

\[
\begin{align*}
L_j x_j + E_j u_j & \leq W_j, \quad \text{if } \begin{bmatrix} x_j, u_j \end{bmatrix} \in \Omega_j \\
x_{j+1} &= f_{PWA}(x_j, u_j) \in \chi'_{j+1} \\
j &= T-1, \ldots, 0
\end{align*}
\]

(31b)

The boundary is: \( x_T = x_f, \ J^*_T(x) = \|Px\|_2 \).

The problem of dynamic program (31) can be solved by back dynamic for multi-parametric mixed integer quadratic method. Consider the first step in dynamic program:

\[ J^*_j(x_{j-1}) = \min_{u_{j-1}} \|Qx_{j-1}\|_2 + \|Ru_{j-1}\|_2 + J^*_j(x_j) \]

Subj. to \( x_f = f_{PWA}(x_{f-1}, u_{f-1}) \in \chi_f \)

(32)

The optimal problem (32) for PWA hybrid system can be divided into \( s \) problems for one step multi-parametric program (\( s \) is the amount of the sub-system). In theorem 1, \( \chi'_{j-1} \) is convex polyhedron set, \( u_{j-1} \) is piecewise affine feedback control law, \( J^*_j(x_{j-1}) \) is piecewise affine quadratic function for \( x_{j-1} \), \( N'_{j-1} \) is the state partitions amount on \( \chi'_{j-1} \). By first step program, the explicit piecewise linear state feedback function between \( u_{j-1} \) and \( \chi'_{j-1} \) can be obtained.

From step \( j = T-2 \) to final step \( j = 0 \), s problem of on step MP-QP can be constructed in every state partition of \( \chi'_{j-1} \), so the amount of \( s \) one step MP-QP problem is \( N'_{j-1} \)'s, and the state partition covers \( \chi_j \). In MP-QP method, there may exist that one convex polyhedron belongs to several state partitions or several goal function values \( J^*_j(x_{j+1}) \). The control signal and goal function can be decided by \( J^*_j(x_{j+1}) \). Calculating in step \( j \) for dynamic program, the explicit optimal control can be obtained in each step.

With the maximal controllable invariant set in [11], maximal set in initiate set is set as feasible set. The explicit controller can be obtained in the following steps:

1. The maximal controllable invariant set is computed by iterate method;
2. Set the invariant set as the feasible set, solve the optimal problem (24) by mp-qp method, invariant set is divided into efficient domain, and the back step reachable set, piecewise control and value function are computed to the corresponding partitions.
3. Given an initial states, the optimal can be obtained according to the partitions.

Consider the bounded disturbance in the explicit controller design, the robust controller can be computed by Pontryagin difference calculation for states set and disturbance [12].

V. SIMULATION

According to the explicit controller design method in section 3, the optimal controller is designed for system (5) based on the PWA model on equivalent points hover and 3m/s. Optimal controller design can be included as follow:

1. Construct the PWA model on UAV;
2. Maximal controllable set is computed as feasible set in flight envelop.
3. The explicit function between control input and states is computed based on mp-qp method.
4. Compute the optimal resolution on the states of UAV.

The UAV X-Cell 60SE is selected as model machine. After trimming calculation, order reduced and discretization, the dynamic on equivalent points can be described as follow:

\[ \dot{x} = Ax + Bu + h \]

\( \sigma = 0 : y \leq 0.5; \)

\[
A_h = \begin{bmatrix} 0.9961 & 0.0054 & 0.1093 & 0 \\ -0.0003 & 0.9898 & 0.0031 & 0 \\ -0.0076 & 0.9269 & 0.1950 & 0 \\ -0.0004 & 0.0047 & 0.0953 & 1.0000 \end{bmatrix},
\]

\[
B_h = \begin{bmatrix} 0.1010 & 0.0006 & 3.9915 & -0.4345 \\ -0.0376 & 0.0154 & 0.1888 & 11.6144 \\ -0.0020 & 0.0005 & 0.0663 & 0.5875 \end{bmatrix}
\]

\( \sigma = 1 : y \geq 0.5; \)

\[
A_i = \begin{bmatrix} 0.9951 & -0.0000 & -0.0003 & 0 \\ -0.0054 & 0.9717 & -0.2777 & 0 \\ 0.0303 & 0.1089 & 0.8838 & 0 \\ 0.0015 & 0.0056 & 0.0940 & 1.0000 \end{bmatrix},
\]

\[
B_i = \begin{bmatrix} -0.0829 & -4.0008 & -0.0000 & -0.0017 \\ -0.1198 & 0.0079 & 3.9646 & -2.1444 \\ -0.1277 & -0.0620 & 0.2234 & 11.2752 \\ -0.0066 & -0.0021 & 0.0075 & 0.5738 \end{bmatrix}
\]

Set system constraints as follow:

\[
\begin{bmatrix} -4 \leq x_1 \leq 4 \\ -1 \leq x_2 \leq 1 \\ -5 \leq x_3 \leq 5 \\ -1 \leq x_4 \leq 1 \\ -10 \leq u \leq -10 \\ h \in \mathbb{R} \\ -0.01 \leq \mathbb{S} \leq 0.01 \end{bmatrix}
\]

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The weigh matrix is designed for optimal controller after experiments: \( P \) is zero matrix, 
\[
Q = \text{diag}(0.101 0 0.01 100),
\]
\[
R = \text{diag}(10 400 4000 30).
\]
After iteration calculation in maximal controllable invariant sets, feasible partitions are divided into 75 domains as Fig.4, where is tangent plane in \( x_4 = 0 \) as the system is 4 dimensions system.

![Controller partition with 105 regions. Cut through \( f = 0.00 \)](image)

In feasible domain, the state can return stable states \( x_\mathcal{F} = [0;0;0;0] \) from the initial state \( x_0 = [2.5;-0.0449;0;0] \) by efficient inputs. Simulation as follow:

![Evolution of states](image)

![Evolution of control moves](image)

![Evolution of outputs](image)

![Evolution of disturbances](image)

From Fig.5 and Fig.6, The system states and output return to equilibration point although with bounded disturbance. Fig. 7 and Fig.8 show the input control ad
system disturbance. Consider bounded disturbance, set the maximal robust controllable invariant sets as feasible domain, the optimal controller can be obtained by Pontryagin difference calculation for reachable set and disturbance set.

VI. CONCLUSION

Based on the method of paper [7], bounded disturbance is considered in this paper. Constrained optimal control problem for unmanned helicopter is studied in this paper. UAV System is abstracted and modeled by PWA hybrid systems first, multi-parametric quadratic program method is proposed to off-line computed optimal control law for real time control. In the feasible domain which is the maximal controllable invariant set, optimal control is computed in each step by back dynamic program. The optimal controller can be obtained by Pontryagin difference calculation for reachable set and disturbance set. The simulation result proves the validity of this method at the end of this paper.

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Li Jianqiang (1980-), born in Guangdong China. He is currently a lecturer with the College of Computer Science and Software Engineering, Shenzhen University, China. He received his B.S degree from the Department of Automation, South China University of Technology, Guangzhou, in 2003 and the Ph.D degree from Department of Automation, South China University of Technology, Guangzhou in 2008. His research interests include: hybrid systems, robotics, and optimal control.

Lu Yahui (1976-), born in Shaanxi China. He is currently a lecturer with the College of Computer Science and Software Engineering, Shenzhen University, China. He received his B.S degree from the Department of Automation, Nanjing university, Guangzhou, in 1996 and the Ph.D degree from Department of computer, Tsinghua University, Beijing in 2008. His research interests include: modeling, robotics, and optimal computing.

Ji Zhen (1973-), born in Jiangsu China. He is currently a professor with the College of Computer Science and Software Engineering, Shenzhen University, Shenzhen China. He received his Ph.D degree from Department of Communication and Information Systems, Xi’an Jiaotong University, Xi’an in 1999.

Pei Hailong (1965-), born in Henan China. He is currently a professor with the Department of Automation, South China University of Technology, Guangzhou China. He received Ph.D degree from Department of Automation, South China University of Technology, Guangzhou in 1992.
Convective Heat Transfer Steady Heat Conduction and Thermal Stress in a Ceramic/FGM/Metal Composite EFBF Plate

Xu Yangjian
School of Civil Engineering, Hebei University of Engineering, Handan 056038, China
Email: xuyangjian@sohu.com

Tu Daihui
School of Science, Hebei University of Engineering, Handan 056038, China
Email: tdhui563@sina.com

Du Haiyang
School of Civil Engineering, Hebei University of Engineering, Handan 056038, China
Email: guduxing@126.com

Abstract—A finite element model is constructed to analyze the steady heat conduction and thermal stress in a ceramic/FGM/metal composite EFBF plate under convective heat transfer boundary. From numerical calculation, when $\zeta_a = \zeta_b = 1$, $T_a = T_b = 300K$ and $T_b = 1800K$, the steady heat conduction and thermal stress distributions in the plate were obtained. The numerical results show that the temperature distribution in the composite plate is more reasonable with the increase of the FGM layer thickness, and compared with $h_2 = 2mm$ the maximum tensile stress of $h_2 = 6mm$ reduces by 36.3%. With the increase of $M$, the temperature on the surface of ceramics reduces by 6.2%, the compressive stress on the metal surface reduces by 28.3%, and the compressive stress on the surface of ceramics increases by 70.2%. With the increase of porosity, there is an abrupt change for temperature at the $y \approx 0.48$, its value is 875 K, and the change of stress at the interface of the three-layered plate increases, and the tensile stress on the surface of ceramics reaches the maximum. Compared with $\zeta_a = \zeta_b = 1$ when $\zeta_a = \zeta_b = 10$, the temperature on the surface of metal reduces by 23.9% and the temperature on the surface of ceramics increases by 44.4%, and the stress on the metal surface increases by 148% and the stress on the ceramic surface increases by 165%. Compared with the nongraded two-layered composite plate, the temperature and the thermal stress of the ceramic/FGM/metal composite plate are very gentle and smooth. The results provide the foundations of theoretical calculation for the design and application of the composite plate.

Index Terms—ceramic/FGM/metal composite plate, steady heat conduction and thermal stresses, FEM, convective heat transfer boundary, EFBF mechanical boundary

I. INTRODUCTION

Functionally graded material (FGM) is a new type of inhomogeneous composite material with special bonding characteristics due to arbitrarily distributed and continuously varied material properties. The advantages of FGM are that such materials can reduce the magnitude of the residual and thermal stresses and increase the strength and fracture toughness. Therefore, FGMs have received considerable attention in the field of structural design subjected to extremely high thermal loading [1-8]. Because it is used widely in high temperature working environment such as aviation and nuclear reactor, and so on, it is important to analyze the thermal stress filed of the body made of the material.

Obata [9-10] and Tanigawa [11] researched thermal stress of pure FGM plate by adopting perturbation and laminated analytical method, respectively. Huang [12] analyzed the thermal elastic limitation of four-layered composite plate with FGM in the middle of the plate. But these methods are too complex so as to lead to a complicated equation system, and are not convenient for engineering application. Therefore, Xu [13-14] studied the problem of transient thermal stress of pure FGM plate under convective heat transfer boundary and during heating and cooling process by adopting simple NFEM.

Based on the above research work, without loss of generality, we present a model of analysis that is ceramic/FGM/metal composite plate. The new composite plate has the advantages of FGM and composite plate. Such as, the heat-resistant and mechanical properties of the new composite plate are better than those of pure FGM plate, and under the same thickness of plate the fabrication cost of the new composite plate is lower than that of pure FGM plate.
In the present article, starting from the heat conduction law, this paper will discuss the steady thermal stress problem of a ZrO$_2$/FGM/Ti-6Al-4V composite EBFB plate under convective heat transfer boundary by the FEM and the Simpson method. We hope that the analytical results obtained will be more close to actual engineering conditions and to obtain some instructive conclusions for the production and application of ceramic/FGM/metal composite plate.

II. MODEL OF ANALYSIS

As shown in Fig. 1, we now consider the steady thermal stress field distributions of a three-layered infinitely long composite EBFB plate made of metal (Ti-6Al-4V) and ceramics (ZrO$_2$) with an interlayer of FGM under convective heat transfer boundary. We have the following assumptions. (1) The lower layer of threelayered plate is metal; $k_m$, $E_m$, $\alpha_m$ and $\nu_m$ denote thermal conductivity, Young’s modulus, the coefficient of linear thermal expansion and Poisson’s ratio of the metal layer, respectively, and the layer thickness is $h_1$. The middle is continuous and arbitrary variant FGM gradient layer; $k(y)$, $E(y)$, $\alpha(y)$ and $\nu(y)$ denote the above material properties of FGM gradient layer, and the layer thickness is $h_2$. The upper layer is ceramics; $k_c$, $E_c$, $\alpha_c$ and $\nu_c$ denote the above material properties of ceramic layer, and the layer thickness is $h_3$. (2) Initially, the plate is under the stress-free status; the initial temperature of the plate is $T_0$. The plate is heated from the lower and upper surfaces by surrounding media by constant $T_a$ and $T_b$. (3) The upper layer is heat insulated; there are no heat sources within the plate. Coordinate axis is chosen as shown in Fig. 1, and the interfaces between the layers are perfectly bonded at all times. $T$ is temperature function. The material’s properties for each same ordinate $y$ are homogeneous and isotropic. Subscripts c and m mean ceramics and metal, respectively. The total thickness of the plate is $b = h_1 + h_2 + h_3$ and $b_1 = h_1$, $b_2 = h_1 + h_2$.

![Figure 1. Ceramic/FGM/metal composite plate.](image)

III. HEAT CONDUCTION ANALYSIS

The steady thermal conduction basic equation of the $i$th layer of the three-layered composite plate is

$$0 = \frac{d}{dy} \left\{ k_i(y) \frac{dT_i(y)}{dy} \right\}, \quad i = 1, 2, 3,$$

(1)

where $k_i(y)$ is the thermal conductivity of per layer of the three-layered composite plate (such as $i = 1$, $k_1(y) = k_{cu}$, the rest on the analogy of this). Thermal conductivity of the FGM layer is $k(y)$. The convective heat transfer boundary and the conditions of continuity of the temperature in the three-layered composite plate and the heat flux at interfaces are expressed in the following form

$$y = 0, k_m \frac{dT(y)}{dy} = \zeta_a T_a - \zeta_b T_b $$

(2)

$$y = b, k_c \frac{dT(y)}{dy} + \zeta_c T_c = \zeta_a T_a , \quad i = 1, 2$$

(3)

Where solving the steady heat conduction problem of linear control equations approximately by adopting FEM, we need to establish relevant functional. The paper adopts one-dimensional FEM to solve the above problem. Under the condition of assumption in this paper, the element functional [15] (5.14) of one-dimensional steady heat conduction problem under the convective heat transfer boundary condition is

$$\pi_e = \int \frac{k^e}{2} \left( \frac{dT}{dy} \right)^2 dy + \zeta^e \left( T^2 - \tilde{T}^e T \right),$$

(4)

where $\zeta^e$, $k^e$ are convective heat transfer coefficient and the thermal conductivity of the element, respectively, the constant values, and not the function of $y$, but these values are different for different element. $\tilde{T}^e$ is the environmental media temperature, and $T$ is the boundary of given convective heat transfer condition.

Consider bar element, the element length is $l$, and two nodes are denoted by $i, j$. The trial function of temperature field is linear distribution.

$$T = a_1 + a_2 y,$$

(5)

where $a_1, a_2$ are the unknown constants.

The temperature of node $r$ is denoted by $T_r$ ( $r = i, j$), we have

$$T_r = a_1 + a_2 y_r, \quad r = i, j.$$  

(6)

We have for any element

$$T_i = a_1 + a_2 y_i, \quad T_j = a_1 + a_2 y_j.$$  

(7)

Then we can write Eq. (7) in matrix form

$$\begin{bmatrix} 1 & y_i \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = T_i.$$

(8)

The unknown constants $a_1, a_2$ in the Eq. (8) can be solved by using of the method of matrix inverse.

$$\begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} 1 & y_i \end{bmatrix}^{-1} \begin{bmatrix} T_i \\ T_j \end{bmatrix} = \frac{1}{y_i - y_j} \begin{bmatrix} 1 & y_i \end{bmatrix} \begin{bmatrix} 1 & y_j \end{bmatrix}^{-1} \begin{bmatrix} T_i \\ T_j \end{bmatrix}.$$  

(9)

Hence

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\begin{align}
  a_i &= \frac{1}{y_j - y_i} \left( y_i T_i - y_j T_j \right), \quad a_s = \frac{1}{y_j - y_i} \left( -T_i + T_j \right). \tag{10}
\end{align}

Substitution of Eq. (10) into Eq. (5) yields the trial function of temperature field:
\begin{align}
  T &= \frac{y_j - y}{I_r} T_i + \frac{y - y_i}{I_r} T_j. \tag{11}
\end{align}

Then we can write Eq. (11) in matrix form
\begin{align}
  T &= N_T^T + N_T^T = \begin{pmatrix} N_i & N_j \end{pmatrix} \begin{pmatrix} T_i \cr T_j \end{pmatrix} = NT^T, \tag{12}
\end{align}

where
\begin{align}
  N = \begin{pmatrix} N_i & N_j \end{pmatrix}, \quad N_i = \frac{y_j - y}{I_r}, \quad N_j = \frac{y - y_i}{I_r}, \quad T^e = \begin{pmatrix} T_i \cr T_j \end{pmatrix}. \tag{13}
\end{align}

The \( T \) in Eq. (12) is the any point temperature on element \( e \). The ordinate \( y \) of the nodes \( i, j \) in element \( e \) can be written by \( y_i, y_j \). We have
\begin{align}
  \text{Node } j: \quad N_i = 0, \quad N_j = 1; \quad \text{Node } i: \quad N_i = 1, \quad N_j = 0. \quad \tag{14}
\end{align}

We can obtain by solving the first derivative of the trial function \( T \) of temperature field in Eq. (11) with respect to \( y \)
\begin{align}
  \frac{dT}{dy} = -\frac{1}{I_r} T_i + \frac{1}{I_r} T_j. \tag{15}
\end{align}

Substitution of Eq. (15) into Eq. (4) yields the functional of element \( e \):
\begin{align}
  \pi_e = \frac{k_e}{2I_r} \left( T_i^2 - 2TT_j + T_j^2 \right) + \frac{\zeta}{2} \left( T_i^2 - T_j^2 \right). \tag{16}
\end{align}

Then we can write Eq. (16) in matrix form:
\begin{align}
  \pi_e = T_i^T \left[ \frac{1}{2} h e T_i - q_i \right], \tag{17}
\end{align}

where
\begin{align}
  q' = \begin{bmatrix} q_i' & q_j' \end{bmatrix} = \begin{bmatrix} 0 \cr \frac{\zeta}{2} \bar{T}_e \end{bmatrix}, \tag{18}
\end{align}

\begin{align}
  h' = \begin{bmatrix} h_e & h_j' \cr h_i' & h_j'' \end{bmatrix} = \frac{k_e}{I_r} \begin{bmatrix} 1 & -1 \\
  -1 & 1 \end{bmatrix} + \zeta \begin{bmatrix} 0 & 1 \end{bmatrix}. \tag{19}
\end{align}

Under the convective heat transfer boundary condition, the finite element basic equation of steady heat conduction in the three-layered composite plate is (see [15] (5.26))
\begin{align}
  H \mathbf{T} = \mathbf{Q}, \tag{20}
\end{align}

where \( H, \mathbf{T} \) and \( \mathbf{Q} \) denote thermal stiffness matrix, unknown node temperature array and node thermal load array, respectively. The elements \( h_{n}^e \) and \( q_{i}^e \) (\( r, s = i, j \)) in matrix \( H \) and \( \mathbf{Q} \) are respectively
\begin{align}
  h_{n}^e = \frac{k_e}{I_r} \left( 2\delta_{n} - 1 \right) + \zeta_{n}^e \delta_{n}, \quad q_{i}^e = \frac{\zeta_{i}^e}{2} \bar{T}_e \delta_{i}, \tag{21}
\end{align}

where \( \delta_{n} \) is the symbol of Kronecker \( \delta \).

IV. THERMAL STRESS ANALYSIS

The strain components \( \varepsilon_{xx}, \varepsilon_{yy} \) and stress components \( \sigma_{xx}, \sigma_{yy} \) of the \( i \)th layer of the three-layered composite plate are given respectively by the relations [11]
\begin{align}
  \varepsilon_{xx} (\bar{\gamma}) &= \varepsilon_{xx} (\bar{\gamma}) + \frac{\bar{\gamma}}{\bar{\gamma}_0} \left( i = 1,2,3 \right), \\
  \sigma_{xx} (\bar{\gamma}) &= \sigma_{xx} (\bar{\gamma}) \times \begin{bmatrix} E_i (\bar{\gamma}) \cr 1 - \nu_i (\bar{\gamma}) \end{bmatrix} \left( i = 1,2,3 \right), \tag{22}
\end{align}

where \( \bar{\gamma} = y / b \) is dimensionless position coordinate, \( \bar{\gamma}_0 \) and \( 1 / \bar{\gamma}_0 = b / r \) denote strain component and dimensionless curvature on the \( \bar{\gamma} = 0 \) plane respectively, \( T (\bar{\gamma}) \) is temperature rise, \( \bar{\gamma}_0 \) and \( 1 / \bar{\gamma}_0 \) are unknown constants and they are determined by the mechanical boundary condition. Supposing that the plate can elongate and bend freely (EFBF), and the unknown constants are determined by the following equilibrium equations
\begin{align}
  \sum_{\gamma} \sigma_{xx} (\bar{\gamma}) \bar{y} d\bar{y} = 0, \quad \sum_{\gamma} \sigma_{yy} (\bar{\gamma}) \bar{y} d\bar{y} = 0. \tag{23}
\end{align}

Substitution of Eq. (23) into Eq. (22) yields the thermal stress:
\begin{align}
  \sigma_{xx} (\bar{\gamma}) &= \frac{E_i (\bar{\gamma})}{1 - \nu_i (\bar{\gamma})} \times \begin{bmatrix} B_i (D_0 - B_i) + (B_i D_0 - B_i D_0) \bar{y} - \alpha_i (\bar{\gamma}) \bar{y}' (\bar{\gamma}) \cr B_i D_0 - B_i \end{bmatrix} \tag{24}
\end{align}

where
\begin{align}
  B_i = \sum_i \frac{E_i (\bar{\gamma})}{1 - \nu_i (\bar{\gamma})} \bar{y} d\bar{y}, \quad j = 0,1,2, \tag{25}
\end{align}

where \( B_i, D_i \) are calculated according to Simpson numerical integration method. It is necessary to illustrate that E, F and B denote elongation, free and bending, respectively. Such as EFBF denotes that the plate can elongate and bend freely.

V. RESULTS AND DISCUSSION

A. Material Properties

To illustrate the foregoing analysis, numerical calculations have been carried out for a ZrO2/FGM/Ti-6Al-4V composite plate. The constant properties of ceramics ZrO2 and metal Ti-6Al-4V are shown in table 1[10].
TABLE I.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Materials</th>
<th>ZrO₂</th>
<th>Ti-6Al-4V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity rate, ( k / W \cdot m K^{-1} )</td>
<td>2.09</td>
<td>7.30</td>
<td></td>
</tr>
<tr>
<td>Elastic modulus, ( E / GPa )</td>
<td>151.0</td>
<td>116.7</td>
<td></td>
</tr>
<tr>
<td>Poisson’s ratio, ( \nu )</td>
<td>1/3</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td>Linear thermal expansion coefficient, ( \alpha / K^{-1} )</td>
<td>( 10.0 \times 10^{-6} )</td>
<td>( 9.5 \times 10^{-6} )</td>
<td></td>
</tr>
</tbody>
</table>

The volume fraction \( V_m(\bar{y}) \), \( V_c(\bar{y}) \) and porosity \( P(\bar{y}) \) in FGM gradient layer are shown as follows [10-11]:

\[
V_m(\bar{y}) = \begin{cases} 
1 - \bar{y}^M & M \geq 1 \\
(1 - \bar{y})^M & M < 1 
\end{cases},
\]  

(26)

\[
V_c(\bar{y}) = 1 - V_m(\bar{y}),
\]  

(27)

\[
P(\bar{y}) = A \beta (1 - \bar{y}), \quad 4 > A \geq 0,
\]  

(28)

where \( M \) is the parameter of the material composition, \( A \) is the coefficient of porosity \( P \). The volume fraction \( V_m(\bar{y}) \) under different \( M \) values is shown in Fig.2.

![Figure 2. The volume fraction \( V_m(\bar{y}) \) of metal phase.](image)

The material properties of the FGM gradient layer are given in the following form [10]:

\[
k(\bar{y}) = \left[ (1 - P^{1/3}) / k_c + P^{1/3} / \left( 1 - P^{2/3} \right) k_b + P^{2/3} k_c \right]^{-1},
\]  

(29)

\[
E(\bar{y}) = E_0 (1 - P) / \left[ 1 + P \left( 5 + 8\nu_0 \right) \left( 37 - 8\nu_0 \right) / \left[ 8(1 + \nu_0)(23 + 8\nu_0) \right] \right],
\]  

(30)

\[
\alpha(\bar{y}) = \alpha_0, \; \nu(\bar{y}) = \nu_0,
\]  

(31)

where \( k(\bar{y}), \; E(\bar{y}), \; \alpha(\bar{y}) \) and \( \nu(\bar{y}) \) denote thermal conductivity, elastic modulus, thermal expansion coefficient and Poisson’s ratio of the FGM gradient layer, respectively. Subscript a means air, and

\[
k^a = k_c + 3k_c \left( k_m - k_c \right) V_m(\bar{y}) / \left[ 3k_c + (k_m - k_c) V_c(\bar{y}) \right],
\]  

(31)

\[
E_0 = E_c \left( E_c + (E_m - E_c)V_m^{2/3} \right) /
\left( E_c + (E_m - E_c)(V_m^{2/3} - V_m) \right).
\]  

(32)

where \( k_m, \; E_m, \; \alpha_m \) and \( \nu_m \) denote thermal conductivity, elastic modulus, thermal expansion coefficient and Poisson’s ratio determined from the mixture rule, respectively.

B. Basic Parameters

The plate thickness \( b \) is 10 mm, and \( h_1 = h_3 \) in this paper. The finite element mesh of the ceramic/metal composite plate with FGM is divided into 1 280 elements and 1 282 nodes under convective heat transfer boundary condition, the smallest side length of the element is 0.015625 mm, \( T_0 = 300K \).

C. Inspecting Validity of Method

The relative convective heat transfer coefficients on the lower and upper surfaces are denoted by \( (\zeta_a, \zeta_c) = h \times (\zeta_a / \kappa_m, \zeta_c / \kappa_c) \). When \( \zeta_a = \zeta_c = 2000 \), this corresponds to the fact that \( \zeta_a \) and \( \zeta_c \) tend to infinity, so we can introduce the first heating boundary condition.

Tables II and III show the inspecting results of heating steady temperature fields obtained from two different methods. From tables II and III, we know that the research method and numerical results in this paper are correct and reliable for the steady temperature fields.

TABLE II.

<table>
<thead>
<tr>
<th>( \bar{y} )</th>
<th>Analytical solutions [9]</th>
<th>FEM solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>0.1</td>
<td>0.0531</td>
<td>0.0531</td>
</tr>
<tr>
<td>0.2</td>
<td>0.1135</td>
<td>0.1135</td>
</tr>
<tr>
<td>0.3</td>
<td>0.1821</td>
<td>0.1821</td>
</tr>
<tr>
<td>0.4</td>
<td>0.2598</td>
<td>0.2598</td>
</tr>
<tr>
<td>0.5</td>
<td>0.3478</td>
<td>0.3478</td>
</tr>
<tr>
<td>0.6</td>
<td>0.4473</td>
<td>0.4473</td>
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<tr>
<td>0.7</td>
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<td>0.5601</td>
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<tr>
<td>0.8</td>
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<td>0.6880</td>
</tr>
<tr>
<td>0.9</td>
<td>0.8336</td>
<td>0.8336</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

TABLE III.

<table>
<thead>
<tr>
<th>( \bar{y} )</th>
<th>Analytical solutions [9]</th>
<th>FEM solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>0.1</td>
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<td>0.0349</td>
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<td>0.9</td>
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<tr>
<td>1.0</td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

Fig.3 shows the parameters and the heating steady thermal stress distribution that solved in this paper, and Fig.4 shows the parameters and the heating transient thermal stress distribution that solved in reference [10]. When the lower and upper surfaces are heated, compared
with Fig. 4, the steady thermal stress field distribution (t = 32 s) of Fig. 3, as the whole, according to the method in this paper, we can know: the shape, bending degree, changing trend of the thermal stress curve and thermal stress value of corresponding points that obtained by the two methods are uniform apparently. So the research method and numerical results are correct and reliable for the steady thermal stress fields, and this proves the validity of the method in reference [10] at the same time.

Fig. 6 shows the effect of the FGM layer thickness on thermal stress. We can know from Fig. 6, in the metal and ceramic layers, the thermal stress figures are almost incline straight lines and the slope of each curve is slightly different. But in the FGM layer, the thermal stress figure is curve and the thermal tensile stress reaches the largest. The compressive stress on the metal surface reaches maximum when \( h_2=2\text{mm} \). The compressive stress on the metal surface reaches minimum when \( h_2=6\text{mm} \). In one word, with the increase of the FGM layer thickness, the thermal stress curves tend to gentle and the stress distribution in the composite plate is more reasonable, and the largest tensile stress of the EFBF composite plate reduces by 36.3%, and also the compressive stress on the metal surface reduces by 17.6%.

**D. Effect of FGM Layer Thickness**

Fig. 5 shows the effect of the FGM layer thickness on temperature. We can know from Fig. 5 that the total change trend of the temperature in the composite plate is that the temperatures change from the smaller temperature in the metal layer to the larger temperature in the ceramic layer. In the metal and ceramic layers, the temperature figures are almost incline straight lines. The gradient of temperature curves in the metal layer is smaller than that of temperature curves in the ceramic layer obviously. But in the FGM layer, the temperature figure is curve, with the increase of the FGM layer thickness, the temperature curves tend to gentle and the temperature distribution in the composite plate is more reasonable. It is noteworthy that the maximum temperature value in the metal surface is 524.2 K and the maximum temperature value in the ceramic surface is 1012 K. Above regular phenomenon is induced by adopting convective heat transfer boundary condition.

**E. Effect of FGM Layer Composition**

Fig. 7 shows the effect of the FGM layer composition on temperature. We can know from the comparison in the curves of Fig. 7 that when \( M=0.2 \) (curve 1) the temperature reaches the minimum on the metal surface, and the maximum on the surface of ceramics. Also, when \( M=1 \) (curve 2), the temperature curve is comparative gentle and smooth, the temperature gradient is between curves 1 and 3, and the temperature distribution in the composite plate is more reasonable. When \( M=5 \) (curve 3) the temperature reaches the maximum on the metal surface, and the minimum on the surface of ceramics. In one word, with the increase of \( M \), the temperature on the
metal surface increases by 3.8%, and the temperature on the surface of ceramics reduces by 6.2%.

Fig. 8 shows the effect of the FGM layer composition on thermal stress. We can know from the comparison in the curves of Fig. 8 that when \( M=0.2 \) (curve 1) the compressive stress reaches the largest on the metal surface, and the minimum on the surface of ceramics. Also, when \( M=1 \) (curve 2), the thermal stress curve is comparative gentle and smooth, the thermal stress gradient is between curves 1 and 3, and the stress distribution in the composite plate is more reasonable. When \( M=5 \) (curve 3) the compressive stress reaches the minimum on the metal surface, and the maximum on the surface of ceramics. In one word, with the increase of \( M \), the compressive stress on the metal surface reduces by 28.3%, and the compressive stress on the surface of ceramics increases by 70.2%.

\[
\begin{align*}
A=0, \; \overline{\sigma_a} = \overline{\sigma_y} = 1 \\
T_0=T_2=300K, T_1=800K \\
h_1=h_2=h_3=3.33\text{mm} \\
1. M=0.2, M=1, 3, M=5 
\end{align*}
\]

Figure 7. Effect of FGM layer composition on temperature field.

\[
\begin{align*}
A=0, \; \overline{\sigma_a} = \overline{\sigma_y} = 1 \\
T_0=T_1=300K, T_2=1800K \\
h_1=h_2=h_3=3.33\text{mm} \\
\end{align*}
\]

Figure 8. Effect of FGM layer composition on thermal stress field.

F. Effect of FGM Layer Porosity

We select the air thermal conductivity rate \( k_a=0.02757 \) W/m·K. Fig. 9 shows the effect of the FGM layer porosity on temperature. When \( A=0 \) (curve 1), the temperature curve is gentle and smooth, and the temperature reaches the minimum on the surface of ceramics, its value is 521K, the maximum on the metal surface, its value is 1007.6 K. When \( A=3.99 \) (curve 5), the variations of the temperature curve becomes big obviously, but the temperature curve is gentle and smooth at the bonding interfaces of the three-layered plate, and there is a abrupt change for temperature at the \( \overline{y} \approx 0.48 \), its value is 875 K, and the temperature reaches the maximum on the surface of ceramics, its value is 1475.5 K, the minimum on the metal surface, its value is 380.7 K. It is noteworthy that compared with \( A=0 \), when \( A=3.99 \), the maximum temperature on the surface of ceramics increases by 46.4 %, and the maximum temperature on the surface of metal reduces by 26.9%.

Fig. 10 shows the effect of the FGM layer porosity on thermal stress. When \( A=0 \) (curve 1), the thermal stress curve is gentle and smooth, and the compressive stress reaches the maximum on the surface of ceramics, the minimum on the metal surface. When \( A=3.99 \) (curve 5), the variations of the thermal stress curve at the bonding interfaces of the three-layered plate becomes big obviously, and the curves appear sharp angle, and the maximum tensile stress value of curve 5 at the interface between metal layer and FGM layer is 9.76 times that of curve 1, and compressive stress on the metal surface increases by 61.9%. It is noteworthy that the tensile stress on the surface of ceramics reaches the maximum. Because it is weak in tension, so the large tensile stress is unfavorable to the strength of ceramics.

\[
\begin{align*}
M=1, \; \overline{\sigma_a} = \overline{\sigma_y} = 1 \\
T_0=T_2=300K \\
h_1=h_2=h_3=3.33\text{mm} \\
\end{align*}
\]

Figure 9. Effect of FGM layer porosity on temperature field.

\[
\begin{align*}
M=1, \; \overline{\sigma_a} = \overline{\sigma_y} = 1 \\
h_1=h_2=h_3=3.33\text{mm} \\
\end{align*}
\]

Figure 10. Effect of FGM layer porosity on thermal stress field.

G. Effect of Different Composite Plate

Fig. 11 shows the effect of the different composite plate on temperature. In the metal layer, the variation law of the temperature curves of two composite plate is similar, and the temperature figures are almost incline straight lines, and the gradient of temperature curves is almost same. But, in the ceramic layer, although the temperature figures of two composite plate are almost incline straight lines, the gradient of temperature curves is...
different, the gradient of temperature curve 1 in the nongraded two-layered composite plate is larger than that in the temperature curve 2 of the ceramic/metal composite plate with an interlayer of FGM. It is noteworthy that the temperature variation at the bonding interface in the nongraded two-layered composite plate becomes large, as shown in curve 1, and the curve appears obtuse angle. Compared with curve 2, the curve 1 of the ceramic/metal composite plate with an interlayer of FGM is very gentle and smooth.

Fig. 12 shows the effect of the different composite plate on thermal stress. In the ceramic and metal layers, the whole variation law of thermal stress curves 1 and 2 is similar, although the temperature figures of two composite plate are almost incline straight lines, the gradient of temperature curves is different. But the thermal stress variation at the bonding interface in the nongraded two-layered composite plate becomes large, as shown in curve 1, and the curve appears sharp angle and reaches peak value. Compared with curve 1, the thermal stress curve 2 of the ceramic/metal composite plate with an interlayer of FGM is very gentle and smooth, and the maximum tensile stress reduces by 49.2%.

\[ \text{H. Effect of Convective Heat Transfer Coefficient} \]

Fig. 13 shows the effect of the convective heat transfer coefficient on temperature field. With the increase of the convective heat transfer coefficient, the variations of temperature curves become big, and the temperature curve 1 is more gentle and smooth than curve 2, and the slope of the curve 2 is bigger than that of curve 1 obviously. Compared with the curve 1, in the curve 2, the temperature on the surface of metal reduces by 23.9%, and the temperature on the surface of ceramics increases by 44.4%.

Fig. 14 shows the effect of the convective heat transfer coefficient on thermal stress. With the increase of the convective heat transfer coefficient, the variations of thermal stress curves become big, and the thermal stress curve 1 is more gentle and smooth than curve 2, and the slope of the curve 2 is bigger than that of curve 1 obviously. Compared with the curve 1, in the curve 2, the maximum compressive stress on the surface of metal increases by 148%, and the maximum tensile stress at the interface between FGM layer and ceramic layer increases by 61.8%, and the maximum compressive stress on the surface of ceramics increases by 165%.

\[ \text{IV. Conclusions} \]

We select a three-layered ceramic/metal composite EFBF in finite long plate with an interlayer of FGM as analytical model. The thermal boundary condition that we consider is convective heat transfer. According to thermoelasticity theory, we derive the finite element basic equation of the one-dimensional heat conduction of the composite plate by using of variational principle. We present a Simpson method for the solution of steady thermal stress formulas of the composite plate. Using FORTRAN language we design the calculation software to obtain numerical results. From numerical calculation,
when $\zeta_a = \zeta_s = 1$, $T_0=400K$ and $T_b=1800K$, the thermal stress distributions and the effect factors are discussed. The numerical results are as follows.

1. With the increase of the FGM layer thickness, the temperature distribution in the composite plate is more reasonable and compared with $h=2\text{mm}$ the tensile stress of $h=6\text{mm}$ reduces by 36.3%.

2. With the increase of $M$, the temperature on the surface of ceramics reduces by 6.2%, the compressive stress on the metal surface reduces by 28.3%, and the compressive stress on the surface of ceramics increases by 70.2%.

3. With the increase of porosity, there is a abrupt change for temperature at the $\gamma=0.48$, its value is $875\text{ K}$, and the change of stress at the interface of the three-layered plate increases, and the tensile stress on the surface of ceramics reaches the maximum.

4. Compared with $\zeta_a = \zeta_s = 1$, when $\zeta_s = \zeta_s = 10 \cdot 6$, the temperature on the surface of metal reduces by 23.9% and the temperature on the surface of ceramics increases by 44.4%, and the stress on the metal surface increases by 148% and the stress on the ceramic surface increases by 165%.

5. Compared with the nongraded two-layered composite plate, the temperature and the thermal stress of the ceramic/FGM/metal composite plate is very gentle and smooth.

ACKNOWLEDGMENT

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The Application of Fuzzy Neural Network in Fault Self-diagnosis System of Automatic Transmission

Kong Huifang
School of Electrical Engineering and Automation, Hefei University of Technology, Hefei, China
Email: konghuifang@163.com

Ren Guoqing
Anhui Jianghuai Automotive Co., Ltd., Hefei, China
Email: rgjiac@163.com

He Jizhu
School of Electrical Engineering and Automation, Hefei University of Technology, Hefei, China
Email: hejizhu7@126.com

Xiao Benxian
School of Electrical Engineering and Automation, Hefei University of Technology, Hefei, China
Email: xiaobenxian@126.com

Abstract—According to the design procedure of fault self-diagnosis system and features of automatic transmission system, the list of relation and mapping between fault symptoms and fault causes are made in this paper. Applying the approach of fault self-diagnosis based on fuzzy neural network, fault diagnosis of the automatic transmission electronic control system is realized. The structure of fuzzy neural network and its corresponding learning method and pretreating strategy about the training samples are introduced in this paper. Using MATLAB as simulation platform, this fault diagnosis method is simulated with neural networks toolbox. The simulation results show that this fault diagnosis approach is effective and applied.

Index Term—fuzzy logic, neural network technique, automatic transmission (AT), fault diagnosis

I. INTRODUCTION

Automatic transmission is an important component of automotive power system and plays a very vital role on full-vehicle performance [1]. In the working process of automatic transmission, because of environmental influence or improper operation, transmission control unit (TCU), sensors and actuators of automatic transmission may have fault. If some parts are out of order, the automobile performance will decrease apparently. Even accident may take place. Therefore, the study of fault self-diagnosis of automatic transmission system has important significance. Using this system, faults can be discovered in time. Fault handling can be done simultaneously. Under some certain conditions, vehicle can still work. Therefore the personnel, equipments and environment will be protected from damage. Further more, this system can provide a basis for maintaining to avoid dismounting blindly. Maintenance efficiency will be improved.

According to the characteristics of automatic transmission, the fault self-diagnosis technique was combined with fuzzy control and neural network technology. Trying to find fuzzy relations of fault symptoms and fault causes in system work progress, fuzzy fault knowledge base was established. The fault knowledge was studied by using neural network. This method is the same with other automatic transmissions, can improve quality and efficiency of fault self-diagnosis.

A. Scheme of Fault Self-Diagnosis

Fault self-diagnosis can be regarded as a processes of two steps [2][3]. The first step is extraction of fault symptoms. It means data extraction and precondition. For automatic transmission electronic control system, many sensors are used, the redundancy relationships between electronic signals are very strong. Inputs of fault symptoms can be analyzed and extracted synthetically by use of these redundancy relationships and expert experiences.
The second step is the continuous mapping of fault symptom vector $X$ and fault reason vector $F$. Fuzzy inference can be used, outputs of fault vector $F$ elements are taking value in reliability region $[0,1]$ of continuous number.

$$X \in \mathbb{R}^n \Rightarrow F \in \mathbb{R}^n$$

$$F = \{f_1, f_2, \cdots, f_n\}, f_n \in [0,1]$$

There is fuzziness in some faults or symptoms in electronic control system, so it is not able to be described by two-valued logic simply. That is to say there is fuzziness in relationships between some faults and symptoms. It is difficult to describe these by using mathematical expression accurately. Fault diagnosis is based on some symptoms generally. Fault causes leading to these symptoms can be judged. So Fault diagnosis is a question of fuzzy inference. Fault diagnosis based on fuzzy inference need to solve the key problems about how to establish fuzzy diagnostic rules database. On the basis of expert experience and knowledge, fuzzy diagnostic rules are built generally. Therefore expert level of studying system performances will influence accuracy of diagnosis.

With neural network technology be widely used, making use of self-learning, methods to establish databases of fuzzy diagnostic rules earn widespread respect in recent years [4]. Artificial neural networks formed by combining fuzzy logic system and neural network, have the advantages of fuzzy logic system that can make effective use of fuzzy information, and have the characteristics of neural network self-learning. Fuzzy neural network can extract empirical rules from sample data directly; obtain fuzzy rules getting closer to the truth by learning; overcome subjectivity of fuzzy logic system to some extent. The methods converting rules and deductions into mapping of neural network will be more suitable for fault self-diagnosis of electronic control system than traditional methods.

**B. Fault Self-Diagnosis Process**

Fig. 1 gives a fuzzy neural network fault self-diagnosis working process. [5]

![Fault self-diagnosis working process](image)

1) Working condition data is collected when fault system is running. Symptom parameters are extracted and normalized.

2) The symptom parameters normalized are blurred, and then are converted into fuzzy sets which are represented by membership.

3) Using the data fuzzed as input parameters of neural network, fault causes are reasoned from fault Symptoms by use of BP algorithm.

4) Based on outputs of network, fuzzy membership vectors of fault causes are obtain. The types of fault causes are determined by analyzing the vectors.

**C. Structure of Fuzzy Neural Network**

A multilayer feed forward neural network of serial-shape structure is adopted in this paper. The network is divided into four layers: pretreatment layer belonged to fuzzy part; the other three layers (i.e. input layer, hidden layer, output layer) belonged to neural network part.

![Structure of fuzzy neural network](image)

Where $X_i$ are input variables and $f_n$ are output fault vectors as shown in Fig. 2. $\mu_i(i, j = 1,2,\cdots,n)$ are degrees of membership, $i$ represents the i-th variable of input, $j$ represents fuzzy division number of corresponding variables. $IW$ and $LW$ are the connecting weights of hidden layer and the connecting weights of output layer respectively.

**D. Improved neural network BP algorithm**

To improve the learning speed and increase the reliability of the algorithm, momentum term and BP network training model of self-adjusting learning rate are introduced in this paper.

Standard BP algorithm can be treated as a static optimization steepest descent algorithm. However, due to the number of optimization parameters is too many, and previous experiences are not considered, so that there must be a shortcoming of slow speed of convergence. The second serious defect is the problem of local extremum. There are many extreme points on hyper surface of objective function $E$ [6]. In accordance with the above optimization method, the local extremums nearby initial value are converged to usually.

To solve these problems, the additional momentum items are drawn into. The shortcoming, which BP network will fall into local minimum point, can be avoided. Weight adjustment will be made stability and
smoothing. More superior solution can be got. The training time can be shortened, and convergence rate can be speeded up by adaptive learning rate. Network is built by the combination of the momentum item addition and adaptive learning rate. Combining additional momentum items with self-adaptive learning rate, sigmoid transfer function having rich non-linear expressive ability is used to optimize BP algorithm. The convergence rate will be speeded and the accuracy of network training will be improved.

The improved BP algorithm with momentum item and self-adaptive learning rate are shown as follows:

\[
w(k+1) = w(k) + \alpha(k) \left[ (1-\eta)D(k) + \eta D(k-1) \right]
\]

\[
\alpha(k) = 2^k \alpha(k-1)
\]

\[
\lambda = \text{sgn}[D(k)D(k-1)]
\]

where: \( w(k) \) represents single connecting weight coefficient, and also represents connecting weight vector;

\[
D(k) = -\frac{\partial E}{\partial w(k)}
\]

represents negative gradient of time \( k \),

\[
D(k-1)
\]

represents negative gradient of time \((k-1)\); \( \alpha \) represents learning rate, \( \alpha > 0; \eta \) represents momentum factor, \( 0 \leq \eta < 1 \).

An additional momentum item is equal to a damping term substantially. It can reduce the oscillating trend of the learning process. So the convergence is improved. If the negative gradient directions of two consecutive iterations are same, it means that the decline speed is too slow. The step length can be doubled. If the negative gradient directions of two consecutive iterations are opposite, it means that the decline speed is excessive fast. The step length can be halved.

II. FAULT SELF-DIAGNOSIS NETWORK MODEL OF AT ELECTRONIC CONTROL SYSTEM

Fault self-diagnosis requests that electronic control system has two functions: acquiring fault information real-time online and unmanned intervention reasoning automatically [7]. Making full use of acquiring field fault information to determine fault causes and fault position rapidly. Automation and intellectualization can be realized.

A. Fault symptoms and fault sets

According to comprehensive literatures and diagnosis expert advice, the several fault types of automatic transmission electronic control system can be summarized as follows:

Sensor faults: frequency signal sensor faults, such as speed sensor, engine speed sensor, input axis speed sensor; analogue signal sensor faults, such as throttle opening sensor, pedal sensor, clutch engaging sensor, choosing position sensor, shift position sensor; switching signal sensor faults, such as all kinds of on-off switch, etc..

Actuator faults: such as choosing motor fault, shifting motor fault, clutch motor fault.

Transmission control unit faults: such as power supply fault, driving chips fault, etc.

Inputs of fault symptom can be summarized as follows:

Analog signals: such as speed signal, engine speed signal, input axis speed signal, transmission ratio, etc. Frequency signals: such as speed signal, engine speed signal, input axis speed signal, transmission ratio, etc. Under different gear positions, redundant relationship is different. Therefore, transmission ratio signal symptom is drawn.

B. Symptom signs fuzzification

The deviation between real input value of electric signal in fault system and ideal value under the same gear position is used as fault symptom signal. The signal that fuzzy diagnosis network treats is fuzzy quantity, so the range of deviation value is divided as follows: zero (ZE), positive small (PS) and positive big (PB). The specific number of fuzzy subsets of fault symptom inputs is determined by practical situation. Frequency signals, pedal signal and throttle opening signal are divided into three fuzzy subsets: zero (ZE), positive small (PS) and positive big (PB) in this paper. The residual analogue signals and transmission ratio signal are divided into a fuzzy subset PB.

The common membership functions are trigonometric function (trimf), ladder function (trapmf) and gauss type function (gaussmf). Trigonometric function and ladder function are beneficial to calculation and treatment.

They are suitable for solving questions not requiring higher completeness of fuzzy information [6]. Gauss type function is smooth and stationary. It describes fuzziness relevantly. But the calculation is complex relatively. Membership functions of fault symptom signals used in system are described as shown in Fig.3. It is needed to point out that transmission ratio signal can be blurred directly if gear position is confirmed..
C. Analysis of Analytical Redundant Relationship between sensors and actuators

Ideal value of working condition data of automatic transmission electronic control system are acquired by a lot of experimental data statistics of sample vehicle and the analytical redundancy relationship between sensors and actuators.

Analytical redundancy is redundant functional relationship existing among measurable variables of diagnosed object. There are two types: direct redundancy and instantaneous redundancy. Analysis on system structure and function is precondition that determines analytical redundancy. Combined with mathematics analysis, all analytical redundancy relationships in automatic transmission electronic control system can be determined.

Mathematical analysis methods is used as follows [8][9].

1. Suppose \( y_i(t) \) \((i = 1, 2, \cdots, m)\) is i-th output of sensors, every \( y_i(t) \neq 0 \).

If \( a_1 y_1(t) + a_2 y_2(t) + \cdots + a_m y_m(t) = 0 \), where \( a_i \) is not all 0, then there are direct redundancies among these m sensors.

2. If inputs and outputs can be expressed by dynamic mathematical model, which is the CARIMA (Controlled Auto-Regressive Moving Average) model:

\[
(1 + a_1 z^{-1} + \cdots + a_m z^{-m}) y(k) = (b_0 + b_1 z^{-1} + \cdots + b_n z^{-n}) u(k) + e(k)
\]

Where \( u(k) \) is input, \( y(k) \) is output, \( e(k) \) is noise. Transient redundancy exists between input and output for SISO (single input single output) system.

Using about mathematics analysis, main redundant relationship can be obtained:

1. There is direct redundancy among speed sensor, engine speed sensor and input axis speed sensor.
2. There is transient redundancy among choosing motor, shifting motor, position signal, and transmission ratio.
3. There is direct redundancy between pedal sensor and throttle opening sensor.
4. There is transient redundancy between throttle opening sensor and engine speed sensor.
5. There is transient redundancy between clutch engaging sensor and clutch motor.

D. Data Acquisition and Processing

The sample data of every gear position of a failure automatic transmission system were collected under different working condition [10]. In accordance with the redundancy relationship existing among signals, and the rather accurate ideal values gotten from theoretical derivation under corresponding conditions in laboratory, the deviations were calculated.

It is difficult to store a variety of ideal values of input signals under different working condition in the TCU when the trials are done on the test vehicle. Analyzing shifting schedule, it is known that each input \( x \) has a limit scope in different gear position. It is possible to calculate the deviation using the following formulas.

\[
\Delta x = \left| x - l_{max} \right|, x > l_{max} \quad (5)
\]

\[
\Delta x = 0, l_{min} \leq x \leq l_{max} \quad (6)
\]

\[
\Delta x = \left| x - l_{min} \right|, x < l_{min} \quad (7)
\]

If the monitoring value is in area \([l_{min}, l_{max}]\), it means that the system works regularly. If not, it means that the system works irregularly.

Using the absolute values of deviations as inputs of fault symptom, fuzzy partition can be simplified. Compared with using values of deviations as inputs, it is confirmed that there is no difference on the control performance. But the number of control rules is decreased. In this way, network size is smaller and training speed is faster.

Because the value ranges of the input fault symptoms are different and numerical difference is rather large in the fault diagnosis system, it is inconvenience to calculate, and the network training time and performances will be affected. It is necessary to normalize the inputs of the network.

If the actual input \( x_0* \) is in the area \([x_{min}, x_{max}]\), the universe of discourse is in the area \([x_{min}, x_{max}]\), then,

\[
x_0 = \frac{x_{min} + x_{max}}{2} + k \left( x_0 - \frac{x_{max} + x_{min}}{2} \right) \quad (8)
\]

Where \( k \) is a proportion factor, \( k = \frac{x_{max} - x_{min}}{x_{max} - x_{min}} \).

Using the above rules, the data are normalized to the area \([0,1]\) in [6][7].

On the basis of the analysis of statistics of the experiences and expert knowledge, the distributions of membership degree of possible fault samples are given. The learning samples can be collated and organized with it for neural network.

The occasional faults exist in the actual test.

The parameter sample values of the occasional faults will have a negative impact on learning and training for the fuzzy neural network. So that there may be a local error of judgment [11][12]. To avoid the occasional faults, two solutions are proposed.

The first is sample pretreatment. 50 grouped data of working conditions are obtained at regular time. The absolute deviations of the each grouped input vector are calculated. The arithmetic mean values are treated as a set of samples. The occasional big deviation of a single sample or a few samples of can be avoided. The frequency of faults determines the size of the mean deviation. If a fault is an occasional, the mean value is a small deviation after it is preprocessed. The accuracy and reliability of the sample parameters are improved effectively.
The second is the processing of fuzzy membership vectors of output fault causes. In a testing period, if a fault membership is in area (0.05, 0.20), it means there may be an occasional fault. Delaying time retesting, if the corresponding membership degree of fault cause returns to 0 before N times detecting presetting is over, detecting is stop. The fault will be an occasional. But the counter will plus 1 at the same time. If the counted number is more than 100, the fault is not an occasional fault and needs to be processed.

E. Fault Self-diagnosis network model

The training sample set is made based on field and expert experiences. The simulation training of fuzzy neural network fault self-diagnosis system is done by use of the Matlab7.0 neural toolbox. The simulation used the three-tier training model of BP network. The specific model is shown in Fig.1. The number of input layer neurons of diagnosis network 24 is equal to the number of fuzzy sets of fault signals symptoms [13]. The number of hidden layer neurons is determined by trial-and-error. The network which had different hidden nodes was trained by a same sample set. The result is shown in the Table1.

Table1 shows that convergence rate of network is fastest when the number of hidden layer neurons is 45, if training error is very small. The least number of training times is only 3334. It can satisfy the system performance.

<table>
<thead>
<tr>
<th>Hidden Number</th>
<th>Training Time</th>
<th>Training Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>7000</td>
<td>0.0457051</td>
</tr>
<tr>
<td>15</td>
<td>7000</td>
<td>0.0127023</td>
</tr>
<tr>
<td>25</td>
<td>7000</td>
<td>0.00203647</td>
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<td>0.00099165</td>
</tr>
<tr>
<td>45</td>
<td>3334</td>
<td>0.00099716</td>
</tr>
<tr>
<td>55</td>
<td>4897</td>
<td>0.000995145</td>
</tr>
<tr>
<td>50</td>
<td>4000</td>
<td>0.000998954</td>
</tr>
<tr>
<td>46</td>
<td>3711</td>
<td>0.000999316</td>
</tr>
<tr>
<td>44</td>
<td>4265</td>
<td>0.000996329</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Num</th>
<th>throttle pedal</th>
<th>throttle opening</th>
<th>clutch engaging</th>
<th>choosing grade</th>
<th>shift</th>
<th>speed</th>
<th>engine speed</th>
<th>input axis speed</th>
<th>transmissio n ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.09 0.91</td>
<td>0.86 0.14 0</td>
<td>0.02</td>
<td>0.02</td>
<td>0.04</td>
<td>0.92</td>
<td>0.08 0</td>
<td>0.94 0.06 0</td>
<td>0.88 0.12 0</td>
</tr>
<tr>
<td>2</td>
<td>0.88 0.10 0</td>
<td>0.05 0.95</td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>1</td>
<td>0</td>
<td>0.92 0.08 0</td>
<td>0.90 0.10 0</td>
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<tr>
<td>3</td>
<td>0.90 0.10 0</td>
<td>0.93 0.07 0</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.71</td>
<td>0.29 0</td>
<td>0.87 0.13 0</td>
<td>0.93 0.07 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>0.99 0.10 0</td>
<td>0.92 0.08 0</td>
<td>0.02</td>
<td>0.01</td>
<td>0</td>
<td>0.91</td>
<td>0.09 0</td>
<td>0.12 0.88</td>
<td>0.90 0.10 0</td>
</tr>
<tr>
<td>45</td>
<td>0.96 0.04 0</td>
<td>0.96 0.04 0</td>
<td>0.03</td>
<td>0</td>
<td>0</td>
<td>0.98</td>
<td>0.02 0</td>
<td>0.71 0.19 0</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Therefore, the selected number of hidden neurons is 45. The number of output neurons is the number of fault types is 13.

Testing the performances of the network which different transfer function forms are combined, we can get a best result if input-hidden layer selects Sigmoid function and hidden-output layer selects linear function Purelin [14][15]. Every output of fuzzy neural network represents a specific fault, its value is in the range of [0,1]. When the network output corresponding to the fault is 1, the fault must exist.

BP network is trained by the function Traingdx (gradient descending with momentum and self-adaptive LR return path). The training target error is 0.001, the initial learning rate is set as 0.001, the momentum factor η is 0.9, the initial weight and threshold value chooses random number between -1 to 1.

For the fault self-diagnosis system, corresponding to 13 kinds of common typical failures of electronic control system, 90 samples are collected and pre-treated. The 45 samples are taken out to be trained, and the other samples are used for testing and simulation.

### III. SIMULATION OF FAULT SELF-DIAGNOSIS BASED-ON FUZZY NEURAL NETWORK

Diagnosis network is trained by learning samples. Initializing weight value and threshold value are random, therefore convergent results of diagnosis network are different every time [12][16]. By many times simulation, the optimal weight value and threshold value are stored in the end of network convergence and database of diagnosis network is established. But under the condition of the same training parameters, the network using BP algorithm cannot converge. The simulation results are shown in Fig. 4, Fig. 5 and Fig 6, respectively. From Fig. 4 and Fig. 5, performance error is about 0.001 after 3334 times training has been done. The results show that the neural network structure and all kinds of parameters are relatively suitable in this paper.

Diagnosis network is simulated for 45 fault examples of automatic transmission electronic control system. The sample symptom inputs of fault testing are shown in Table II. The simulation results of diagnosis network are shown in Table III (partial samples). Comparing the diagnosis results with the fault reasons of samples, the conclusion can be drawn. The accuracy rate of fault prediction of the fault self-diagnosis network can reach 95%. The error curve of the test samples simulation and actual results is shown in Fig. 7. The maximum error is about 0.1. It shows that diagnosis network is generalization and precision is relatively high.

#### Table III: Simulation Result of Fault Testing

<table>
<thead>
<tr>
<th>Num</th>
<th>f_1</th>
<th>f_2</th>
<th>f_3</th>
<th>f_4</th>
<th>f_5</th>
<th>f_6</th>
<th>f_7</th>
<th>f_8</th>
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<tbody>
<tr>
<td>1</td>
<td>0.9692</td>
<td>0.0539</td>
<td>0.0229</td>
<td>0.0010</td>
<td>0.0315</td>
<td>0.0139</td>
<td>0.0247</td>
<td>0.0334</td>
<td>0.0213</td>
<td>0.0205</td>
<td>0.0179</td>
<td>0.0270</td>
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<tr>
<td>2</td>
<td>0.0452</td>
<td>0.9783</td>
<td>0.0012</td>
<td>0.0793</td>
<td>0.0213</td>
<td>0.0010</td>
<td>0.0432</td>
<td>0.1023</td>
<td>0.0306</td>
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</tr>
<tr>
<td>3</td>
<td>0.0271</td>
<td>0.0102</td>
<td>0.8706</td>
<td>0.0384</td>
<td>0.0072</td>
<td>0.1195</td>
<td>0.0053</td>
<td>0.0377</td>
<td>0.0190</td>
<td>0.0151</td>
<td>0.0136</td>
<td>0.0863</td>
<td>0.0286</td>
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</tr>
<tr>
<td>44</td>
<td>0.0004</td>
<td>0.0304</td>
<td>0.0084</td>
<td>0.0282</td>
<td>0.0011</td>
<td>0.0376</td>
<td>0.0002</td>
<td>0.0102</td>
<td>0.0069</td>
<td>0.0421</td>
<td>0.0074</td>
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<td>0.1160</td>
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<tr>
<td>45</td>
<td>0.0017</td>
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<td>0.0417</td>
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<td>0.0009</td>
<td>0.0066</td>
<td>0.0167</td>
<td>0.0275</td>
<td>0.0341</td>
<td>0.1007</td>
<td>0.0348</td>
<td>0.0016</td>
<td>0.9314</td>
</tr>
</tbody>
</table>

**Sim. Results**

- throttle pedal sensor fault
- throttle opening sensor
- clutch engaging sensor fault
- engine speed sensor fault
- input axis speed sensor fault

**Fig 4.** Training error curve of network using BP algorithm

**Fig 5.** Training error curve
Because the results which the nerve network converges and looks for optimal results are not same each time, neither are the diagnosis network models. The above testing model is the optimal model got from training many times. Without loss of generality, we use same samples to test 10 networks of random training generation. The testing includes the network using BP algorithm and optimized BP algorithm respectively. Considering the BP algorithm can not reach a very small error, the error is chosen to 0.01 to test. Statistical results are shown in Table IV.

The statistical results show the network using optimal BP algorithm can make decision for diagnosis system. The optimized network model has higher accuracy rate and training speed than the network model using BP algorithm obviously.

<table>
<thead>
<tr>
<th>Optimization algorithm of BP</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Rate</td>
<td>92.7%</td>
<td>92.7%</td>
<td>92.7%</td>
<td>92.7%</td>
<td>92.7%</td>
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<td>92.7%</td>
<td>92.7%</td>
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<tr>
<td>Average Time</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tbody>
</table>

BP algorithm
<table>
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<th>3</th>
<th>4</th>
<th>5</th>
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<th>7</th>
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</tr>
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<tbody>
<tr>
<td>Correct Rate</td>
<td>70.4%</td>
<td>70.4%</td>
<td>70.4%</td>
<td>70.4%</td>
<td>70.4%</td>
<td>70.4%</td>
<td>70.4%</td>
<td>70.4%</td>
<td>70.4%</td>
</tr>
<tr>
<td>Average Time</td>
<td>91.11s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IV. CONCLUSIONS

The model of fault self-diagnosis based-on fuzzy neural network can diagnose faults in automatic transmission electronic control system effectively. Transplanting diagnosis model into TCU, states of the system can be monitored in real time. This method provides a basis for fault treatment on-line effectively. Simulation results show that security and reliability of the system are improved. The fault causes can be pointed. The accuracy rate of fault self-diagnosis is rather high. This method can be used in engineering.

REFERENCES


So far, she has worked at Hefei University of Technology for 20 years from 1989. She is an Associate Professor now. The number of her published articles is more than 40, such as: Study on AMT Fuzzy Shifting Strategy and Realization, The IEEE International Conference on Automation and Logistics, ICAL Qingdao, 2008.9; Starting Process Control for the Clutch of Automated Mechanical Transmission, International Forum on Information Technology and Applications, IFITA Chengdu, 2009; Research of Fuzzy Control Technology on AMT Vehicle Clutches, the 6th World Congress on Intelligent Control, Dalian, 2006. Her research interests were in the fields of the control theory and control engineer in theory until 2003. With the development of the automobile industry of China, it is obvious that performances of vehicle will be improved greatly if advanced control theory is applying to vehicle. Since 2003, her research has been devoted to solving problems of the automatic transmission control. Her major field of study is to apply advanced control theory to improve reliability and adaptability of vehicle.

Ren Guoqing was born in Anhui Province, China, in1966. B.S., Vehicle Engineering, Department of Automotive Engineering, Hefei University of Technology, in 2003. He is a senior engineer in Anhui Jianghuai Automotive Co., Ltd., Hefei, Anhui, China.

He Jizhu was born in Anhui Province, China, in1984. B.S., Automation, Automation Department, Hefei University., in 2006. He has been a undergraduate at Hefei University of Technology, Hefei, Anhui, China, since 2006. His research direction is electronic control technology for automobile safety.

Xiao Benxian was born in Anhui Province, China, in1964. Ph.D., Power Electronics and Power Drive, School of Electrical Engineering and Automation, Hefei University of Technology, Hefei, Anhui, China., 2002.6. He is a Professor at School of Electrical Engineering and Automation, Hefei University of Technology, Hefei, Anhui, China.
Fuzzy Random Dependent-Chance Programming Models of Loan Portfolio

Dongjing Pan
Department of Computer Science and Technology, Dezhou University, Dezhou Shandong 253023, China
E-mail: pdj1970@163.com

Abstract—The environment of loan in bank is very complex, there are not only random factors but also fuzzy factors, so the return rates of loan often have fuzzy random characteristic. Mean chance is a measure of fuzzy random variable. This paper proposes two fuzzy random dependent-chance programming models of loan portfolio, one is minimize the mean chance of a bad outcome under the certain expected return rate, one is maximize the mean chance of the prospective return rate under the certain expected return rate. Hybrid intelligent algorithms are employed to solve the models. Finally, two numerical examples are given to show the validity and feasibility of the models and algorithms.

Index Terms—dependent-chance programming, loan portfolio, mean chance, fuzzy random

I. INTRODUCTION

In order to distribute risk, the bank puts loan in the different projects, which is loan portfolio. Essentially, it is portfolio selection. Loan portfolio is that the bank should decide how to allocate the certain capital in proportion so as to obtain the maximal return rates and the minimal risk. Since Markowitz[1] initialized the mean-variance model of portfolio selection, many scholars propose many different methods to solve portfolio problem. Tang[2] gave a kind of probability criterion portfolio investment model, in the model, the objective is to maximize the probability of the prospective return rare. Under the constraint of certain return rate, Sheedy[3] establishes the asset allocation decision model when the risk changes. Ning[4] gives chance programming model of loan portfolio when the return rate is fuzzy. Dietsch and Petey[27] proposed a internal credit risks model about SME loan. Huang[16] measured portfolio risk by the variance based on credibility and proposed two new credibility-based fuzzy mean-variance models. Tanaka and Guo[15] quantified mean and variance of a portfolio through fuzzy probability and possibility distributions. These models’ objective is mainly maximize the return rates under the constraint of certain risk, or minimize the risk under the constraint of certain return rate. Risk is primarily mathematically defined in three ways: variance, semivariance and a probability of a bad outcome. Based on Markowitz’s mean-variance model, a large numbe of extensions have been proposed[5,6,7,8]. Semivariance is another measure of risk proposed by Markowitz[9], semivariance is an important improvement of variance because it only measures the investment return below the expected value. Many models have been built to minimize the semivariance from different angles[10,11].

The third popular definition of risk is a probability of a bad outcome initially by Roy[12]. Much research has been undertaken to find ways of minimizing the probability of the bad outcome[13,14]. However, the above studies mainly focused in two directions: stochastic environment and fuzzy environment. But the investment environment is so complex, sometimes we have to deal with the uncertainty of both fuzziness and randomness simultaneously. For example, the loan return rate can be regarded to be triangle fuzzy variable $(\rho - 0.1, \rho, \rho + 0.1)$, and $\rho$ is random variable. Thus we have to face “fuzzy return rates with random parameters”. To deal with this type of uncertainty, this paper proposes that return rates be regarded as fuzzy random variable. Huang[23] gave a new optimal model of portfolio selection with random fuzzy returns, the paper proposed the primitive chance measure of risk, but the primitive chance measure only measures the maximum possibility of a random fuzzy or fuzzy random event occurs under a given probability level, and she did not research optimal model in fuzzy random environment. So in this paper, we consider the loan portfolio problem in fuzzy random environment, and because the mean chance measures the mean or expected possibility of the fuzzy random event, it can show the possibility of the fuzzy random event more extensive than primitive chance, so we use the mean chance of a bad outcome to measure the risk. Base on mean chance, this paper paper proposes two new dependent-chance programming models, one is minimize the mean chance of a bad outcome under the certain expected return rate, another is maximize the mean chance of the prospective return rate under the certain expected return rate, and designs hybrid intelligent algorithms to solve the models.

The rest of the paper is organized as follows. For better understanding of the paper, some basic knowledge about fuzzy random variables is introduced in section 2. In section 3, we propose two new dependent-chance programming models based on mean chance. In order to give a general algorithm for the models, hybrid intelligent
algorithms integrating fuzzy random simulation, neural network and genetic algorithm are designed in section 4. In section 5, two numerical examples are given to show the new models and the efficiency of the algorithms. Finally, a brief summary of this paper is given in section 6.

II PRELIMINARIES

Fuzzy random variable is a math description of fuzzy random phenomenon, it has different math definitions, it was first introduced by Kwakernaak [17,18], then Puri and Ralescu [19], Liu and Liu [20] gave the different measure of fuzzy random variable. And according to the need of different theory, many scholars gave the different mathematical definitions and different measures of fuzzy random variable. In this paper, we use the definitions of fuzzy random variable given by Liu and Liu [20]. Roughly speaking, a fuzzy random variable is a measurable function from a probability space to a collection of fuzzy variables. The primitive chance measure, mean chance measure of a fuzzy random variable have been defined by Liu [21], and the concepts of expected value operator of fuzzy random variable was also presented by Liu [24]. Fuzzy random theory play an important role in solving optimization problems involving both fuzziness and randomness. In this paper, we will employ the fuzzy random theory to solve the loan portfolio problem in a fuzzy random environment.

In order to better understanding this paper, some concepts of probability, possibility, necessity and credibility measure were first briefly reviewed, and then we introduce the concept of a fuzzy random variable and the expected value, primitive chance measure, mean chance measure of a fuzzy random variable.

Definition 1 Let Ω be a nonempty set, and A a σ-algebra of subsets of Ω. The set function Pr is called a probability measure if

(1) Pr(Ω) = 1;
(2) Pr(A) ≥ 0 for any A ∈ A;
(3) for any countable sequence of mutually disjoint events \{A_i\}

Then the triplet (Ω, A, Pr) is called a probability space.

Definition 2 Let Θ be a nonempty set, and P(Θ) the power set of Θ, if for each A ∈ P(Θ), there is a nonnegative number Pos(A), called possibility, such that

(1) Pos(ϕ) = 0, Pos(Θ) = 1; 
(2) Pos(\bigcup_i A_i) = \sup_i Pos(A_i) for any arbitrary collection \{A_i\} in P(Θ).

Then the triplet (Θ, P(Θ), Pos) is called a possibility space.

Definition 3 Let ξ be a fuzzy variable on a possibility space (Θ, P(Θ), Pos) with membership function μ, and r a real number. The possibility, necessity, and credibility of a fuzzy event, characterized by ξ ≤ r, is defined by

\[ \text{Pos}(\xi \leq r) = \sup_{u \leq r} \mu(u), \]
\[ \text{Nec}(\xi \leq r) = 1 - \text{Pos}(\xi > r) = 1 - \sup_{u > r} \mu(u), \]
\[ \text{Cr}(\xi \leq r) = \frac{1}{2} \left( \text{Pos}(\xi \leq r) + \text{Nec}(\xi \leq r) \right). \]

The expected value of a fuzzy variable is defined by

\[ E[\xi] = \int_0^\infty \text{Cr}(\xi \geq r) dr - \int_0^0 \text{Cr}(\xi \leq r) dr. \]

In order to avoid the action of \(-\infty - \infty\), at least one of the two integrals of above formula is finite.

Definition 4 (Liu and Liu [20]) A fuzzy random variable ξ is a measurable function from a probability space (Ω, A, Pr) to a collection of fuzzy variables.

Example 1 Let ξ = (ρ - 0.5, ρ, ρ + 1.5), and ρ ∈ exp(1), then ξ is called a fuzzy random variable.

Example 2 Let (Ω, A, Pr) be probability space, if Ω = (ω_1, ω_2, ..., ω_m) and η_1, η_2, ..., η_m are fuzzy variables. Then the function

\[ \xi(ω) = \begin{cases} η_1, & \text{if } ω = ω_1 \\ η_2, & \text{if } ω = ω_2 \\ \vdots & \vdots \\ η_m, & \text{if } ω = ω_m \end{cases} \]

is a fuzzy random variable.

Definition 5 (Liu and Liu [20]) Let ξ be a fuzzy random variable defined in probability space (Ω, A, Pr), The expected value of ξ is defined by

\[ E[ξ] = \int_0^\infty \text{Pr}(ω ∈ Ω | E[ξ(ω)] ≥ r) dr - \int_0^0 \text{Pr}(ω ∈ Ω | E[ξ(ω)] ≤ r) dr. \]

In order to avoid the action of \(-\infty - \infty\), at least one of the two integrals of above formula is finite.

Definition 6 (Liu[21], Gao and Liu[22]) Let \( \xi = (ξ_1, ξ_2, ..., ξ_n) \) be fuzzy random vector that is defined in probability space (Ω, A, Pr), \( f : R^n → R^n \) is measurable function. Then the primitive chance of a fuzzy random event characterized by \( f(ξ) ≤ 0 \) is a function from [0,1] to [0,1], defined as

\[ \text{Ch}(f(ξ) ≤ 0)(α) = \sup{β | \text{Pr}(ω ∈ Ω | Cr(f(ξ(ω)) ≤ 0) ≥ β) ≥ α} \]
We call \( Ch[f(\xi) \leq 0](\alpha) \) \( \alpha \) primitive chance of the fuzzy random event \( f(\xi) \leq 0 \).

**Theorem 1** (Gao and Liu[22]) Let \( \xi \) be fuzzy random vector that is defined in probability space \((\Omega, \mathcal{A}, Pr)\), \( f : R^n \rightarrow R^m \) is measurable function, then \( Ch[f(\xi) \leq 0](\alpha) \) is a decreasing function of \( \alpha \).

**Definition 7** (Liu[24]) Let \( \xi = (\xi_1, \xi_2, \ldots, \xi_n) \) be fuzzy random vector that is defined in probability space \((\Omega, \mathcal{A}, Pr)\), \( f : R^n \rightarrow R^m \) is measurable function. Then the mean chance of a fuzzy random event characterized by \( f(\xi) \leq 0 \) is defined as

\[
Ch^a\{ f(\xi) \leq 0 \} = \int_0^1 Ch\{ f(\xi) \leq 0 \}(\alpha) d\alpha
\]

The value of the primitive chance at \( \alpha \) measures the maximum possibility of a fuzzy random event occurs under a given probability level \( \alpha \), while the mean chance measures the mean or expected possibility of the fuzzy random event[26]. The geometric meaning of mean chance is shown in Fig.1, mean chance equals to the area encircled by the curve and the coordinate axis.

![Fig.1 Geometric meaning of mean chance](image)

### III TWO NEW DEPENDENT-CHANCE PROGRAMMING MODELS OF LOAN PORTFOLIO

Supposing the bank will loan for \( n \) projects, let \( x_i \) represent the loan proportion for the \( i \)th project, \( X = (x_1, x_2, \ldots, x_n) \) is decision vector, \( \xi = (\xi_1, \xi_2, \ldots, \xi_n) \) is the vector that is composed of return rates of \( n \) kinds of loan, \( \xi_i \) represents the \( i \)th return rate, it is a fuzzy random variable, \( R_0 \) is the preset bad outcome return rate. In order to avoid risk, we can minimize the mean chance of the return rates less than the preset bad outcome \( R_0 \) under the constraint of expected return rates no less than \( \mu \), so the following model can be given:

\[
\min Ch^a\left( \sum_{i=1}^{n} x_i \xi_i \leq R_0 \right) \\
s.t.
\]

\[
E\left[ \sum_{i=1}^{n} x_i \xi_i \right] \geq \mu
\]

\[
\sum_{i=1}^{n} x_i = 1
\]

\[
x_i \geq 0, \ i = 1, 2, \ldots, n
\]

If we set the prospective return rate is \( R_i \), the target is to maximize the mean chance of the return rates more than \( R_i \) under the constraint of expected return rates no less than \( \mu \), we can get the following model:

\[
\max Ch^a\left( \sum_{i=1}^{n} x_i \xi_i \geq R_i \right) \\
s.t.
\]

\[
E\left[ \sum_{i=1}^{n} x_i \xi_i \right] \geq \mu
\]

\[
\sum_{i=1}^{n} x_i = 1
\]

\[
x_i \geq 0, \ i = 1, 2, \ldots, n
\]

Because the return rates of loan are fuzzy random variables, it is hard to find out crisp equivalents of the above models, so hybrid intelligent algorithms are employed to solve the models.

### IV HYBRID INTELLIGENT ALGORITHM

Now we mainly take model(1) for example to illustrate the solving process. Since return rates are fuzzy random variables, it is difficult to solve model(1) in traditional ways. To provide a general solution to the model (1), we design a hybrid intelligent algorithm integrating genetic algorithm(GA), fuzzy random simulation and neural network(NN). Fuzzy random simulation is applied to compute the objective values of mean chance \( Ch^a\left( \sum_{i=1}^{n} x_i \xi_i \leq R_0 \right) \) and the expected return rate \( E\left[ \sum_{i=1}^{n} x_i \xi_i \right] \), GA is employed to find the optimal solution. In order to reduce the computational work, neural network is trained to approximate the objective values of mean chance \( Ch^a\left( \sum_{i=1}^{n} x_i \xi_i \leq R_0 \right) \) and the expected return rates \( E\left[ \sum_{i=1}^{n} x_i \xi_i \right] \).

#### A Fuzzy random simulation:

We should utilize fuzzy random simulation to estimate the uncertain functions[24]:
\[ U_1 : x \rightarrow Ch^n \left( \sum_{i=1}^{n} x_i \xi_i \leq R_0 \right) \]
\[ U_2 : x \rightarrow E \left[ \sum_{i=1}^{n} x_i \xi_i \right] \]

Fuzzy random simulation for \( U_1 (x) \): we first compute primitive chance
\[ Ch^n \left( \sum_{i=1}^{n} x_i \xi_i \leq R_0 \right) \]
through step 1 to step 4.

Step 1 Generate \( \omega_1, \omega_2, \ldots, \omega_m \) from \( \Omega \) according to the probability measure \( Pr \).

Step 2 Compute the credibility
\[ \beta_k = Cr^n \left( \sum_{i=1}^{n} x_i \xi_i (\omega_k) \leq R_0 \right), \quad k = 1, 2, \ldots, m \]
respectively, by fuzzy simulation.

Step 3 Set \( m' \) as the integer part of \( am \).

Step 4 Return the \( m' \) th largest element in sequence \( \{ \beta_1, \beta_2, \ldots, \beta_m \} \).

Let \( \alpha \) change from 0 to 1, then \( Ch^n \left( \sum_{i=1}^{n} x_i \xi_i \leq R_0 \right) \)
can be computed through the following formula
\[ Ch^n \left( \sum_{i=1}^{n} x_i \xi_i \leq R_0 \right) = \int_0^1 Ch^n \left( \sum_{i=1}^{n} x_i \xi_i \leq R_0 \right) (\alpha) d\alpha \]
In the above step 2, the fuzzy simulation process of \( Cr^n \{ f (\xi) \leq R_0 \} \) is described as follows:

Generate \( \theta_k \) in \( \Theta \) evenly and make \( Pos \{ \theta_k \} \geq \varepsilon \), let \( v_k = Pos \{ \theta_k \}, \quad k = 1, 2, \ldots, N \), \( \varepsilon \) is a small number enough, the credibility of \( Cr^n \{ f (\xi) \leq R_0 \} \) can be estimated by the following formula
\[ L = \frac{1}{2} \left( \max_{1 \leq k \leq N} \{ v_k \ \mid f (\xi (\theta_k)) \leq R_0 \} \right) \]
\[ + \min_{1 \leq k < N} \left( 1 - v_k \ \mid f (\xi (\theta_k)) > R_0 \right) \]
fuzzy simulation value of \( Cr^n \{ f (\xi) \leq R_0 \} \).

Fuzzy random simulation for \( U_2 (x) \) is described as follows:

Step 1 Set \( e = 0 \).

Step 2 Generate \( \omega \) from \( \Omega \) according to the probability measure \( Pr \).

Step 3 \( e \leftarrow e + E \left[ \sum_{i=1}^{n} x_i \xi_i (\omega) \right], \quad E \left[ \sum_{i=1}^{n} x_i \xi_i (\omega) \right] \)
can be computed by fuzzy simulation.

Step 4 Repeat the second to third steps for \( N \) times.

Step 5 \( E \left[ \sum_{i=1}^{n} x_i \xi_i \right] \leftarrow e / N \).

In the above step 3, the fuzzy simulation process of expected value of \( E \{ f (\xi) \} \) is as following step 1 to step 8.

Step 1 Set \( g = 0 \).

Step 2 Generate \( \theta_k \) evenly in \( \Theta \) and make \( Pos \{ \theta_k \} \geq \varepsilon \), let \( v_k = Pos \{ \theta_k \}, \quad k = 1, 2, \ldots, N \), \( \varepsilon \) is a small number enough.

Step 3 Let \( a = f (\xi (\theta_1)) \land \cdots \land f (\xi (\theta_N)) \),
\[ b = f (\xi (\theta_1)) \lor \cdots \lor f (\xi (\theta_N)) \].

Step 4 Generate \( r \) evenly in \( [a, b] \).

Step 5 If \( r \geq 0 \), then \( g \leftarrow g + Cr \{ f (\xi) \geq r \} \).

Step 6 If \( r < 0 \), then \( g \leftarrow g + Cr \{ f (\xi) \leq r \} \).

Step 7 Repeat the fourth to sixth steps for \( N \) times.

Step 8 \( E \{ f (\xi) \} = a \lor 0 + b \lor 0 + g \cdot (b - a) / N \).

B Train NN

We use BPA back propagation algorithm to train NN to approximate the objective value of mean chance
\[ Ch^n \left( \sum_{i=1}^{n} x_i \xi_i \leq R_0 \right) \]
and the expected return rates
\[ E \left[ \sum_{i=1}^{n} x_i \xi_i \right] \] [24]. First, generate training data set, one training data is expressed as \( \{ x_1, x_2, \ldots, x_n, U_1, U_2 \} \),
where \( U_1 = Ch^n \left( \sum_{i=1}^{n} x_i \xi_i \leq R_0 \right) \) and
\( U_2 = E \left[ \sum_{i=1}^{n} x_i \xi_i \right] \). \( U_1, U_2 \) can be computed by fuzzy random simulation. When generating input data \( \{ x_1, x_2, \ldots, x_n \} \), we set \( x_i = x_i / (x_1 + x_2 + \cdots + x_n) \), \( i = 1, 2, \ldots, n \), which ensure that \( \sum_{i=1}^{n} x_i = 1 \) always holds. Then use BPA back propagation algorithm to train NN. The training purpose is to find the most suitable weights \( \omega \) that can minimize the error between the output of NN and \( U_1, U_2 \). It is usually enough to train the NN with one hidden layer. In the paper, the NN has one hidden layer connecting the input layer and the output layer in a feed-forward way and has two neurons in the output layer.

Supposing the NN has \( l \) neurons in the input layer, \( p \) neurons in the hidden layer and \( m \) neurons in the output layer. Now, there are \( N \) samples
\[ \{ x_{k,1}, x_{k,2}, \ldots, x_{k,l}; d_{k,1}, d_{k,2}, \ldots, d_{k,m} \}, \quad k = 1, 2, \ldots, N \].

When the \( k \)-th sample is used, the outputs of the hidden neurons are
For is not feasible, we set until it is feasible. If and always hold. Then check their satisfaction, as follows:

C Genetic algorithm:
Initialization process: We randomly initialize \( \text{pop\_size} \) number of chromosomes, a chromosome is expressed as \( (x_1, x_2, \ldots, x_n) \). \( x_1, x_2, \ldots, x_n \) are randomly generated in the interval \([0,1]\). Let

\[
x_i = x_i / (x_1 + x_2 + \cdots + x_n) , \quad i = 1, 2, \ldots, n
\]

ensure that \( \sum_{i=1}^{n} x_i = 1 \) always holds. Then check their feasibility by NN, if \( E[\sum_{i=1}^{n} x_i \xi_i] \geq \mu \), it is a feasible chromosome.

Selection process: We select chromosomes by spinning the roulette wheel such that the better chromosomes will have. The selection process is as follows:[24]

First, if there are \( \text{pos\_size} \) chromosomes \( V_1, V_2, \ldots, V_{\text{pop\_size}} \) at the current generation, we can order these chromosomes from good to bad, the better the chromosome is, the smaller the ordinal number it has. Let a parameter \( a \in (0,1) \) in the genetic system be given, we can define the rank-based evaluation function as follows

\[
eval(V_i) = a(1-a)^{i-1}, \quad i = 1, 2, \ldots, \text{pop\_size}
\]

Note that \( i = 1 \) means the best chromosome, \( i = \text{pop\_size} \) means the worst one.

Secondly, calculate the cumulative probability \( q_i \) for each chromosome \( V_i \),

\[
q_0 = 0 , \quad q_i = \sum_{j=1}^{i} \text{Eval}(V_j) , \quad i = 1, 2, \ldots, \text{pop\_size}
\]

where \( \text{Eval}(V) \) is evaluation function.

Thirdly, generate a random number \( r \) in \((0, \text{pop\_size})\), and select the chromosome \( V_i \) if \( r \) satisfies

\[
q_{i-1} < r < q_i .
\]

Fourthly, repeat the third step \( \text{pop\_size} \) times and obtain \( \text{pop\_size} \) copies of chromosome.

Crossover operation: A crossover parameter \( p_c \) is defined first[24]. Repeating the following process from \( i = 1 \) to \( \text{pos\_size} \): generating a random number \( r \) from the interval \([0, 1]\), the chromosome \( V_i \) is selected as a parent if \( r < p_c \). We denote the selected parents by \( V'_1, V'_2, V'_3, \ldots \), and divided them into the following pairs: \((V'_1, V''_2), (V'_3, V'_4), (V'_5, V'_6), \ldots \). The crossover operation on each pair is illustrated by \((V'_i, V''_j)\). At first, we generate a random number \( c \) from the open interval \((0,1)\), then the operator on \( V'_1 \) and \( V''_2 \) will produce two child \( X \) and \( Y \) as follows:

\[
X = cV'_1 + (1-c)V''_2 , \quad Y = (1-c)V'_1 + cV''_2 
\]

If \( X = (x_1, x_2, \ldots, x_n) \), \( Y = (y_1, y_2, \ldots, y_n) \). Let

\[
x_i = x_i / (x_1 + x_2 + \cdots + x_n) , \quad y_i = y_i / (y_1 + y_2 + \cdots + y_n) , \quad i = 1, 2, \ldots, n ,
\]

which ensure that \( \sum_{i=1}^{n} x_i = 1 \) and \( \sum_{i=1}^{n} y_i = 1 \) always hold.

Checking whether \( E[\sum_{i=1}^{n} x_i \xi_i] \geq \mu \) and \( E[\sum_{i=1}^{n} y_i \xi_i] \geq \mu \) through NN, if both children are feasible, then we replace the parents with them. If not, we keep the feasible one if it exists, and then redo the crossover operator by regenerating a random number \( c \) until two feasible children are obtained or a given number of cycles is finished.

Mutation operation[24]: We define a parameter \( p_m \) as the probability of mutation. This probability gives us the expected number of \( p_m \cdot \text{pos\_size} \) of chromosomes undergoing the mutation operations. Repeating the following steps from \( i = 1 \) to \( \text{pos\_size} \): generating a random number \( r \) from the interval \([0,1]\), the chromosome \( V_i \) is selected as a parent for mutation if \( r < p_m \). For each selected parent \( V_i \), we mutate it in the following way. Let \( M \) be an appropriate large positive number. We choose a mutation direction \( d \) in \( \mathbb{R}^n \) randomly. Let \( X = V + M \cdot d \). If \( X = (x_1, x_2, \ldots, x_n) \), let

\[
x_i = x_i / (x_1 + x_2 + \cdots + x_n) , \quad i = 1, 2, \ldots, n ,
\]

checking the feasibility through NN. If \( X \) is not feasible, we set \( M \) as a random number between 0 and \( M \) until it is feasible. If the above process cannot find a feasible solution in a predetermined number of iterations, then we set \( M = 0 \).

D Hybrid intelligent algorithm
The hybrid intelligent algorithm that is integrated fuzzy random simulation, genetic algorithm and NN is summarized as follows[24]:

Step 1 Generate training data set for the following uncertain functions by fuzzy random simulation.
\[ U_1 : x \rightarrow Ch^a (\sum_{i=1}^{n} x_i \xi_i \leq R_0) \]

\[ U_2 : x \rightarrow E[\sum_{i=1}^{n} x_i \xi_i] \]

Step 2 Train NN to approximate the objective value of mean chance \( Ch^a (\sum_{i=1}^{n} x_i \xi_i \leq R_0) \) and the expected return rates \( E[\sum_{i=1}^{n} x_i \xi_i] \).

Step 3 Determine the population size \( pos \_size \), crossover probability \( p_c \), mutation \( p_m \) in genetic algorithm.

Step 4 Initialize feasible \( pos \_size \) chromosomes. Use the trained NN to check the feasibility of chromosomes.

Step 5 Update the chromosomes by crossover and mutation operations in which the feasibility of offspring may be checked by the trained neural network.

Step 6 Calculate the objective values for all chromosomes by the trained neural network.

Step 7 Compute the fitness of each chromosome according to the objective values.

Step 8 Select the chromosomes by spinning the roulette wheel.

Step 9 Repeat the fifth to eighth steps for a given number of cycles.

Step 10 Report the best chromosome as the optimal solution.

The method to solve model(2) is similar.

V NUMBER EXAMPLE

To illustrate the optimization idea and to test the effectiveness of the proposed algorithm, two numerical example is presented here. Supposing there are five kinds of loan in model(1) and model (2), each return rate is fuzzy random variable, described as follows.

\[ \xi_1 = (\rho_1 - 0.012, \rho_1 + 0.045, \rho_1 + 0.075, \rho_1 + 0.075) \]
\[ \xi_2 = (\rho_2 - 0.015, \rho_2 + 0.06, \rho_2 + 0.06) \]
\[ \xi_3 = (\rho_3 - 0.02, \rho_3 + 0.04, \rho_3 + 0.085, \rho_3 + 0.085) \]
\[ \xi_4 = (\rho_4 - 0.02, \rho_4 + 0.05, \rho_4 + 0.09, \rho_4 + 0.09) \]
\[ \xi_5 = (\rho_5 - 0.016, \rho_5 + 0.08, \rho_5 + 0.08) \]
\[ \rho_3 \sim N(0.01,0.02^2) \]
\[ \rho_4 \sim N(0.03,0.03^2) \]
\[ \rho_5 \sim N(0.02,0.04^2) \]

Let \( R_0 = -0.02 \), \( \mu = 0.05 \), the model(1) is formulated as follows:

\[ \begin{aligned}
 & \min Ch^a (\sum_{i=1}^{n} x_i \xi_i \leq -0.02) \\
 \text{s.t.} & E[\sum_{i=1}^{n} x_i \xi_i] \geq 0.05 \\
 & \sum_{i=1}^{n} x_i = 1 \\
 & x_j \geq 0, \ i = 1, 2, \ldots, n
\end{aligned} \]

the model(3) is solved through running hybrid intelligent algorithm, the parameters in the algorithm are set as follows: 500 cycles in simulation, 2000 data in NN(NN has 5 input neurons, 15 hidden neurons, 2 output neuron), 400 generations in GA, the population size \( pop \_size = 30 \), the crossover probability \( P_c = 0.3 \), the mutation probability \( P_m = 0.2 \). The run of the hybrid intelligent algorithm shows the best allocation proportion is \( X^* = (0.4348, 0.0994, 0.2103, 0.2124, 0.0431) \). The minimal mean chance of the return rates less than the preset bad outcome -0.02 is 0.073272. The genetic process of algorithm is shown as Fig.2:

![Fig.2 Genetic process of algorithm for model(3)](image)

In order to further test the effectiveness of the designed algorithm, we use more numerical experiments with different values of parameters in the GA. The results are shown in Table 1.

<table>
<thead>
<tr>
<th>Number of generations</th>
<th>pos_size</th>
<th>( P_c )</th>
<th>( P_m )</th>
<th>Objective value</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>30</td>
<td>0.3</td>
<td>0.2</td>
<td>0.073272</td>
</tr>
<tr>
<td>400</td>
<td>50</td>
<td>0.5</td>
<td>0.2</td>
<td>0.073232</td>
</tr>
<tr>
<td>400</td>
<td>80</td>
<td>0.3</td>
<td>0.5</td>
<td>0.073221</td>
</tr>
<tr>
<td>500</td>
<td>60</td>
<td>0.1</td>
<td>0.4</td>
<td>0.073222</td>
</tr>
<tr>
<td>500</td>
<td>100</td>
<td>0.6</td>
<td>0.3</td>
<td>0.073225</td>
</tr>
<tr>
<td>800</td>
<td>30</td>
<td>0.3</td>
<td>0.3</td>
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</tr>
<tr>
<td>800</td>
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<td>0.3</td>
<td>0.2</td>
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</tr>
<tr>
<td>1000</td>
<td>70</td>
<td>0.2</td>
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</tr>
<tr>
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<td>30</td>
<td>0.3</td>
<td>0.2</td>
<td>0.073261</td>
</tr>
</tbody>
</table>
From table 1, we can see when different values of parameter in GA are set, the objective value changes very tiny, so the designed algorithm is robust to set parameters and effective to solve the model(3).

Let \( R_1 = 0.07 \), \( \mu = 0.05 \), the model(2) is formulated as follows:

\[
\begin{align*}
\max \ & Ch^n \left( \sum_{i=1}^n x_i \xi_i \geq 0.07 \right) \\
\text{s.t.} \ & E[\sum_{i=1}^n x_i \xi_i] \geq 0.05 \\
& \sum_{i=1}^n x_i = 1 \\
& x_i \geq 0, \ i = 1, 2, \cdots, n
\end{align*}
\]

Through running hybrid intelligent algorithm we solve model(4), the parameters setting are as same as above. The run of the hybrid intelligent algorithm shows the maximal mean chance of the return rates more than the prospective return rate 0.07 is 0.556277, the best allocation proportion is \( X^* = (0.0192, 0.0059, 0.0363, 0.9251, 0.0136) \), the genetic process of algorithm is shown as Fig.3:

\[\text{Fig.3 Genetic process of algorithm for model(4)}\]

Similarly, we test the effectiveness of the designed algorithm for model(4) through setting different values of parameters in the GA. The results are shown in Table 2.

From table 2, we can see that the designed algorithm is robust to set parameters and effective to solve the model(4).

<table>
<thead>
<tr>
<th>Number of generations</th>
<th>pos_size</th>
<th>( P_c )</th>
<th>( P_m )</th>
<th>Objective value</th>
</tr>
</thead>
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</tr>
<tr>
<td>1000</td>
<td>30</td>
<td>0.3</td>
<td>0.2</td>
<td>0.568431</td>
</tr>
</tbody>
</table>

\[\text{VI CONCLUSION} \]

In the paper, we discuss the optimization of loan portfolio under fuzzy random environment, give two new dependent-chance programming models of loan portfolio based on mean chance and design hybrid intelligent algorithms integrating genetic algorithm, fuzzy random simulation and neural network to solve the models. At the end, two numerical examples are presented to illustrate the modelling idea and the effectiveness of the proposed algorithm.


Dongjing Pan, was born in Dezhou Shandong, China in 1970. She received her bachelor’s degree from Shandong Teachers’ University in 1991, the specialty is computer science and technology, and she received her master’s degree from Shandong Teachers’ University in 2002, the specialty is management science and engineering. Shandong Teachers’ University is in Jinan Shandong, China. She is a teacher in the department of computer science and technology, Dezhou University. Her job title is Associate Professor. Currently, her research interests include operating system, uncertain programming, hybrid intelligent algorithm, loan portfolio, risk investment, etc.

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Research on Target Detection and Automatic Extraction of Region of Interest in Infrared Serial Images

Hu Guang
School of Computer Science & Technology, Yantai University, Yantai, China
Email: Ghu0459@163.com

Yuan Shengzhi
Department of Science and Technology of Weapons, Naval Aeronautical Engineering Institute, Yantai, China
Email: yuanshengzhi_hy@sina.com

Abstract—Infrared imaging guidance is a research hotspot in accurate terminal guidance field now. An idea on automatic extraction of region (ROI) of interest in infrared serial images is proposed in order to treat intelligently infrared serial images which are captured. The target detection algorithm of target is researched and the applying scene of the target detection algorithm is confirmed based on analysis for the features of infrared serial images. According to differences of detection algorithm for infrared serial images between static and dynamic scenes, the corresponding detection and extraction algorithm of ROI is discussed respectively. The algorithms are all simulated in real scene. A new stepwise approaching and recurring threshold search algorithm based on two-dimensional maximum entropy principle was proposed by studying recurring formulation optimized of two-dimensional maximum entropy in order to realize to detect target and extract ROI of serial images under complex background. The algorithm above realizes automatic extraction of ROI in Infrared serial images. The results improve the efficiency of accurate terminal guidance and they have good application value by practicing.

Index Terms—infrared serial images, ROI, target detection, stepwise approaching and recurring threshold search algorithm, accurate guidance

I. INTRODUCTION

In modern battles, long-distance attacking missile develops to intelligent, high precision and remote controllability. Midcourse guidance uses GPS/INS with terrain matching. Terminal guidance uses radar, infrared imaging technology or infrared imaging technology with data link. Infrared imaging guidance technology can auto-search, auto-capture, auto-identify target, then can auto-trace target because there are many features such as high precision, good anti-interference, good concealment capability and so on and it has been research hotspot in accurate terminal guidance field [1].

At present, the infrared seekers has been the second products whose type products are AAWS-M in America and Triget belongs to German, France and Britain. The information captured by infrared seekers usually is serial image [2]. To treat infrared serial images intelligently is the precondition for accurate terminal guidance, and we can make infrared seekers have better tracing target ability. From martial application, region of interest (ROI) of target in serial images is the region in moving target. So the process of automatic extraction of ROI in infrared serial images is the process of detecting moving target then extraction moving target region.

II. CHARACTERS ANALYSIS OF INFRARED IMAGES

Infrared images can represent space distribution of infrared radiances between the target and its background. The follows are the characters of infrared images [4]:

1. Infrared images represent temperature distribution of the object. They are gray images and there are not colors or hatching. So there is lower resolution for human.

2. There are higher space correlativity and lower contrast for infrared images because of much physical interference.

3. The definition of infrared images is lower than visible images because the space resolution and detection ability of infrared imaging system are not as good as visible CCD array.
4. There are many noises in infrared images.
5. There is a little changing range in gray values of infrared image. So there are obvious wave crest in histogram of infrared image compared with histogram of visible image. This paper made experiment using Lena image and Infrared tank image. The result shows in Fig.1.

   The bounds between target and its background are very blurry and there are many noises in infrared image because there are more details in infrared image captured in complex environment. There are obvious temperature differences between the target and the background in infrared image while they have different gray ranges in the image. So we should study target detection algorithms in various situations firstly if we’ll extract ROI of target automatically.

III. ANALYSIS OF THE TARGET DETECTION ALGORITHM

There are three methods on moving target tracking currently: optical flow method [5], background difference method [6] and frame difference method [7]. Optical flow method extracts moving target region by using the optical flow feature on target changing over time. The advantage of optical flow method is that it can treat bigger shift between frames because there is little moving restriction between frames of target. The disadvantage of optical flow method is that it is difficult up to real-time if there is not hardware support, and its computing process is very complex and its anti-noising ability is lower [8]. So this paper is not to discuss this method and is mainly to research target detection algorithm in static and dynamic scenes based on studying background frame difference method and difference method.

A. Principle and Analysis of background difference method

Background difference method is the most direct method to detect target. It detects moving target by computing the difference of current frame with background reference model in image series. Suppose, at t time, the image of background reference model is \( f_b(t) \), the image of current frame is \( f_c(t) \), then the image of background difference is

\[
f(x, y, t) = |f_c(x, y, t) - f_b(x, y, t)|.
\]

(1)

Suppose, the segmentation threshold is \( T \), and then the binary difference image is

\[
\bar{d}(x, y) = \begin{cases} 
1 & f(x, y, t) \geq T \\
0 & \text{otherwise}
\end{cases}.
\]

(2)

Background difference method adapts to the situation that the background has small changes. In real application, we should update the background reference model with other methods continually if there are complex situations or uncertain movements. The key of background difference method is that is to establish and update the background reference model [9].

B. Principle and Analysis of frame difference method

The basic principle of frame difference method is to decide various information of moving target such as location and shape by computing gray difference of pixels in adjacent frame images. The common methods are adjacent frame images difference method and symmetrical difference method.

1. Adjacent frame images difference method

The computing process of adjacent frame images difference method is following:

\[
d_k(x, y) = |I_k(x, y) - I_{k+1}(x, y)| = \begin{cases} 
0 & d_k(x, y) \geq T \\
1 & d_k(x, y) < T
\end{cases}. \tag{3}
\]

Here, \( I_k(x, y) \) and \( I_{k+1}(x, y) \) are two sequential frame images, \( d_k(x, y) \) is a frame difference image, \( T \) is the binary threshold.

2. Symmetrical difference method

Symmetrical difference method also is named difference method of three sequential frame images. That is, we can capture the contour of middle frame target by the difference among three sequential frame images. The method can eliminate background affects brought by moving, and then we can capture the contour of moving target exactly.

Suppose, \( I_{k-1}(x, y), I_k(x, y) \) and \( I_{k+1}(x, y) \) are three sequential frame images respectively, \( d_{k-1k}(x, y) \) and \( d_{k+1k}(x, y) \) are the binary images after difference by adjacent frame images, and then:

\[
d_{k-1k}(x, y) = \begin{cases} 
1 & |I_k(x, y) - I_{k-1}(x, y)| \geq T_1 \\
0 & |I_k(x, y) - I_{k-1}(x, y)| < T_1
\end{cases}, \tag{4}
\]

\[
d_{k+1k}(x, y) = \begin{cases} 
1 & |I_{k+1}(x, y) - I_k(x, y)| \geq T_2 \\
0 & |I_{k+1}(x, y) - I_k(x, y)| < T_2
\end{cases}. \tag{5}
\]

Here, \( T_1 \) and \( T_2 \) are the binary threshold.

Set \( \tilde{d}(x, y) \) is symmetrical difference image, and then:

\[
\tilde{d}(x, y) = \begin{cases} 
1 & d_{k-1k}(x, y) \cap d_{k+1k}(x, y) = 1 \\
0 & d_{k-1k}(x, y) \cap d_{k+1k}(x, y) = 0
\end{cases}. \tag{6}
\]

C. Application of target detection algorithm

The background difference method is of high and accurate tracking speed, but it must estimate background by establishing background reference model. If we detect moving target in complex battle environments, usually, to establish a reasonable background reference model is
difficult because the background of infrared serial images is very complex. The frame difference method is of high computing speed and can fit dynamic background immediately, so it is adapted to the infrared serial images in there are more blurry details. There is good detecting affect using frame difference method while motionless background. But, it is difficult to detect target effectively if there are complex moving backgrounds in imaging system and targets [10-11].

IV. TARGET DETECTION OF INFRARED SERIAL IMAGE IN STATIC SCENES

For serial images that are in static scenes, we can detect moving target by background difference whose background model can be established by background modeling. But we should analyze many frame images through the whole background modeling process and the background model is difficult to adapt to background changing. In this paper, we studied target detection algorithm based on difference fusion.

A. Target detection algorithm based on difference fusion and study online

In order to resolve the updating puzzle of background model for background difference, we designed a target detection algorithm based on difference fusion and study online by combining frame difference method with background difference method according to correlative ideas mentioned in reference [12]. The flow chart follows in Fig.2.

This algorithm supposes every background pixels in serial image satisfy with Gaussian distribution. First, we complete background model by study and update online. Second, we do difference between two adjacent frame images by using the frame difference method, we can distinguish background point from changing region, and we fit changing region with corresponding region in background by using background difference method, and then we can distinguish exposure region from moving object. Last, we can segment moving target from infrared serial images.

B. Experiment and analysis of target detection algorithm for serial images in static scenes

We select infrared serial images of battle plane (There are 110 frames, the size of every frame image is 256*200, the size of battle plane image is from small to big.) as experiments object. We found that there was little change of the background from the 31th frame image to the 70th frame image and it was similar from the 71st frame image to the 101st frame image by analyzing the serial images carefully. Here, the battle plane is facing target. So we considered it as our experiment object. According to Fig.2, the follows are the experiment steps:

1. To select the 1st frame as initial background image and to initialize background model.
2. To do difference between adjacent frame image selected then to detect changing region.
3. To detect target from difference image by using background model then to update background model.
4. To do binary difference image then to do morphology filtering.
5. Not to detect moving target until return step 3.

We select two groups of images (the 38th frame and the 39th frame, the 99th frame and 100th frame) to verify result in real experiment. The result on the 38th frame and the 39th frame shows in Fig.3 (a)-Fig.3 (f). The result on the 99th frame and the 100th frame shows in Fig.4 (a)-Fig.4 (f).

V. TARGET DETECTION OF INFRARED SERIAL IMAGE IN DYNAMIC SCENES

A. Analysis of Target detection of infrared serial image in dynamic scenes

Detection technology on moving target is very important in military reconnaissance and weapon guidance fields. The background of moving target be detected usually is complex background in military applications. Now, there were more problems in the process of detecting moving target if we used the frame difference method simply [13]. Many experts have brought up a plenty of ways to adapt to various situations and these results were all successful [14-16]. Lately, many researchers studied the moving target detection in the side of image matching and image registration. Reference [17] brought up an infrared target detection method based on background matching of adjacent frame images, frame difference and threshold segmentation in complex environment. Reference [18] brought up an infrared target detection method based on Gabor method, feature point matching and image transform. But there are some disadvantages in real time for above-mentioned. Obviously, the method based on feature point matching is very effective if the image is very clear. But, it is very difficult to match the feature points between the adjacent frames if the image is blurry. It will reduce precision greatly if feature points match error. So, this paper proposed a moving target detection algorithm to register image based on QP_TR trust region.
B. Moving target detection algorithm to register image based on QP_TR trust region

Moving target detection algorithm to register image based on QP_TR trust region is designed based on global motion compensation and difference method. This algorithm is similar as other algorithms but the global motion parameters between the adjacent frames in this paper is computed by QP_TR trust region algorithm [19]. The framework of the algorithm follows in Fig.5.

Considering our military application, almost equipments are thought as moving rapidly. So suppose the moving model is:

\[
\begin{align*}
    u &= x + \Delta x, \\
    v &= y + \Delta y.
\end{align*}
\]  

(7)  

(8)

Here, \( \Delta x, \Delta y \) represent global moving parameters of images.

The correct \( \Delta x, \Delta y \) will minimize the gray difference of pixels between adjacent two frames, that is,

\[
E^2(\Delta x, \Delta y) = \sum_{x, y} [f_k(x, y) - f_{k-1}(x, y)]^2 = \\
\sum_{x, y} [f_k(x + \Delta x, y + \Delta y) - f_k(x, y)]^2.
\]

(9)

Equation (9) will be the min-value if \( \Delta x, \Delta y \) are correct.

Here, the problem to register image is transformed the problem to optimize parameters, that is,

\[
\min_{(\Delta x, \Delta y) \in \mathbb{R}^2} E(\Delta x, \Delta y) .
\]

With that, we should search \((\Delta x, \Delta y)\) to minimize \(E(\Delta x, \Delta y)\). This problem to optimize parameters may be resolved by QP_TR trust region algorithm. There are bigger moving distances between adjacent frames because imaging equipments moves with its carrier rapidly. This distance is mapped to bigger \((\Delta x, \Delta y)\). We must use steady strategy layered based on Gaussian pyramid decomposition method in order to avoid QP_TR trust region algorithm running into local infinitesimal, that is, moving parameters computed on higher level will be mapped as initial value on lower level. Set the image is decomposed to \(L\) levels, the shift parameter computed on the \(L\) level is \((\Delta x, \Delta y)\) then the initial value of shift parameter on the \(l\)-th level is \((2\Delta x, 2\Delta y)\).
The follows are that the computing process of moving parameters based on QP_TR trust region algorithm on the $l^0$ level:

1. To center as the center of the image on this level, we segment a sub-image as our image to compute whose width and height are $1/S$ of width and height of original image respectively.

2. If this level is the highest level then to initialize $\Delta x_0 = \Delta y_0 = 1$, else $\Delta x_0 = 2(\Delta x)_{l-1}$ and $\Delta y_0 = 2(\Delta y)_{l-1}$. As same time as, $\Delta_0 = \min(C_{L-1}, R_{L-1})/4 \cdot \Delta_{min} = 1, MAX_{nec} = 100$.

3. Consider $f(x) = E^2(\Delta x, \Delta y)$ as target function, we optimize our sub-image above by QP_TR trust region algorithm and then obtain $(\Delta x, \Delta y)$, that is the global shift parameter between adjacent frames on this level.

C. Experiment and analysis of target detection algorithm for serial images in dynamic scenes

This paper selected two frames images of infrared tank (The size of the image is 256×200) in a complex background to validate the effect of our algorithm. Suppose that the images are decomposed to $L$ layers. First, we do two-layer decomposition on the adjacent frame images based on Gaussian pyramid decomposition method (The decomposition effect follows in Fig.6).

Then, to start from the highest layer $l=L-1$, we do not iterate above process until $l=0$. Here, we obtain the last motion parameter $(\Delta x, \Delta y)$ that is translation vector. Set $S=4/3$, $L=2$ and $(\Delta x)_0 = (\Delta y)_0 = 1$ as initialization. The translation vector is $(\Delta x)_1 = 11.3384$ and $(\Delta y)_1 = 14.8817$ by QP-TR trust region algorithm on the layer of $l=1$, the translation vector is $(\Delta x)_2 = 22.6768$ and $(\Delta y)_2 = 29.7634$ by QP-TR trust region algorithm on the layer of $l=0$, at last, we can obtain the last translation vector is $(\Delta x)_b = 22.6772$ and $(\Delta y)_b = 29.7668$ by iterates in a certain range. In application, we carry on shift correction to the second frame using the translation vector (23, 30) then carry on image registration to the adjacent frame images, and last we use frame difference method to optimize the image after registration. In order to explain the importance of the image registration algorithm based on QP_TR trust region, we compared the image by frame difference method with the image by registration. The effect is followed in Fig.7-(a). From Fig.7-(b), we find that our algorithm can eliminate a majority of background noises after morphology filtering, so we can extract target by threshold segmentation method.

Threshold segmentation is the most common method that is a region segmentation technology. This technology adapted to segment the image in which the target and its background hold different gray ranges respectively. The main disadvantage above methods is they can not segment the different size target effectively or they can not uniform real-time with effectiveness. OTSU and invariant moment methods ask the size of the target is bigger than 30% [23], and with decrease of relative area of the target, the segmentation efficiency will drop rapidly. The two-dimensional maximum entropy method only extends one-dimensional optimization to two-dimensional optimization simply since it can segment different size target accurately. But the computing speed of the method is so slow as to cost times, and it can not meet real-time. This paper proposes a new stepwise approaching and recurring threshold search algorithm based on two-dimensional maximum entropy principle that will improve the image segmentation speed, so it can meet real-time in application.

A. Analysis of stepwise approaching and recurring threshold search algorithm based on two-dimensional maximum entropy principle

The image segmentation based on two-dimensional maximum entropy principle is to produce two-dimensional histogram by gray and the adjacent region gray means of every pixel in the image, and then select the best threshold according to this two-dimensional maximum entropy principle.
histogram. The two-dimensional histogram shows in Fig.8. Here, the X-coordinate is gray level and the Y-coordinate is local gray means. The element $r_{ij}$ in the two-dimensional histogram represents the number of times one pixel appears. The gray level of the pixel is $i$ and the adjacent region gray means is $j$. Set threshold vector is $(s,t)$. The histogram is divided to four quadrants. Here, quadrant-A is the background, quadrant-B is out target, quadrant-C and quadrant-D are pixels and noises neighboring the target edge.

The global two-dimensional entropy is defined [22]:

$$H(s,t) = \ln|P_A(1-P_A)| + \frac{H_A}{P_A} + \frac{H_L-H_A}{1-P_A}.$$  \hspace{1cm} (10)

Here, $H_A = \sum_{j=1}^{r} \sum_{i=1}^{s} P_{ij} \ln \frac{P_{ij}}{P_A}$, $P_{ij} = \sum_{j=1}^{r} \sum_{i=1}^{s} \frac{P_{ij}}{P_A}$, $P_A = \sum_{j=1}^{r} \sum_{i=1}^{s} P_{ij}$, $H_L = \sum_{j=1}^{r} \sum_{i=1}^{s} \frac{P_{ij}}{P_A} \ln \frac{P_{ij}}{P_A}$.

We can obtain the best $(s,t)$ by maximizing $H(s,t)$. The process of recurring optimization is following:

$$P_t(s+1,t) = P_t(s,t) + \sum_{j=1}^{r} P_{ij} + 1.$$  \hspace{1cm} (11)

$$P_t(s,t+1) = P_t(s,t) + P_t(s-1,t+1) - P_t(s-1,t+1) + P_{ij}.$$  \hspace{1cm} (12)

$$H_t(s+1,t) = H_t(s,t) - \sum_{j=1}^{r} P_{ij} |\log P_{ij}|.$$  \hspace{1cm} (13)

$$H_t(s,t+1) = \sum_{j=1}^{r} P_{ij} |\log P_{ij}|.$$  \hspace{1cm} (14)

We can reduce the algorithm complexity with image threshold segmentation from $O(L^2)$ to $O(L)$ by recurring optimization. The key ideas that improve running efficiency are to reduce times for logarithm computation and iterating. The basic idea of stepwise approaching and recurring search algorithm is that, to search the approximate threshold in two-dimensional histogram with rough-scale then to search the accurate threshold near the approximate threshold. The method improves running efficiency because it avoids iterating and logarithm computing in the gray scales in no threshold. Two-dimensional histogram with rough-scale is a less scale two-dimensional histogram by combining the corresponding elements in original histogram.

Suppose $f(x,y)$ is a two-dimensional gray image whose size is $M*N$ and whose total gray level is $L$, $G(s,t)$ is the corresponding two-dimensional histogram defined by $D = \{(s,t) \mid 1 \leq s \leq L, 1 \leq t \leq L\}$, the value of $G(s,t)$ is $g_{st} = f_{st}/M*N$. Suppose the two-dimensional histogram with rough-scale is $G'(s',t')$ defined by $D' = \{(s',t') \mid 1 \leq s' \leq L/2, 1 \leq t' \leq L/2\}$, the value of $G'(s',t')$ is $g'_{s't'} = \sum_{s'=2t'-(r-1)}^{s'=2t'+(r-1)} \sum_{t'=2s'-(r-1)}^{t'=2s'+(r-1)} \sum_{s'=2t'-(r-1)}^{s'=2t'+(r-1)} g_{s't'}$. The scale of $G(s,t)$ then the scale of $G'(s',t')$ is $\frac{L}{r'}$, $\frac{L}{r'}$, here, $2^m$ is the gray span in $G$ corresponding every gray level in $G'$.

Now, we discuss the algorithm in continuous space. Set $s$, $t$, $s'$ and $t'$ are continuous variables then:

$$\iint_D G(s,t)dsdt = \iint_{D'} G'(s',t')ds'dt'.$$  \hspace{1cm} (15)

And $G'(s',t') = 2^m*2^m*G(2^ns',2^nt')$ because of $s = 2^ns'$ and $t = 2^nt'$. Both histograms are similar. Only is the two-dimensional entropy of the image maximum while the gray corresponding one point is segmentation threshold. The two-dimensional entropy of the image is smaller deviation the point farther. So we can obtain the approximate threshold from $G'$. According to above definition, we’ll compute the accurate threshold after searching the approximate threshold.

**B. Automatic extraction ROI of infrared images**

There are more pixels and better region connection in ROI relative to the background. We’ll obtain a binary image including target and discrete noises after we segment infrared serial images using threshold method. In order to extract ROI automatically, we should eliminate false alarm points with that recover the connection of target region, exact search binary image, and then extract the accurate target fasthest by various technologies. In this paper, the main extraction steps are order statistics filtering, mathematical morphology filtering and extraction rectangle ROI.

**C. Analysis of Result**

In this paper, we extracted ROI automatically in three infrared images whose sizes were all 768*576. The images are showed in Fig.9. Here, the first image is the first infrared image that is a tank distance of 100m and there is not noise in the image. The second infrared image is a warship distance of 1000m and the third infrared image also is a warship distance of 3500m, there are noises in the second and third images. The segmentation effect based on OTSU method shows in Fig.10. The segmentation effect based no invariant moment method shows in Fig.11. The segmentation effect based on this paper shows in Fig.12. Mask based on ROI automatic detection shows in Fig.13. Obviously, OTSU method and invariant moment method are all size-sensitive while the segmentation effect is the best based on our algorithm.

The image segmentation times based on various method shows in Table I. The time of searching threshold method based on our algorithm can be reduced rapidly compared with other methods. The searching efficiency improved 17.8% compared with the method mentioned in reference [24].
threshold search algorithm based on two-dimensional maximum entropy principle and realized to extract ROI of infrared serial images automatically. All experiments were conducted in order to validate above algorithms. They are proved that our studying can not only meet common requirement for accurate guidance in modern battle but also is reliable and effective, which has significant utility value.

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Hu Guang comes from School of Computer Science & Technology locates in Yantai University of Shandong Province of China. He was born in September 10, 1974. His educational background is master of engineering was earned from Department of Science and Technology of Weapons of Naval Aeronautical Engineering Institute of China in 2005. His major field of study are computer vision graphics, image process or pattern recognition.


Yuan Shengzhi comes from Department of Science and Technology of Weapons of Naval Aeronautical Engineering Institute of China. He was born in 1977. His educational background is PHD was earned from Department of Science and Technology of Weapons of Naval Aeronautical Engineering Institute of China in 2009.

Approximation Algorithm and Scheme for RNA Maximum Weighted Stacking

Hengwu Li
School of Computer Science and Technology, Shandong Economic University, Jinan, China
Email: hengwuli@mail.sdu.edu.cn

Huijian Han and Zhenzhong Xu
School of Computer Science and Technology, Shandong Economic University, Jinan, China
Email: {hanhuijian, xuzz_001}@yahoo.com.cn

Abstract—Pseudoknotted RNA structure prediction is an important problem in bioinformatics. Existing polynomial time algorithms have no performance guarantee or can handle only limited types of pseudoknots. In this paper for the general problem of pseudoknotted RNA structure prediction, maximum weighted stacking problem is presented based on stacking actions, and its polynomial time approximation algorithm with $O(n \log n)$ time and $O(n)$ space and polynomial time approximation scheme are given. The approximate performance ratio of this approximation algorithm is 3. Compared with existing polynomial time algorithm, they have exact approximation performance and can predict arbitrary pseudoknots.

Index Terms—RNA structure, approximation algorithm, approximation scheme, pseudoknot

I. INTRODUCTION

RNAs are versatile molecules: messenger RNAs carry genetic information and act as the intermediary agent between DNAs and proteins; ribosomal RNAs, transfer RNAs, and other non-coding RNAs play important structural, regulatory, and catalytic roles in cells [1]. To understand fully the various functions of RNAs, we need to first understand their structures. The primary structure of an RNA is the sequence of nucleotides (that is, the four different bases $A$, $C$, $G$, and $U$) in its single-stranded polymer. However, these sequences are not simply long strands of nucleotides. In RNA, complementary bases of guanine and cytosine pair ($G$, $C$) by forming a triple hydrogen bond, and these of adenine and uracil pair ($A$, $U$) by a double hydrogen bond; additionally, these of guanine and uracil can form a single hydrogen bond base pair. An RNA folds into a three-dimensional structure by these hydrogen bonds, that are nonconsecutive in the sequence. The three-dimensional arrangement of the atoms in the folded RNA molecule is its tertiary structure; the collection of base pairs in the tertiary structure is the secondary structure. Experimental test of RNA tertiary structure is too expensive and time consuming to meet practical need, so predicting RNA structure prediction by computer becomes a basic method and issue in computational biology [2][3].

The secondary structure of an RNA is the scaffold of its tertiary structure. RNA secondary structure prediction is the first step to predict RNA tertiary structure from RNA sequence. The best algorithm Zuker predicts RNA secondary structure without pseudoknots with $O(n^3)$ time and $O(n^3)$ space for a sequence of length $n$ and is implemented by MFOLD and ViennaRNA programs. But they couldn’t predict pseudoknots. Among the most prevalent RNA structures is a motif known as the pseudoknot. Pseudoknots play a variety of diverse roles in biology [2]. Plausible pseudoknotted structures have been proposed [4] in 1985 and confirmed [5] in 1998 for the 3’ end of several plant viral RNAs, where pseudoknots are apparently used to mimic tRNA structure. Recently, pseudoknots were confirmed in some RNAs of humans and many other species [6][7]. Currently pseudoknot is not included in the majority of the study for RNA secondary structure prediction. Finding the best secondary structure including arbitrary pseudoknots has been proved to be NP-hard [8].

Most methods for RNA folding which are capable of folding pseudoknots adopt heuristic search procedures and sacrifice optimality. Examples of these approaches include quasi-Monte Carlo searches and genetic algorithms. These approaches are inherently unable to guarantee that they have found the best structure, and consequently unable to say how far a given prediction is from optimality [9][10].

A different approach to pseudoknotted prediction is the maximum weighted matching algorithm, considering only the base paired action and no stacking action. The maximum weighted matching algorithm folds an optimal pseudoknotted structure in $O(n^6)$ time with low accuracy and seems best suited to folding sequences for which a previous multiple alignment exists [11]. Another approach adopts dynamic programming to predict the tractable subclass of pseudoknots based on complex thermodynamic model in $O(n^5)$-$O(n^6)$ time[12]-[14].

Adjacent base pairs form stack, stacking and base pairing actions in RNA molecules are the most primary and stable actions [8]. Maximum stacking problem has also attracted close attention in RNA secondary structure
prediction containing pseudoknots. Ieong presented the problem of maximum stacked base pairing number \[8\]. Lyngsø presented the problem of maximum stacking number, proved this problem belongs to \(NP\)-hard class and designed its polynomial time approximate scheme \[15\].

Lyngsø treat all stacks as the same. RNA structural experimental results indicate that the different types of stacks have the different energy, and the energy of stack is determined by the type of its base pairs. So we present maximum weighted stacking problem based on biological stacking and base pairing actions, and discuss its algorithm and complexity.

We give a polynomial time approximation algorithm with \(O(n\log n)\) time and \(O(n)\) space, and a polynomial time approximate scheme to predict arbitrary pseudoknots. The approximate performance ratio of this algorithm is 3.

Compared with existing polynomial time algorithm, which can handle only limited types of pseudoknots or have no performance guarantee, they have exact approximation performance and can predict arbitrary pseudoknots.

In section 2 we present the maximum weighted stacking problem. In section 3 we give a polynomial time approximation algorithm. In section 4 we give a polynomial time approximate scheme (PTAS). In section 5 we briefly conclude the paper.

II. RNA STRUCTURE PREDICTION

One single-stranded RNA molecule can be viewed as a sequence of \(n\) symbols (bases) drawn from the alphabet \(\{A, C, G, U\}\). Let sequence \(s=s_1s_2\ldots s_n\) be a single-stranded RNA molecule, where each base \(s_i\in\{A, U, C, G\}\), \(1\leq i\leq n\). The subsequence \(s_{i,j}=s_is_{i+1}\ldots s_j\) is a segment of \(s\), \(1\leq i\leq j\leq n\).

To a first approximation, one can model its secondary structure as follows. If \(s_i\) and \(s_j\) are complementary bases \((A\&U, C\&G, U\&G)\), then \(s_i\) and \(s_j\) may constitute a base pair \((i, j)\). Each base can at most take part in one base pair, in other words, the set of base pairs forms a matching. It also turn out that secondary structures are noncrossing as Fig.1.

**Definition1** (RNA secondary structure, \(S\)) Concretely we say that a secondary structure \(S\) on \(s\) is a set of base pairs \(S=\{(i, j)\}\), where \(i, j\in\{1, 2, \ldots, n\}\), that satisfies the following conditions.

(i) \((No\ sharp\ turns.)\) The ends of each pair in \(S\) are separated by at least three intervening bases; that is, if \((i, j)\in S\) then \(i+j<3\).

(ii) For any pair \((i, j)\) in \(S\), \((i, j)\in\{(A, U), (C, G), (U, G), (U, A), (G, C), (G, U)\}\).

(iii) \(S\) is a matching: no base appears in more than one pair.

(iv) \((The\ noncrossing\ condition.)\) If \((i, j)\) and \((k, l)\) are two pairs in \(S\), then they are compatible, that is, they are juxtaposed (e.g. \(i<j<k<l\)) or nested (e.g. \(i<k<j\)).

Base pair and internal unpaired bases construct loops. If \((i, j)\) and \((i+1, j-1)\in S\), base pairs \((i, j)\) and \((i+1, j-1)\) constitute stack \((i, i+1; j-1, j)\), and \(m\geq 1\) consecutive stacks form the helix \((i, i+m; j-1, j)\) with the length of \(m+1\). The energy of helix \((p, p+m-1; i-m+1, i)\) is denoted as \(E(p, p+m-1; i-m+1, i)\).

If base pairs \((i, j)\) and \((k, l)\) are incompatible, they constitute pseudoknots \((i<k<j<l)\) as Fig.1.

Stack is the only type of loops that stabilize the secondary structure \[8\]. Maximum stacking number problem treat all stacks as the same. In RNA, complementary bases of guanine and cytosine pair \((G, C)\) form a helix and uracil pair \((A, U)\) by forming a double hydrogen bond; additionally, these of guanine and uracil can form a single hydrogen bond base pair. RNA structural experimental results indicate that the different types of base pairs and stacks have the different energy, and the energy of stack is determined by the type of its base pairs. So we present maximum weighted stacking problem based on biological stacking and base pairing actions, and discuss its algorithm and complexity.

**Definition2** (stacking fold model of pseudoknotted RNA structure prediction, \(SFM\)): For RNA sequence \(s\), \(s\in\{A, U, C, G\}\), a secondary structure \(S\) is a set of base pairs such that if \((i, j)\in S\) then

(i) The ends of each pair in \(S\) are separated by at least four intervening bases; that is, if \((i, j)\in S\), then \(i+j<3\).

(ii) For any pair \((i, j)\) in \(S\), \((i, j)\in\{(A, U), (C, G), (U, G), (U, A), (G, C), (G, U)\}\).

(iii) \(S\) is a matching: no base appears in more than one pair.

(iv) If \((i+1, j-1)\in S\), then \((i, j)\) and \((i+1, j-1)\) form stack with the weight of \(w(i, i+1; j-1, j)\).

(v) If \((i+1, j-1), (i', j'), (i'+1, j'-1)\in S\), \(s_i=s_{i'+1}, s_j=s_{j'-1}\), and \(s_{i+1}=s_{i'+1}, s_{j+1}=s_{j'-1}\), then \(w(i+1, j-1)=w(i', j'-1)\). That is, the size of stacking force is determined by base pair itself and adjacent bases pair.

(vi) If \((i, j+1)\in S\), then the weight of \(S\) is \(W(S) = \sum_{1\leq i, j\leq n} w(i, i+1; j, j+1)\).

So the determinant problem of maximum weighted stacking is to determine if there is a secondary structure \(S\) under \(SFM\) model with \(W(S)\geq K\) for given RNA sequence \(s\) and constant \(K\). The optimal problem of maximum weighted stacking is to find a secondary structure \(S\) with maximal weight for given RNA sequence \(s\) under \(SFM\) model.

If \(W(i, i+1; j, j+1)=-E(i, i+1; j, j+1)\), then the solution of maximum weighted stacking is the minimal energy structure. Not only the weight maybe the value of energy,
but also maybe the results of phylogeny analysis, or other auxiliary information.

**Definition 3:** If \((i, j), (i+1, j-1), \ldots, (k, l)\) are all base pairs in \(s_j, i<k<l\), then the structure enclosed by \((i, j)\) and \((k, l)\) is denoted as stem \(S[i, j]\), and the length of \(S[i, j]\) is denoted as \(L[S[i, j]]=(k-i+1)\).

**Lemma 1:** Let the length of stem \(A[i, j]\) is \(LA[i, j]\). We split \(A[i, j]\) into \(k\) segments: \(a_1, a_2, \ldots, a_k\), such that \(L_a[i, j]+L_a[i+2, j]+\cdots+L_a[i+k]=LA\). The number of stacks in the \(k\) segments is \(\sum L_a[i, j]=LA-k\).

Proof:
By the definition of stem, the base pairs in \(A[i, j]\) are \((i, j), (i+1, j-1), \ldots, (i+LA[i, j]-1, j-LA[i, j]+1)\) and the number of stacks in \(A[i, j]\) is \(LA[i, j]-1\).

Similarly, the number of stacks in \(a_i\) is \(L_a[i, j]-1, 1 \leq i \leq k\).

So the number of stacks in the \(k\) segments is \(\sum L_a[i, j]=LA-k\).

**Theorem 1:** The maximum weighted stacking problem belongs to NP-hard.

**Proof:**
If \(W(i, i+1, j-1, j)=1\), the maximum weighted stacking problem becomes the maximum stacking number problem, which belongs to NP-hard [15]. The proof is by reduction from the BIN PACKING problem, known to be strongly NP-hard [16].

In the BIN PACKING problem, we are given \(k\) items of sizes \(a_1, \ldots, a_k\) and \(B\) bins each with capacity \(C\), and have to determine whether the items fit into the bins. Or in more mathematical terms, we need to determine whether the \(k\) elements \(a_1, \ldots, a_k\) can be partitioned into \(B\) sets, with the sum of elements in any set at most \(C\). Given an instance of BIN PACKING, we construct the RNA sequence \(s\) and the target \(K\).

\[
s = C_{a_1}AC_{a_2}^c A \ldots AC_{a_k}^c AAAGC_{AG}^C A \ldots AG_{C}^C
\]

\[
K = \sum_{i=1}^{k} a_i - k
\]

\(K\) is the sum of all \(a_i\) minus the number of stack. As \(A\)'s can only form base pairs with \(U\)'s in SFM model, all base pairs in a legal structure for \(s\) will be \((C, G)\) base pairs and \(s\) clearly meets the assumptions discussed above. Furthermore, any \(C\) in \(s\) is separated from any \(G\) in \(s\) by at least three other bases, so any otherwise unpaired \(C\) can form a legal base pair with any otherwise unpaired \(G\) in \(s\).

Hence, we can find a structure \(S\) with \(W(S)=K\) iff we can partition the \(k\) substrings of \(C\)'s of lengths \(a_1, \ldots, a_k\) into \(B\) groups that can each be fully base paired using one substring of \(C\) consecutive \(G\)’s; i.e. the total length of the substrings of \(C\)’s in any group can be at most \(C\). Clearly this is possible iff the original BIN PACKING problem has a solution.

The length of \(S\) is \(\sum a_i+k+B\). As BIN PACKING is strongly hard we can assume that are all \(a_1, \ldots, a_k\) \(B, C\) polynomially bounded by the size of the original BIN PACKING instance.

Hence, \(|s|\) is also polynomially bounded by the size of the original BIN PACKING instance. Clearly the same holds for a fair representation of the target \(K\). Constructing \(s\) and \(K\) in time polynomial in the size of their representations is trivial.

So the theorem is true, and the maximum stacking number problem is a special case of the maximum weighted stacking problem. In fact, the maximum weighted stacking problem is a special case of the maximum weighted independent set.

### III. Approximation Algorithm

We further simplify sequences \(s\), change \(G\) into \(A\), change \(U\) and \(C\) into \(B\), then base pair \((A, U), (C, G)\) and \((G, U)\) into \((A, B)\), the type of stacking is reduced into three classes \((A, A; B, B), (A, B; A, B), (B, A; B, A)\).

#### A. Approximation Algorithm

**Definition 4:** Given arbitrary subsequences \(s_{i, j}\) and \(s_{j, k}\) of \(s\), if \(1 \leq i < k \leq l \) or \(1 \leq k < i \leq j\), then \(s_{i, j}\) conflicts with \(s_{j, k}\).

**Lemma 2:** If we group all stacks of \(s\) into two sets \(((A, B), (B, A)), (A, B); (B, A))\) and \((A, A); (B, B)\) by the type of stack, then \(W(s) \leq 2*max(A_1, A_2)\). \(A_1\) is the weight of maximum stacks formed by \{\((A, A; B, B)\}\} set, and \(A_2\) is the weight of maximum stacks formed by \{\((A, B; A, B)\)\} set.

**Proof:**
For stacking structure, there are properties of the relative independence and partition, which make the element only form stack with the element in the same set. The stacks from the different set may conflict, so they can’t stay in \(S\) at the same time. So \(W(s) \leq A_1 + A_2 \leq 2*max(A_1, A_2)\).

According to above theory, we design an approximation algorithm \(\text{SA}\) for the maximum weighted stacking problem as follows.

#### B. Performance

**Lemma 3:** Given the subsequence \(SB=B^k\) and \(SA=[s_{i, j}A^m|2 \leq i \leq k]\), we descending sort \(SA\) by the length of \(s_{i, j}\), take out the subsequence from \(SA\) in turn and match that from \(SB\), then the number of matched stacks is the biggest one.

**Proof:**
Let \(max(s)\) be \(M\). When \(k \leq M\), the lemma is obviously right.

When \(k=M+1\), the subsequence \(A^M\) will match with \(B^k\), then the number of stacks is \(k-2\). If we use the subsequence \(s_{i, j}\) with the length of less \(M\), then the number of stacks is less than \(k-2\) according to lemma 1.

We suppose that the lemma is right when \(k=m+M\).

When \(k=m+1\), the length of stacks is more than \(m-2\) in our algorithm. If we replace the selected subsequences with the other subsequences in \(SA\), then the length of stacks would less than or equal to the replaced one by lemma 1. So the general matched stacks is less than or equal to our result.

Therefore the lemma is right.

**Lemma 4:** For any instance \(I\) for the maximum weighted stacking problem, let the optimal solution be \(OPT(I)\) with the weight of \(W(OPT(I))\), and the solution of
SA is SA($i$) with the weight of $W(SA(i))$, then $W(OPT(i)) \geq W(SA(i)) \geq 3$.

Proof:
The set of $A_i$ and $B_i$ is corresponding to the stacking class of $(A, A; B, B)$. Let the optimal solution to the stacking class of $(A, A; B, B)$ be OPT($A_1$) with the weight of $W(OPT(A_1))$.

The stack formed by step1 is belong to perfect match, so the number of matched stack $\geq$ that of stack in OPT($A_1$) formed by corresponding elements.

The number of stack formed by step2 $\geq$ that of stack in OPT($A_1$) formed by corresponding elements by lemma3.

Let the number of stack in split $B_i$ be $N_i$, and the number of stack formed by corresponding elements in OPT($A_1$) be $O_i$. Let the number of stack formed by $AZ$ be $NAZ$, the number of stack in split $BZ$ be $NBZ$, and the number of stack formed by corresponding elements in OPT($A_1$) be $OZ$.

1) If $AZ \geq BZ$ and $B_i \neq \emptyset$, then $A_i = \emptyset$, and the length of $A_i$ matched with $B_i$ is at least 3.

Let the element number of $B_2$ is $k$, then $N_2 \geq 2k/3$. But $O_2 \leq k$, so $N_2 \geq (2/3)O_2$.

Let the element number of $B_3$ is $k$, then the length of $A_k$ corresponding to $B_3$ is more than 3. $N_3 \geq 4k/3$, and $O_3 \leq 2k$, so $N_3 \geq (2/3)O_3$.

Let the element number of $B_4$ is $k$, then the length of $A_k$ corresponding to $B_4$ is more than 2. $N_4 \geq 2k$, and $O_4 \leq 3k$, so $N_4 \geq (2/3)O_4$.

When the length of $B_k$ is more than 4, each split can at most reduced one stack. Let $BZ = k$, then $NAZ \geq 2k/3$. The number of reduced stack in splitting $BZ \leq k/5$, so $NBZ \geq (NAZ - k/5) \geq (7/10)NAZ \geq (7/10)OZ$.

2) If $AZ \geq BZ$ and $B_3 = \emptyset$, then the length of $A_k$ corresponding to $B_3$ is equal to 2, or more than 3.

When the length of $A_i$ is equal to 2, each of $B_3$ can form stack only with one $A_i$. Let the number of element in $B_i$ is $k$, the number of $A_k$ corresponding to $B_i$ is greater than $k$, therefore the optimal value can be get after segmentation.

When the length of $A_k$ is greater than 3, $N_3 \geq 4k/3$. In addition, $O_3 \leq 2k$, so $N_3 \geq (2/3)O_3$.

When the length of $B_k$ is greater than 3, each split can at most reduce one stack. Let $BZ = k$, there are four cases as follows.

a) If the length of corresponding $A_i$ is equal to 2, and $B_i$ is an even number, then the splitting of $BZ$ can not reduce the number of stack.

b) If the length of corresponding $A_i$ is equal to 2, and $B_i$ is an odd number, then $NAZ \geq 3k/5$. Because the reduced number $\leq k/5$, $NBZ \geq (NAZ - k/5) \geq (2/3)NAZ \geq (2/3)OZ$.

c) If the length of corresponding $A_i$ is greater than 2, and the length of $B_i$ is equal to four, then $N_4 \geq 2k$, which the number of elements in $B_i$ is equal to $k$. In addition, $O_4 \leq 3k$, so $N_4 \geq (2/3)O_4$.

Given $s=s_1s_2...s_n$, let the weight of $(A,A:B,B), (A:B:A,B)$ and $(B,A:B,A)$ is $W(A,A:B,B), W(A:B:A,B)$ and $W(B,A:B,A)$ respectively.

Approximation algorithm SA:

step1: Search all $A^i$ subsequences and $B^i$ subsequences $(2 \leq k \leq n)$ in $s$, put them into sets $A_1,A_2,...A_n$ and $B_1,B_2,...B_n$ by the length.

Then count $AZ=|A_1|+|A_2|+...+|A_n|$ and $BZ=|B_1|+|B_2|+...+|B_n|$. At last match all subsequences of $A_i$ and $B_i$ one by one, delete matched elements and record the number of matched elements $P_i$.

step2: If $AZ \geq BZ$, descending sort the elements in $B_0,B_1,...,B_2$, put the elements of $A_0,A_{i+1},...,A_2$ on them in turn by descending sort. If $AZ < BZ$, descending sort the elements in $A_0,A_{i+1},...,A_2$, then $B_0,B_1,...,B_2$ on then in turn by descending sort.

Then cut the sequence according to $B_0,B_1,...,B_2$ to make best of forming stacks and calculate the number of stacks $S_{12}$. If $AZ \geq BZ$, then cut the sequence according to $A_0,A_{i+1},...,A_2$ to make best of forming stacks and calculate the number of stacks $S_{12}$.

$S_i=\sum_{k \geq 2k} (x-1)*P_i + S_{12}.$

Step 3: Search all subsequences of $AB$ and $BA$ in $s$, then built graph $C_1$ and $C_2$ using the subsequences as vertexes, and evaluate the vertexes with $W(A,B:A,B)$ or $W(B,A:B,A)$ by the type of stack.

If the sequence corresponding to $C_1$ conflicts with the subsequence corresponding to $C_2$, draw a line between the vertexes.

Step 4: Calculate the maximum weighted independent set formed by $C_1$ and $C_2$, then delete the vertexes which not belong to the maximum weighted independent set, and count the number of stacks $S_2=|C_2|/2$, $S_1=|C_1|/2$.

Sequence: AAABBBABBBAABA

Figure 2. Example of approximation algorithm

...
Proof:
Let the stem in $OPT(I)$ are $x_1, x_2, ..., x_m$ with the length of $l_1, l_2, ..., l_m$ and the energy of $E_1, E_2, ..., E_m \geq 1$.

$\forall x_q \in OPT(I), 1 \leq q \leq m, \text{ if } l_q \leq K, \text{ then we choose that } E_q = E_{x_q}, \text{ otherwise we divide } x_q \text{ into stem with the length of } 2, \text{ and group these stems into } K \text{ set } x_q \in x_{l_2} \text{,..., } x_{l_8}.$

$X_q = \{ (i,i+1): j-1, \}, \text{ if } (i+k+1,i+k+2) \leq K - 2(\text{...}) \}$

$X_q = \{ (i+i+1,i+2): j-2,j-1, \}, \text{ if } (i+k+2,i+k+3: j-K-3, j-2, \text{...}) \}$

$X_q = \{ (i+k,i+k+1,i-k+1-j-k, \text{...} (i+2K-1,i+2K+2: j-2K-2, j-k-K) \}$

Let the energy of $X_{q_1}, X_{q_2}, ..., X_{q_k}$ be $E_{X_{q_1}}, E_{X_{q_2}}, ..., E_{X_{q_k}}$ respectively, then $E_{x_q} = E_{x_q} + E_{x_{q_2}} + E_{x_{q_k}}$.

After that, we sort $E_{X_{q_1}}, E_{X_{q_2}}, ..., E_{X_{q_k}}$ such that $E_{X_{q_1}} \geq E_{X_{q_2}} \geq E_{X_{q_3}}$ and delete the energy $E_{X_{q_k}}$ in order to just divide $x_q$ into stems whose length is not more than $K$.

For example, for $x_1, x_2 \in OPT(I)$ in Fig.3, when $k=4$, we divide $x_1$ into four groups of 1-4, then delete the energy of the second group so that $x_1$ is divided into two stems with the length of 2 and 4.

Let the sum of left energy is $E_{x_q}$ then

$E_q = (E_{x_{q_1}} + E_{x_{q_2}} + ... + E_{X_{q_k}})(K-1) + k(K-1) E_{x_q}/K$.

After above handle, all helices in $OPT(I)$ become the structures formed by the stems whose length is not more than $K$, then $\sum_{1 \leq q \leq K} E_q \geq \sum_{1 \leq q \leq K} E_{x_{q_1}}(K-1) \text{OPT}(I)/K$. Also the length of sequence $x_{q_1}$ is $i$, so each partition of $s$ meets the condition $x_{q_1} y_{q_2} + x_{q_2} y_{q_2} + ... + x_{q_k} y_{q_k} \leq i$.

Obviously $SAA[I]$ is the optimal structure formed by stems whose length is not more than $K$.

Therefore, $SAA[I] \geq \sum_{1 \leq q \leq K} E_{x_{q_1}}(K-1) \text{OPT}(I)/K$

$OPT(I)/SAA[I] \leq (K-1)/I(1/K)$.

Lemma7: Given an RNA sequence $s$ of length $n$, algorithm SAA computes the maximal energy that can be formed by $s$ in $O(n^2dk)(\text{time})$ and $O(n^dk)$ space.

Proof:

The time complexity of Step1 is $O(Kn)$.

The time complexity of Step2 is $O(KnlogKn)$.

The time complexity of Step3 is $O(K\sum_{2 \leq i \leq n} (x_{i+1})(x_{i+1}))$.

The time complexity of Step4 is $O(K(\sum_{2 \leq i \leq n}(x_{i+1}))$.

By the condition $x_{i+1}y_{i+1} + x_{i+2} y_{i+2} + ... + x_{i+d} y_{i+d} \leq i$, we can see that when $i$ is big enough, $x_{i+2} y_{i+2} \leq (i+2d)^8$.

So the time complexity of algorithm SAA is $O(K\sum_{2 \leq i \leq n} (x_{i+1})(x_{i+1})) = O(K\sum_{2 \leq i \leq n} (i+2d)^8) = O(n(2dk)^8)$.

By the condition $n_1 + n_2 + ... + n_{d} \leq (K-1)n$ and $n_1 \leq n_2 \leq ... \leq n_{d}$, we can see that the space complexity of algorithm SAA is $O(n(2dk)^8)$.

Theorem3: The Algorithm SAA is a $1+\epsilon$ approximation algorithm for the problem of constructing a secondary structure $S$ with maximal energy for given RNA sequence $s$ under SFM model, $\epsilon = 1/(K-1)$, $K \in \mathbb{N}$ and $K \geq 2$.

Proof:

By Lemmas 6 and 7, the result follows.
V. CONCLUSION

In this paper for the general problem of pseudoknotted RNA structure prediction, maximum weighted stacking problem is presented based on stacking, and its polynomial time approximation algorithm with $O((\log n)^k)$ time and $O(n)$ space and polynomial time approximation scheme are given. The approximate performance ratio of this approximation algorithm is 3. Compared with existing polynomial time algorithm, they have exact approximation performance and can predict arbitrary pseudoknots.

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Hengwu Li, Male, was born in Jiaonan city, China, in 1969. Ph. D. in Computer Software Theory and Techniques of Shandong University, China, in 2008. Li’s major field of study is analysis and design of algorithm.

He is an ASSOCIATE PROFESSOR in School of Computer Science & Technology of Shandong Economic University and Shandong Prov. He participated in the work in 1991 and has long been engaged in computer technology in teaching and research work. He has published more than 20 papers in academic journals at home and abroad. For example: Prediction for RNA Planar Pseudoknots (Journal of Progress in natural science, 2007); New Algorithm for Predicting Ribonucleic Acid Secondary Structure Including Pseudoknots (Journal of tongji university, 2004); A Polynomial Algorithm to Compute the Minimum Degree Spanning Trees of Directed Acyclic Graphs with Applications to the Broadcast Problem. (Journal of Discrete mathematics, 2008). His current research interests include analysis and design of algorithm, biological computation and electronic commerce.

Dr. Li is a member of Computer Society of Shandong Province, Shandong Prov. Key Lab of Digital Media Technology, and IEEE. Prof. Han received third prize of Shandong Province Natural Science Award in 2007.

Huijian Han, Male, was born in HeZe city, China, in December 19, 1971. In 2000, Han is a master majoring in Computer Software Theory and Techniques of Shandong University, China, and now as Computer Applied Technique Ph. D. candidate in Shandong University. Han’s major field of study is texture mapping of CG.

He is a PROFESSOR, MASTER TUTOR in School of Computer Science & Technology of Shandong Economic University and Shandong Prov. Key Lab of Digital Media Technology, in Jinan city, China. He participated in the work in 1992 and has long been engaged in computer technology in teaching and research work. He has published more than 30 papers in academic journals at home and abroad and participated in the preparation of two books. For example: Computer Graphics (Beijing, China: Science Press,2005); Concise Guide to Computer Graphics (Beijing, China, Higher Education Press,2007); Determining Knots by Minimizing Energy(Beijing , China, Journal of Computer Science and Technology, 2006). His current research interests include CG&CAGD, computer simulation and algorithm design.
Prof. Han is a member of Chinese Association for System Simulation, Computer Society of Shandong Province, and Academic Committee of Shandong Prov. Key Lab of Digital Media Technology. Prof. Han received third prize of Shandong Province Natural Science Award in 2005, received first prize of Science and Technology Progress Award of People's Republic of China Ministry of Education in 2007 and received Outstanding Contribution Award from the Shandong Provincial Science and Technology Association in 2008.

Zhenzhong Xu, Male, was born in Qingzhou city, China, in January 1, 1956, Bachelor in Computer Science and Technology of Shandong University, China, in 1982. Xu’s major field of study is soft engineering. He is a PROFESSOR, MASTER TUTOR in School of Computer Science & Technology of Shandong Economic University in Jinan city, China. He participated in the work in 1982 and has long been engaged in computer technology in teaching and research work. He has published more than 20 papers in academic journals at home and abroad and participated in the preparation of three books. For example: Date Structure (Beijing, China: Science Press, 2004); Concise Guide to Computer Graphics (Beijing, China, Higher Education Press, 2007); Prediction for RNA Planar Pseudoknots (Journal of Progress in natural science, 2007). His current research interests include soft engineering, biological computation, MIS, CAD, computer simulation and control.

Prof. Xu is a member of Computer Society of Shandong Province, and Academic Committee of Shandong Prov. Key Lab of Digital Media Technology. Prof. Xu received third prize of Science and Technology Progress Award of People's Republic of China Ministry of Gym in 2005, received Outstanding Contribution Award from the Shandong Provincial Education Association in 2007, and received Outstanding Contribution Award from the Shandong Provincial Science and Technology Association in 2005.
Research on Spatial Data Line Generalization Algorithm in Map Generalization

Yufeng Zhu\textsuperscript{1,2}
1. School of Info-Physics and Geometries Engineering, Central South University, Changsha, China
2. Faculty of Geoscience and Geomatics, East China Institute of Technology, Fuzhou, China
yfzhu@ecit.edu.cn

Shijian Zhou, Tieding Lu
Faculty of Geoscience and Geomatics, East China Institute of Technology, Fuzhou, China
sjzhou@ecit.edu.cn, tdlu@ecit.edu.cn

Abstract—Map Generalization is one of the hotspot issues in GIS. It is the most imperative field for intelligence in GIS. The uncertainty and data quality of map generalization should be attached importance to in map generalization. The conventional methods of process of line generalization in map generalization are be introduced in this paper, and analysis decline in the quality of integrated because of uncertainty of method on process of line generalization currently. Author introduced the curve fit algorithm about line generalization in map generalization, then analysed it in detail. Curve fit algorithm is better than conventional algorithm through analysis of experimental data.

Keywords—curve fit, map generalization; line generalization, auto choice

I. INTRODUCTION

The request of line feature in map generalization is that it should keep curvilinear character and minimum distortion and avoid dithering and self-intersection etc. So, after analyzing line feature and then on the condition that curvilinear character is kept, the line gets smooth and data quantity is compressed\textsuperscript{1}.

Now many scholars have researched the way of line feature (Douglas-Peucker Algorithm, Li-Openshaw Algorithm, direct and indirect methods) in map generalization to colligate the line feature, then kept the points after colligation as fit subsection points\textsuperscript{2,3,4}. The methods discussed above were that which was joining feature points by beeline and dashing out the points among feature points. But the uncertainty of line feature colligation cause the distortion of graph, coarseness of curve and self-intersection etc.\textsuperscript{5,6}.

After introducing the conventional methods of line generation, a main factor of linear element of map would be discussed—Curve Fit Algorithm. Comparison of experimental data through curve fitting algorithm and conventional algorithm derived, when we adopt curve fitting to colligate maps, fountain line feature should be replaced by fit curves which could be better to express characters of fountain line feature between feature points.

II. ALGORITHMS OF LINE GENERALIZATION

A. Douglas-Peucker algorithm

Douglas-Peucker algorithm actually is the improvement of the down from the limit law. The shortcomings of the algorithm is that it is possible to delete the points whose deviation error bigger than tolerance, and if reverse the curve\textsuperscript{7}, the results may be different. Several people had made the Douglas-Peucker algorithm at the same time about 1973. It is a conventional algorithm which can compress curve vector data and approximate polygonal curve.

Douglas-Peucker algorithm is a method which is the whole to the local and from coarse-to-fine to determine the curve point compression process after the reservation. The advantage is that a translation, rotation invariance, and the sampling results would be consistent if it was given curve and tolerance.

Douglas-Peucker algorithm step is:

1) Virtual would connected a straight line between beginning point and ending point of curve, and would obtained the distance from the remaining points to the straight-line;

2) The largest distance elected from step 1) then compare with threshold (Fig.1 a), if the distance is larger than threshold, the point (point 4) which is maximum distance of the straight-line should be remained, otherwise, the all points between the beginning-point and ending-point should be deleted.

3) Dividing the known-curve into two parts to deal with, the largest points from various parts would be elected to compared with threshold, to make a decision choice (Fig.1 b, between point 1 to point 4, point 2 and point 3 should be deleted, between point 4 to point 6,
point 5 should be remained), this process would not stop until no point be deleted. Renumber the point (Fig.1 c).

Figure 1. Douglas-Peucker Algorithm

How to select the distance of threshold in Douglas-Peucker algorithm? It generally is used to the smallest visual objectives SVO method to calculate the distance of threshold (1). This method would take the distance threshold as the objective scale of the smallest visual objectives (SVO) corresponding to the actual distance between the grounds. This method also can be described as natural solution of the distance threshold.

Objective scale of the smallest visual objectives (SVO) corresponds to the ground distance $F_c$ can be calculated by (1):

$$F_c = S_t \times D \times \left(1 - \frac{S_s}{S_t}\right)$$ (1)

In formula (1): $S_t$ is denominator of the objective scale; $D$ is diameter of the smallest visual objectives SVO (size of the objective scale on map); $S_s$ is molecular of source data scale; $F_c$ is SVO corresponding to the ground distance of the objective scale.

$$X'_i = \text{INT} \left(\frac{X_i}{F_c}\right) \times F_c$$

$$Y'_i = \text{INT} \left(\frac{Y_i}{F_c}\right) \times F_c$$ (2)

In formula: $F_c$ can be calculated by (1).

2) Indirect algorithm would be used to judge and process repeatedly in objective space;

The reservation and remove of points in algorithm, actually means that the process is operated by original line element $L$ of source scale space, in which the starting point and ending point of $L$ remain unchanged.

In Fig. 2, points 1, 2, 3 of original line element $L$ are transformed to points $1'$, $2'$, $3'$ of $L'$, these points became to a repeat point; Point 4 became to point $4'$, points 5, 6, 7, 8 became to a repeat point after transformed, point 9 became to point $9'$.

B. Indirect generalization algorithm

Indirect generalization algorithm can be described as based on the principle of image resampling indirect curve fit algorithm. The first step of this algorithm is directly taking the points of original lines transform to the objective-scale space, and then indirectly judging in the objective-scale space. At last, back to the source data scale space to select.

We select line elements $L(X_0, Y_0; X_1, Y_1; \cdots; X_n-1, Y_{n-1})$ which is containing $n$ points as original line elements before generalization. The calculating step of indirect generalization algorithm is as follows:

1) Taking line elements of source scale space transform to objective scale space, calculating by (1), in objective scale space, line elements $L$ should be changed by $L'((X'_0, Y'_0; X'_1, Y'_1; \cdots; X'_{n-1}, Y'_{n-1})$).

2) Indirect algorithm would be used to judge and process repeatedly in objective space;

The reservation and remove of points in algorithm, actually means that the process is operated by original line element $L$ of source scale space, in which the starting point and ending point of $L$ remain unchanged.

In Fig. 2, points 1, 2, 3 of original line element $L$ are transformed to points $1'$, $2'$, $3'$ of $L'$, these points became to a repeat point; Point 4 became to point $4'$, points 5, 6, 7, 8 became to a repeat point after transformed, point 9 became to point $9'$.

Figure 2. Source scale space line element $L$ transform to objective scale space $L'$
Direct generalization algorithm also can be described as a new direct generalization algorithm based on the laws of nature. Its calculating step is as follows:

1) The objective scale of the smallest visual objectives (SVO) correspond to the ground distance $F_c$ can be calculated by (1);

2) In Fig. 3, beginning to the start point A of the line element, point A is selected to the first generalization point, and then choice backward point by point to calculate straight-line distances $d_i$ ($i=1,2,\cdots,n$), if $d_i \leq F_c$, this point should be removed, or kept, and the point kept would be chosed as a new point, and then to work with the behind of points to judge and choice, repeat this step till to point B.

### D. Calculating Comparison of the smallest visual objectives (SVO) $F_c$

$F_c$ of Douglas-Peucker algorithm, Indirect generalization algorithm, Direct generalization algorithm etc can be calculated by (1).

In table 1–4, the data is the real distance and the ground area of every objective scales such as 1:500, 1:1000 generalized by the smallest visual objectives SVO of different scales.

#### TABLE I.

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<th>1:25000</th>
<th>1:50000</th>
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#### TABLE III.

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</table>
III. DESCRIPTION OF ALGORITHM

The steps of algorithm are following as Fig.4:

Suppose Arc segments of vertex were supposed as $P_i(x_i, y_i)\,(i = 0, 1, 2, \ldots, n)$, total number of vertexes are $n + 1$.

1) The first fit subsection point were taken as the beginning point of arc segments, and this point was taken as the first currently fit subsection point $S_1$;

2) A fit vertex array $\text{FitVerts}$ would be composed by the currently fit subsection point $S_k$ which is $P_i$ in the arc segment of vertex and the next point of the currently fit subsection point $P_{i+k}$, and memorize sequence number $nIndex = i$ of the next fit subsection point, then search the next fit subsection point $S_{k+1}$.

   a) The fit subsection point was judged following the rule of Auto-search, if $S_{k+1}$ was subsection point, the curve fit should be required, otherwise, the next point would be chose as $P_{i+2}$ into the fit vertex array $\text{FitVerts}$.

   b) If the points in $\text{FitVerts}$ could be carried on curve fitting task and followed the rule of Auto-search of the fit subsection point, then update the next sequence number $nIndex$ of fit subsection point as the last sequence number $nIndex$ (etc. $nIndex = i + 2$) of the last point, loop step a) and b) till came to the end-point of arc.

   c) If points in steps a) and b) didn't follow the rule of Auto-search of fit subsection point, the next sequence number $nIndex$ of fit subsection point should not be updated.

   d) When its loop came to the end of the arc, if $nIndex = S_k$, then $nIndex = S_k + 1$, and update the next fit subsection point $S_{k+1} = nIndex$.

3) The step 2) would repeated until find next fit subsection point $S_{k+1}$ till coming to the end of arc segment, $S_{k+1} = n$ viz., the last fit subsection point is the end of arc segment.

4) Memorize sequence $S_k(x_k, y_k)\,(k = 0, 1, 2, \ldots, m - 1)$ of fit subsection points, the total fit subsection points of arc segment are $m(m \leq n)$.

Many scholars have had a detailed research in module of curve fit and have emboldened relevant fit module of line feature, this paper would adopt the methods discussed by former scholars into the fit way of different line feature.

IV. AUTO-SEARCH RULE OF FIT SUBSECTION POINT

The paper concretely put forward 5 rules of Auto-search; which should be selected according to the detailed situation. The rules are as follows:

1) The rule of approaching should be extended by fit curve (rule of distance);

Threshold distance was calculated by $D = d \times F_c$, $d$ changes based on practical instance, $F_c$ required by aim distance on the spot of SVO following (3):

$$F_c = S_i \times D \times \left(1 - \frac{S_s}{S_r}\right)$$

In formula (3), $S_i$ is denominator of aim scale; $D$ is diameter of SVO; $S_s$ is denominator of source data scale. $F_c$ is practical distance of target scale corresponded by SVO.

   a) Calculated the shortest distance between points which participates in fitting to fitting curve; acquiring max $D_0$ among all most short distances.

   b) Calculate extremism points of fitting curve and judge fountain arc points corresponded by extremism points, and then calculate the distances between these points, solve max $D_i$ in these distances.

   c) Calculate the distance $D_{max} = max(D_0, D_i)$, if $D_{max} \leq D$, then it sufficed rule of distance, considering currently points as fitting subsection points.

2) Rule of area

Threshold choosing of area: $S = d \times F_c \times F_c$, $F_c$ is acquired by (1); it would be changed with the extent of particular of reserved details.

The area enclosed by fountain line feature and axis could be calculated by $S_0 = \sum_{i=0}^{n-1} S_i$;
The area enclosed by fitting curve and axis could be calculated by \( S_1 = \sum_{j=0}^{m-1} S_j \);

\[ D \text{-value of areas could be calculated by } \Delta S = |S_0 - S_1| \text{.} \]

if \( \Delta S \leq S \), then it suffices rule of area, consider currently points as fitting subsection points. 

According to examples of experiment, rule of distance was fitted for circs of holding the shape of curve, while rule of area was fitted for circs of simplifying details of curve, so combining two rules together; it not only could simplify details, but also could hold the shape of curve.

5) Combined rule of 1) and 3) 

According to examples of experiment, graphics which adopted rule of length would cause a larger distortion, adds the Constraint Condition of rule of distance, and the effect of Curve Generalization would be improved.

V. EXAMPLE ANALYSIS

By using three colligated arithmetic of map and arithmetic of auto-selecting fitting subsection points, it could carry through the colligation of graphics. By way of showing the uncertainty of colligation of line feature mount of Vertex Data of graphic, areas of graphics and source and target shapes, length and shape-preservation
etc has been calculated after colligation. Including: 1. For Synthesis Algorithm of segments of line, the square sum of vertical distances were calculated among vertexes and lines which are after colligation. 2. For Synthesis Algorithm of fitting curve, the square sum of distances were calculated among vertexes and lines which are after fitting.

![Figure 5. Comprehensive fountain graphic of example](image)

![Figure 6. Chart of vertex data compared between Generalization Algorithms and auto-choosing algorithms of fitting subsection](image)

![Figure 7. Chart of area of polygon compared between Generalization Algorithms and auto-choosing algorithms of fitting subsection points](image)

![Figure 8. Chart of girth of polygon compared between Generalization Algorithms and auto-choosing algorithms of fitting subsection points](image)
VI. ARITHMETIC SUMMARY

Though the comparative experiment of the example mentioned above, it could explain that fitting Algorithm put forward could ensure line feature out of dithering and self-intersecting and keep shape characteristic of curve. It also has a simplified and slick effect, satisfying the request of Comprehensive to line feature. It incorporates as follows:

1) It could be revealed in the graphic after generalization algorithm that fitting subsection points which could choose colligation result automatically could keep the shape characteristic of graphic, hold a least distortion, lubricate curves and avoid self-intersecting.

2) The whole kinds of ways which colligate the area of polygon and length are almost the same. Indirect method and Generalization Algorithm of curve fitting were correspondingly better. Indirect method was correspondingly better in aspect of keeping the shape of graphic, but there were many source data points kept and a small quantity of data compression; there were less contrast between indirect method and Generalization Algorithm of curve fitting, however, vertex data of graphic after colligation were less then other generalization algorithm (especially direct and indirect methods).

3) It could be deduced from results of graphics and data that large scale map which adopted fitting method could get the same effect of generalization algorithm, it also could make the best of the information of each points of original map. Amount of data of graphic got a distinct condensation\textsuperscript{12}. Especially when the same original data points should be required after the all kinds of generalization algorithms, the effect of fitting method was superior to other Generalization Algorithms.

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REFERENCES


Yufeng Zhu was born in Jinxian, Jiangxi, China, in 1981. He received the Master degree in cartography and geographic Information engineering from East China Institute of Technology (ECIT), Fuzhou, China, in 2005. He is currently studying toward the Doctor degree in geodesy and surveying engineering, School of In-Physics and Geometries Engineering, Central South University (CSU), Changsha, China.

As a teacher of East China Institute of Technology, Fuzhou, China, his research topics include intelligence algorithm, research of GIS, mining surveying, and application of InSAR technology.

Shijian Zhou was born in Anfu, Jiangxi, China, in 1966. Prof. He received the Master degree in geodesy and surveying engineering from Wuhan University (WHU), Wuhan, China, in 1988. And received the Doctor degree in geodesy and surveying engineering from Wuhan University (WHU), Wuhan, China, in 1994.

He is famous of data processing of surveying. His research topics include surveying adjustment, spatial data, quality evaluation of GIS, and application of GPS.

Tieding Lu was born in Shaanxi, China, in 1974. He received the Master degree in geodesy and surveying engineering from East China Institute of Technology (ECIT), Fuzhou, China, in 2002. He is currently studying toward the Doctor degree in geodesy and surveying engineering, School of Geodesy and Geometries, Wuhan University (WHU), Wuhan, China.

His research orientation is surveying data processing and geodesy.
The Demonstration of Cloud Retrieval System Model

An Junxiu
School of Software Engineering, Chengdu University of Information Technology (CUIT), Chengdu, 610025, China
Email: anjunxiu@cuit.edu.cn

Abstract—With the rapid growth of networks digital information on the internet, the development and application of information retrieval technology is becoming inevitable. Based on the study of search engine and mobile search engine, according to the development of current technology, we experts put forward the cloud retrieval system model. The model consists of the cloud information layer, cloud retrieval cluster system, the user query box. The cloud retrieval cluster system consists of the cloud collecting layer, the cloud processing layer, the cloud index layer, the query layer of clouds, the cloud interface layer, data storage stratus layer, the cloud retrieval monitoring system, the clouds management system and scheduling system. In this paper, it is researched the function that the core level should complete and the core technology detailedly, and it has accomplished this model. The results of testing the model is shown that the system function can realize correctly, its performance is good and steady. The demonstration of this model gives the retrieval technology of massive information a scheme to develop thinking.

Index Terms—cloud retrieval system, cloud computing, clouds collecting layer, cloud index layer, parallel index

I. THE ELICITATION OF THE MODEL OF CLOUD RETRIEVAL

Recently, the U.S. Agency for International Data Corporation and EMC Corporation jointly issue a latest research report of which the title is «Economic constraints, the "Digital Universe" expansion expand». It is that the digital content of the whole world approach to 500 billion GB, its operating cost is about of 12 trillion dollars. IDC estimates that if we print out the contents of these data and bound into books, its height is enough to more than 9 times of the distance between Pluto and the earth. If we convert the production rate of the digital content to the thickened rate of books, the rate is faster than the fastest space rocket of the NASA (National Aeronautics and Space Administration). According to the above visual example, it makes us deeply feel the rapid growth of data, and digital information has become massive information. The generation of massive information makes the development and application of information retrieval is becoming inevitable.

In the autumn of 2006, Google put forward a concept named "cloud computing", cloud computing is the development of parallel computing, distributed computing and grid computing. Cloud computing is the result that virtualization, utility computing, infrastructure as a service ( IaaS ), platform as a service ( PaaS ), software as a service ( SaaS ) etc., all the concept mixed, evolved and jumped, that is cloud computing makes massive information become clouds group.

According to Google's "cloud computing", Baidu's "box Computing" and the trends of the current search engine, We put forward that cloud retrieval will be the main Momentum of the next generation of Internet. Cloud retrieval is the information retrieval based on cloud computing and box computing, and more is to provide services based on cloud computing. For users, as long as there are terminal unit that can connect in the Internet, they can use this terminal unit to input the information they want to know, cloud retrieval system will automatically retrieve the clouds layers quickly, and find the information of users need, rapidly pass the feedback to the users.

II. THE FRAME OF THE MODEL OF CLOUD RETRIEVAL

The model of cloud retrieval system consists of cloud information layers, cloud retrieval cluster system and user query box. The cloud retrieval cluster system consists of cloud collecting layer, cloud processing layer, cloud index layer, cloud query layer, cloud interface layer, data storage layer cloud, cloud retrieval monitoring system, cloud management and scheduling system, its structure is showed in Figure 1.

Cloud Acquisition Layer uses network robots to collect the information from the Cloud Information Layer. In order to improve Search performance, The whole set of processes running for robot will take the mode of parallel processing, that is, The work of collecting the web information will finished by multiple robots which are distributed on multiple computers. In order to coordinate the scheduling task reasonably, we design a coordinator to work with multiple robots. Coordinator will make logical division to the network which are need to search, and then assigned to the robot. The robot will downloading the web page which it is responsible for in itself logical division, and they can exchange the downloading tasks with each other by the coordinator, except that, we will store the web pages in the local storage, and the robots will communicate with each other.
by the high-speed local area. But it will cause the degradation of system performance because of communication of the network frequently. So the robots will take the mode of batch processing, they will store the URL temporarily which will send to coordinator, and the robot exchange datum when the storage reach to the certain number. In this communication, the robots will give their own store URL to the coordinator, and then get the new URL from the coordinator. Finally, the search results will be stored into the storage clouds by the coordination. This had to climb up the URL in the kinds of information through the internal code conversion, web page structure analysis, denoising, extract text, link analysis, at the same time the robots will judge the links whether useless or not, and will be moved the if useless, the thread of each robot draw off the URL information from the crawling web pages and store it to the URL extraction library.

For the characteristic that the scale of cloud retrieval cluster is large-scale, we divided all the nodes into several groups, each group contains a number of nodes to maintain the independence between the groups. At the same time, we select a number of workstations that have good performance, storage capacity, high bandwidth, to manage other working nodes within the group, for retrieve distributed, parallel-oriented to provide the most reliable support. In order to improve retrieval efficiency, and achieve distributed execution among between the layers, the function modules within each layer achieve parallel execution, the working scheduling is completed by the cloud management and scheduling system, which is like a butler program, concertedly handling the work of cloud retrieval. The cloud monitor software monitors the "peaceful coexistence" of the entire cloud retrieval system, such as monitoring whether there are too intensive visits from a single source IP address and so on. Only under such a framework of the cloud retrieval, we can achieve improvements on the scale, speed, accuracy, comprehensiveness and others of massive information

Cloud processing layer will cure the information, that is, the collected information must be filter firstly, remove duplicate link of the network, control code, and useless information. And in order to improve the retrieval efficiency, in the processing layer, cloud retrieval system uses text classification program to classify web pages to achieve the fast, accurate information on the search page, then word program participle the collecting the raw received information word processing, get entry sequence documents, and to use a certain model of the information which constitute the information model.

Cloud index layer uses inverted index technology to complete cloud retrieval, it uses the indexing process to get the entry sequence of the original document compiling the index entry operation in the previous step. That is, scanned entry sequence file, generated raw data index table, and completed the conversion of data format to accommodate the main index of input requirements. In order to improve the response speed, the index should be placed in the memory queue. In order to reduce storage space, it not only need to do the index compression, but also to sort the index page. It's necessary to use multiple or multi-level index when the amount of data expanded to the index can not be directly. Finally all the retrieved information need store into a distributed storage clouds.

The storage cloud is mainly to study the storage structure of information, refined to interact with each layer, it will need to design different storage structure and data distribution methods. Users choose the type of retrieval according to any query terminal, then a query message will be send to query layer cloud through the cloud interface layer. This layer is to scan, search and compare the information. That is, Using the inquiry procedure to search the relevant information of the original document, then uses the method of sorting process which is using the weight calculation, in the end to sort out the results after completed, then the search results will be send to eventually users through the cloud layer interface.

Clouds gathering layer uses the network robots to collect the information of the cloud information layer together, Cloud processing layers of the information processing, cloud index layer uses the Inverted Index technology to achieve cloud search, and stores all the retrieved relevant information that be searched in the storage clouds distributed. The users can pass the information which they want to search to the cloud interface layer through any queries Terminal and the cloud interface layer, this layer does the scanning, searching, and contrast treatment, through the cloud interface layer, it sends the search results to users. During this period, the storage stratus and monitoring systems monitor all the processes, cloud management systems and dispatching system is responsible for handling exceptions, the role of them were different, but are both intended to enable all processes completing the task stably and efficiently.

For the characteristic that the scale of cloud retrieval cluster is large-scale, we divided all the nodes into several groups, each group contains a number of nodes to maintain the independence between the groups. At the same time, we select a number of workstations that have good performance, storage capacity, high bandwidth, to manage other working nodes within the group, for retrieve distributed, parallel-oriented to provide the most reliable support. In order to improve retrieval efficiency, and achieve distributed execution among between the layers, the function modules within each layer achieve parallel execution, the working scheduling is completed by the cloud management and scheduling system, which is like a butler program, concertedly handling the work of cloud retrieval. The cloud monitor software monitors the "peaceful coexistence" of the entire cloud retrieval system, such as monitoring whether there are too intensive visits from a single source IP address and so on. Only under such a framework of the cloud retrieval, we can achieve improvements on the scale, speed, accuracy, comprehensiveness and others of massive information
searching, and but the major changes in working methods of the system will enhance the user's search experience.

III. THE REALIZATION OF THE CORE LAYER OF THE CLOUD RETRIEVAL SYSTEM MODEL

The model of cloud retrieval system uses Vim+Linux as the development platform, builds based on C++ and RubyOnRails, used the GCC to compile, use Vim to complete the working of coding, and project uses AutoTools to manage and automation to compile the deployment, uses Lighttpd to design running server. Using a developing model of one-stop services, based on the different characteristics which they are embodied in each layer, thus providing a more intelligent and personalized service.

A. The research of Cloud collecting Layer

The work process of the cloud collecting layer is first to collect the information on the Internet, then to pre-process information that is collected, to extract the URL information, to store the URL information in the original repository of URL, to transcode the web documents that will be obtained as the final data format in accordance with the design and store in the database. Therefore, the main function of clouds collecting layer includes: the Simulation achievement of HTTP protocol, the encoding conversion of web page files, the achievement of URLRank algorithm, the extraction algorithms of URL, the preservation of the state of robots crawling, the achievement of multi-threaded robot, the flow control of the robot program, the definition of original data file storage format and so on.

In order to improve the searching performance of the robot, the set entire process of the robot running uses the way of parallel handling, that is making multi-robots which were distributed on multi-computers do the work of web content collection simultaneously. In order to make it better to exchange information between computers, computers and databases, we design the parallel coordination to control the entire distributed computer cluster. Coordinator divides the network connection which needs to be searched logically, then distributes the logical connecting partitions that have been divided rationally to the robot. Each robot is responsible for downloading web pages within their own logic partition and through the coordinator to exchange the storage of downloading task each other, the main algorithm of robots is shown in Figure 2.

1) The simulation HTTP protocol

Through the interpretation of HTTP protocol, package and achieve simulation HTTP protocol, and work out the appropriate interface, it makes network robot convenient to use and construct different HTTP requests in order to achieve efficient use of program code. Using C language to achieve HTTP protocol must pass the Socket to have a simulation, and achieve the communication between the Web servers. HTTP Socket class declared outset, this class mainly achieves some methods the HTTP protocol-related, such as the connection with the Web server, sending the request, access to Head information, access to web information, and closing the connection and so on. And then focus on achieving the sending and parsing of HTTP protocol. The sending of HTTP protocol includes the sending of header information packaging that HTTP requests; the parsing of HTTP protocol includes the parsing of the head part that the Web server returns and body, as well as the disposed of a status of different treatment that server returns.

```c
while (robot administrator does not end robot program) {
    if (robot's URL list is empty) exit procedures;
    else read a URL A;
    if (the URL A has already been visited) continue;
    if (the visit of URL A is unsuccessful) {
        put the URL A into the URL database that can not be visited;
        continue;
    }
    get source code of web pages;
    analysis and extraction the hyperlink of web pages;
    if (web pages' source code format is not the UTF-8 format)
        Transform code for the source code of web page;
    Store the web source;
    add the URL A to the database that has already been visited;
}
```

Figure 2. The main algorithm of network robot

2) The encoding conversion of the Web documents

When Web robots climb a lot of information on the Internet the coding that different web server uses is different, including UTF-8, GB, GB2312, GB18030 … and many other web pages encoding formats, but the encoding used under Linux servers is all the UTF-8. Thus, when climbing the data file of different Web pages, the first thing you need to do is encode the conversion, and need to design the appropriate encoding converter.

In accordance with HTML standards, in the <meta> sub-tag of the<head> </head> tag using “charset” attribute indicates the encoding standard of Web page file. The transcoding algorithm first reads the “charset” attribute in the Web page “meta” tags. If you read it, then conduct code conversion, and continue to carry out the next function; if you do not find the code tags, it is necessary to test the encoding of Web page file. Testing method is to traverse all types of common coding information, until the status of code return success, and then carry out the next step.

In Linux, it is mainly using iconv() function for encoding conversion, the parameters that iconv() function is required are: the type of target encoding, the type of transcoding, the stored pointer of the target data, a stored pointer of transcoding Data. If the conversion is successful, it indicates the data type of the original code is the coding of “from_code” encoding; if unsuccessful, continue conversion until the conversion is successful.

3) UrlRank algorithm

There exists a matter of data update time for the cloud retrieval, it is not real-time for all the data that can be
searched. For the cloud retrieval, the phase-change of static web page files is much smaller than that of dynamic pages, so you can base on the structure of URL to design a method to calculate the URL weights. That is for a URL link, if the directory structure where the web document locates is deep, it’s defaulted that its importance can be on the relatively low; if the parameters that the page files passed are too many, this page on the default has a large dynamic changes, it will reduce the weight of URL page accordingly. Eventually forms a maximum of 10, gradually decreasing UrlRank algorithm.

B. The Study of Cloud Processing Layer

The main function of the cloud processing layer includes: receiving data from the original web page files, defining the participle sub-algorithm, Chinese word processing, English word processing, the processing of quantifiers and numbers, punctuation handling, the research of the storage format of row index and other functions.

1) The Detailed definition of input format

Cloud processing layer reads data and resects words from the originals data files that are stored in the network robot, so the segmentation process must parse out each data file from the original data file, read out starting position of a web page file in the original data file and record other information of this web data file, so need to design a new data structure: data structure of page information, named HtmInfo. The data structure of this page information records the URL of the web page, the position pos starting offset, the end position of the offset posEnd, page data content "content". And then passes the data by the format of Figure 3 to the cutting device, the cutting device will cut word for the data content and store the segmentation results in the outcome document.

```c
struct HtmInfo{
    string url;
    int pos;
    int posEnd;
    string content;
};
```

Figure 3. The structure of input data

2) The core algorithm of cloud processing layer: segmentation

Segmentation algorithms generally use two matching programs, which are the maximum matching segmentation forward, the minimum matching segmentation reversed, and then the words well segmented are generated according to a certain format is row index file is stored. This system model uses the forward maximum matching algorithm to cut words, in the process of achieving algorithm it recognizes quantifiers, time, English, punctuation and other different types of words, so that it makes the results of segmentation more accurate, and segmentation devices is more intelligent. Figure 4 shows the processes of segmentation system of cloud processing layer.

```
start the segmentation device;
while (segmentation has not finished) {
    read the web page information from the original web page files;
    pack the information of web pages into a structure, enter the segmentation device;
    while (article segmentation has not finished) {
        if (Chinese)  Chinese word processing;
        if (English)  English word processing;
        record segmentation results;
    }
}
close page files;
```

Figure 4. The process of segmentation system in cloud processing layer

First, after reading a section of the text, the segmentation device cut the vocabulary words by maximum length, based on system-defined words, at the beginning of each segmentation cycle, it records that the state of the current cycle is Chinese, English, characters, numbers, and then cut words by different word processing. If it is figures, it will judge whether it is the decimal fraction, the year or a quantifier? If it is English, directly separate it into different English words; if it is Chinese, then enter the Chinese forward maximum matching algorithm for segmentation. If there are some words that doesn’t exist in the dictionary terms, such as "is", "yes" and so on, then dispose it as a word break. It uses the "/" to separate between the different nature of the words, and ultimately store the segmentation results in row index file.

3) Design the storage format of data file

When Segmentation is completed, generally there are two kinds of data storage formats, one is the data format of a dictionary, one is the data storage format of the segmentation results, Figure 5 shows the data storage format of the segmentation results.

In the storage structure, each unit includes three lines. The first line is the Web page URL, it is the unique identify of the information in the Web page; The second line shows the start position and end position of migration of the content of this article in the original data file pages; The third line records the result of segmentation. It uses "/" to separate between the results. This program can only record the position of some words in segmentation results, rather than record a text messages, it greatly reduces physical storage space and indexing retrieval speed of the index file.

C. The study of cloud index layer

The cloud index layer is the basis of that the cloud retrieval can quickly find the information. According to the in-depth studies for the inverted index technology, put forward the improving program---aggregated address inverted index. Aggregated address inverted index technology can effectively achieve to determine several consecutive keyword indexes, it uses the words and terms
as index entry to design an efficient index structure. Aggregated address inverted index technology can expand every index database into different storage nodes in the system, so it is convenient to use parallel distributed index database in the system, improve its performance of high concurrency. It not only ensures a high data density, but also improves the flexibility of indexing, decreasing the technical difficulty of indexing, indexing has greatly enhanced the efficiency of that the system is making indexes at the same time.

http://www.csit.edu.cn/En/Undergraduate/Projects.html

Among the data block structure shown in Figure 6.

<table>
<thead>
<tr>
<th>Term</th>
<th>FileName</th>
<th>StartPos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Term1</td>
<td>FileName1</td>
<td>StartPos1</td>
</tr>
<tr>
<td>Term2</td>
<td>FileName2</td>
<td>StartPos2</td>
</tr>
<tr>
<td>......</td>
<td>......</td>
<td>......</td>
</tr>
<tr>
<td>Term n</td>
<td>FileName n</td>
<td>StartPos n</td>
</tr>
</tbody>
</table>

The second part is the inverted file that inversion table identified by the file name, the table mainly for keywords corresponding inverted file, as shown in Table 2. Inverted file according to a certain category of mechanism will store the index in the system disk, the system uses the distributed storage strategy, storing index classification in different nodes, you can quickly search the needed index information in a smaller scale. This is due to a certain extent, reduce the problem of inversion table which makes too much I/O overload.

### Table II. Inverted Table Structure

<table>
<thead>
<tr>
<th>File</th>
<th>Data Clock1</th>
<th>Data Clock2</th>
<th>......</th>
<th>Data Clock n</th>
</tr>
</thead>
<tbody>
<tr>
<td>File1</td>
<td>Data Clock1</td>
<td>Data Clock2</td>
<td>......</td>
<td>Data Clock n</td>
</tr>
<tr>
<td>File2</td>
<td>Data Clock1</td>
<td>Data Clock2</td>
<td>......</td>
<td>Data Clock n</td>
</tr>
<tr>
<td>......</td>
<td>......</td>
<td>......</td>
<td>......</td>
<td>......</td>
</tr>
<tr>
<td>File n</td>
<td>Data Clock1</td>
<td>Data Clock2</td>
<td>......</td>
<td>Data Clock n</td>
</tr>
</tbody>
</table>

Inverted table uses the keywords "Word" to identify, uses the "length" of the interception of information as length, and the following is a structure array of the detailed information of keyword appearing in each document. The "Score" is the total number of word frequency appearing. "Pos" is the pointer position where the word appears in the file; "Type" is the information type of word in the document. "Others" is the subsidiary information of the word, which is used to expand, its information is temporarily empty.

After setting the aggregate address inverted index table, we get a certain degree of relevance ranking when we store the detailed URL information by the word frequency and the location where the word is, which will make the order of URL information stored. When searching the information, if the URL information exceeds a certain threshold value in the search, it will be making a series of information ranking in the front as key information, while ignoring poor correlation information. This makes that the index content can be located quickly, reduces the inverted form of visits, and indirectly, makes the document compressed to a certain extent.

### D. The research of the cloud query layer

Figure 7 shows the basic functions of the cloud query layer. The index scanner reads the index tables from the main index database to the finder, after the finder makes some set operations and weighting operations, the finder delivers them to the multi-word processor to handle and make further weighting, and finally delivers them to the sorter to sort and exports them to the query front-end.

1) The detailed definition of the index scanner

The function of the index scanner is to scan index files, from which it can parse the document lists, that is, word frequency and location array that the documents correspond to. The description of the algorithm of the index scanner is shown as Figure 8.
frequency and the location of keywords algorithm to reset the web content priority level, eventually returning the information the users require. Experiments show that this can ensure a high enough correlation without a waste of computing resources.

\[ \text{PR}(A) = (1-d) + \frac{d}{\text{PR}(T1)/C(T1)+\ldots+\text{PR}(Tn)/C(Tn)} \]

Among it, \( \text{PR}(A) \) is a web level of page A; \( \text{PR}(T1) \) is a web level of page T1, and page T1 links to page A; \( C(T1) \) is the number of links out of the page; d is a damping coefficient, of which values is between 0-1.

\[ v = \sum 10^n + \sum (10 \times k^2) + \sum \text{Dis}() \]

The "n" is the times of the current keywords appearing in the current documents, that is word frequency. Word frequency is the number of words appearing in Web pages. When the times of a word appearing in a web page is more higher, it explains it has the high degree of association of keywords. However, the higher the frequency of a word appearing in a variety of pages is, the lower it correlates with the theme; "k" is the length of the current matching consecutive keywords sequence; \( \text{Dis}() \) is the function of the distance form the n to n-1 words, and you can get \( \text{Dis}() = 500/((Xn-Xn-1)^*[Xn-Xn-1]) \).

4) The detailed definition of the document summary generation algorithm

The program generates the summary of the current documents aim at searching words, which is used to display on the result displayed pages. The algorithm the former 20 entries where the positions of the longest matching sequence from the multi-pattern matching algorithm takes, and takes the back 20 entries to form a document summary, which can be perfectly shown the content of the key words in the document. The description of the document summary generation algorithm is shown as Figure 9.

5) The non-back multi-words continuously pattern matching algorithm

The non-back multi-words pattern matching algorithm has solved searching and sequencing in case of a number of keywords, which is to find the continuous entries that have the same keyword sequence which is all or part of the key words from the index list. In the search process
about the technology, the key words of the query strings are parallel query, that is, each keyword not traversing the index database by the order, but traversing the index database at the same time. The location data in each index entry can’t go back, that is, finding the appropriate match (full or maximum matching) to return, and not search the related phrases in the sequence of words any more repeatedly. The following is the detailed achievement of the non-back continuous multi-words pattern matching algorithm.

```
int result_item_multikeys_weight(result_item_t * item)
{
    for (i = 0; i < item->index->len; i++)
    {
        /* start word */
        memset(lastpos, 0, (sizeof(int)*item->index->len - i));
        curidx=g_array_index(item->index, index_item_t *, i);
        for (j = 0; j < curidx->pos->len; j++)
        {
            /* the start pos */
            is_match = TRUE;
            lastpos[0] = g_array_index(curidx->pos, int, j);
            for (k = 1; k < item->index->len - i; k++)
            {
                /* words follows */
                idxptr = g_array_index(item->index, index_item_t *, i + k);
                for (;lastpos[k] < idxptr->pos->len &&
                    (pos=g_array_index(idxptr->pos, int,lastpos[k])) - lastpos[0] < k; lastpos[k]++)
                    if ((pos - lastpos[0] != k) || is_match)
                        break;
            }
            item->weight += 10 * (k - 1) * (k - 1);
            /* assign the weight value */
            if (max_k < k)
            {
                max_k=k; item->max_pos=lastpos[0];
            }
        }
    }
    free(lastpos);
}
```

**E. The research of the data storage stratus**

The data storage layer clouds play a supportive role in the whole cloud retrieval system architecture, implement the separation storage of programs and data, and data storage of each layer as "clouds", and implement data interaction between the cloud layer and the main body of the cloud retrieval system, which includes the cloud acquisition layer, the cloud processing layer, the cloud index layer and the cloud query layer. The data storage layer clouds use the method of centralized storage, which can improve storage efficiency and reduce the complexity of the massive data management, and user-centered, improve the application performance and availability. No matter what terminals that users apply are, the cloud retrieval cluster system can recognize is merely its logical mirroring, which makes the data storage layer clouds can focus on the data management and operation, without worrying about the problem that the re-allocation needs to shut down and the start causes data loss, and ensures of the user's normal use. The following is the detailed data interaction in each layer:

In the cloud acquisition layer, the system will use the URL repository to extract as the URL information library, and then store the information of the original web page files; after the segmentation of the cloud processing layer, the system separates the original web documents entered into single vocabularies, uses "/" to separate words, and the final segmentation results will be stored in a separate participle library, the storage in accordance with a specific format is mainly achieved through a specific WordOutFile; In the cloud index layer, the system through the index program generates an index for the importing entry sequence files, to improve the finder to find the storage location of the original data, to extract metadata and generate the performance the of summary information, and finally store them in the index database; In the cloud query layer, when the search terms are as the keywords to search, the system directly reads a document list which contains the entries from the index library and sort them in accordance with the number the documents appear.

The cloud retrieval system through the use of the cloud management and scheduling system puts the data that generate in different stages to classify storage, achieves effective data management further and implement personalized search for users analysis.

**IV. SYSTEM OPERATION AND TEST RESULTS**

After the exploitation of the cloud retrieval system model is completed, by the way of comprehensive tests and stress tests to test the system, it can guarantee the quality of the system. After testing each subsystem separately and making sure that each subsystem works well, we associate with each subsystem together and make a comprehensive test to the whole system. Re-collect data, cut up words, make up index, and send the query requirement the front-end, analyze returned results, analyze the background logs, and make a comprehensive test analysis.

The cloud retrieval system in the real application scenario has a relatively high using frequency, in order to verify the performance and work situation of the system under the circumstance of high pressure, and the system is tested by the pressure. The test method is mainly to use software to simulate randomly various keyword combinations to make the stress test of 200 times per second concurrent requests assembly. The test is completed in the charge of using 10 processes to provide services on the server including the 4-core Xeon processor and the 2G memory. Statistical results show that the system can respond to 200 requests per second. The test results show that the system functions are correctly implemented, and the performance acts well and
V. CONCLUSION

The information that the cloud retrieval faces is massive, the formats and the structure of information are various, and the quality of information is ragged, the content that it refer to is extensive. The user community that cloud retrieval faces is not a relatively neat users. Therefore, what the cloud retrieval gives is not a narrow-related sequence, but the statistical integration of priority order that reflects a variety of factors, such information that reflects is popular, without considering the personality differences between different users. In fact, different users have distinctive personality due to the different factors such as the level of education, working environment, they wish the cloud retrieval can provide personalized service, that is, the query results in line with the user's individual needs. In order to achieve personalized cloud retrieval, it comprehends and counts the web data mining and the behavior of user. According to the iterative interaction between the user and the cloud retrieval system, the system will ultimately provide users with personalized services. To analyse the user's all kinds of information and to establishing the user access model is the key of building personalized cloud retrieval system model.

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REFERENCES

Study on Rational Application of eXtensible Business Reporting Language

Hongming Chen
School of Economics and Management, Changsha University of Science and Technology, Changsha city, P.R. China
chmdsh@163.com

Wenchuan Sun
School of Economics and Management, Changsha University of Science and Technology, Changsha city, P.R. China
wenchuansun@126.com

Abstract—Extensible Business Reporting Language (XBRL) has developed rapidly since its birth as one of accounting information processing standards and the latest technology. The governmental departments (including finance, taxation, business and other institutions), listed companies, famous software companies, academic institutions and other professions are paying more and more attention to the research in the finance information field by using XBRL. Related projects, academic conferences and discussion have been initiated to study its application and benefit. This has, in turn, lead to a new research applications upsurge in the field of accounting information management. However, the phenomenon that the advantages of XBRL were magnified is also apparent. In order to spread and apply XBRL, it is vital to objectively understand its advantages and limitations of XBRL, to constantly explore its applicable areas, and to have a good working knowledge of how it can be further developed. Being a business reporting language with many advantages, XBRL is not 100% perfect. There is still a huge distance between XBRL and the ideal network business reporting language. Based on system analysis on the research of XBRL in China and the research data samples selected from the Listed Companies in China Shanghai Stock Exchange from 2005 to 2006, the test demonstrated that the present enterprise does not obtain the superior earnings from the XBRL application, thus those enterprises cannot become the prime promoter of XBRL application. Currently, the shortcomings and performance bottlenecks in XBRL application are: Firstly, XBRL can only solve the problem in data performance format, but cannot fix the problem for the main reason for the existence of a multi-report form system and in the disclosure of information. Secondly, as there are many different systems and bodies of Taxonomy, the use of XBRL to compare and analyze accounting information in cross-regional or cross-country is not meaningful. Even in the same country, a number of organizations based on different Taxonomy will face the same problem when comparing financial and accounting information. Finally, there are inherent flaws of XBRL, such as large data storage capacity demand, inefficient implementation and excessive reliance on network security. It is bound to put enormous additional construction IT costs to companies, and may lead to ‘IT investment black hole’. Based on the research above, this paper proposes some methods and direction to solve or alleviate the problems this study found and questioned. In the research developing process of XBRL, if the problem questioned in this paper can obtain effective solutions, we can believe that this technology will bring significant changes to the accounting profession. XBRL will become the promotional power of convergence of international accounting standards. Finally, not only will it make the enterprises’ accounting information reporting mechanized, standardized and transparent, but it will also reduce the risk of fraud in accounting to a certain extent.

Index Terms—Instruction, The rational cogitation of XBRL application, XBRL application and discussion in China, Discussion, Conclusion

I. INTRODUCTION

XBRL (eXtensible Business Reporting Language) is an application of XML (eXtensible Markup Language) on the commercial report information exchange. XBRL provides a kind of standardized method to create and publish financial reports and other information by increasing marks on the financial information content. As a result, collection, processing, and conversion of internal and external financial information have become relatively easy. Before the XML technology was used, the network financial report was mainly applied to HTML technology and PDF text format [1]. The HTML provides marks to hypertext original documents and directs browsers to show page information in order. The client depends on a browser to explain both HTML and transmit information to end-users. HTML is only a simple demonstrative language which defines styles, forms and contents in the same document. HTML merely pays attention to the related content on browser's demonstration. So it is unable to express and discriminate the concrete connotation of financial data. Searching network financial report based on the HTML language is often like looking for a needle in haystack [2]. The PDF format is similar to graphic file. Users can read it very clearly but cannot obtain the data automatically. Both the Stock Exchange and intermediary institutions have to re-processing the financial information published by Listed Companies. A lot of manual intervention not only increase the error rate in processing data, but also increases costs across the
board. Due to the lack of a uniform data standard, different accounting entities organize accounting data according to their own standards and formats. In return, data exchanging and sharing become more and more difficult [3].

Many countries and regions in the world, such as the United Kingdom, the United States of America, Canada and Australia, are actively involved in developing and applying XBRL. The rapidly development of XBRL leads to an upsurge of research applications, in the field of accounting information management [4]. However, a phenomenon that magnifies advantages and fuzzes application drives is also apparent. In order to spread and apply XBRL, it is vital to objectively understand its advantages and limitations of XBRL, to constantly explore its applicable areas, and to have a good working knowledge of how it can be further developed. This study makes a multi-angled analysis on a few prevalent views of XBRL in terms of standards, technology, management and application drive. Moreover, questions are raised and discussed, and then several conclusions are made for reference. The authors hope to bring a further and more profound reflection on XBRL application. Section 2 contains rational cogitation of XBRL application. In section 3 presents XBRL application in China by using the event study approach. Section 4 discusses several key questions on XBRL application. Finally, section 5 summarizes the most important results of the paper and presents some ideas for further research.

External financial reporting to external parties is, however, only one aspect of XBRL. The standard also has the potential to be used for tax filings or for other regulatory purposes, such as reports to the regulators of financial institutions. This would allow corporations to maximize their investment in producing financial information in XML format. One of the reasons that the companies that produce accounting software are heavily involved in XBRL is that they see XBRL being built directly into accounting and database software. XBRL may assist global corporations in the “rollup” of accounting data and reports between group members that report under disparate GAAPs and employ different computerized accounting systems. Closer to the transactional level, it may be that internal general ledger journal entries will use XML and XBRL. Eventually, XBRL will move upstream to the point that internal-events reporting will be in XML and XBRL. One major problem that companies now have is pulling together information generated by disparate systems throughout their organizations. If all these disparate systems can map their internal outputs to XML and XBRL, then combining this information will be relatively routine, as compared to the complex tasks that global corporations must currently undertake in the internal reporting process.

Up to this point, the discussion has focused on expanding financial reporting. However, Fig. 1 illustrates expanding beyond financial reporting. The four blocks in the center of Fig. 1 can be viewed as four cells in a 2_2 matrix. Vertically, reporting can be divided into external and internal. Horizontally, the contents of the reports could be divided between financial and operational. The larger arrow in the background of Fig. 1 illustrates the evolutionary flow of the expanding XBML domain. Initially, XBRL is focused on external financial reporting.

As was also illustrated in Fig. 2, in the near future, XBRL will next move upstream and become an integral part of internal financial reporting. Then, XBRL will expand to include nonfinancial business operations reporting. Finally, over the next several years, XBRL will expand to include external business performance reporting. Eventually, companies who use XBRL for external business reporting will be easier for investors and analysts to compare in terms of business performance metrics, since the reporting syntax will be based on a standard specification, namely, XBRL [5].

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II. THE RATIONAL COGITATION OF XBRL APPLICATION

If a company wants to apply XBRL to disclose their financial report, it needs to use the marks from the classified standard which is stipulated in advance, and places companies’ financial data in corresponding label to compose instance documents.

After nearly 10 years’ technical Specifications and Taxonomy upgrading and optimizing continuously, XBRL has been the favorite of many economic organizations in the world. Both in academia and real practice, a phenomenon that magnifies advantages and fizzes application drive is also attendant at present. If we do not identify them carefully, these questionable points will affect the health development of XBRL.

A. XBRL can not eliminate the barriers of financial information-sharing completely

Currently, the reasons that different financial information users cannot share business information disclosed by the same company are following:

• The problem of data manifestations (technology problem). It is inconvenient to extract and process the information in unstructured forms, such as Word, PDF, HTML, and so forth. And the information in structured forms, such as relational database in DBF format, cannot be used online directly [6].
• The difference of Index System (Taxonomy problem). Different index systems are regulated and restricted by guidelines of respective industries. For the same terms, such as profit, may have different understandings [7]. Thus it is difficult for different users to share the information released by companies.
• Motivation of Information release. Subjectively, companies do not hope to share the information completely with Government Departments. From the different motivation, companies may not disclose their complete information. Even more release false information to public [8].

XBRL can only solve the problem of data form, but cannot unify the different reporting systems which are long-existing. It is almost impossible to reduce the number of financial fraud by applying XBRL only. Although, from the technical point, we may select the metadata to save and release accounting, the disclosed accounting information may contain all details of company's interior business systems. This will affect business security of companies.

B. It is impossible to enhance the transparency of financial information obviously by XBRL application

XBRL is a standard method not a new accounting system. It is not able to change the data in accounting system. XBRL concerns on methods of financial information processing. It is a classification data level of accounting system, rather than an acquisition data level. Since XBRL data released by accounting entities is not the original data, its effectiveness is distrustful [9].

If all companies in stock market adopt XBRL to disclose their financial information, perhaps speed and convenience of information transmission would enhance as result of XBRL technical characteristic. But stock market’s transparency and norms might not improve consequentialy. In other words, there is no guarantee that XBRL can improve the quality of accounting information and avoid accounting information distortion effectively.

C. XBRL cannot eliminate contradictions between accounting international and localizable

There are different accounting criterions and various ways to name account. Current Taxonomies are draw up by the accounting authoritative organizations of different countries. Based on the technology infrastructure and application status quo of XBRL, even in the same country, the differences of professional judgments in details maybe have tremendous influence on the financial report which follows the same accounting criterions. The international XBRL organization proposed a FRTA (Financial Report Taxonomy Architecture) in April, 2005, and they hope raising the Taxonomy consistency between different countries. However, analyses of experts indicate that only Global GAAP can achieve the true unification of global Taxonomy.

It is unable to contrast the financial reports instance documents which based on the different Taxonomy in details. During Taxonomy development and application phases, its domain should be expanded as far as possible. So that information-sharing and information-using scope will be based on the same Taxonomy Architecture and follows the identical information disclosure standard (Erice, 2004). Therefore, XBRL application can only promote various accounting authoritative to be more similar with each other, but not eradicate the contradiction.

D. XBRL application needs huge investment

XBRL, as a form of XML, inherits the advantages and disadvantages of XML. Principal aspects which have been questioned are following:

• XBRL require larger storage space;
• The processing speed of XBRL information is not as quick as database system;
• The information processing systems based on XBRL are still not perfect enough;
• It is very difficult to develop its own XBRL system based on enterprise interior Taxonomy;
• It needs huge conversion costs to transform enterprise information system which based on relational database into XBRL-based one;
• Development of XBRL information system needs new methodology;
• The transformation of IT knowledge and ability;
• The software industry should promote new tools and platforms unceasingly to support fast development of enterprise XBRL Taxonomy and improve the efficiency of generation, storage and conversion of instance documents;
• Lacks of sufficient funds and successful experience for massive XBRL applications;
• Information system programme based on the relational database has been investing massive
construction expense and becoming mature. If a large numbers of working information systems need to convert to information systems which based on XBRL, it is bound to consider enormous additional IT construction costs, which may lead to 'IT investment black hole'.

A. XBRL puts new demands on the network

The XBRL service is Internet-based message processing and exchange methods. Yet, in nature, the Internet is insecure. XBRL services will not reach their full potential without good security. Access control techniques, based on user IDs and passwords, can protect files or data from unauthorized access, but cannot guarantee information integrity. Thus, alternative security approaches might compensate these limitations [10].

Additionally, dependence of network may affect XBRL processing speed [10]. As XBRL adopts XML technologies such as Schema and XLink, therefore when XBRL documents being processing, Specification and Taxonomy need to be visited momentarily to verify the legitimacy and consistency of the information. Those Specifications and Taxonomies are stored on XBRL International organization website, W3C organization website as well as website of XBRL organization in various countries. So its processing speed is directly related to communication network quality. If the network service condition is inappropriate, the information processing efficiency could be reduced. Although there is no experimental study about data-processing speed difference between relational database system and XBRL system, we could assume that relational database system could be superior in information processing efficiency on the basis of their current storage methods and search tools. After long-term development, the relational database system has a range of advanced algorithms and SQL support, but XBRL system has not it yet.

F. Information provider is not the main driving power to promote XBRL

Due to XBRL characteristic and huge application investment, company is not willing to share their information with information users considering their security and benefit. Companies, XBRL information provider, have little intense motility in developing and applying XBRL. On the contrary, the greatest beneficiary of applying XBRL is information collectors and external users rather than the provider. Probing the companies' original impetus of XBRL application is the key of promoting XBRL.

It is not believed that company implements XBRL project led by the natural superiority of XBRL technology. Therefore, we should probe the reasons of the company to implement XBRL plan voluntarily. And we need to study what respective characteristics companies have on whether or not implemented XBRL? What signal will be transmitted to the capital market? Is it necessary that supervisory department impose a mandatory requirement on companies to implement XBRL projects, if the company does not implement XBRL voluntarily? And will the mandatory regulation of applying XBRL increase the social welfare or waste of resources only?

III. XBRL APPLICATION AND DISCUSSION IN CHINA


The existing researches show there are plus response from investment and application in information and technology stock market [11]. But Dos Santos et al. (1993) found that there is an uncertain relationship between market response and IT investment [12]. Application of XBRL belongs to a financial investment. The investment can be recognized in the financial statement. The market anticipation of the application expense is transitory. The anticipation cannot heavily impact on future cash flow. So the application of XBRL cannot influence the companies’ value significantly. However, if these extra information releases to stock market, investors may pay more attention to future cash flow. The information will let the investors know the cost is durative and will affect cash flow after successful introduction.

A. Test model designs

Based on Efficient Market Hypothesis, investors will response after companies blaze non-financial information, for example they will apply XBRL standard. If investors believe XBRL application will benefit companies’ future business performance, they may adjust their anticipation of the companies’ cash flow, and response before companies’ declaration. As a result, stock price will fluctuate and produce stock abnormal returns. Presently, in the information technology investment market, different researchers’ empirical tests give different results. The proposal model following will apply event study approach which belongs to finance metrology, to test whether or not abnormal returns exist in Chinese stock market after companies’ declaration of applying XBRL standard.

Different research object need to choose different event window. Relatively long event window setting may receive more influence information on the event, but this kind of setting may also easily receive influences of other factors on the stock price. To avoid other factors'
influence, in the information and technology research field, short event window is preferable. So, we define the day 0 when the Listed Companies apply XBRL to release their quarter finance report as the event day (when \( t = 0 \)). We follow the short event window method and define the event window as before and after 3 days of day 0. (\( t \in [-3, +3] \)).

The samples of this study are selected randomly from the Listed Companies in China Shanghai Stock Exchange from 25th June, 2005 to 22nd May, 2007.

\[
E[R_{it}] = \mu_{i} + \varepsilon_{it}, \ t \in [-3, +3]
\]

\[
\text{Var}[\varepsilon_{it}] = \sigma_{i}^{2}
\]

\[
\mu_{i} = \frac{1}{-4 - (-203) + 1} \sum_{h=-203}^{-4} R_{it}, \ h \in [-203,-4]
\]

Where:
\( R_{it} \) is \( i^{th} \) company’s real returns in time \( t \);
\( \varepsilon_{it} \) is disturbance term. Which mean is 0;

\[
\text{Std. Deviation} = \sigma_{i}^{2}
\]

Normal Return defines as real returns minus anticipation returns which are not influenced by the event. As follows show:

\[
AAR_{it} = \frac{1}{50} \sum_{j=1}^{50} AR_{ij}, t \in [-3, +3]
\]

\[
CAR_{it} = S \sum_{j=1}^{50} AAR_{ij}, t \in [-2, +3]
\]

Statistics hypothesis test: in the t time point, the null hypothesis \( H_{0} \) is:

\[
H_{0}: CAR_{it} = 0
\]

Its T-Test Statistic is:

\[
T_{CAR} = \frac{CAR_{it}}{S(CAR)/\sqrt{n}}
\]

\[
S(CAR) = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (CAR_{it} - CAR_{i})^{2}}
\]

B. The test result and analysis

We use the model above to test samples’ data, and depict the AAR & CAR in Table 1 and Table2:

Analysis of influence factors of mode. There are several influence factors we need to concern.

\begin{itemize}
  \item Firstly, sometimes, especially when using small sample to study, the empirical test result may influence heavily by one or two companies.
  \item Secondly, based on above event study steps, we can see that during the research steps, we need to choose, such as the length of event window, samples, Returns Models of NR, Estimate Window span, Signification Test methods and so forth. These choices must bring some kind of uncertainty to the related results and explanations.
  \item Last but not least, Dec. 30th, 2005 is a special date. This date selection may influence the test results directly.
\end{itemize}

About how to calculate normal returns in event study approach, several methods have been used frequently, such as Mean-adjusted Returns Model, Market- adjusted Returns Model and Risk-adjusted Returns Model. In this study, we apply constant mean return model which belongs to Mean-adjusted Returns Model. Although constant mean return model is a simple one, this model could get similar result to other complicated models [13]. On the other side, constant mean return model has its own advantages in China market. According to the characteristic of China stock market, Mean-adjusted method fits to the research which price response weak and hard to ascertain. By using mean-adjusted model, the changes of stock price can be checked easier from the event’s influence. To avoid Annual Report’s influence on Normal Return (NR) estimating, a relatively long estimate durance, Day -200 is used in this model.

Constant mean return model assume \( i^{th} \) company’s NR is constant during the event window. Then we can define:

\[
E[R_{it}] = \mu_{i} + \varepsilon_{it}, \ t \in [-3, +3]
\]

\[
Var[\varepsilon_{it}] = \sigma_{i}^{2}
\]

\[
\mu_{i} = \frac{1}{-4 - (-203) + 1} \sum_{h=-203}^{-4} R_{it}, \ h \in [-203,-4]
\]

Where:
\( R_{it} \) is \( i^{th} \) company’ real returns in time \( t \);
\( \varepsilon_{it} \) is disturbance term. Which mean is 0;

\[
\text{Std. Deviation} = \sigma_{i}^{2}
\]

Normal Return defines as real returns minus anticipation returns which are not influenced by the event. As follows show:

\[
AAR_{it} = \frac{1}{50} \sum_{j=1}^{50} AR_{ij}, t \in [-3, +3]
\]

\[
CAR_{it} = S \sum_{j=1}^{50} AAR_{ij}, t \in [-2, +3]
\]

Statistics hypothesis test: in the t time point, the null hypothesis \( H_{0} \) is:

\[
H_{0}: CAR_{it} = 0
\]

Its T-Test Statistic is:

\[
T_{CAR} = \frac{CAR_{it}}{S(CAR)/\sqrt{n}}
\]

\[
S(CAR) = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (CAR_{it} - CAR_{i})^{2}}
\]

B. The test result and analysis

We use the model above to test samples’ data, and depict the AAR & CAR in Table 1 and Table2:

Analysis of influence factors of mode. There are several influence factors we need to concern.

\begin{itemize}
  \item Firstly, sometimes, especially when using small sample to study, the empirical test result may influence heavily by one or two companies.
  \item Secondly, based on above event study steps, we can see that during the research steps, we need to choose, such as the length of event window, samples, Returns Models of NR, Estimate Window span, Signification Test methods and so forth. These choices must bring some kind of uncertainty to the related results and explanations.
  \item Last but not least, Dec. 30th, 2005 is a special date. This date selection may influence the test results directly.
\end{itemize}
According to Figure 3, fifty companies' CAR increases slowly from Day -2. It means, in advance, stock market has small scope response on using XBRL to publish quarter finance report. CAR arrives its maximum, 0.00741, on Day 1. According to Equation 9, we can calculate TCAR (TCAR = 0.3701) which is smaller than critical value (2.4469) under 5% confidence interval. This shows the proclaiming influence on stock market is not significant. CAR starts decreasing on Day 2. And decrease to -0.00243 on Day 3. Though Wilcoxon Test, we find that in the fifty samples, 24 of 50 CAR are plus, 26 of 50 are minus. There is not huge difference. The event influence is not significant.

IV. DISCUSSION

A. The costs of XBRL application

Companies cannot take extra-benefit from the application of XBRL. On the contrary, companies may pay more money for applying XBRL to release their financial report.

- Information production cost. Companies need to pay much money for releasing the information during the data collection, processing and transferring processes. If the information needs investigation, investigation cost also need to be paid [14].
- Litigation cost. Latency litigation cost is an immateriality cost of information release (AICPA, 1976). Deficient release and the misleading intent results in litigation cost.
- Competitive advantage loses. Information release may affect the competitive advantage of the companies [15]. It will be easy to lose its competitive advantage by releasing information. The releasing time, detailed degree and the receiver are key factors on this issue [14].
- Compliable cost and canvass cost. Companies may spend money on obeying the compulsion release regulation issued by related government sections. For the sake of convincing whether or not releasing some kinds of information, companies may face the canvass cost [15].

B. The requirements of XBRL's successful application

According to AICPA's programming, XBRL will not change accounting standards. XBRL aims to help professional or general information users obtain the information rapidly and easily from stock exchange by more efficiency and more reliable methods. The basic characteristic of XBRL is the permission of catching and exchanging financial information from different software platform freely by the financial information users. The requirements of XBRL’s successful application are:

- The Specification and Taxonomy should be suitable for most of companies. The XBRL specification specifies the format of XBRL documents and how to create a standard XBRL document. The Taxonomy defines the uniform labels of company's financial report. Each item has only one definition. Guide committee should in charge with the Specification and Taxonomy.
- Application program which accord with the Specification. The application program is similar to the accounting software which is nowadays widely used by companies. It can help the information providers to edit and release financial report based on XBRL standards. The application software should be provided by XRBL software suppliers [16].
- Transfer information to special or other different types of form. This is special software for coding the information in special or other different types of form. It will help accounting information users catch the information online from the financial report which following XBRL standard. At the same time, it could transfer the information format into what the users want. Those different types of form should be developed by different software companies.
- Excavate the initial drive of XBRL application. Surveillance department of government is the first beneficiary of XBRL application. So the research on this subject should be dominated by government. The initial drive ought to come from the cooperation of related government departments and organizations. Experiencing the stages from government predominating to academia, then to cooperative academic organization, finally to company application union, the substantial and successful application of XBRL will achieve. It the other words, after sound and perfect research chain, application chain and industrial chain constructing, large scale XBRL applications will succeed.

V. CONCLUSION

XBRL is one of the business reporting languages which has many advantages. It will become a good choice for companies when they release their financial information, even as the interrelated standards of XBRL are been perfected gradually. However, XBRL is only a standard format of electronic document for financial reporting. Applying XBRL cannot replace nowadays expression of operational and financial circumstances of a company, nor substantially enhance the quality of financial reports.

It is difficult to unify different Taxonomies in different countries, which is the basis of using the XBRL Taxonomy as the construction. Data processing and
storing technologies are still not enough perfect currently. So there is a gap between the ideal XBRL and the real-life one. In the research developing process of XBRL, if the problem questioned in this paper can obtain effective solutions, we can believe that this technology will bring significant changes to the accounting profession. XBRL will become the promotional power of convergence of international accounting standards.

External information user, not the companies which apply it, will benefit most from XBRL technology. How to inspire the initial drive to apply XBRL is the key to pushing the technology further. In China, the government is the first beneficiary of applying XBRL, so the initial drive should come from the government. Experiencing the stages from the government predominating to academia, then to cooperative academic organization, finally to the company application union, the substantial and successful application of XBRL will come true.

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REFERENCES


Hongming Chen is a professor in the School of Economics and Management, Changsha University of Science and Technology, Changsha city, P.R. China. He received BS, MSc, PhD in Information System and Management from Hunan University.

His major research interests include accounting information system, business administration. His papers appeared in many journals and International Conferences, such as Accounting Research, International Forum on Computer Science-Technology and Applications. IPCSTA. Professor Chen had written several
books, for instance Computer accounting theory and application (Hunan science and technology Press), Visual FoxPro 6.0 Design and accounting computerization model (Hainan Publishing house).

Professor Chen is the member of Accounting Society of China, and the trustee of Accounting Society of Hunan Province and Accounting Society of Changsha city.

Wenchuan Sun received a BS degree in Business Administration from Central South University in 2007. Her research interests include Accounting information system and information management. She has published several papers in quality journals and conferences.
Personality’s Influence on the Relationship between Online Word-of-mouth and Consumers’ Trust in Shopping Website

CHEN Hui
School of Economics and Management, Beijing University of Posts and Telecommunications, Beijing, China
Email: Chen-hui@vip.sina.com

Abstract—This paper did a survey on 162 college students, with an aim to find out the role of consumers’ personality in their trust in the website as far as the online word-of-mouth is concerned. All the data collected are analyzed by SPSS 15.0 and LISREL. It shows that there is a significant difference between the introverted consumers and the extroverted consumers viewing their attitude towards online word-of-mouth. When the online word-of-mouth is affecting the consumers’ trust in shopping websites, the introverted and extroverted influence exist difference.

Index Terms—Online word-of-mouth, Trust, Personality

I. INTRODUCTION

Being a new media able to provide an open, fair, cheap and efficient access for information, the Internet has played a more and more important role in people’s daily life. At present, it is very common to use the E-media to communicate with each other, which results in a wide spread of virtual communication. The Internet has also made the online shopping a common thing, the consumers can publish their opinions conveniently on the website, including the quality, the price, and the style of the product, the service of the website and the online sellers and the delivery speed.

The research shows that the potential online consumers may refer to other consumers’ comment when they are about to shop. The online word-of-mouth is becoming more and more influential. Our (Chen & Li 2009) research shows that the online word-of-mouth published in the shopping websites’ BBS has an influence on the online consumers’ trust in the shopping websites. However, what are the factors in control?

According to the research done on consumer behavior, the consumers’ personality is affecting their shopping behavior and shopping decision. The influence of the consumers’ personality on virtual shopping and virtual shopping decision is yet to be discussed. The main purpose of this paper is to explore this aspect, mainly focusing on the specific types of information when consumer of different personalities are looking for the online word-of-mouth and the role of the personality in affecting consumers’ trust in websites.

II. LITERATURE REVIEW

A. Online Word-of-mouth

The generation of online word-of-mouth

With the development of e-commerce, online word-of-mouth also has attracted a lot of attention. The consumers use Internet to search for information about product quality, price, service, delivery. Because of the virtual shopping environment, consumers take some risk before they make shopping decisions. Therefore, online word-of-mouth, as a source of information, is also considered by consumers.

Stauss (1997, 2000) discussed the influence of online communication on consumer, which used ‘Internet consumer communication’ to define the information about products online, a kind of word-of-mouth. It makes a potential consumer communicate with many other people about the product information.

Hanson (2000) used online word-of-mouth or electronic word-of-mouth to describe computer-mediated word-of-mouth. The consumers use e-mails, user groups, online forums to transfer information. Hennig-Thurau et al. (2004) pointed out that consumers use WebPages to collect the information from other consumers, which can be defined as electronic word-of-mouth.

The types of online word-of-mouth

According to Kiecker & Cowles (2001), there are four types of online word-of-mouth: Spontaneous word-of-mouth: consumers use their WebPages or e-mail as communication channel to transfer information. Quasi-Spontaneous word-of-mouth: consumers use BBS or virtual communities of shopping sites to transfer information. Independent-or Third Party-sponsored word-of-mouth: the sellers create websites and help consumers to transfer information about product or service.

In this research, I focus on Quasi-Spontaneous word-of-mouth. I define it as consumer-generated comments.
These comments are all from the BBS or virtual communities of shopping sites.

The influence of online word-of-mouth

Bickart & Schindler (2001) defined the type of online information as used User-generated online information and marketer-generated online information. Consumers used those as information collecting channels. The researchers collected information about consuming potential, expected consuming expense, product knowledge, thought and interest of those consumers. User-generated online information is from the BBS, marketer-generated online information is from the WebPages of sellers. After 12-week data collection, they found that consumers who collect User-generated online information are more interested in the products.

With 252 students as research objects, Smith, Menon & Sivakumar (2005) found that online shoppers made buying decisions with the information from other consumers who have bought same products.

Based on the 616 virtual community members’ data, Gruen, Osmonbekov & Czaplewski (2006) thought that online word-of-mouth influence the perceived value of product and the intention of loyalty.

In the real world environment, researchers focused on the positive and negative information on the shopping decision-making and they found out negative information has more influence on the decision-making.

In this research, I focus on the influence of consumer-generated comment on consumer trust to online sellers.

B. Trust Model

Based on the traditional trust theories, there are three trust models: rational-emotional trust model, institutional-interpersonal trust model and faith-intention trust model. Rational-emotional Trust Model

This model analyzes trust from both the rational and emotional aspects. The consumer trust in the e-commercial transaction context is determined by two aspects: First, the buyer will analyze the competitive power, marketing ability, brand influence of the seller. Second, the buyer will analyze the honesty, credibility, benevolence and integrity of the seller and consider its customer care to determine whether this seller is reliable and credible.

Institutional-interpersonal Trust Model.

Institutional trust is a trust in the whole Internet environment, and interpersonal trust is an appraisal for credibility of the seller on the Internet. The related literatures taking interpersonal trust into consideration believed that transaction itself is an interactive interpersonal process. Compared with the normal interpersonal relation, the buyer in the transaction process is in the inferior position. Only when knowing a lot about the seller’s competitive power and benevolence, combining with the satisfaction based on the previous transactions, the buyer can judge the seller’s credibility and determine his/her own buying behaviors.

Faith-intention trust model

McKnight (1998) put forward the two-dimensional trust: intention and faith. The intention of trust is: in the given environment, even if the bad results may happen, the object is still willing to trust others. The definition of the faith of trust is: in the given environment, the object believes that others are benevolent, capable, honest and predictable. In the context of e-commerce, the faith of trust includes the faith and the expectation of online customers toward the online sellers which are related to the trust. The intention of trust is the degree that the customer is willing or intended to trust the seller on the shopping site, even if they risk a deception.

In my research, I mainly care about the interpersonal trust, which is between the consumer and seller. In interpersonal dimension, basically I use Gefen’s three-dimensional trust (2002), which are ability, benevolence and integrity.

C. Personality And Online Word-of-mouth

According to the Consumer Information Search Theory in Consumer Behavior Theory, the consumers depend on the external information when they are doing the shopping or making the shopping decision, although the degrees varied. When it comes to the same external information, it’s decisive for dependent consumers; while it might only be a facilitator for independent consumers.

The influence of information provider’s personality on the online word-of-mouth

During the diffusion of online word-of-mouth, the information provider is the main part of the process, the prior user of the product or the consumption and the trust-deliver which means the degree of his wiliness of spreading the online word-of-mouth and the appropriate opportunity are the decisive factors as to the diffusion of online word-of-mouth.

As for the personality, Hawkins pointed out that consumers who are affected by the collectivism are more likely to spread their shopping experience or information to the relevant groups. Money R.B. et al., after researching the differences between the different consumers’ influence on the diffusion of online word-of-mouth, found that compared to the introverted consumers, the extroverted consumers are more likely to share the shopping information with their family members and friends.

The influence of information receiver’s personality on the online word-of-mouth

The online word-of-mouth receiver, being the one affected by the online word-of-mouth, the degree of the information acceptance will not only affect its shopping behavior or decision, but also is an important index for evaluating the diffusion of the online word-of-mouth. The better the receivers’ understanding and acceptance, the more possibilities the receiver makes the same decision as the online word-of-mouth, which reflects the positive effect of the diffusion of online word-of-mouth. The main factors affecting the receiver’s acceptance is the receivers’ personality, wiliness and receiving ability.

Personality is a stable psychological characteristics gradually formed in the psychological development. The development of the consumer’s personality is affected by
such background factors as development environment, education, society and heritage. They are the antecedents in the receiving of online word-of-mouth, among which, culture is a decisive factor in the formulation of consumers’ personality. For example, when researching the cross-cultural spread of online word-of-mouth, Bruce noticed that the consumers under the Japanese culture are more active in searching the online word-of-mouth compared to the American consumers, and the possibility is higher under the same cultural background than the different ones, and the influence is greater. At the same time, according to the consumer information search behavior in the Consumer Behavior, the consumers are affected by the external information to some extent, however, as for the same information, the influences are varied. For dependent consumer, the external information might be decisive for the shopping decision; but for the independent consumer, it might only be a facilitator. Therefore, I can clearly see that the online word-of-mouth receiver’s personality is an important factor in the process of online word-of-mouth spreading.

This research mainly used one of the Big Five Personality Traits: extroversion (introverted, extroverted) to research the consumers’ attention on the online word-of-mouth and the adjustment function of the personality traits.

D. The Classification of Online Word-of-mouth

In my previous research, I studied about 1,000 comments of consumers on BBS and virtual communities of shopping sites after their shopping behaviors. In that research, I used empirical factor analysis to analyze the data, then the results showed the contents of comments could be divided into four dimensions: Service, Product and price, Self-display and After-sale action (Chen, 2009). Service refers to the solutions to all the problems the customers may have in the process of decision-making, product delivery and receiving, product operation, etc. According to different service phases, service can be divided into three dimensions: customer service, logistics and packing, after-sales service and solutions. Product and price refers to the comments of quality and price of the product in the shopping sites. Self-display can be divided into two dimensions: background description of the consumption and feeling of the consumers. After-sale action comment means a feedback for the specific website, the specific seller or other consumers after purchasing and using the products or services. Moreover, After-sale action comment can be divided into two dimensions: action (measured in deeds) and suggestion (measured in words).

Based on this, I developed the questionnaire of "Comments on shopping sites, which is composed of 29 items.

E. The Relationship Between Online Word-of-mouth and Consumer Trust

With the development of social networking, online word-of-mouth, being an important component of the shopping websites, has become more and more welcomed by the online shoppers. It is shown that the consumer’s purchasing ability is greatly affected by his surrounding people. In the shopping website, the majority consumers will first look for adequate information at the comment community and then make their shopping decisions. At present, most shopping websites provide the community for publishing comments on product and the purchase. In some western countries, I can even find those comparison shopping websites which aim at searching the consumers’ comments and make comparisons. Therefore, I can say that there is significant relationship between the online word-of-mouth and consumer trust, and it has been proved by lot scholars from different angles, both home and abroad.

Liu et al. studied about 284 Korean adult consumers who have the online shopping experience in the past year and found that: (1) When shopping online, consumers mainly consider the four factors of comments, the first factor is related to the product returned, restitution, after-sales service, namely dissatisfaction solution factor; The second factor is related to the delivery time, the accuracy of product delivered, product packaging, namely the product delivery factor; The third factor is that with the product quality, product attributes, product design, namely the product attributes factor; The fourth factor is related to the product price, delivery costs and payment, namely money factor. (2) The factors associated with the product attributes and the after-sale dissatisfaction solutions are very influential on the online shopping. On the contrary, the product delivery factor and the money factor did not affect the online shopping intention. Therefore, I need to manage the product attributes factor and the after-sale dissatisfaction solution.

When a consumer is buying a certain product, there is a decision making process, although differed with the product type and purchaser type. However, a typical purchasing decision process usually includes the following aspects: Demand recognition, information collecting, comparison, purchase decided and after-purchase activity. During the information collecting phase, the information comes from the following channels: (1) personal channel: from the interpersonal relationship with family members, relatives, neighbors and colleagues. (2) business channel (main source and can be monitored by the enterprises): advertisements, introduction by the salesperson, package of the products and the instructions for the products. (3) public channel: mass media such as TV, radio and magazines. (4) experience: from their own contact with the products. The existence of virtual community expands the sources of information and enables the community members to search professional and well-targeted brand and its information. At the same time, the virtual community has also rewritten the meaning of the source of experience, enabling community members to observe and learn from the experience of others, and be supported. These benefits arise primarily from the online word-of-mouth within the virtual brand community.

It is also proved by Ni Yegang in his paper after an empirical study that the content of the comments has a significant influence on the consumer trust. He arrived at
the conclusion: "Consumers have more trust on the
product on which comments are allowed to express."

According to iResearch’s latest release - "China E-
consumer Decision-making Research -2008", the
reputation of the online shops is the primary factor in the
E-consumer’s decision-making, after-sale service and
comment are the focus of the E-consumers. 70% of E-
consumers used the user comment to help their decision
making. The Information authenticity, usefulness, the
credibility of the commentators and the number of
comments are the most concerned user comment
attributes.

My research (Chen, 2010) found out that, Service
comment has weak influence on the trust in the consumer
websites. Service comment has influence on neither
Capability nor Honesty.

Product and price comment has strong influence on the
trust in the consumer websites. Products comment has
strong influence on Capability and Honesty.

Self-display comment has strong influence on the trust
in the consumer websites. Self-display comment has
strong influence on Benevolence.

After-sale actions’ comment has strong influence on
the trust in the consumer websites. After-sale actions’
comment has strong influence on Benevolence.

III. HYPOTHESES AND MODELS

In this research, I used the questionnaire designed by
myself “the questionnaire of comments on shopping
sites”, and divided the shopping website comments into 4
domains: Service, Product and price, Self-display and
After-sale action.

Meanwhile, according to the questionnaire developed
by Gefen in 2002 for testing cyber trust which was based
on Mayer’s three-dimensional model in 1995, this paper
divides the trust into three dimensions: Capability, honesty and benevolence.

Capability is the combination of profession, technology, competency and experience of online sellers. Honesty refers that online sellers have some regulations and principles to protect the online consumers. Benevolence refers that online sellers will behave kindly to shoppers without self-interested profit motive. They may give up their potential interest and treat the consumer benevolently.

I classify the consumers’ personality types according
to the extroversion domain in the Big Five Personality
Traits.

The consumers who are intolerant of uncertainty would
prefer to have a clear view of the things before making a
decision, so they tend to search for and evaluate
information before buying. While at the same time,
compared to the introverted consumers, the extroverted
consumers are more independent, more adventurous
rather than conservative, so I can make a guess that
consumers of different characteristics might have
different concerns for the online word-of-mouth, so come
the following assumptions:

H1: as for the attention of the comment on the service,
there is significant difference between the extroverted and
introverted consumers.

H2: as for the attention of the comment on the product
and the price, there is significant difference between the
extroverted and introverted consumers.

H3: as for the attention of the comment on the shop
owners’ self display, there is significant difference
between the extroverted and introverted consumers.

H4: as for the attention of the comment on the after-
sale service, there is significant difference between the
extroverted and introverted consumers.

It is proved by some empirical researches that the
comments of the products exert an obvious influence on
the consumers. In the information exchange mechanism,
it is also pointed out that by providing a detailed
introduction of the product, an objective evaluation by a
third party, virtual advisers and by establishing virtual
communities which enable a free exchange of
information between consumers, the shopping sites will
influence the consumers’ trust. In the purchasing process,
extroverted consumers are more likely to be influenced
by the external environment, which means the great
degree of herd mentality. While the introverted
consumers are more concentrated on the heart, which
means they are not likely to be affected by the external
environment. That is to say, compared to the introverted
consumers, the extroverted consumers are more
vulnerable to the external interference. Therefore, I can
suggest that speaking of the influence of the comments on
the trust of shopping websites. It is greater on the
extroverted consumers than the introverted consumers,
thus the following hypothesis:

H5: Compared to the extroverted consumers, the
introverted consumers’ trust on the websites’ ability are
more easily to be affected by the comments on service.

H6: Compared to the extroverted consumers, the
introverted consumers’ trust on the websites’ honesty are
more easily to be affected by the comments on service.

H7: Compared to the introverted consumers, the
extroverted consumers’ trust on the websites’ ability are
more easily to be affected by the comments on the
products and prices.

H8: Compared to the introverted consumers, the
extroverted consumers’ trust on the websites’ honesty are
more easily to be affected by the comments on the
products and prices.

H9: Compared to the introverted consumers, the
extroverted consumers’ trust on the websites’ benevolence are
more easily to be affected by the comments on the
shop owners’ self display.

H10: Compared to the introverted consumers, the
extroverted consumers’ trust on the websites’ honesty are
more easily to be affected by the comments on the after-
sale service.

IV. RESEARCH METHODOLOGY
A. **Research Objectives**

The study chose the college students as the sample for doing the questionnaire. The reasons for choosing the college students are: First, because of the fact that the objects of empirical research are online shoppers. According to report of February, 2009 provided by the iResearch Research Institute (I Research), the majority of internet active consumers are the college students; the proportion is up to 70%, among them, most are with bachelor degree. Therefore, it is representative of choosing college students as the sample. Moreover, the research aims at investigating the different perceptions of trust in the shopping websites’ comments among different personalities, so the focus of the survey sample is to cover different consumers of different personalities.

B. **Research Materials**

This questionnaire is composed of four parts.

The questionnaire of Comments on Shopping Sites

It is composed of 29 items, mainly measuring the degrees of the concerns of the E-consumers for the following 4 aspects: service, product and price, consumer self-display and after-sale service. The questionnaire of ‘Comments on shopping sites’ is from my previous study, which has certified the validity and credibility (Chen, 2009). I use Likert scale to measure the degree of concern of online consumers before they make online shopping decision, from “1” to “6”, means “not concern” to “concern a lot”. The questionnaire of Trust on Shopping Sites

The questionnaire of ‘Trust on shopping sites’ is the one from Gefen (2002), which has also certified the validity and credibility. It also used Likert scale to measure the degrees of agreement of online consumers to the shopping websites, from “1” to “6”, means “totally disagree” to “totally agree”.

The questionnaire of personality

The study used the Mini-Marker questionnaire developed by Saucier, the questionnaire is composed of 8 categories of adjectives from which the respondents are asked to determine the consistency with their personality. The 8 adjectives can determine the extent of the respondents’ extroversion. The questionnaire used Likert scale, “1” to “9”, means from "totally incompatible" to "full compliance" correspondingly. The questionnaire of demographics

It is used to survey the E-consumers’ basic information, including gender, age, marital status, education background, location of surfing the Internet, the times of online shopping and the name of websites frequently visited.

C. **Statistic Methods**

First I used the SPSS 12.0 to analyze the responsibility and validity of the data, and then used the Lisrel to do the structural equation analysis.

V. **Research Results**

A.. **The Demographic Information of The Sample**

I distribute 200 questionnaires and collects 194. Eliminating invalidate ones, the final number of validate questionnaires is 162. The demographic data of research objects is in Table I.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Gender</th>
<th>Age</th>
<th>Education degree</th>
<th>Locations of surfing Internet</th>
<th>Times of online shopping per month</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>19-24</td>
<td>25-30</td>
<td>Bachelor</td>
</tr>
<tr>
<td>number</td>
<td>97</td>
<td>65</td>
<td>128</td>
<td>34</td>
<td>118</td>
</tr>
<tr>
<td>Proportion</td>
<td>59.9%</td>
<td>40.1%</td>
<td>79%</td>
<td>21%</td>
<td>72.8%</td>
</tr>
</tbody>
</table>

B. **The Reliability of The Questionnaire**

I use Cronbach’s Alpha to analyze the internal reliability of each dimension in the questionnaires. The Cronbach’s Alpha value is shown in Table II. The results show that the reliability can be accepted of every dimension.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Service</th>
<th>Product and price</th>
<th>Self-display</th>
<th>After-sale service</th>
<th>Ability</th>
<th>Honesty</th>
<th>Benevolence</th>
</tr>
</thead>
<tbody>
<tr>
<td>α</td>
<td>0.527</td>
<td>0.578</td>
<td>0.471</td>
<td>0.575</td>
<td>0.506</td>
<td>0.548</td>
<td>0.747</td>
</tr>
</tbody>
</table>

C. **Concerns for Comments Between Different Personality**

Mini-Marker calculates the combined score to determine the person’s characteristics. This research used the same method, the respondents scored from 1 to 36 are marked as introverted consumers, and those from 37 to 72 are marked as extroverted consumers. It shows that, among the 162 respondents, 70 are introverted and 92 are extroverted.

I used the one-way ANOVA to measure the different degrees of concerns for different domains of the comments on online shops between two different kinds of consumers. Sig= 0.05 is the dividing level, when sig <
0.05, it means there is significant difference between the two personalities, when $\text{sig} > 0.05$, it means the difference is not significant. The results can be found in Table III.

### TABLE III.
THE DIFFERENCE IN CONCERNS FOR COMMENTS IN WEBSITES BETWEEN THE INTROVERTED AND EXTROVERTED CONSUMERS

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>Df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service</td>
<td>1.038</td>
<td>1</td>
<td>1.038</td>
<td>1.868</td>
</tr>
<tr>
<td>Quality and Price</td>
<td>.926</td>
<td>1</td>
<td>.926</td>
<td>.923</td>
</tr>
<tr>
<td>After-sale activity</td>
<td>7.935</td>
<td>1</td>
<td>7.935</td>
<td>11.561</td>
</tr>
</tbody>
</table>

The result shows that there is a significant difference between the introverted and extroverted consumers in their concerns for the self-display. The average score for the introverted consumers is 3.77, while it is 4.17 for the extroverted consumers. There is also significant difference between the introverted and extroverted consumers in their concerns for after-sale activities. The average score for the introverted consumers is 3.62, while it is 3.17 for the extroverted consumers. It means that the introverted consumers have a higher degree of concern for the after-sale activity than the extroverted consumers. However, I cannot find significant difference between the two types of consumers in their concerns for service, product quality and price. Therefore, Hypothesis 1 and 2 are denied, Hypothesis 3 and 4 are confirmed.

### D. The Influence of Comments on Trust Between Different Personality

The empirical model and the goodness-of-fit SEM acquired by analyzing the introverted consumers’ relative data, using LISREL, is statistical acceptable. The result can be found in Table IV.

### TABLE IV.
THE GOODNESS-OF-FIT OF SEM FOR INTROVERTED CONSUMERS

<table>
<thead>
<tr>
<th>$\chi^2$/df</th>
<th>RMSEA</th>
<th>NFI</th>
<th>NNFI</th>
<th>CFI</th>
<th>GFI</th>
<th>IFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.51</td>
<td>0.087</td>
<td>0.83</td>
<td>0.87</td>
<td>0.80</td>
<td>0.84</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Without considering the other variables, I can see the degrees of significance of the influences that the variables of online shopping sites’ comments have on the extroverted consumers’ trust in the website are: the comments on the product and price have a significant influence on the extroverted consumers’ trust in the website’s ability; the comments on the product and service have a significant influence on the extroverted consumers’ trust in the website’s ability; the self-display of other consumers have a significant influence on the extroverted consumers’ trust in the website’s ability; the comments on the after-sale activity have a significant influence on the introverted consumers’ trust in the website’s benevolence. The results are shown in Fig. 1.

### Figure 1. The model of “consumers’ comment on websites influences introverted consumer trust”

The empirical model and the goodness-of-fit SEM acquired by analyzing the extroverted consumers’ relative data, using LISREL, is statistical acceptable. The result can be found in Table V.

### TABLE V.
THE GOODNESS-OF-FIT OF SEM FOR EXTROVERTED CONSUMERS

<table>
<thead>
<tr>
<th>$\chi^2$/df</th>
<th>RMSEA</th>
<th>NFI</th>
<th>NNFI</th>
<th>CFI</th>
<th>GFI</th>
<th>IFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.23</td>
<td>0.050</td>
<td>0.83</td>
<td>0.87</td>
<td>0.80</td>
<td>0.74</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Without considering the other variables, I can see the degrees of significance of the influences that the variables of online shopping sites’ comments have on the extroverted consumers’ trust in the website are: the comments on the product and price have a significant influence on the extroverted consumers’ trust in the website’s ability; the comments on the product and service have a significant influence on the extroverted consumers’ trust in the website’s ability; the comments on the after-sale activity have a significant influence on the introverted consumers’ trust in the website’s benevolence. The results are shown in Fig. 2.

### Figure 2. The model of “consumers’ comment on websites influences extroverted consumer trust”
Based on the above results, Hypothesis 5, 8 and 9 are rejected; Hypothesis 6, 7 and 10 are confirmed.

VI. DISCUSSION

A. The Degrees of Concern for The Comment in The Shopping Websites

There is no significant difference between the introverted and extroverted consumers’ concerns for the comments on services. And both the introverted and extroverted consumers’ concerns for the comments on services are above the middle value. It means that both the introverted and extroverted consumers are more concerned about the comments on the services of the online shops. The main reasons for shopping online are the convenience and efficiency, so they might pay special attention to the online shopping process and customer service quality.

The significant difference between the introverted and extroverted consumers’ concerns for the comments on the product and price cannot be found. From average score of both groups, I can see that both the introverted and extroverted consumers show a special concern for the comments on product and price. The result is also achieved by Tsai. This kind of comment involves product itself, price and payment, which are the nature attributes for the consumers’ final decision as to which product or service to buy and thus draws special attention from the consumers. Therefore, both the extroverted consumers and extroverted consumers give the same weight to this kind of comment.

There is significant difference between the introverted and extroverted consumers’ concerns for the consumers’ self-display. Extroverted consumers have comparatively more concerns for the comments such as the consumers’ self-display. The extroverted consumers are more easy-going. They like to communicate with the salesperson or other consumers, and like to take others’ comment on the products in the traditional shopping mode. Whereas, the introverted consumers have less communication with other people, thus less attention on others’ self-displays.

There also exists significant difference between the introverted and extroverted consumers’ concerns for the comments on after-sale activities, and the introverted ones have more concerns than the extroverted ones. Introverted consumers cannot stand the high degrees of uncertainties, so they tend to focus more on the feasibility of the product and convenience of the service. They are more cautious in the buying process, which can account for the different degrees of concern for the after-sale service between the introverted and extroverted consumers.

B. The Personality’s Role

Many factors in the comments on the websites can have a direct or indirect role in the consumer’s trust in the website. However, as for the introverted and extroverted consumers, there is a difference in the comments’ influence on their trust in the website.

For the extroverted consumers, the comments on the service influence their trust in the websites’ honesty; the comments on the product and price influence their trust in the websites’ ability; the comments on the after-sale service influence their trust in the websites’ benevolence. The extroverted consumers are more willing to communicate, and communicate with other people during the buying process, thus more possibility of being influenced by the external information. The introverted consumers are more tranquil. They don’t like to have much communication with others, thus more cautious in the buying process, less possibility of being influenced by the external information such as comments and advertisements. In other words, the extroverted consumers are more susceptible to the external information, while the introverted consumers attach more importance to the natural quality of the commodity and not likely to be influenced by the external environment.

The extroverted consumers are less likely to be influenced by the following aspects: the comments on service influencing the trust in the websites’ ability, the comments on the product and price influencing the trust in the websites’ honesty and the self-display influencing the trust in the websites’ benevolence. The introverted consumers are cautious in their buying decision, so they would attach adequate importance to certain information of the products and comments, such as the feasibility and price of the products. These aspects would exert a comparatively huge influence on the buying decision. Extroverted consumers like adventure and changes, so they are easily to accept the things. Therefore, although they can easily accept the external information, they cannot have an in-depth understanding compared to the introverted consumers. This leads to the fact that the extroverted consumers are less influenced in the above 3 aspects.

C. Research Limitations And Future Research

First, there are some limitations in variety of the sample’s profession, age and education degree, which might possibly lead to some errors in the sample’s representativeness. Second, the questionnaire is based on the respondents’ memory, so their choices might be affected by some objective elements, which may also lead to a divergence of the actual situation.

So the statistical scope of the sample should be expanded in the future study, the classification of the content of the comments, trust and personality should be standardized, where possible, under the conditions of laboratory experiments to study ways to reduce the error.

Perspectives on the future research:
1. Research the inner psychological characteristics of the consumers

After the empirical research, the study shows that personality have a certain influence on certain stages during the buying process, and the traditional consumer behavior research shows that the other aspects of the consumer psychological traits such as the consumer innovation, emotion stability and impulse will exert certain influence on the decision making, so the future research can focus on these aspects, and further discuss.
their influence on E-consumers’ comments and trust in the website.

2. Research the influence that the types of shopping websites might have on the E-consumers’ comments and trust in the websites.

At present, there are different types of shopping websites in China, such as the C2C shopping platform, professional B2C websites and other online department stores. Different types of websites have their own advantages and disadvantages. Whether there is a significant difference between the website features? Whether the consumers have different trust in the online word-of-mouth and in the websites? These are all to be researched in the future.

VII. CONCLUSION

1. For the concerns for the self-display, there is significant difference between the introverted consumers and extroverted consumers. The extroverted consumers pay more attention to the other consumers’ self-displays.

2. For the concerns for the after-sale activity, there is significant difference between the introverted consumers and extroverted consumers. The introverted consumers pay more attention to the other consumers’ after-sale activities.

3. Compared to the extroverted consumers, the comments on the service are more likely to influence the introverted consumers’ trust in the website’s honesty.

4. Compared to the introverted consumers, the comments on the products and price are more likely to influence the extroverted consumers’ trust in the website’s ability.

5. Compared to the introverted consumers, the comments on the after-sale service are more likely to influence the extroverted consumers’ trust in the website’s benevolence.

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The new Development in Support Vector Machine Algorithm Theory and Its Application

LIU Taian  
College of Environment and Spatial Informatics China University of Mining & Technology, Xuzhou, China  
Department of Information and Engineering Shandong University of Science and Technology, Taian, China  
Email: LTA999@163.COM

WANG Yunjia  
College of Environment and Spatial Informatics China University of Mining & Technology, Xuzhou, China

WANG Yinlei  
Department of Information and Engineering Shandong University of Science and Technology, Taian, China  
Email: Wylei2003@163.COM

LIU Wentong  
Nanyang Technological University, Singapore, Singapore

Abstract—As to classification problem, this paper puts forward the combinatorial optimization least squares support vector machine algorithm (COLS-SVM). Based on algorithmic analysis of COLS-SVM and improves on it, the improved COLS-SVM can be used on individual credit evaluation. As to regression problem, appropriate kernel function and parameters were selected on the analysis of support vector regression (SVR) algorithm. This paper proposes the forecasting model of coal mine ground-water-level based on SVR algorithm and improves on it. In another regression problem, it improves on successive overrelaxation for support vector regression (SORR) algorithm to measure the cholesterol content of a blood sample concerning the three kinds of plasma lipoproteins (VLDL, LDL, HDL) in medical science. The numerical experiment results show that improved COLS-SVM has effective classified forecast ability. For details in the paper part Ⅱ.

As to regression problem, the SVR is applied to forecast coal mine ground-water-level in this paper. Appropriate kernel function and parameters are selected on the analysis to SVR algorithm. This paper improves on the forecasting model of coal mine ground-water-level based on the SVR algorithm and determines the forecast of the input factor and the output factor according to the physical geography and the hydrology geology situation of the chosen mining area. The numerical experiment results show that the forecast outcomes have compatibility with the actual measurement results. We verify that the improved forecasting model of coal mine ground-water-level has been effective, and provide a new effective method to the forecasting of coal mine ground-water-level. For details in the paper part Ⅲ.

In another regression problem, as to classification problem of successive overrelaxation for support vector (SOR), it improves on successive overrelaxation for support vector regression (SORR) algorithm, to measure the cholesterol content of a blood sample concerning the three kinds of plasma lipoproteins (VLDL, LDL, HDL) in medical science. The numerical experiment has proved that the improved SORR is effective and has better regression precision compares with the standard SVR algorithm and the speed of study is improved. This paper provides a new method for the cholesterol measurements in clinic. For details in the paper part Ⅳ.

I. INTRODUCTION

In the algorithm theory and application of support vector machine, the research of classification and regression problems, has important theoretical significance and application value.

As to classification problem, this paper puts forward the COLS-SVM with algorithm of combinatorial optimization for reference. Based on algorithmic analysis of COLS-SVM and improves on it, the improved COLS-SVM is used on individual credit evaluation. Through comparing with Lagrange Support Vector Machine (LSVM) and K-Nearest Neighbor (KNN), the numerical experiment results show that improved COLS-SVM has effective classified forecast ability. For details in the paper part Ⅱ.

As to regression problem, the SVR is applied to forecast coal mine ground-water-level in this paper. Appropriate kernel function and parameters are selected based on the analysis to SVR algorithm. This paper improves on the forecasting model of coal mine ground-water-level based on the SVR algorithm and determines the forecast of the input factor and the output factor according to the physical geography and the hydrology geology situation of the chosen mining area. The numerical experiment results show that the forecast outcomes have compatibility with the actual measurement results. We verify that the improved forecasting model of coal mine ground-water-level has been effective, and provide a new effective method to the forecasting of coal mine ground-water-level. For details in the paper part Ⅲ.

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II. THE INDIVIDUAL CREDIT EVALUATION BASED ON IMPROVED COLS-SVM
A. Individual Credit Evaluation Background

Individual credit system is an important part of state credit systems and individual credit evaluation is a general reflect of individual capital and credit situation. It has great significance and application value to evaluate individual credit using Support Vector Machine (SVM) and a lot of work has been done in this filed [1][2][3]. We put forward the combinatorial optimization least squares support vector machine algorithm (COLS-SVM) basing on the combinational optimization algorithm and by basing on algorithmic analysis of COLS-SVM, and improves on it, we use improved COLS-SVM in individual credit evaluation and have made new development in this filed.

B. The COLS-SVM Algorithm

1) The Combinatorial Optimization Algorithm

LS-SVM doesn’t have sparse solutions [4] and we divide the training sample set into two subsets to train LS-SVM respectively and the parameter is the same as full training sample set. This kind of training makes the space complication degree much less than that of the full training sample set concerning LS-SVM, so to provide more feasible condition to establish LS-SVM fast algorithm.

To combine the two subsets used to train LS-SVM respectively together linearly, and then we have \( f_1(x), f_2(x) \):

\[
y = \beta_1 f_1(x) + \beta_2 f_2(x)
\]

among which: \( \beta_1 + \beta_2 = 1 \)  \( (1) \)

To achieve the minimum derivations of full training samples so to satisfy:

\[
\min e \cdot e'
\]

s.t. \( \beta_1 + \beta_2 = 1 \)  \( (2) \)

Among which: \( e = y - (\beta_1 f_1(x) + \beta_2 f_2(x)) \)

Owing to \( \beta_1 + \beta_2 = 1 \),

\[
e = y - (\beta_1 f_1(x) + \beta_2 f_2(x))
= (\beta_1 + \beta_2) y - (\beta_1 f_1(x) + \beta_2 f_2(x))
= \beta_1 (y - f_1(x)) + \beta_2 (y - f_2(x))
\]

If: \( e_1 = y - f_1(x), e_2 = y - f_2(x) \),

Then: \( e = \beta_1 e_1 + \beta_2 e_2 \)  \( (3) \)

So the above optimization problem changes into:

\[
\min (\beta_1 e_1 + \beta_2 e_2) \cdot (\beta_1 e_1 + \beta_2 e_2')
\]

s.t. \( \beta_1 + \beta_2 = 1 \)  \( (4) \)

Introduce Lagrange \( \eta \) to get the Lagrange function of the above optimization problem:

\[
L(\beta) = (\beta_1 e_1 + \beta_2 e_2')^2 + \eta (\beta_1 + \beta_2 - 1)
\]

Owing to the above convex optimization problem according to Karush-Kuhn-Tucke, the minimum sufficient and essential condition of \( L(\beta) \):

\[
\begin{cases}
\frac{\partial L(\beta)}{\partial \beta} = 0 \\
\frac{\partial L(\beta)}{\partial \eta} = 0
\end{cases}
\]

(6)

So

\[
\begin{align*}
2\beta_1 e_1 \cdot e_1' + 2\beta_2 e_2 \cdot e_2' + \eta_1 &= 0 \\
2\beta_2 e_2 \cdot e_2' + 2\beta_2 e_2 \cdot e_2' + \eta_1 &= 0 \\
\beta_1 + \beta_2 - 1 &= 0
\end{align*}
\]

To solve (7) to get:

\[
\beta_1 = \frac{e_2 e_2' - e_1 e_1'}{e_1 e_1 + e_2 e_2' - e_1 e_2'}
\]

(8)

In the above solutions, if \( e_2 e_2' < e_1 e_1' \) or \( e_1 e_1' < e_2 e_2' \), get minus solution. The combined SVM from different random training samples from the same sample space tends to have a positive solution rather than a minus one, thus needs to have a limiting condition: \( \beta_1, \beta_2 \geq 0 \). under \( \beta_1, \beta_2 \geq 0 \), the solution of optimization problem may get directly based on formula (8)

That is:

\[
\beta_1 = \begin{cases}
0 & \beta_1 \leq 0 \\
\frac{\beta_1}{\beta_1} & 0 < \beta_1 < 1 \\
1 & \beta_1 \geq 1 \\
1 - \beta_1 & \beta_1 = 1 - \beta_1
\end{cases}
\]

(9)

(10)

To divide the training sample set into two subsets to train LS-SVM respectively to bind them together linearly so to get the minimum derivation. To promote this idea: the training sample is \( m \) subsets, and each subset to training its LS-SVM, and to put them together linearly and to do sparse trimming, and finally get the whole training sample set LS-SVM.

2) The Algorithm Analysis and Improvement

According to the combinatorial optimization idea, we combine the \( m \) LS-SVMs of the training sample sets linearly one by one, and then do the sparse trimming after the combination. We can get the COLS-SVM by concluding the above process [3].

By extracting the training sample subsets, we train LS-SVM, and combinatorial optimization, sparseness, repeated cycles calculating to COLS-SVM algorithm, finally got the training samples of the LS–SVM. Each cycle time complexity is \( O(m(\eta + 2p(k + p))) \).

Because \( m = 1/p \), \( \eta = (p - 2\Delta)/\Delta \), each cycle time complexity rewrite for \( O(1/\Delta)(k + p)^2 \). In practical application, \( \Delta, l \) and \( k \) are constant, time complexity is increasing function for \( p \). Based on the above improvement ideas, in the first round of circulation,
ordinal linear combination \( m \) disciplinal LS-SVM of the training sample subset, and at the same time sparse, then we combined the result of before the round cycle with LS-SVM of \( lb \) of after a cycle training sample subset by linear, and at the same time sparse \( p \) training sample, just so cycle until the stability for \( SV \) vector, termination cycle. Summarize the process, we get improved accurate COLS-SVM algorithm.

Algorithm: Improved accurate COLS-SVM.

Step1: Given training sample set \( T = \{ (x_1, y_1), \cdots, (x_n, y_n) \} \in (X, Y) \), among which \( x_i \in X = R^n \), \( y_i \in Y \in R \), ..., \( l \), to do unification with \( T \) using the formula (8), and arrange the training samples randomly in \( T \).

Step2: empty \( TS_1 \), \( TS_2 \), \( SV \), and null \( \alpha_{S1}, \alpha_{S2}, \alpha_S, Q_{optm}, test_Q \) choose the proper kernel function \( K(x_1, x_j) \) and parameter \( C \), and initialize the finally reserved \( k SV \) and the training sample \( m \) among the training sample subsets;

Step3: to draw \( k \) and \( p \) training samples in order, and put into \( TS_2 \) respectively;

Step4: to use LELS-SVM to train \( f_1(x) \), \( f_2(x) \) of \( TS_1 \), \( TS_2 \) of the training sample subsets of LS-SVM;

Step5: To use the formula (8--10) to calculate \( \beta_1, \beta_2 \) for the full training sample set;

Step6: To use \( \beta_1 \times \alpha_{S1} \) and \( \beta_2 \times \alpha_{S2} \) to replace \( \alpha_{S1} \) and to put the training sample from \( TS_2 \) into \( TS_1 \) as supplement;

Step7: In \( TS_1 \), delete the \( p \) training samples with the least absolute value in \( \alpha_{S1} \). To train again LS-SVM/\( f_1(x) \) of \( TS_1 \) of the training sample subsets by using LELS-SVM algorithm;

Step8: To calculate sum of deviation square \( Q \) of \( f_1(x) \) in training samples;

Step9: If \( Q < Q_{optm} \), put training samples in \( TS_1 \) into \( SV \), \( \alpha_{S1} \) into \( \alpha_S \), \( Q \) into \( Q_{optm}, test_Q = 1 \);

Step10: Judge whether the needle of training sample in \( T \) directs to the end or not, if yes, turn it to Step12;

Step11: To draw \( p \) training samples from \( T \) and put them into \( TS_2 \), and use LELS-SVM algorithm to train LS-SVM: \( f_2(x) \) of \( TS_2 \) of training sample subsets, then turn to step5;

Step12: Judge \( Test_Q \), if \( Test_Q = 1 \), arrange randomly the training samples in \( T \) and turn the needle to the first training sample, null \( Test_Q \) and turn to Step11;

Step13: Training concluded.

C. Individual Credit Evaluation Applications Based on Improved COLS-SVM

Use improved COLS-SVM to classify individual credit evaluation. With the individual credit characteristic data in document [2] for reference, to make numerical experiments for construction bank, commercial bank and general individual credit characteristic data we designed. Experiment environment: Pentium IV3.0G CPU, 1024MB memory, Windows XP operating system, Matlab6.5.

Using improved COLS-SVM in designed 2), to compare with LSVM [5], KNN classification method to conduct data comparison experiment to get the following superficies: By experimenting with the marking data of the individual credit characteristic data of construction bank and commercial bank, to verify the effectiveness of COLS-SVM. To draw 3 groups of the individual credit characteristic data from the two banks to do training experiment to get \( SV \) and related parameters, then to draw another 3 groups to make testing experiment, among which LSVM algorithm degree of a polynomial \( d=3 \), KNN classification method \( k=15 \) The experiment as following: (Improved COLS-SVM is marked as COLS-SVM*). TABLE I. THE MARKING DATA CLASSIFICATION ACCURACY RATE OF A CONSTRUCTION BANK

<table>
<thead>
<tr>
<th>Samples</th>
<th>COLS-SVM*</th>
<th>LSVM (d=3)</th>
<th>KNN (K=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>0.851</td>
<td>0.767</td>
<td>0.656</td>
</tr>
<tr>
<td>500</td>
<td>0.843</td>
<td>0.753</td>
<td>0.637</td>
</tr>
<tr>
<td>1000</td>
<td>0.829</td>
<td>0.746</td>
<td>0.609</td>
</tr>
<tr>
<td>Average</td>
<td>0.841</td>
<td>0.755</td>
<td>0.634</td>
</tr>
</tbody>
</table>

TABLE II. THE MARKING DATA CLASSIFICATION ACCURACY RATE OF A COMMERCIAL BANK

<table>
<thead>
<tr>
<th>Sample</th>
<th>COLS-SVM*</th>
<th>LSVM (d=3)</th>
<th>KNN (K=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>0.873</td>
<td>0.798</td>
<td>0.697</td>
</tr>
<tr>
<td>500</td>
<td>0.862</td>
<td>0.776</td>
<td>0.673</td>
</tr>
<tr>
<td>1000</td>
<td>0.859</td>
<td>0.732</td>
<td>0.645</td>
</tr>
<tr>
<td>Average</td>
<td>0.865</td>
<td>0.769</td>
<td>0.672</td>
</tr>
</tbody>
</table>

From the two tables, it is easy to see that COLS-SVM* has better classification ability than LSVM-polynomial kernel function and KNN classification. The average experiment accuracy rates are respectively 84.1% and 86.5% and has the characteristic of less number of dimensions, higher accuracy rate. (Number of dimensions 19 for construction bank, 16 for commercial bank)

Using general characteristic data in document [2] to continue the numerical experiment. To draw 3 groups respectively from the training sample and testing sample to conduct data experiment to get \( SV \) and related parameters, among which among which LSVM algorithm degree of a polynomial \( d=3 \), KNN classification method \( k=15 \) The experiment as in Table III:

TABLE III. THE GENERAL DATA CLASSIFICATION ACCURACY RATE

<table>
<thead>
<tr>
<th>Samples</th>
<th>COLS-SVM*</th>
<th>LSVM (d=3)</th>
<th>KNN (K=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>0.926</td>
<td>0.857</td>
<td>0.718</td>
</tr>
<tr>
<td>500</td>
<td>0.915</td>
<td>0.849</td>
<td>0.709</td>
</tr>
<tr>
<td>1000</td>
<td>0.911</td>
<td>0.852</td>
<td>0.673</td>
</tr>
<tr>
<td>Average</td>
<td>0.917</td>
<td>0.853</td>
<td>0.700</td>
</tr>
</tbody>
</table>

According to the table III, used in general characteristic data we designed, COLS-SVM* proves to have better classification ability with an average accuracy rate of 91.7%, comparing with LSVM algorithm degree of a polynomial and KNN classification method. Owing to less number of dimensions (10), the accuracy rate is higher.
D. Summary
Owing to Combinatorial Optimization Algorithm idea, put forward COLS-SVM and improve on it, and apply it to compare with LSVM polynomial kernel function algorithm and KNN classification method and to do the numerical experiment, thus get the classification result in individual credit grade, the numerical experiment shows: COLS-SVM* has better classification forecasting ability and has made new development in individual credit evolution.

III. THE IMPROVED FORECAST MODEL COAL MINE GROUND-WATER-LEVEL BASED ON SVR

A. The Coal Mine Ground-water-level forecasting

Background
In the energy industry, coal exploitation is a high risk industry, which often has some mine flooding accidents and brings heavy loss to the life and property security of our country and people. So the research on the forecast of the coal mine underground water level has important theoretical and practical significance, which is an issue with many influencing factors, highly non-linear and temporal [6][7][8] series.

Support Vector Regression Algorithm (SVRA) is a method to regression prediction and function approximation. SVRA has not only strict theory base [9][10][11], but also can well resolve such practical problem as non-linearity, high dimension and local minima. So, it is a good method to forecast Coal Mine Ground-water-level with SVRA.

B. The theory of prediction with SVRA and improvement

SVM is originally proposed for classification. It is a new Machine Learning method based on Statistical Learning Theory. Because of the use of kernel function and Structural Risk Minimization, SVM has good performance to classification with limited samples. SVM is formulated as a convex quadratic programming, so the minima which are found are global optimal solutions. SVRA is a method to regression prediction and function approximation.

SVM is good at solving regression prediction problem by utilizing an appropriate loss function [12]. The ε -insensitive loss function is used usually. When \( |y - f(x)| \leq \varepsilon \), there is no loss. The ε -insensitive loss function is that

\[
L_\varepsilon(y) = \max\{0, |y - f(x)| - \varepsilon\} \quad (11)
\]

We consider a given train data set \( D = \{(x_1, y_1), \ldots, (x_n, y_n)\}, x \in \mathbb{R}^d, y \in \mathbb{R} \). For linear regression problem, SVR would like to find regression prediction function:

\[
f(x) = (\omega \cdot x) + b \quad (12)
\]

Where, \((\omega \cdot x)\) is inner product, \(\omega \in \mathbb{R}^d, b \in \mathbb{R}\).

By utilizing largest margin principle, ε-insensitive loss function and Lagrange function, we get the optimization problem [11]:

\[
\min_{\alpha} \frac{1}{2} \sum_{i,j=1}^{l} (\alpha_i - \alpha_i^*) (\alpha_j - \alpha_j^*) (x_i \cdot x_j) - \\
\sum_{i=1}^{l} (\alpha_i - \alpha_i^*) y_i + \sum_{i=1}^{l} (\alpha_i + \alpha_i^*) \varepsilon \quad (13)
\]

\[
s.t. 0 \leq \alpha_i, \alpha_i^* \leq C, \ i = 1, 2, \ldots, l \quad (14)
\]

\[
\sum_{i=1}^{l} (\alpha_i - \alpha_i^*) = 0 \quad (15)
\]

Where, \(C\) is penalty parameter, \(\alpha, \alpha^*\) are Lagrange multipliers.

By solving convex quadratic programming (13)-(15), we get the optimal solution

\[
\vec{\alpha} = (\alpha_1, \alpha_1^*, \alpha_2, \alpha_2^*, \ldots, \alpha_i, \alpha_i^*)^T
\]

So, we get the regression prediction function

\[
f(x) = \sum_{i=1}^{l} (\vec{\alpha}_i - \vec{\alpha}_i^*) (x_i \cdot x) + b \quad (16)
\]

For nonlinear regression problem, by utilizing an appropriate kernel function, we can get nonlinear regression function. The samples can be project to high dimension space by inner product where the linear approximation can be done. Kernel function

\[
K(x_i, x_j) = \phi(x_i) \phi(x_j)
\]

So, we get the regression prediction function for nonlinear regression problem

\[
f(x) = \sum_{i=1}^{l} (\vec{\alpha}_i - \vec{\alpha}_i^*) K(x_i, x_j) + b \quad (18)
\]

The advantages of utilizing ε-insensitive loss function in support vector regression machine is that only the Lagrange multipliers \(\alpha_i - \alpha_i^*\) of the samples outside the Strip region are not to equal zero. The vectors are named as support vector that their Lagrange multipliers are not equal to zero.

By adding \(b\) to problem (18), we get the optimization problem [13][14][15]:

\[
\min_{w, b, \xi} \frac{1}{2} \|w\|^2 + C \sum_{i=1}^{l} (\xi_i^* - \xi_i) \quad (19)
\]

\[
s.t. \quad ((w, b)(x_i, l) - y_i) \leq \varepsilon + \xi_i^*, \ i = 1, 2, \ldots, l
\]

\[
\xi_i \geq 0, \ i = 1, 2, \ldots, l
\]

Let \(z_i = (x_i, l)^T \in \mathbb{R}^{n+1}\), \(h = (w, b)^T \in \mathbb{R}^{n+1}\). Problem (19) turns into that
\[
\min_{\alpha, b, \xi, \xi^*} \frac{1}{2} \|y\|^2 + \frac{1}{l} \sum_{i=1}^{l} (\xi_i + \xi^*_i)
\]

\[
s.t. (y_i - h \cdot z_i) - y_i \leq \varepsilon + \xi_i, i = 1, 2, \ldots, l
\]

\[
y_i - (h \cdot z_i) \leq \varepsilon + \xi^*_i, i = 1, 2, \ldots, l
\]

\[
\xi_i \geq 0, i = 1, 2, \ldots, l
\]

The dual problem of problem (19) is as follows:

\[
\min \frac{1}{2} \sum_{i=1}^{l} (\alpha_i^* - \alpha_i)(\alpha_j^* - \alpha_j)(z_i \cdot z_j)
\]

\[
+ \varepsilon \sum_{i=1}^{l} (\alpha_i + \alpha_i^*) - \sum_{i=1}^{l} y_i (\alpha_i - \alpha_i^*)
\]

\[
s.t. 0 \leq \alpha_i, \alpha_i^* \leq C, i = 1, 2, \ldots, l
\]

(21)

C. Establishing improved forecast model of Coal Mine Ground-water-level

1) Determining forecast factor and output factor

Dynamic underground water level is a direct reflection of equilibrium status of the regional underground water level, which is an integrated externalization of the aquifer structure, properties, circulating conditions and the interaction between the supplies and the drainage factors. The actual measurement data of a mine area of Shandong are taken to do the forecast model of underground water level experiment. Based on the relevant data analysis, the main factors that affect the underground water level of digging are amount of precipitation, evaporation capacity, exploitation and riverway flux. Besides, with a comprehensive consideration of the hysteresis of all the factors and the self-correlation of the underground water level and regarding the amount of precipitation and measured underground water level in the former period as the impact factors, six impact factors are obtained as hefts of the input vectors supporting vector regression machine: amount of precipitation \(X_1\), evaporating capacity \(X_2\), exploitation \(X_3\), river flux \(X_4\), precipitation in the former period \(X_5\) and measured underground water level in the former period \(X_6\). Forecasting underground water level \(Y\) is taken as the output value of the model. So the forecasting issue of underground water level in the digging can be transformed to a support vector regression forecasting one with six characteristic variables and one output.

2) The improved forecasting model of Coal Mine Ground-water-level based on SVR

We are given the actual measurements of ground-water-level \(\{(x_i, y_i), \ldots, (x_l, y_l)\}\), where pattern \(x_i \in \mathbb{R}^6\) consists of the factors which effect the forecast of ground-water-level and \(y_i \in \mathbb{R}\) is the value relating to ground-water-level, \(i = 1, 2, \ldots, l\). We can train the given sets \(\{(x_i, y_i), \ldots, (x_l, y_l)\}\) by SVR. Then we can get the improved forecast model of ground-water-level:

\[
y = \sum_{i=1}^{l} (\alpha_i^* - \alpha_i)K(x_i, x_j) + b
\]

(22)

D. Numerical experiments

We proceed the numerical experiments under the conditions that the CPU is Pentium IV3.0G, Memory is 1024MB, and operating system is Windows XP. The testing program of improved forecast model of ground-water-level utilizes Matlab6.5. The numerical experiments are based on the history data of a mine area of Shandong.

All data is distributed into train set and test set firstly. We get the regression prediction function based on train set. The accuracy of regression prediction function is tested based on test set.

The data of numerical experiments consist of observation value of long-time observation hole O6-2. History data 1 to 30 are used as train samples. History data 31 to 66 are used as test samples. The comparative results of the forecast values of ground-water-level of hole O6-2 with factual values are showed in Table IV.

<table>
<thead>
<tr>
<th>Time</th>
<th>Factual values(m)</th>
<th>Forecast values(m)</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009.1</td>
<td>12.57</td>
<td>12.48</td>
<td>-0.72</td>
</tr>
<tr>
<td>2009.2</td>
<td>13.72</td>
<td>13.79</td>
<td>+0.51</td>
</tr>
<tr>
<td>2009.3</td>
<td>13.85</td>
<td>13.90</td>
<td>+0.36</td>
</tr>
<tr>
<td>2009.4</td>
<td>14.26</td>
<td>14.37</td>
<td>+0.77</td>
</tr>
<tr>
<td>2009.5</td>
<td>14.71</td>
<td>14.82</td>
<td>+0.75</td>
</tr>
<tr>
<td>2009.6</td>
<td>15.69</td>
<td>15.77</td>
<td>+0.51</td>
</tr>
<tr>
<td>2009.7</td>
<td>16.35</td>
<td>16.43</td>
<td>+0.49</td>
</tr>
<tr>
<td>......</td>
<td>......</td>
<td>......</td>
<td>......</td>
</tr>
</tbody>
</table>

From Table IV, we conclude that forecast values are consistent well with factual values. Average relative error is 0.38%, which verifies that the improved forecast model (22) is effective.

Table IV only includes forecast values of one long-time observation hole. When we forecast the observation values of other long-time observation hole, the input factor and the long-time observation data of observation hole which is affected geographically should be considered.

The comparative result of the forecast values of ground-water-level of 6 holes with factual values are showed in Table V.

<table>
<thead>
<tr>
<th>Hole number</th>
<th>Factual values(m)</th>
<th>Forecast values(m)</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O6-1</td>
<td>16.38</td>
<td>16.45</td>
<td>+0.43</td>
</tr>
<tr>
<td>O6-2</td>
<td>16.59</td>
<td>16.63</td>
<td>+0.24</td>
</tr>
<tr>
<td>O6-3</td>
<td>16.73</td>
<td>16.87</td>
<td>+0.84</td>
</tr>
<tr>
<td>O6-4</td>
<td>16.69</td>
<td>16.72</td>
<td>+0.18</td>
</tr>
<tr>
<td>O6-5</td>
<td>16.85</td>
<td>16.81</td>
<td>-0.24</td>
</tr>
<tr>
<td>O6-6</td>
<td>16.72</td>
<td>16.79</td>
<td>+0.42</td>
</tr>
</tbody>
</table>
From Table VI, we conclude that the improved forecast model (22) is effective for different observation hole. The forecast values are consistent well with factual values. Average relative error is 0.31%.

The real-time forecast values of observation hole O3-1 are listed in Table VI.

### Table VI. Comparative Result of the Real-Time Forecast Values of Ground-Water-Level of Hole O3-1 with Factual Values

<table>
<thead>
<tr>
<th>Time</th>
<th>Factual values(m)</th>
<th>Forecast values(m)</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009.10</td>
<td>13.79</td>
<td>13.82</td>
<td>+0.22</td>
</tr>
<tr>
<td>2009.11</td>
<td>13.26</td>
<td>13.34</td>
<td>+0.60</td>
</tr>
<tr>
<td>2009.12</td>
<td>12.84</td>
<td>12.76</td>
<td>-0.62</td>
</tr>
<tr>
<td>2010.01</td>
<td>---</td>
<td>12.35</td>
<td>---</td>
</tr>
<tr>
<td>2010.02</td>
<td>---</td>
<td>12.87</td>
<td>---</td>
</tr>
<tr>
<td>......</td>
<td>......</td>
<td>......</td>
<td>......</td>
</tr>
</tbody>
</table>

From Table VI, we conclude that the improved forecast model (22) is effective.

### E. Summary

There are two innovation points in this paper. The Forecasting Model of Coal Mine Ground-water-level is proposed based on SVR algorithm, and improves on it. Choosing the appropriate kernel function and the parameters of Forecasting Model in this paper based on cross validation methods via parallel grid search in SVR algorithm.

By factual testing and analysis to the Ground-water-level of a digging in one mine area of Shandong, we conclude that:

① Cross validation methods via parallel grid search is used in choosing the parameters of regression model, which avoids aimlessness and randomness of choice, and raises the forecast accuracy.

② The numerical experiments show that the improved Forecasting Model of Coal Mine Ground-water-level proposed basing on SVR is effective. Experiments and forecast are stable. We propose and improve on a new effective method to the Forecasting Coal Mine Ground-water-level in this paper.

### IV. THE CHOLESTEROL MEASUREMENT BASED ON IMPROVED SORR

#### A. The Cholesterol Measurement Background

The measurement of cholesterol in human’s blood is of great significance to the clinical diagnosis of cerebrovascular disease. If the content of cholesterol is over low or over high, there may be a disorder in cholesterol metabolism; therefore a method which is more accurate and effective for the content determination of cholesterol is needed in clinical assay. This work is our continuative research and has new advances.

According to the algorithm SOR put forward by Mangasarian for classification problem [16], we can do a generalization in the regression problem, and improve the standard algorithm SVR (support vector regression), then we get support vector regression algorithm SORR, and improve on it, and apply it to the medical field -- cholesterol content determination in three kinds of plasma lipoprotein (VLDL , LDL , HDL), providing a new method for the clinical content determination of cholesterol.

#### B. The Improved SORR Algorithm

To apply the algorithm SOR put forward by Mangasarian for classification problem into the regression problem and get support vector regression algorithm SORR, and improve on it. The detail method is shown below:

If we get the nonlinear regression function is:

$$f(x) = w^\top \phi(x) + b$$

In the nonlinear instances, the optimization problem:

$$\min_w \frac{1}{2} w^\top w + C \sum_{i=1}^{l} (\xi_i^+ + \xi_i^-)$$

s.t. $w^\top \phi(x_i) + b - y_i \leq \varepsilon + \xi_i^+$

$$\xi_i^+, \xi_i^- \geq 0, \quad i = 1,2,\ldots,l$$

Can be transformed into the optimization problem:

$$\min_w \frac{1}{2} w^\top w + \frac{1}{2} b^2 + C \sum_{i=1}^{l} (\xi_i^2 + \xi_i^-^2)$$

s.t. $w^\top \phi(x_i) + b - y_i \leq \varepsilon + \xi_i^+$

$$\xi_i^-, \xi_i^+ \geq 0, \quad i = 1,2,\ldots,l$$

Using Lagrange function shown below to solve them (26–27), specific reference [17].

By learning, we get the regression function as shown:

$$f(x) = \sum_{\alpha_i \in \mathcal{V}} (\alpha_i - \alpha_i^+) K(x_i, x) + b$$

Observing the analysis before, we find that the support vector regression algorithm we put forward requires one less constraint condition than standard SVR, and there is not an upper bound for the parameter in optimization problem, thereby the computational complexity is reduced and the speed of study is improved. Later we will prove it by numerical experiments, and apply it to the content determination of cholesterol in plasma lipoproteins.
C. The Numerical Experiments of Cholesterol Measurement

The data source is data file Choles_all.mat in Matlab, the data include 264 patients’ blood samples and the corresponding cholesterol content in the three plasma lipoproteins—HDL, LDL and VLDL, every blood sample is made up of spectral data which contains 21 kinds wavelength in the electrophoresis belt. Using blood samples, we can construct a support vector regression to regression estimate the content of cholesterol in every plasma lipoprotein.

Testing environment: Pentium IV processor, 3.0G CPU, 1024MB RAM, Windows XP operation system. Using the Matlab6.5 programming to prove the improved SORR mentioned before.

In experiment we use regression to estimate the content of cholesterol in each plasma lipoprotein corresponding to each blood sample, use the content and actual content to obtain the related coefficient R, R can reflect the property of regression estimation [18].

\[
R = \frac{\text{Cov}(f(x), y)}{\| f(x) \| \cdot \| y \|} \tag{29}
\]

Among \(|R|\leq 1, f(x)\) is the regression estimated blood data corresponding to each plasma lipoprotein (264x1 column vector), y is the corresponding actual content (264x1 column vector), the closer R is to 1, the more accurate the regression estimation is.

1) The experiment of study speed

To train with the whole parameters, and take \(\varepsilon=0.1\) in both algorithms SVR and improved SORR, using the Gaussian kernel function:

\[
K(x, x) = \exp(-\|x - x\|^2 / \sigma^2)
\]

Take parameter \(\sigma^2=1\), when changing between \(C=10^0, 10^1, 10^2, \ldots, 10^{10}\).

Using both algorithms SVR and improved SORR to regression estimate the cholesterol content in plasma lipoprotein LDL, the study speed is shown in the diagram VIII as below: (Improved SORR is marked as SORR*)

<table>
<thead>
<tr>
<th>C</th>
<th>1</th>
<th>10</th>
<th>10^2</th>
<th>10^3</th>
<th>10^4</th>
<th>10^5</th>
<th>10^6</th>
<th>10^7</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVR</td>
<td>1.96</td>
<td>2.01</td>
<td>2.35</td>
<td>2.46</td>
<td>5.27</td>
<td>5.48</td>
<td>5.51</td>
<td>5.62</td>
</tr>
<tr>
<td>SORR*</td>
<td>1.85</td>
<td>1.97</td>
<td>2.03</td>
<td>2.12</td>
<td>2.65</td>
<td>2.87</td>
<td>2.95</td>
<td>3.07</td>
</tr>
</tbody>
</table>

As we can see from Table VII, when \(C=10^0-10^{10}\), two algorithms average learning time is little difference, but with the increase of \(C=C(10^2-10^{10})\), an average of study time is 5.6 s about SVR algorithms, but improved SORR algorithms is 3 s, improved SORR than SVR fast learning about 46%. This also has concerned with us machine performance. For the same HDL, VLDL cholesterol content regression estimation, basically the same conclusion.

2) The regression precision experiment

Draw randomly 1/3 of the data samples mentioned before to exercise, and use the whole sample to test, and take \(\varepsilon=0.1\) in both SVR and SORR*, using the Gaussian kernel function, take parameter \(\sigma^2=1\). When apply different value to C, the regression estimation results by two algorithms are compared in diagram VIII as shown.

<table>
<thead>
<tr>
<th>C</th>
<th>0.735</th>
<th>0.901</th>
<th>0.791</th>
<th>0.916</th>
<th>0.612</th>
<th>0.811</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVR</td>
<td>0.810</td>
<td>0.912</td>
<td>0.802</td>
<td>0.923</td>
<td>0.601</td>
<td>0.826</td>
</tr>
<tr>
<td>SORR*</td>
<td>0.901</td>
<td>0.928</td>
<td>0.869</td>
<td>0.925</td>
<td>0.632</td>
<td>0.833</td>
</tr>
<tr>
<td>C</td>
<td>0.841</td>
<td>0.932</td>
<td>0.672</td>
<td>0.927</td>
<td>0.567</td>
<td>0.843</td>
</tr>
<tr>
<td>SVR</td>
<td>0.831</td>
<td>0.943</td>
<td>0.634</td>
<td>0.933</td>
<td>0.581</td>
<td>0.836</td>
</tr>
<tr>
<td>SORR*</td>
<td>0.832</td>
<td>0.941</td>
<td>0.635</td>
<td>0.945</td>
<td>0.579</td>
<td>0.841</td>
</tr>
</tbody>
</table>

As we can see from Table VII, different values for C, SORR* compare with SVR, SORR*’s Learning precision is improved. Equally, when C is given a constant value, we give parameter \(\sigma^2\) different values for experimental comparisons, and get the same conclusion. To a breakthrough in the algorithm theory, we must make innovations.

D. Summary

Using the improved SORR to regression estimate the content of cholesterol in three different plasma lipoproteins, we compare it with SOR in study speed and regression precision, the experiment data proves: improved SORR is more accurate, comparing with the standard support vector regression algorithm SVR, it guarantees the regression precision and improves the study speed, provides a new method for clinical determination of cholesterol. As we can see, to apply this method to real clinical diagnosis, we need to combine it with other methods and do further research.

IV. Conclusion

This paper is about the support vector machine (SVM) classification problem and regression problems algorithm and its application research. TO the Financial Calculation and the Forecasting Coal Mine Ground-water-level and the Plasma Lipoprotein Cholesterol Measurement, the COLS-SVM algorithm and the Model and SORR algorithm are put forward, and improve on them. The numerical experimental results show that the improved COLS-SVM and mine ground-water-level improved Forecasting Model and improved SORR algorithm are effective.

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LIU Tai-an was born in Tai'an city of Shandong province, China in 1963. He is a Ph. D. Candidate, in China University of Mining and Technology, Xuzhou China, major study in data mining and software engineering.


He is a senior member of China Computer Federation, is an excellent reviewer of “Chinese Sciencepaper Online”.

WANG Yun-jia was born in Jianhu city of Jiangsu province, China in 1960. He is a professor and Ph. D. supervisor, in China University of Mining and Technology, Xuzhou China, is a director of Institute of Natural Resource Information and Economy, is a dean of School of Environmental Science and Spatial Informatics. His research interests include data mining and digital mines. He is a committee member of international society of mine surveying, editorial committee member of Acta Geodaetica et Cartographica Sinica (AGCS).

WANG Yin-lei was born in Xintai city of Shandong province, China in 1972. He is a master's degree, major study in teaching methodology of physics subject.

He is an assistant in department of basic courses of Shandong University of Science and Technology. His current research interests include physics teaching and software engineering, published articles:① “The solution of the harmonic oscillator with electric charge at the electric field in the coordinate basis”, Yibin, China, Journal of Yibin University, Dec. 2008 Vol. 12 No. 12. ② “The universe conception of Einstein”, Leshan, China, Journal of Leshan Normal College, May. 2009 Vol. 24 No. 5.

LIU Wen-tong is a student of Nanyang Technological University in Singapore.
Study on Pricing Model of Online Auction under Competitive Strategy

Yu Min
Information Technology Application Research Institute, School of Economic Information Engineering, Southwestern University of Finance and Economics (SWUFE), Chengdu, China
Email: zqh@swufe.edu.cn

Pubu Zhuoma, Zhou Qihai and Xu Jing
School of Economic Information Engineering, Southwestern University of Finance and Economics (SWUFE), Chengdu, China
Email: pz009@163.com

Abstract—E-commerce auction has the auction properties unlike ordinary e-commerce transactions. The online auctions, allowed bidding, become into a new trading model based on the network for the exchange and auction technology. This paper firstly gives the overview of the online auction pricing mechanism and introduces the e-commerce auction market and its characteristics on the one hand. On the other hand, it discusses the factors affecting the price of online auctions from three aspects, the information flow, the business objectives and the risk factors. And then, it discusses the six types of e-auction pricing strategy. Lastly, facing the factors and the different strategies, it presents the win-win pricing model on the online e-commerce auction British-based both for auction operators and consumers.

Index Terms—e-bidding, auction, pricing strategy

I. INTRODUCTION

Online auction means that the individual and business achieve price negotiations transactions via the Internet. E-commerce auction allows the pricing competition, determined by consumers to value one particular commodation, and bidding, and then, businesses choose whether to accept the offer of e-commerce activities. The sellers have increased competition through the Internet trading patterns, so the buying behavior of consumers becomes increasingly complicated and more cautious for network information processing. If the buyers and sellers can trust each other and smooth transactions, it will be able to bring more benefits for both sides.

A. Characteristics of Online Auction Market

Auction trading model, the seller can decide the type of auction items and the commodity prices, but the other buyers can participate in bidding, and even decide the final selling price of goods. The auction site offers trading platform for the two sides, who can trade activities in this virtual platform. Since a web auction model of web page type is with around the clock without rest, coupled with global number of Internet users, so the opportunity of auction merchandise transactions are more available than the traditional auction market [1].

Online auction is a new auction, which have some new features and mechanisms compared to traditional auctions. Firstly, the online auction breaks through the traditional auction in time and location constraints, and it should be more free, more flexible, more efficient, as well as lower operating costs and participation costs for auction. Secondly, they have the variety of different types of auction items [2]. Taking into account the cost of the auction, the value of products in traditional auction sale is generally high, while for the online auction, its range and types of auctions keep up to date with the pace of market demand, containing the works of art on hundreds of millions of dollars, real estate, and some snack foods on one or two dollars. Buyers and sellers can just be an auction addiction. Thirdly, they have the different ending fashion. At present, the online auction mainly uses two kinds of ending fashion. Firstly, it finished in accordance with the prior end time of the auction, such as eBay's auction rules; and the other is similar to the traditional English-style ending way of the auction rules, “3G” rules, that is, at the end of auction, if customers bid, it could also extend the time of auction, for example, Amazon's auction rules. Lastly, as the online auction continues for a long time, most of the websites provided the tender agent to bid a fair and rigorous way to help customers, which are more convenient and effective for participation in the tender [3]. And bidders do not need to keep in the computer from time to time for auction progress, which is difficult to achieve in the traditional auction. In addition, the bidders also handle more complex transactions, so the auction rules may simultaneously adjust the bid requirements and dissemination of information.

B. Domestic Online Auction Market

On a global scale, the online auction market includes eBay and other major players in dozens of auction sites, and hot areas are mainly in the United States and European countries. And e-Bay, Yahoo, Amazon, uBid,
QXL, and Overstock six are the leaders in home situation. With the high-speed growth of TaoBao and steady development of eBay, the online auction users in Mainland China have expanded rapidly. According to the statistics showed that by 2006, Chinese registered users of online auction have exceeded 30 million, and an average annual growth rate is of 43 percent [4].

Domestic online auction market has the following characteristics. Inexpensive products occupy about half of the share. There are also a certain amount of high-end auction items, such as real estate, but the area is still lagging far behind foreign countries. In the auction site, the ranks of professional sellers are stronger, which suggested that C2C mode and B2B models are interlinked. At the same time, the competitors in C2C platform and B2B platform apply the availability of resources and integration of the conditions. The online auction market in the next few years will continue growth rapidly, and the size and turnover of the user of online auction will be rising fast. So China’s online auction market also need to strengthen in the competitive mechanism, pricing models, and credit mechanisms, in order to attract more consumer market.

II. FACTORS AFFECTING THE PRICE OF ONLINE AUCTIONS

A. Formating Mechanism of Auction Price

Auction sites are available to a public space for the sellers, so that the sellers can provide the product images, product information and commodity prices of auction to visitors for reference, and the more important is the commodity prices of auction, and even some buyers will consider the current bid commodity, bid price, the reserve price and other price information. The supply and demand in market determine the market price [5].

B. Factors Affecting the Price of Online Auctions

The pricing decision-making for commodity is a complex process. Sellers not only need to consider the cost of goods, as well as many other environmental factors, so as to the Online auctions pricing, which will be subject to many factors, such as the impact of external factors and internal factors, for example, economics, culture, political environment, and the cost of the product itself, even competition, as well as demands, time value, and risk factors. The specific factors can be summarized as follows.

Firstly, decision-makers obtain the relevant information for commodities through various channels, which stimulated decision-makers’ potential demand for investment, then there is the impulse to the online auction of goods, and also with pricing decisions for the online auction commodity [6]. For the use of the Internet auction sellers of goods, the pricing decisions of external incentives are the information flow, and internal motivation is the investment demand. The information flow on online auction of goods contains the market demand information for the commodity and historical data related on-line auction items. The greater this information flow, the better for pricing decisions of policy makers.

Secondly, different decision-makers have different business objectives in the use of online auctions. For example, some sellers hope to improve the corporate image; some sellers In order to operate the long-term business on the online auction, are willing to sell low-priced auction items; and others want to win favorable rates online. As the auction sellers’ the business goals are different, the sellers’ pricing decisions affect pricing decisions. And the different objectives embodied in the different pricing decisions, such as maximizing revenue as their goal, the greatest probability of turnover as the goal, and having long-term business goal.

And lastly, Both for the seller and the buyer, the online auction have risks. Online auction basically carried out through the auction system, and the virtual network can complete the transaction not meeting with each other, so the risks of online auctions have been much greater than the other forms of business activity. Because of the electronic media, buyers and sellers can not reach physical transaction objects, so the greatest risk of online auctions comes from the transaction information asymmetry. For the seller, the buyer's credit risk is the most important risk factors. If the buyers do not buy goods after bidding, the seller will pay closing costs at this time but did not sell merchandise. Sites are difficult to prevent a user to register multiple users, and the user's true identity is sometimes difficult to ascertain. And the buyers’ fraud is also divided into categories. For example, a buyer bids for a similar item using a different pseudonym, which made the price have increased because of the multiple tender, and this also made some potential buyers can not bid. And then, in the last moment of the auction, the buyer would withdraw its high bid, so that he only earned a very low bid price of goods. Some bidders will reduce the level of competition through collusion, thereby reducing the transaction price of goods. In addition, for defective items, buyers may trying to get a refund before return an article, but once a refund, they do not return the items. In order to avoid such risks, there are auction credit evaluation system, and third-party hosting services. For example, in order to win the trust of shoppers, TOM eBay launched a third-party hosting services. And on the one hand, the payment and delivery process risks not only increase the cost of sellers, but also affect their long-term business and demolish its reputation. Sometimes, the seller can not determine the success buyers will pay or not [7]. On the other hand, for the buyers, the risk in the online auction process contains the following reasons. The security risks in the payment process, including transportation costs and lost time-consuming effort, as well as the risk of online payment, is the first risks. And then, the purchasers are not satisfied with bidding goods, which included the sellers’ fraud, for example, non-delivery of goods, and the false description. If the buyer used a credit card payment, sellers sometimes have the buyer's name and credit card numbers, easily lead to financial fraud. The seller uses a better picture than the actual items, even false images to describe the
items to be auctioned. In many cases, the auction items do not match the actual goods and are different from the buyers’ understanding and expectations. And even the sellers increase the implicit costs in order to make themselves more benefits after the auction. Lastly, the sellers sell black market items, including copies of software, music CD, and video, which do not require packing boxes, warranty certificate, and instructions [8].

C. The Impact of Auction Evaluation for Pricing

Another feature, valued by participants in online auctions, is the user rating system, the credibility of the evaluation system. Most auction sites have established a credit rating system to record each user’s transactions in the past received evaluations, which converted to a reputation score through weighted average method, representing the users’ credibility in a virtual trading market. Relevant research from eBay, acquired by TOM, argued that the higher the score of the seller’s reputation, the greater the likelihood auction [9].

As buyers and sellers are subject to sites’ reputation evaluation system, a seller’s credit scores online transactions have become an important decision variable [10]. While for the transaction price of the auction in terms, the study found that the buyer’s bid is directly related to the valuation of the goods, but there is no significant contact with the seller reputation.

III. THE TYPES OF ONLINE AUCTION PRICING STRATEGY

Traditional auctions are divided into four basic types, English auction, Dutch auction, first-price sealed auction and second-price sealed-bid auction. Based on the auction of the traditional classification, online auctions are divided into the following several types.

Online English auction is a forward auction format, whose rules contain that the second bidders bid higher than the previous one, and the highest bidder obtain the right to purchase merchandise when the auction reached the bidding deadline [11]. In the auction process, bidders can browse through the history of the price to determine their maximum bid on the items to the system. When the auctioneer gradually made up-outcry and the bid is higher than the highest bid in the real psychological valuation, one person is refused, and the other one will success [12].

Online Dutch auction is a public auction of price reduction. Dutch auction transactions are large amount of items mostly [13]. If a seller has a large number of identical items to sell, he can use the reverse auction format. Different from the traditional Dutch auction, online Dutch auction principle is: in the absence of the price decline, at the end of the generally bidding deadline, the highest bidder get the number of commodities as he needs, and if there is residual goods, they was taken up by the second highest bidder[14]. In the auction process, the buyer can accept all outcries below their psychological valuation, and in order to maximize return, he can also choose to outries close to other buyers’ psychological valuation.

Collective bargaining is different from the traditional type of online auctions, which is no bidding process [15].

The auction website provided the collective price based items price, starting price, and then, a large number of buyers constitute a large shopping group landing the seller registration form before the items indicated by the number of different levels. The more the number of buyers, the price will be lower, but usually there will be a minimum price [16].

Bargain hunting buying is unlike a traditional auction. In this transaction form, buyers cannot join the online auction bid for goods temporarily, but chose price paragraph according to the goods’ price curve. Once the commodity prices shoot down on this price segment, the system will send a notification, telling buyers that the number of the current collection has reached the price he wanted, and he would join a collective automatically.

Reverse auction is pricing from the seller, which competes for the chances that the sellers provide consumers with services [17]. Reverse auction can provide consumers’ demand for the products, service demand and price positioning, as well as other related information, and then, the businesses on a competitive basis decided the final product and service providers, which enable consumers to achieve optimal performance and low cost.

Buy it Now means that the seller fixed the price of the goods before the transaction, so buyers have no room for bargaining. After completion of the transaction, buyers paid according to a price. If the seller sold more than one commodity, the transaction will continue until the buyer to purchase all the goods.

In 1981, Myerson, Riley and Samuelson showed that the general conditions of Vickrey revenue equivalence theorem [18]. In many risk-neutral potential buyers, the private valuation of auction is subject to a common increasing distribution and independent of each other, and then the auction will have the same expectations of income based the following conditions. The buyer with the highest signal is always a winner; the remainder of their expectations is zero for all the buyers with the lowest valuation. With this condition, under the complete information of online auctions, the results of single auction are the same for the different types, that is, the traded price is the second highest psychological assessment, and the sellers’ earnings is also the second highest psychological assessment [19].

IV. THE WIN-WIN PRICING MODEL ON THE ONLINE E-COMMERCE AUCTION

A. Pricing Making Index System

There are these following prerequisites studied in this paper on the online auction items.

(1) The on-line auctions items used the online English auction way, there is proxy bidding mechanism.

(2) When the seller vendors want to sell the goods under the online auctions merchandise, an auction of the film for a number of auction items is a single piece for every customer.
(3) There are the initial decision-making analysis under the auction, while setting the starting price $q$ and the reserve price $r$.

(4) The minimum bid increment is $\varepsilon \ (\varepsilon > 0)$, which offers customers the smallest increment given in advance and fixed.

(5) The seller of online auction of goods does not set the duration of the auction automatically, that is near the end of the auction, buyers bid within a few minutes, the auction end time will not automatically be extended.

(6) The buyers are rational and experienced, who participate in the auction, and the valuation of goods from the buyer is the highest price of goods willing to pay for the auction.

The mathematical modeling of auction of goods on the online auction pricing decision-making process involves a series of indicators. And the modeling of variables needs to use a precise definition, specifically as shown in Table I.

<table>
<thead>
<tr>
<th>Table I. Pricing Model Index Table</th>
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<tbody>
<tr>
<td>Index</td>
</tr>
<tr>
<td>$q$</td>
</tr>
<tr>
<td>$r$</td>
</tr>
<tr>
<td>$\varepsilon$</td>
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<tr>
<td>$T_n$</td>
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<tr>
<td>$P_n$</td>
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<tr>
<td>$P_N$</td>
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<td>$V_{sh}$</td>
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<td>$V_n$</td>
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<td>$K$</td>
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<td>$O_{P_n}$</td>
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<tr>
<td>$C_d(r)$</td>
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<td>$C_e(P_n)$</td>
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<td>$\alpha$</td>
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<td>$\beta$</td>
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<tr>
<td>$M$</td>
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<td>$P_{fi}$</td>
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</tbody>
</table>

B. The Time Factors of Win-win Pricing Model on E-commerce Online Auction

Online auction pricing decision-making process is a dynamic process, and one part of the auction process in the online auction of goods, which will be step in line with the auction process, and this decision-making starts from the registration of the auction items and extends to the end time of arrival of the auction [20].

The time factor is one important factor to consider for the seller when he made pricing decisions, because it directly affects the valuation of goods for auction buyers.

If the bidders have sufficient time to participate in the entire process of the online auctions’ merchandise, he can raise the price by the bid rate in online auctions minimum gradually until it reaches the highest auction items he was willing to pay for the goods. And if the other buyers bid the goods beyond the highest auction items he was willing to pay for the goods, he will withdraw from the auction. Taking into account the online English auction rules, if multiple buyers bid for the same price, the auction will make the distribution of auction items according to rules of "first offer, first served" [21]. Therefore, the buyer looks to be successful in the auction of goods, the optimal bidding strategy is to pay the price of goods by the original intent of the auction to the goods valuation, of course, he also needs taking into account risk factors.

Therefore from the comprehensive analysis of two points above, the optimal bidding strategy of the bidders who participate in the process of online auctions of goods is to pay the highest price he will willing to for its valuation of the goods. The valuation of goods from bidders will affect the seller's pricing decision-making, following on the bidder's valuation analysis.

Customer valuation of auction's goods will subject to the following two factors.

(1) Bidders are the original valuation of second-hand goods, which is not subject to any factors that impact the valuation of second-hand goods.

(2) Bidders degree of influence by the outside information, where the external information includes second-hand goods market prices and demand, online auctions have been carried out in time, online auction, the current price of second-hand goods, has the frequency of bids.

When the bidder has not received any price outside information, the bidders were not other factors impact on the valuation of goods for auction is still the original valuation [22]. When the bidders were able to obtain and online auctions auction items related to all the information, the bidders were the valuation of goods for auction only with the obtained information about the outside world, but its valuation of the auction items unrelated to the original. Actually in the process of online auctions auction merchandise, the customer is not possible to obtain all the market information, but can only get part of the market information, so information on the bidder's valuation of the outside world there is some of the impact. The number of bidders, such external factors can be performance through the time indirectly. As time progresses, the customer arrival rate will be certain, and the number of bidders and the number of bidding will increase, and then the most visible manifestation is that the current prices of the auction of goods will increase in the auction process as time progress. Therefore, in the main analysis time here, the potential bidders for the impact of human valuation.
As time progresses, the customer arrival rate certain circumstances, has led to the current commodity price increases the auction. Network openness of information, allowing new entrants into the auction process, bidders can see in front of all the bidders who bid situation, access to part of the price information. At the same time, new entrants into the potential bidders who bid the psychological as time progress, the current price increases have taken place in the following changes.

(1) The on-line auctions bidders, who has been entered the auction, have to bid on auction items, which will result in the increasing prices of auction items. The potential new entrants into the auction system will find existing prices of goods and competitors from the auction bidders in the state of competition in the auction items, and also will estimate the price of the auction’s items in the future. Therefore, new entrants’ bidders who produced the successful psychology and will also increase the valuation of its auction items accordingly in the fierce competition.

(2) The new entrants’ bidders will make out the price analysis to those successful bid of bidders entered the online auction system, and found there were some affirmation from the other bidders for the auction in the value of goods. These kinds of consensus on the auction value of the goods will certainly the auction system, the valuation of potential bidders who played the role of positive feedback, making it to the auction to increase the valuation of goods.

(3) At the beginning of the online auction process, the starting price of the reference price of bidders into the auction system is q. As time progresses, the current price of the auction items rise, potential bidders entered the auction process will bid in the higher prices, so the auction reference price will be the current price of goods. By reference to prices, new entrants to the Bidder at this time than the first valuation of the bidder to enter the valuation have increased [23]. This shows that the bidders were on the auction items will be subject to a time limit of the valuation factors. As time progresses, at each moment the current price of auction items may be different, enter the online auction items to the auction process, bidders were the valuation of goods increased.

Because of the convenience of online auctions, bidders, who bid for each process, may only spend a few minutes or even a few seconds time, and the process of online auctions of goods is usually a few days ago. In accordance with the time consumed by each bid, the auction process can be divided into multiple stages, which reflects the impact to the time on the bidder's valuation. This paper divided whole process of online auctions of goods into N stages, each time point is of $T_n$. As Table 1 shows, the entire time length of online auctions of goods $T$ with $N + 1$. In each moment $T_n$, the commodity's current price is $P_n$. At this time, the new potential bidders into the auction process are subject to the current commodity prices, the valued range is $[0,V_n]$. As time progresses, new entrants will bid within the range at the time $T_n$, which resulted in the next moment $T_{n+1}$, and the current commodity prices $P_{n+1}$, and then, the new price once affected the next time the valuation of the scope of the bidder again. After such a cycle, at the end of the auction time, the final auction price formed for terms. So the final price was decided by the scope of the bidder's valuation decision on the last time.

### Table II.

<table>
<thead>
<tr>
<th>Auction time</th>
<th>$T_0$</th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_{n-1}$</th>
<th>$T_n$</th>
<th>$T_{n+1}$</th>
<th>$T_N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope of bidder's valuation</td>
<td>$[0, V_0]$</td>
<td>$[0, V_1]$</td>
<td>$[0, V_2]$</td>
<td>$[0, V_{n-1}]$</td>
<td>$[0, V_n]$</td>
<td>$[0, V_{n+1}]$</td>
<td>$[0, V_N]$</td>
</tr>
<tr>
<td>Auction commodity prices</td>
<td>$q$</td>
<td>$P_1$</td>
<td>$P_2$</td>
<td>$P_{n-1}$</td>
<td>$P_n$</td>
<td>$P_{n+1}$</td>
<td>$P_N$</td>
</tr>
</tbody>
</table>

The above analysis shows that each bidder who bid the auction of goods must spend a certain time. As time goes on, the current prices of auction goods increased, so the new auction bidders also increased the ceiling for the valuation of goods. Supposed in each moment, the maximum rate of new entrants’ upper limit $V_n$ for the current auction are the same to the rate of price $P_n$ of goods. Therefore, in the time $T_n$, Bidders upper limit on the valuation of goods for auction are as follows: $V_n = V_{n-1} + P_{n-1}$, $V_{n+1} - V_n = P_{n+1} - P_{n}$, $V_n = \frac{(P_n - P_n)(V_{n+1} - V_n) + V_{n+1}}{P_{n+1} - P_n}$.

Based on the above formula, it can obtain each time $T_n$ on-line auction process and the auction limit of new potential bidders into the auction process $V_n$. In the solving process of $V_n$, firstly, they need to determine $V_0$. Throughout the auction process with all entered into the auction process, potential bidders were related to the valuation limit. As the online auction starting time, to enter the auction system, all potential bidders were Bidders only a small part, so the valuation of start time, Bidders is also far less than the initial valuation of the ceiling limit. Under normal circumstances, $V_0$ is the 50 percent of $V_n$. The above formula shows that, as time increases, bidders who bid for goods, making the current commodity prices, further also affected new entrants’ the scope at this moment, and allowing new entrants into the auction bidding process, increased the ceiling of human
valuation, and then the next moment commodity prices improve.

C. The Win-win Pricing Model on The Online E-commerce Auction

In the current auction mechanism, the seller can decide the lowest price level he is willing to sell this product, namely reservation price. When the consumer is willing to bid higher than this reservation price, this transaction can be effective immediately. However, consumers can only know whether the seller had set the reservation price, but will not know what the reservation price is, so the highest bid of the purchaser must be higher than the reservation price set by the seller, which means the deal is a success. For the other model, if the buyer purchase the goods based on the direct purchase price set by the seller, this transaction will end immediately. Myerson theorem proved that in maximizing the price of the auction seller, optimal auction is with a price discriminatory in the case of asymmetric information. Therefore, when both sides ended the transaction, they can open Web platform to give advice and evaluation, so that both sides can maintain the security of transactions, but also provides a reference to the future of consumer transaction basis.

If the model makes maximizing their earnings as the targets of the auction pricing decisions based on a win-win decision-making between the sellers and the customers, the aim of the pricing decision-making on online auction items contains the performance goals and time targets for revenue, and time objectives can also indirectly through the opportunity cost that is also a seller as part of the proceeds. And at the same time, the time goals can also improve the efficiency of auction transaction, so as to win the return buyers. Based on the time factors of win-win pricing model on e-commerce online auction. The win-win pricing model on the online e-commerce auction is as follows.

Max \( R(r) = \max \{ P_n(r) - C_d(r) - C_r(P_n) + O_p, 0 - P(C_r + O_p) \} \)

\( P \geq M; \)

\( 0 \leq q \leq r \leq V_k \)

\( O_{P^n} = \alpha \beta P^n; \)

\( M = V_m - O_{P^n}; \)

\( P_n(r) = \sum_{i=1}^{k^*} P_{ri} \)

\( k^* = \frac{V_m - r}{\epsilon}. \)

This model is based on maximizing the return \( R(r) \) as the model’s objective and decision variables is the reserve price. Among them, \( P \) and \( P \) indicated that online auction transactions probability and the probability of non-traded goods respectively; \( C_d(r) \) is for the cost of sellers to list the auction items, whose value is related with reserve price; \( C_r(P_n) \) is for the pay of sellers after closing the transaction’s costs, and its value is related with the final auction commodities’ price \( P_n(r) \), which is a function of the reserve price \( r \) as variables, \( P_n \) is the various possible price in the transaction, \( P_n^* \) is the probability of the various possible price. \( k^* \) is the number of times from the reserve price \( r \) to the maximum \( V_n \) of customers in the final valuation; \( \epsilon \) is as bidder's the smallest rate of increase price; \( V_m \) is for the seller's utility of the auction of goods; \( O_{P^n} \) is for the opportunity cost of the commodities’ prices \( P^n \); \( \alpha, \beta \) are the interest and risk factors respectively of the opportunity cost; \( M \) is for the final price of auction items, which the seller can accept. This model is about a general model on the auction merchandise pricing decisions of online auctions, and through solving this model, it can achieve the reserve price \( r \) of pricing decisions to maximize satisfaction the auction transaction revenue, which can be solved specifically through the following method.

The analysis of historical data and experimental method can determine the customer valuation distribution function \( F(V) \). Firstly, under the initial valuation \( [q, V_n] \) all potential bidders may reach the expectations price \( P_n(r) \) when the auction time \( T \) arrives. As the network proxy mechanisms exist, Bidders would bid his true valuation. But the network showed the rate \( \epsilon \) is a rise, so the final transaction price is not the highest price of the auction bidders who are willing to pay for goods. To facilitate the calculation, the bidder of the auction items were valued as the smallest divisible number of the rate \( \epsilon \). All potential bidders by making products people are willing to pay the highest price \( \{0, \epsilon, 2\epsilon, ..., q, q + \epsilon, q + 2\epsilon, ..., r, r + \epsilon, ..., V_n\} \). Therefore, the last possible auction price is a collection of discrete random variables \( \{r, r + \epsilon, ..., V_n\} \) where \( i \in [0, k^*] \)

\( k^* = \frac{V_n - r}{\epsilon}. \)

And then it can get the final transaction price \( P_n^* \) according to customer valuation distribution function \( F(V) \). Using the all expect formula, if the seller determined the starting price \( q \) and \( P_n(r) \) based on the reserve price \( r \), combined with the seller and the real risk-bearing capacity of the bidder’s psychoanalysis, the bidder will choose the right pricing strategies, such as the mantissa pricing strategies, and determine the final reserve price and the expectations of the price of auction items. When the two sides finished the transaction, the customers can give advice and evaluation on the open Web platform, which can also maintain their transaction
security, but also provide a reference to the future of consumer transaction basis.

In this model, the auction ending time $T$ is for the end time of the auction, but in the actual situation, the auction process can end at any one time $T_n$ for analysis, and reach the decision-making moment for meeting the sellers’ satisfaction, thus end online auction process at ahead. Therefore, in the practical implementation of the pricing decision-making process, decision-makers need to make further adjustments to adapt to the changes in online auctions progress. For the consumers, at this time, the time efficiency of auction transaction is greatly enhanced, reducing the opportunity costs of both sides, making the buyer’s expected surplus as zero. The reserve price of goods and auction items’ prices at this time not only reached the revenue maximization, but also improve the efficiency of the entire auction, which can be said to be a win-win strategy for the auction.

V. CONCLUSIONS

In conclusion, firstly, online auction operators need to maintain a good reputation. The purchase price, current bid and the seller's rating presented interactions. When the seller operators maintained a good evaluation, the direct changes in the level of the purchase price will also affect the willingness of consumers the bid price level. However, if the sellers have a negative evaluation, the product was not so easy to attract consumers to bid to buy. Thus, consumers gave the sellers’ evaluation, which is a very important resource, so online auctions operators need to maintain a good evaluation scores properly. Secondly, solving the credit problem can reduce risk of online auction environment, addressing information privacy, integrity, and non-repudiation, even identification, as well as the security in the logistics and payment processes. China is going the construction of the smart ID card to establish security authentication mechanism, which will has played a certain role to reduce the risk of online auctions. Bidders for the specific attitude towards risk of the auction items reflected in the valuation of the degree, the less tolerance for risk, the lower the valuation of goods for auction. On the contrary, the greater the customers’ tolerance for risk is, the valuation of goods for auction is closer to the original valuation. But for the sellers’ specific attitude towards risk, if their tolerance for risk is greater, the set reserve price will be lower. The consumers have different buying behavior according to the different sources of information. Nowadays, the information of online auctions provided is very rich, so how to select useful information is a key factor for consumers. There are too many risks and uncertainties coupled with online auctions, so the relationship of trust between people is the most basic consideration. If the sellers were able to provide the best products and services, as well as produce the best service reputation, they will be able to improve their competitiveness, and at the same time, consumers will also increase confidence and attitudes in order to enhance the buying opportunity for higher benefits.

In China, the construction of smart ID card are establishing, and the security authentication mechanism in Certification Center will reduce the risk of online auctions auction merchandise and play a certain role. The specific attitude of bidders towards risk of the auction items can be reflected in the valuation of the degree, the less tolerance for risk, the lower the valuation of goods for auction. On the contrary, if the tolerance for risk is greater, the valuation of goods for auction will be closer to the original valuation. The specific attitude of sellers towards the risk can be reflected in the reserve price. If the sellers have greater tolerance for risk in the similar objectives agreed under the premise of the auction, the set reserve price will be lower. And on the contrary, if the tolerance for risk of seller is smaller, the set reserve price will be higher. For the different sources of information, consumers have different buying behavior. Nowadays the information of the online auctions present is very rich, so how to select useful information out to consumers is a key factor. And then, there are too many risks and uncertainties, the relationship of trust between people are the most basic consideration. If the seller were able to provide the best products and services to produce, the best service reputation will be able to improve their competitiveness, and consumers will also increase confidence and attitudes in order to enhance the buying opportunity for mutual access to higher benefits. An auction mechanism involves two parts, the allocation rules and the pay rules. The distribution rules in the standard auction are the same, namely, the highest bidder will be successful, while the payment rules are changing, but the change of the payment rules in the model under the assumption does not affect the expectations of the auction bidders expected earnings and expenditures, the impact is bidders equilibrium bidding strategy. Lastly, an auction mechanism contains two parts, the allocation rules and paying rules governing. Distribution rules in the standard auction are the same, while the payment rules are changing. But the change of the payment rules does not affect the expected earnings and expenditures of the auction bidders, but bidders’ equilibrium bidding strategy.

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Yu Min, School of Economic Information Engineering, SWUFE (Southwestern University of Finance and Economics), China. She graduated in 1982 from UESTC (University of Electronic Science and Technology of China), China. Her research interests are in computer application and e-commerce.

PuBuZhuoMa, born in Lhasa, Tibet in 1982, works in Tibet University, master degree, studies in financial and trading e-business in Southwest University of Finance and economy of China. Her research interests is in e-commerce.

Zhou Qihai is a Full Professor (from 1995), Doctor’s (and Master’s) tutor and a head of Information Technology Application Research Institute, School of Economic Information Engineering, SWUFE (Southwestern University of Finance and Economics, China). He graduated in 1982 from Lanzhou University, China; has been working in SWUFE since 1982, filling posts from Teaching Assistant (1982-1987), lecture (1987-1991), vice professor (1991-1995, promoted anomaly in 1991), professor (1995-today, promoted anomaly in 1995); and got the titles of both “Outstanding experts (enjoyed government subsidies) with outstanding contributions of Sichuan province, China” (summa cum laude of Sichuan province government, 1996) and “One hundred academic and managerial leading heads of China informationalization” (summa cum laude about this field in China, 2006). He has published 47 academic books and 218 academic papers; and is Chair or Organizing Chair of some important international conferences. His research interests are in algorithm research, computational geometry, isomorphic information processing, economics & management computation, eBusiness, and so on. More about Prof. Zhou Qihai is shown here:

http://www.iitaa.com/Member-ZhouQiHai.doc

An Emerging Experience Factory to Support High-Quality Applications Based on Software Components and Services
(Invited Paper)

Jeff Tian
Computer Science & Engineering Dept., Southern Methodist University, Dallas, Texas 75275, USA
Email: tian@lyle.smu.edu

Abstract—Software components and services (SCS) are playing an increasingly important role in software engineering, particularly as building blocks of systems that demand high quality and dependability. A major impediment to advances in developing such systems is the difficulty of providing objective evaluations and conducting rigorous experiments to determine the efficacy of selected SCS and the resulting systems. This paper presents a framework that facilitates such experimentation to measure SCS quality in the target usage environment, to provide unbiased quality assessment, and to support effective usage of SCS in high quality applications. We are building a comprehensive collection of usage scenarios in a set of target operational profiles and a flexible defect classification and analysis framework and related quality analyses. Our work will form the first step of an operational experience factory for SCS. Resulting repositories and supporting facilities from applying our approach to web-based applications are included to demonstrate its viability.

Index Terms—software quality assurance, experience factory, software components, software services, usage-based testing and operational profiles, web-based applications

I. INTRODUCTION

Software components and services (SCS) are used as building blocks for many software systems and software-intensive systems ranging from embedded systems to general heterogeneous systems for net-centric operations (NCO) and service-oriented architecture (SOA). Commercial-off-the-shelf (COTS) and open-source (OS) SCS play an essential role in such systems. Some of these applications are mission-critical and must meet stringent dependability requirements, including high reliability, availability, safety, and security; while others require high resilience, fast response, preservation of confidentiality, etc. A major impediment to advances in developing such systems is the difficulty of conducting rigorous experiments to determine the efficacy of selected components or services and the resulting systems.

This paper describes a recent attempt at developing such an approach and related supporting infrastructure that facilitates such experimentation. A key differentiating feature of our approach is the ability to measure SCS quality in the target usage environment and to provide unbiased quality assessment, unlike testing and measurement in an environment envisioned by SCS developers. The overall infrastructure will form the first step of an operational experience factory [1], including a rich repository of data, models, packaged experience, and other software and hardware artifacts and supporting facilities, that will permit researchers to experimentally validate their SCS and systems for realistic application environments as well as under extreme conditions, and to experiment with various system design decisions to optimize the performance and quality of the resulting systems.

As the initial increment of this comprehensive experience factory, we have developed some core functions and related supporting facilities, and applied them to the web application domain. Our supporting facilities consist of 1) target environment and usage capturing facilities that capture real-world application scenarios in operational profiles to allow for testing of SCS under realistic usage environments and to test SCS’s performance under hostile environments via boundary extension and fault injection, and 2) quality and defect analysis facilities that provides integrated instruments to evaluate specific quality attributes of SCS and relate them to observable defects from different perspectives. Resulting repositories and supporting facilities from applying our approach to web-based applications are included to demonstrate its viability.

II. THE NEED FOR AN SCS EXPERIENCE FACTORY

One major goal in software engineering is to deliver high-quality software products under budgetary, schedule, and other constraints, or to minimize risks of undesirable consequences such as in-field failures, budget overruns, schedule delays, and project cancellations. The concept of software quality is generally associated with good user experience characterized by the absence of observable problems or failures caused by internal faults and/or environmental disturbances. A quantitative measure of quality meaningful to both the users and the developers is product reliability, which is defined as the probability of failure-free operations for a specific time period or input set under a specific environment [2]. Dependability is a broader concept that encompasses reliability, availability, safety, security, etc. [3].
Software testing and quality assurance activities play a central role in assuring product quality by executing software, observing its behavior, analyzing its artifacts to locate and fix related problems or by analyzing the working product directly using either static or dynamic means. These activities aim to validate software against user requirements under the actual or simulated usage environments or to verify that product specifications and designs are followed in the implementation product. During the software development process, they are typically captured in the so-called V-model, as illustrated by the left diagram of Figure 1.

Most traditional testing techniques attempt to cover major functions, execution paths, partitions and boundaries, or new and modified features [4]. They use coverage information as the stopping criteria, with the implicit assumption that higher coverage means higher quality. Alternately, product reliability goals can be used as an objective criterion to stop testing, which requires statistical usage-based testing under an environment that resembles actual usage by target customers [2]. Another important factor that affects the choice of testing techniques is the increasing size and complexity of software systems, which makes many coverage goals infeasible or impractical to achieve.

The cost and schedule constraints for modern software development, maintenance, and service integration dictate that not everything be developed from scratch. SCS are reused and integrated to form new systems or to deliver required functionalities via dynamic composition. The former approach can be characterized as component-based development that has been around for decades but has gained new momentum in the last few years, particularly with the maturation of the market for commercial-off-the-shelf (COTS) components and the proliferation of open source SCS. The latter approach can be characterized by the net-centric operations (NCO) capabilities and/or service-oriented architecture (SOA) paradigm where system capabilities are dynamically composed at runtime. However, improper reuse and integration of SCS into target systems and environments may lead to operational failures and sometimes severe consequences, such as the improper reuse of software for the Ariane 5 rocket, primarily due to the mismatch between the intended usage of SCS and their actual usage environment [5]. Therefore, a key concern for effective reuse lies in characterizing the actual usage environment and scenarios so that proper selection and/or adaptation of SCS can be carried out to ensure high quality.

In either of these SCS-based approaches, system elements must meet certain quality goals to ensure the overall system quality. On one hand, SCS are typically subjected to limited internal testing that only includes unit and component testing subphases performed by the component developers, due to the non-existence of the composite system yet. The integration and system testing subphases are left out, as illustrated by the right diagram of Figure 1. On the other hand, integration testing and system testing subphases for component-based systems are usually the responsibility of system integrators, without the benefit of the expertise of component developers. There is a big gap between the target usage environment under which the SCS need to be tested by system integrators and what the SCS was subjected to in their unit and component testing.

In addition, different users and stakeholders have different concerns, and their expectations of quality will be expressed in different quality attributes at different expected levels. Furthermore, most of the quality and dependability attributes are environment-sensitive [6]. For example, reliability is not only related to the number of internal faults, but also the usage scenarios that trigger the observed external failures [2]. To provide realistic evaluations of quality for SCS, we need to test and
evaluate SCS under an environment that resembles the realistic usage environments.

Therefore, there is an urgent need to evaluate the quality of individual SCS and their contribution to the overall system quality. In addition, the analytical facilities and experimental support are needed to permit informed decision making in choosing appropriate SCS and system architecture to maximize the overall system quality.

On the other hand, substantial progress has been made in supporting software development and quality improvement through the use of the so-called experience factory (EF) [1] that consists of a collection of data, models, tools, and packaged experience supported by a dedicated group with the aid of related software tools, such as implemented in the the NASA Software Engineering Laboratory (NASA/SEL) [7]. Figure 2 illustrates the general operational relations of the EF matched to the software development process following the V-model. In this paper, we adapt EF to the specific application environment of SCS to support the specific quality goals. Some core functions and related supporting facilities of this experimental EF have already been implemented and applied to several web based applications, which are described in details after we outline our overall framework.

III. AN EXPERIENCE FACTORY FOR SCS: ARCHITECTURE AND INITIAL APPLICATION DOMAIN

The overall infrastructure of our support facilities is derived from an extension and customization of an experience factory [1] depicted in Figure 3 for COTS components and open-source/other SCS. This infrastructure bridges the gap between what the component vendors provide and what the users of composite systems need.

It helps the system integrators test, evaluate, and select proper SCS to compose the system prior to deployment, or to assemble the system on the fly. It also aids in validating systems in realistic environments and assuring overall system quality. It implements an open experience factory [1] customized for the community consisting of vendors of COTS/open-source components and individual services on the one side and system integrators, dynamic assemblers, and users of NCO/SOA systems on the other side, much like the Software Engineering Laboratory (SEL) did for NASA and its contractors [7]. This infrastructure consists of four interconnected units:

- a testing facility that recreates or simulates realistic target application environments and usage scenarios as well as usage under extreme and/or hostile conditions;
- an evaluator of component quality to empirically guide the selection and customization of SCS for system integration or service composition;
- an estimator of composite system quality based on that of its SCS and system architecture;
- an optimizer that takes a multivariate approach to recommend optimal system solutions.

The evaluator gets its primary data input from the testing facility. It may also use data from existing SCS and system testing/usage directly. The estimator utilizes the SCS evaluation results from the evaluator, and the optimizer utilizes the results from both the the evaluator and the estimator. The architecture of our EF and its general usage are illustrated in Figure 3. Currently, we have implemented the first two of the above (testing facility and evaluator) for a restricted web SCS, which
will be the focus of this paper. The last two (estimator and optimizer) are future extensions to the current work.

We applied the above approach to some web-based applications where web components and services are routinely used to implement and support various functions over the web. This series of case studies builds upon and extends our previous work applying and adapting traditional testing and quality measurement to the web application domain [8]–[11]. We started with an academic web site, Engineering School website at Southern Methodist University (SMU/SEAS, http://www.seas.smu.edu), where we have full access to the web server logs, source contents, and statistical reports produced by existing tools. Then, we gradually expanded our case studies to include three diverse web sites, including: the Open Source Project KDE website (http://www.kde.org), an online catalog showroom website for a small company (hereafter labeled SCC), and a commercial website for a large company in the telecommunications industry with extensive amount dynamic contents to support important of e-Commerce activities (hereafter labeled LTC). A final web site is a social networking site (SNH) that we have been working on since 2009. The results from these applications constitute the initial contents of our repository.

IV. CAPTURING SCS USAGE SCENARIOS TO SUPPORT TESTING

The key feature of our testing facilities is the provision for realistic capturing and simulation of target usage environment under both normal and abnormal usage conditions.

A. A repository of operational profiles for realistic testing

An operational profile (OP) is a quantification of the way a software system is or will be used in field [2]. Two commonly used types of OPs are: 1) Musa’s flat OP [2], [12], a list of disjoint set of operations and their associated probabilities of occurrence; and 2) Markov OP [13], [14], a finite state machine (FSM) with probabilistic, history-independent state transitions. For large systems, a collection of Markov chains may be organized into unified Markov models (UMM) [9].

We use both Musa OP and UMM in a hierarchical structure [15] to better reflect the heterogeneous nature of NCO/SOA systems. A diverse set of OPs are constructed to target a wide variety of operational environments, unlike in the traditional application of OP in testing where only one OP is needed for a generic customer usage environment. Musa OP can be constructed either through stepwise refinement [12] or supported data collection/analysis [2]. Ad hoc software tools and procedures
were also accumulated from our previous work in constructing Markov OP by first building the underlying FSM and then obtaining state transition probabilities for application domains ranging from defense to commercial and telecommunications [9], [15]. These tools are enhanced and integrated to form part of the basic collection of tools of our EF for SCS.

Data for OP construction can come from actual measurement of usage at customer installations, often with the help of some monitoring tools or system traces or logs, survey of target customers, or usage estimation based on expert opinions. As an independent party detached from either the customers or the component/service vendors, this EF for SCS will provide an objective way to build a collection of OPs to bridge the gap between the operational environments under which vendor testing was performed and the actual usage environments where customer applications will be executed. This independence will enable us to overcome data sensitivity issues, and accumulating OPs from a wide user base, which will also help with “intended” usage from potential customers for new systems or applications. Each user will start with an analysis of her own application environment, and find the best OP available from our OP collection, to evaluate components comprising her system. If a close match cannot be found, a new OP will be constructed under the guidance of our EF for SCS.

B. A repository for testing the robustness and under extreme conditions

Various forms of testing for system robustness in handling unexpected input or scenarios can be supported by our EF for SCS. The simplest form of such testing will involve techniques such as boundary analysis and input domain testing [4], [16]. These techniques will be tailored to focus on anticipated and unanticipated extreme conditions, instead of internal boundaries and adjacent domains since they have already been tested extensively by the SCS providers.

Fault injection is a testing technique that purposefully introduces faults into systems to measure their response so that corresponding software design or implementation changes can be made to eliminate or tolerate similar faults [17]. These faults are typically related to rare-events or environmental disturbances, thus beyond the coverage scope or usage scenarios of normal testing. A closely related technique is mutation testing, where mutants, or small, localized software changes, can be introduced systematically [18]. Alternatively, software faults can be injected systematically based on defect classification data [19] or identified high-risk areas [16]. Most available tools are only suitable for a limited set of hardware or transient faults. There is limited availability of tools for injecting software faults, such as JACA and related tools (ATIFS, etc.) [20] for runtime data corruption, and Holodeck (http://www.securityinnovation.com/holodeck/) for Windows/web-service fault simulation. We are currently working on adapt these tools and other research tools for mutation testing, and develop new tools and capabilities for defect- or risk-based testing.

C. Implementation: Web usage profiles

We have established some common patterns of web usage based on the web sites we studies, which also validated various related observations by other researchers that led to our hierarchical usage modeling [15]. At the top level, we use Musa’s operational profiles, which allows us to pay special attention to highly usage types of functions and/or components. Table I gives such an OP for the SMU/SEAS web site, listing the number of requests for different types of files by web users over 26 days and the related probabilities. The adaptation and application of OP-based testing would ensure that frequently used web components are adequately tested, which in turn, would have a great impact on web site reliability improvement.

Going beyond simple hit counts for individual components or elements, we can construct our UMMs to model the overall web navigation patterns by target users. In general, such navigations are clustered, such as plotted in Figure 4, showing the cross references of individual webpages of the same web site. The sorted names of individual official pages are used as indexes in Figure 4. Each point represents a cross-reference from a specific page indexed by its x-axis value to another specific page indexed by its y-axis value. A propositionally larger dot represents the number of duplicate cross-references. The references within a unit is then typified by the short distance between their indexes due to the same leading string in their names. The associated cross references would be represented by points close to the diagonal. The usage frequencies as well as the cross-reference frequencies are very unevenly distributed, as shown by the uneven distribution of points and masses in Figure 4, thus justifying our use of statistical testing to focus on high-risk/high-leverage areas.

Figure 5 shows the top-level Markov chain of the UMM for the SMU/SEAS web site. Each node is labeled by its associated web file or directory name, and the total outgoing direct hits calculated. Each link is labeled

<table>
<thead>
<tr>
<th>File type</th>
<th>Hits</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>.gif</td>
<td>438536</td>
<td>57.47%</td>
</tr>
<tr>
<td>.html</td>
<td>128869</td>
<td>16.89%</td>
</tr>
<tr>
<td>directory</td>
<td>87067</td>
<td>11.41%</td>
</tr>
<tr>
<td>.jpg</td>
<td>65876</td>
<td>8.63%</td>
</tr>
<tr>
<td>.pdf</td>
<td>10784</td>
<td>1.41%</td>
</tr>
<tr>
<td>.class</td>
<td>10055</td>
<td>1.32%</td>
</tr>
<tr>
<td>.ps</td>
<td>2737</td>
<td>0.36%</td>
</tr>
<tr>
<td>.ppt</td>
<td>2510</td>
<td>0.33%</td>
</tr>
<tr>
<td>.css</td>
<td>2008</td>
<td>0.26%</td>
</tr>
<tr>
<td>.txt</td>
<td>1597</td>
<td>0.21%</td>
</tr>
<tr>
<td>.doc</td>
<td>1567</td>
<td>0.21%</td>
</tr>
<tr>
<td>.c</td>
<td>1254</td>
<td>0.16%</td>
</tr>
<tr>
<td>.ico</td>
<td>849</td>
<td>0.11%</td>
</tr>
<tr>
<td>Cumulative</td>
<td>753709</td>
<td>98.78%</td>
</tr>
<tr>
<td>Total</td>
<td>763021</td>
<td>100%</td>
</tr>
</tbody>
</table>

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with its direct hit count, instead of branching probability, to make it easier to add missing branching information should such information become available later. Infrequent direct hits to other pages are omitted from the model to simplify the model and highlight frequently followed sequences. Lower-level models are also produced for the nodes “/gradadmission/” and “/recruit/” in the top-level model. These models can be used to support our hierarchical strategy for statistical usage-based testing. Similarly patterns were also observed by the other web applications we studied, and also independently validated by other researchers [21].

V. SUPPORTING SCS QUALITY EVALUATION AND DEFECT ANALYSIS

To accommodate different users’ concerns, expectations and application environments in our evaluator, quality evaluation for SCS and systems will be based on problem or defect characterization under the realistic usage environment.

A. External quality evaluation from a customer/user’s perspective

For each application, the identification of relevant quality attributes will be carried out with direct involvement of customers, users, or domain experts. This will yield a list of quality attributes that are meaningful to specific customers under specific environments. Each attribute can be measured or evaluated using data from our testing facilities, or additional data from operational use, product development or existing testing. In some cases, external system logs, traces, and problem reports, such as access and error logs for many web-based applications [9], [10], [15], data from system monitoring tools [22], and defect repositories for open source software [23], also provide valuable information. All these data sources will be used for our comprehensive quality evaluation, supported by our EF for SCS.

Quality assessment typically takes the form of analyzing execution under this realistic usage environment and related failures, where a failure is an observable behavior deviations from user expectations [24]. For example, product reliability can be directly measured using our testing facilities, and captured by such measures as failure intensity and MTTF (mean-time-to-failures) estimated by fitting testing data to various reliability models [2]. For some quality attributes, such as safety and security, some rating levels in an ordinal scale can be used when a direct quantification is infeasible. The heterogeneous components in the NCO/SOA applications generally demonstrate vastly diverse operational behavior and characteristics. In such a system, interface failures due to erroneous interactions among different components may dominate [25]. The OPs of our testing facilities can be customized to model the interface/interactions among different components, with the rest of the system viewed as a generic “user” of a given component, and the testing results can be evaluated accordingly. In addition, system robustness can be evaluated using results from extreme or hostile testing described previously.

For each component under each OP, this evaluation will yield a quality vector whose individual elements are the corresponding values of assessment results for specific quality attributes, to form part of the data repository to be maintained and supported in our EF for SCS.

B. Defect analysis for both internal and internal quality evaluation

Since there is a causal relationship between faults and failures, where a fault is a problem in software implementation that may cause failures [24], indirect quality assessment can be carried out by assessing faults and their characteristics. For SCS studied in this paper, the usage environments characterized by our OPs are typically different from SCS vendors’ testing environment, and a fault may trigger different failures under different application scenarios. By examining both the fault criticality and exposure via an OP-based assessment method we developed previously [8], [10], internal faults can be mapped into external failures. This approach will avoid the costs associated with testing for the same fault under different environments.
To systematically collect and analyze defect data, orthogonal defect classification (ODC) [19] developed by IBM and adopted by others can be customized and used. ODC has an extensive category of defect attributes, with data collected by testers or inspectors on defect discovery (external failure view) and by developers or maintainers upon defect fixing (internal fault view). Because of the uneven distribution of defects [26], analysis of ODC-like data can help us screen out low-quality SCS and select only high-quality SCS for inclusion in composite systems.

For open source components, we also have the opportunity to examine the source code so that an empirical relationship can be established between internal characteristics such as size, complexity, process and the external quality [27], [28]. This relationship can then be used to estimate external SCS quality and for SCS selection.

C. Implementation: Profiling reliability growth under usage-based testing

Under the idealized environment under usage-based testing using operational profiles, the fault that caused each observed failure can be immediately identified and removed, resulting in no duplicate observations of identical failures. This upper limit on potential reliability improvement can be measured by the reliability change (or growth) through the duration when such defect fixing could take place. Quantitative evaluation of the reliability growth potential can be captured by the purification level \( \rho \) [16] defined as:

\[
\rho = \frac{\lambda_0 - \lambda_T}{\lambda_0} = 1 - \frac{\lambda_T}{\lambda_0}
\]

where \( \lambda_0 \) and \( \lambda_T \) are the initial and final failure rates, respectively, estimated by a fitted software reliability growth model (SRGM). A larger \( \rho \) value is associated with more reliability growth, with \( \rho = 1 \) associated with complete elimination of all potential defects, and \( \rho = 0 \) associated with no defect fixing at all. \((1 - \rho)\) gives us the ratio between \( \lambda_T \) and \( \lambda_0 \), or the final failure rate as a percentage of the initial failure rate.

Figure 6 plots the reliability growth evaluation using Goel-Okumoto (GO) model [29] for the KDE data over 22 days, with usage time measured by the number of cumulative bytes transferred. It gives us a reliability growth potential of \( \rho = 87.1\% \). When we used other usage time measurements, including hits, users, sessions, \( \rho \) values for KDE fall into a tight range between 86.7% and 88.9%. In other words, effective web testing and defect fixing equivalent to 22 days of operation could have reduced the failure rate to about 11% to 13% of the initial failure rate; or, equivalently, almost all the original problems could have been fixed. Similar results were also obtained for the other websites we studied.

D. Implementation: Defect classification and analysis for static and dynamic web applications

Inspired by ODC for traditional software systems [19], we developed a new defect classification and analysis technique for the web, mapping all the important ODC attributes to our framework [11]. We started this development by identifying defect impact as error type from error logs or response code from access logs [9]. The dominant “missing file” problems represent interface problems, which can be fixed by either supplying the requested files or correcting the referring links. The new web defect classification scheme we developed include the following attributes: response code, file type, owner type, directory level, referrer type, agent type, and observation time period. We successfully applied this classification scheme to classify and analyze web access logs for the SMU/SEAS and KDE web sites. The majority of these broken links were from internal links. Therefore, the identification and correction of the internal problems represent realistic opportunities for improved web software reliability based on local actions. The high-risk areas, or areas with substantially higher defect rate and/or defect share, were identified, with specific recommendations on how to deal with them for reliability improvement.

For dynamic web applications, such as LTC, many more “internal defects” were reported during development and maintenance activities. Although some HTTP responses carry successful response codes, they may not meet the software requirement specifications, and should be considered faults and reported as such. On the other hand, some HTTP faults may not be detected by testing. Significantly more information can be obtained if we can use both these data sources. The dynamic web ODC attributes are based on both the web log data and internal defect data from web development and maintenance activities, as modified below:

- Failure type is captured by two attributes, HTTP response code and domain specific failure types related to internal defects such as the 17 types [8] we used for LTC.
- File type is updated to include program files (Java, JavaScript, VBS, ActiveX, etc.), Cgi-Bin, etc.
- Owner type is expanded to include administrator,
programmer, user, etc.
- Directory level is also expanded to include a directory type attribute.
- Referrer type is further refined to reflect how the links were dynamically generated.

We have a semi-automatic approach to Web-ODC data extraction, with internal defect data obtained similar to in original ODC while web logs based defect data obtained using our script programs. These data and script programs form part of the repository and support facilities of our EF for SCS.

E. Implementation: Profiling accelerated defect discovery via defect classification and prioritization

For test prioritization, we use defect density, the ratio of unique defect over unique files. So areas associated with high defect density are identified as high risk areas, and they are tested and fixed first. Log data are split into two parts: first part as training data and 2nd part as testing data. Risks are identified and prioritized by analyzing the training data. Then test cases are selected and executed in the order guided by the obtained risk profiles. To simulate this effect, we sort the file accesses in the testing data by the prioritized areas in the risk profile, and record and accumulate the corresponding web access problems. This prioritized testing by risk based on our analysis results can be compared to various coverage based testing by comparing their respective defect discovery profiles [30].

Coverage-based testing is similarly simulated on the testing data in a similar way to produce corresponding defect discovery profiles, but without using the prioritized list above. Instead, the testing data can be sorted in the directory levels meaningful to the web domain, because people commonly assume Web files in different directory level have different priorities and conduct coverage based testing by directory order schema. That is, Web files is categorized by directory level and each level is tested at a time by the assigned order. Some may test Web files in the ascending directory level order because they think Web files in the upper level are more important than those in lower levels. Others may conduct the test in descending directory order. Yet others may create and maintain a specific list of directory-level testing order and use it to guide coverage testing.

Figure 7 shows the defect discovery profiles of coverage-based testings guided by risks and several variations of directory orders for LTC. The horizontal axis represents the unique file accesses, and the vertical axis represents the unique failures. As we can see from this result, risk-based testing compares favorably to all other types of coverage-based testing in finding and fixing higher proportions of web defects early.

We also performed similar comparative studies in the other four web sites of quite different characteristics to cross-validate the results above and to draw some general conclusions. In addition to the directory-level orders, the testing data are also sorted in the following orders meaningful to the web domain: dictionary-order, reverse dictionary-order, ascending directory-level, descending directory-level, and random directory-level. Dictionary-order coverage testing is to test the Web files by the alphabetical order of their full file name which includes the file path. That means all the tests for Web files in the same sub-directory are finished before tests for other sub-directories. In other words, dictionary-order and other variations above simulate the test scenario which test the website one subsite a time.

In all these comparative studies, risk-based testing outperforms other coverage testing: Most of the time, the defect discovery curve for risk-based testing on top of other curves. An defect discovery curves over the other curves means given certain time constraint or resources, this testing methodology can find more defects than others under time and budget constraints.

VI. CONCLUSIONS AND PERSPECTIVES

We have developed and initially validated an approach that will enable rigorous experimental quality assessment of software components and services (SCS). A key differentiating feature of our approach is the ability to measure SCS quality in the target usage environment and to provide unbiased quality assessment, unlike testing and measurement in an environment envisioned by SCS developers.

Our emerging experience factory for SCS consists of 1) testing facilities that capture real-world application scenarios in operational profiles to test SCS under realistic usage environments and to test SCS’s performance under hostile environments via boundary extension and fault injection, and 2) quality evaluating facilities that provides comprehensive evaluation of specific quality attributes of SCS from different perspectives. Future work planned include an estimator that quantifies composite system quality based on that of its SCS and system architecture; and an optimizer that performs global optimization based on specific perspectives and associated value assessments using data envelopment analysis and other multivariate optimization techniques.

When fully implemented, this research will include a rich repository of data, models, packaged experience,
COTS/OS SCS vendors to companies and organizations and systems engineering. It will help parties ranging from a scientifically based experimental paradigm for software systems based on COTS/OS SCS and help foster a strong scale, and scope of experimental research in NCO/SOA to experimentally validate their SCS and systems for and supporting facilities, that will permit researchers to experimentally validate their SCS and systems for realistic application environments as well as under extreme conditions. It would substantially raise the quality, scale, and scope of experimental research in NCO/SOA systems based on COTS/OS SCS and help foster a strong scientifically based experimental paradigm for software and systems engineering. It will help parties ranging from COTS/OS SCS vendors to companies and organizations interested in NCO/SOA solutions achieve high reliability, dependability, and other quality goals.

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Abstract — In computational flow visualization, integration based geometric flow visualization is often used to explore the flow field structure. A typical time-varying dataset from a Computational Fluid Dynamics (CFD) simulation can easily require hundreds of gigabytes to even terabytes of storage space, which creates challenges for the consequent data-analysis tasks. This paper presents new techniques for visualization of extremely large time-varying vector data using high performance computing. The high level requirements that guided the formulation of the new techniques are (a) support for large dataset sizes, (b) support for temporal coherence of the vector data, (c) support for distributed memory high performance computing and (d) optimum utilization of the computing nodes with multi-cores (multi-core processors). The challenge is to design and implement techniques that meet these complex requirements and balance the conflicts between them. The fundamental innovation in this work is developing efficient distributed visualization for large time-varying vector data. The maximum performance was reached through the parallelization of multiple processes on the multiple cores of each computing node. Accuracy of the proposed techniques was confirmed compared to the benchmark results. In addition, the proposed techniques exhibited acceptable scalability for different data sizes with better scalability for the larger ones. Finally, the utilization of the computing nodes was satisfactory for the considered test cases.

I. INTRODUCTION

The massive progress in high performance computing resources enabled the simulation of complex phenomena in unprecedented details. Examples include data from the study of weather forecasting, crash simulation, crack propagation in a material, unsteady flow surrounding flying vehicles, seismic signals from geological strata, and the merging of galaxies. A typical time varying dataset from a Computational Fluid Dynamics (CFD) simulation can contain hundreds of time steps, and each time step can have more than millions of data points. Generally, multiple values are stored at each data point. As a result, some datasets can easily require hundreds of gigabytes to even terabytes of storage space, which creates challenges for the consequent data analysis tasks. When scientists attempt to visualize and understand the data generated from simulations, the huge size of the data is one of the major challenges. To address these challenges, a lot of research work has been pursued [1, 2, 3, 4] focusing on large scale data visualization. However, most of the techniques were developed for the visualization of scalar data [4].

Visualization of vector data has also been an active area of research [5, 6]. For large scale time-varying 3D vector fields, fewer studies have been conducted [7, 8] for several reasons. First, the size of the vector data sets is three times or more that of the corresponding scalar field. Therefore, traditional workstations generally do not have the memory capacity or the processing power needed to visualize such huge data sets. Second, when directly applied to 3D vector data, most of the effective 2D vector field visualization methods face the “visual clutter” problem. Finally, additional attention to temporal coherence is required for visualizing time varying vector data. Consequently, previous work [5, 9] for vector field visualization focused primarily on 2D data sets, steady flow fields, and the topological aspect of the vector fields (such as, the associated seed/glyph placement problem).

In this paper, new techniques for visualizing large time varying 3D vector fields are presented. The accuracy and performance of the proposed techniques were compared to other existing ones. Distributed memory architecture is addressed therefore we have considered off the shelf systems like WINDOWS and LINUX clusters as well as distributed memory high performance computers. Furthermore, utilizing a cluster of workstations with multi-core processors was also addressed, as the multi-core processors are now main stream, with the number of cores increasing, expecting to reach hundreds of processors per chip in the future [10].

II. BACKGROUND AND RELATED WORK

A. Path-line visualization

The existing techniques for vector data visualization can be classified into glyph and field line based methods [5, 6], dense texture methods [7, 8, 9], clustering-based methods [11, 12], and topology-based methods [13, 14].
In field-line based methods, Lane [5] developed a particle tracing system to generate particle traces in unsteady flow fields. The system was used to visualize several 3D unsteady flow fields from real world problems. The performance of the system was mainly influenced by the computational mesh, the number of time steps and the number of seed points. The disadvantage was that the particle traces were performed sequentially. Later in [15], Kenwright and Lane presented an efficient algorithm to compute particle paths, streak lines and time lines in unsteady flows with moving curvilinear grids. The time integration, the velocity interpolation, and the step size control were all manipulated in the physical space, which avoided the need to transform the velocity field to the computational space. The problem of the point location and the interpolation in the physical space was simplified by decomposing hexahedral cells into tetrahedral ones.

In the cases where the data sets are larger than the memory size of the used workstation, many research groups focused on parallel I/O operations to overcome this problem. Ueng et al. [16] presented an out-of-core approach for interactive streamline construction for large unstructured tetrahedral meshes containing millions of elements. The out-of-core algorithms use an OctTree to partition and restructure the raw data into sub-sets stored in disk files for fast data retrieval.

The rapid growth of the data set sizes raised the need for efficient visualization techniques. In this manner, the use of High Performance Computing (HPC) became a rich field of research to visualize large scale steady and time-varying scalar fields [4]. Research examples for steady flow include; Ahrens et al. [17] where a parallel data streaming architectural approach was presented to handle the large scale visualization problems on a cluster of workstations. For vector field visualization, Bruckschen et al. [18] presented a method for real-time visualization of arbitrarily large time-varying vector fields. They proposed an out-of-core scheme in which two distinct preprocessing and rendering components to enable real-time data streaming and visualization. This approach yielded low latency application start-up times and small memory footprints.

Afterwards, Ellsworth et al. [19] proposed methods to produce an interactive visualization for CFD data sets using particle tracing and streak-lines. They also presented an algorithm for the computations of particle tracing using a cluster of workstations. This algorithm can be adapted to work with multi-block curvilinear meshes. In addition, they discussed how scalars can be extracted and used to color the particles. This research proved that the out-of-core visualization can be scaled to more than 300 billion particles while still achieving an interactive performance on PC computing platform.

Researchers like Bachthaler et al. [3] adopted a texture based technique for vector field visualization on curved surfaces using parallel computation via GPU cluster computers. By using parallelization, both the visualization speedup and the maximum data set size were scaled with the number of computing nodes. Many issues pertaining to the parallel GPU-based vector field visualization were addressed in [3]. These issues include the reduced locality of memory accesses caused by particle tracing, the dynamic load balancing for changing camera parameters, as well as the combination of image space and object space decomposition in a hybrid approach.

Hongfeng Yu et al. [20] presented a parallel path line construction method to visualize large time-varying 3D vector fields. A 4D representation of the vector field was introduced to make a time accurate depiction of the flow field. The constructed hierarchical representation of the 4D vector field enabled the interactive visualization of the flow field at different levels of abstraction.

A. Stream surface visualization

Stream surfaces, surfaces everywhere tangent to the flow, are a viable solution for the visualization of 3D vector fields. Firstly they do not suffer from the visual complexity the same way seeding many streamlines can. Secondly, depth cues can be easily added using shading. Hultquist [27] proposed a technique for steam surface construction from stream-lines. The technique approximated the stream surface by triangular tilling of adjacent pairs of integrated stream-lines. This algorithm accessed the sampled field data more efficiently and provided better control over the sampling density across the width of the evolving surface representation. But, the algorithm failed in flow fields which have divergence, convergence, or curvature. In [28], V. Gelder et al. described a method for generating stream surfaces, given a three dimensional vector field defined on a curvilinear grid. The method can be characterized as semi-global; that is, it tried to find a surface that satisfied constraints over a region, expressed as integrals (actually sums, due to discreteness), rather than locally propagating the solution of a differential equation. Gelder presented a method for generating stream surfaces that simultaneously solves constraints over a large region of space, rather than working in one local region at a time. Yet, there was an element of downstream propagation. The efficiency was based on the fast procedure for solving tri-diagonal linear systems. The implementation so far had limited flexibility. Garth et al. [29] presented an explicit algorithm for the integration of stream surfaces that was based upon Hultquist’s original idea [27] of advancing a front of connected stream-lines through the flow field and adaptively inserting and deleting streamlines where the flow diverges or converges. The algorithm eliminated this shortcoming by employing streamline integration based on arc length rather than parameter length, which proved to be a more intuitive and accurate approach for the creation of a graphical representation. Schaftitzel et al [30] introduced a point-based algorithm for computing and rendering of stream surfaces in 3D flows. Surface points were generated by particle tracing, and an even distribution of those particles on the surfaces was achieved by selective particle removal and creation. Texture-based surface flow visua-
lization was added to show inner flow structure on those surfaces. The visualization method was designed for steady and unsteady flow alike: both the path surface component and the texture-based flow representation were capable of processing time-dependent data. In addition Schafitzzel et al. presented a real-time method for creating and rendering stream surfaces and path surfaces that enabled the user to manipulate seed curves interactively, even for unsteady flows. The streamlines and path-lines were generated by a GPU-based particle tracking algorithm. They dealt with local flow divergence by inserting and removing particles according to the particle-density criterion. Based on the particle traces, the corresponding surfaces were created and displayed by point set surfaces.

Garth et al. [31] presented a novel approach for the direct computation of integral surfaces. The approach was based on a separation of the integral surface computation into two stages: surface approximation and generation of a graphical representation. The proposed method was based on the adaptively-refined advancing front paradigm, and was applicable to visualize both stationary and time-varying vector fields. Treatment of the latter was achieved in a streaming fashion, thus allowing the method to work even on extremely large datasets with thousands of time steps.

McLoughlin et al. [32] introduced an algorithm for the construction of stream and path surfaces that was fast, simple and didn’t rely on any complicated data structures or surface parameterization, thus making it suitable for inclusion into any visualization application. This algorithm will be the base-line of our new technique for stream surfaces visualizing.

In this paper, we address the problem of visualizing time varying vector data using both path-lines and stream surfaces techniques on vector data visualization. In this manner, new techniques for visualizing huge datasets are introduced. The proposed techniques best utilize a cluster of workstations with multi-core processors. Hybrid architecture is introduced, in which the distributed memory architecture is combined with the shared memory parallelism.

The rest of the paper is organized as follows: Section III describes the main system architecture and the preprocessing phase which is applied on the data before visualization, while section IV describes the proposed visualization pipelining techniques. In section V, the results of the techniques applied to multiple data-set sizes are presented and discussed. Finally, section VI contains the conclusions and the future work.

III. ARCHITECTURE AND DATA PREPROCESSING

In this paper, we mainly adopted distributed memory architecture for the proposed technique. As shown in Fig. 1, the proposed visualization system consists of central rendering, I/O management, user interface and a data root for communicating with HPC facilities.

The proposed visualization system is based on the Visualization Tool Kit (VTK) [21], as an application builder for the implementation of several visualization algorithms. The core toolkit should be an object oriented cross-platform software package and have an easy interface for the classes that perform visualization algorithms, rendering and interaction techniques.

The first challenge is the huge size of the data sets under consideration, which cannot be loaded in the main memory of a single workstation. When using distributed memory based visualization, a preprocessing step should be performed to partition the data sets. This step is performed by the master computing node in order to facilitate loading data by the working computing nodes. In this manner, the input to the preprocessing step is several files. Each one contains the datasets of a specific time step. Domain partitioning is considered as one of the most eminent techniques of the out-of-core visualization researches [2].

Each of the input files is parsed and restructured in an OctTree, which has n leaves at its end; these leaves represent new smaller files, which will be the input for the computing nodes. Each node in the OctTree consists of a containing cube representing a subset of the main dataset. Starting with the first file that represents the first time step, from m time steps, a containing cube is generated to contain all the dataset. The vertices of this cube are inserted into the parent node of the OctTree as an object. Then, the containing cube is decomposed into smaller sub-cubes using three cutting planes perpendicular to the x, y and z axes. Each sub-cube is inserted in the OctTree as a child node for the parent cube. Next, each sub-cube is examined against the stopping condition. If it doesn’t meet the condition, it will be decomposed again into smaller sub-cubes using the same method. These new sub-cubes are also inserted as children for the parent cube in the OctTree. The cubes are to be divided into smaller cubes in a breadth first manner. This process continues until all leaves containing cubes of the OctTree satisfy the stopping condition. A cube is considered satisfying the stopping condition, when it represents a segment of the dataset smaller than a predefined threshold. The threshold is defined by the size of the maximum dataset that computing nodes can process independently. Fig. 2 shows a 2D representation of the OctTree for a 2D data set.
IV. PROPOSED VISUALIZATION TECHNIQUES

The proposed technique uses domain partitioning between the computing nodes along with pipelining architecture to distribute computations between the computing nodes and utilize them efficiently. In this manner, the proposed technique combines the use of distributed memory architecture with the shared memory parallelism to improve performance and scalability.

A. Path-Line visualization

To achieve the best performance and scalability, the proposed technique tries to keep all computing nodes fully utilized all the time. The system architecture for this technique consists of one master node responsible for data preprocessing and handling of tasks, one node working as data storage, one rendering node and computing nodes as shown in Fig. 3. Message Passing Interface (MPI) is used as the main communication backbone between nodes [22]. After the preprocessing phase, each data file representing a time step is divided into smaller ones. These files are shared between computing nodes. Information about all the computing nodes is stored in a hash table in the master computing node. The key element of the hash table is the computing node number. The value of each key is an object containing the time step and the file number that is currently loaded in the computing node memory as shown in Fig. 4. For the path-lines to be visualized, a stack of seeding points is constructed on the master computing node and shared between all the other computing nodes.

The pipeline starts by constructing an OctTree on the master node, while the data set is divided into small ones and transferred to the data storage (as explained before in the preprocessing phase). Each computing node requests a seeding point to process, from the master node, and the master finds the most appropriate one to be sent. To find the mesh cell that contains this seeding point, the corresponding computing node searches the OctTree to find the containing sub domain. Next, the computing node applies the Fan Cell Searching algorithm [23] to know which mesh cell contains this seeding point. The corresponding computing node searches the OctTree to find the containing sub domain. Next, the computing node applies the numerical integration method [24] to advance the path-line. The advancement of the path-line is returned to the master computing node to be inserted in the queue. Information (like time-step, file number where the seeding point is located, and the cell number that contains the most recent point on the path-line) is saved with the seeding point to help the master node in identifying the best computing node for further advancement as shown in Fig. 5.

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When computing node requests another seeding point, from the master computing node, the master node identifies the file that is already in its memory. Therefore, it sends the most appropriate seeding point to this computing node. This process is performed through searching the queue, for a seeding point, using the time step and the file number. If none is found, the master searches for a seeding point within the same time step only. If there is no seeding point in the same time step, or the file number, the master node sends any seeding point in the next time step to the computing node. This reduces the time needed to load the data file to the computing node’s memory and decreases the number of fetch processes. During the idle time of the master node, it parses the OctTree for each seeding point in the queue to identify its containing sub-cube (file number).

In this fashion, the master computing node starts a single thread for each computing node. Each thread is responsible for all the communication between the master node and the computing nodes. All these threads share the main memory of the master node, which contains the OctTree. The data storage machine uses memory caching module to reduce the reading time.

B. Computing nodes with multicore processors

The same pipelining architecture is modified to make use of computing nodes with multiple core presences employing OPENMP [25]. In this manner, each computing node will serve with multiple cores running in parallel and sharing the same memory. Using multi-core adds some constrains to the technique in order to optimize the usage of the shared memory of the multi-core processor. If we deal with each core as a separate node, each process will load different file in the memory. As the memory capacity of the computing node can load only one data file, the maximum file size in the preprocessing step will be divided by the number of cores per processor. To achieve better utilization for the memory of each computing node, the hash table, that keeps the information about the computing nodes, has to be changed to contain information about the different cores of each node as shown in Fig. 6. The master node will try to optimize the assignment of the seeding points using the information in the modified hash table. This optimization comes through the assignment of the seeding points located in a single data file to the cores of a single computing node if possible.

C. Stream surface visualization

The implementation of the proposed technique for stream surface visualization is based on the easy integral stream surface algorithm introduced by McLoughlin [23]. This algorithm proposed a special handling for the divergence, convergence and rotation.

The integral surface is constructed from quad primitives. The technique is based on two important distances to consider when constructing a new quad: \( d_{sep} \), the distance between neighboring flow line points that correspond to the same integration time \( t \) and \( d_a \) the advancement distance. To obtain a smooth and accurate surfaces, the appropriate length of \( d_{sep} \) and \( d_a \) is determined so that we maintain an appropriate sampling rate of the underlying vector field. The sampling rate is guided by the Nyquist Limit, namely, the sampling frequency must be (at least) twice that of the underlying data frequency for accurate reconstruction. Thus we choose an initial \( d_{sep} \): \( d_{sep} < \frac{1}{2} d_{sample} \).

Divergence and convergence is tested while advancing in the flow field. As soon as any quad reach \( d_{sep} > 1/2 \)
and $\alpha > 90$ and $\beta > 90$ we simply divide the quad. When $d_{sep}^i < \frac{1}{2} d_{sample}$ and $\alpha < 90$ and $\beta < 90$ it is handled by terminating the middle flow line. Two quad primitives are merged into a single quad as shown in Fig. 7.

V. RESULTS AND DISCUSSION

The proposed technique for path-line visualization was tested and evaluated using a 8 GB dataset of the unsteady flow in Driven Cavity [26]. The technique was tested on a cluster of workstations consists of 16 workstations. Each one has a 2.5 GH Pentium Intel processor with dual cores. To confirm the accuracy of the proposed technique, the results of constructing 1000 path-lines using the proposed technique were compared to the results performed using VTK (stand alone on a single workstation). The maximum percentage difference introduced with different numbers of computing nodes is shown in Fig. 8 for both of the two modes (the distributed visualization only and the distributed visualization utilizing the multi-cores of each computing node). As shown, the accuracy of the proposed technique is proved, since the difference is within 2-6%.

The results of constructing a stream surface with 1000 seeding points using the proposed technique were compared to the VTK results (stand alone on a single workstation). The maximum percentage difference introduced with different numbers of computing nodes is shown in Fig. 9 for both of the two modes. As shown the accuracy of the proposed technique is proved as the difference is within 5-10%.

Next, the scalability of the proposed techniques was evaluated for both of the two modes in path-lines and stream surface visualization. The processing time for constructing 1000 path-lines and a stream surface was measured as shown in Fig. 10.a and Fig. 10.b. The processing time is drastically decreased as the number of computing nodes increased with better improvement using the second mode (the distributed visualization utilizing the multi-cores of the computing nodes). The relative speedup for both of the two modes of the proposed techniques is shown in Fig. 8.c. This figure indicates that better speedup can be achieved using the multi-core processors. Both implementations (modes) proved to achieve a good load balancing results as show in Fig. 10.d and Fig. 10.e. All processors achieved good processing utilization within an acceptable range between 85-95% for path-lines and 80-90% for stream surfaces.

VI. CONCLUSION AND FUTURE WORK

A distributed path-line and stream surface based visualization technique for large 3D time varying vector data is presented and clearly studied. The proposed techniques partition the data sets between the available computing nodes via domain partitioning, and employ a pipelining architecture to decrease the path-lines construction time. The pipeline was modified to fully utilize the computing nodes contains multi-core processors. In this manner, the proposed techniques introduced a hybrid architecture, in which the distributed memory architecture is combined with the shared memory parallelization. The techniques were also used for stream surface visualization. The accuracy of the proposed techniques was confirmed in comparison with the results of the VTK (stand alone on a single workstation) with maximum difference of about 6% in path-lines visualization and 10% in stream surface visualization. Then, performance and scalability analyses were conducted for the proposed techniques using data sets with different sizes. The proposed techniques exhibited acceptable scalability for different data sizes with better scalability for larger data sets. In addition, the scalability improved drastically when utilizing the multi-cores of each computing node. This improvement came close to almost 200% for 16 computing nodes with dual core processors. As a future work, the proposed technique can modified to consider more sophisticated visualization methods like flow volumes.
The processing time (in seconds) for constructing 1000 path-lines.

The processing time (in seconds) for constructing stream surface.

The speedup for constructing 1000 path-lines.

The load balance for constructing 1000 path-lines.

The load balance for constructing stream surface.

Figure 10. Performance and scalability analysis of the proposed technique.

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A DIC-based Distributed Algorithm for Frequent Itemset Generation

Preeti Paranjape-Voditel, 
Department of Computer Applications, Shri Ramdeobaba Kamla Nehru Engineering College, Nagpur, Maharashtra, India 
Email: preetivoditel@gmail.com

Dr.Umesh Deshpande 
Department of Computer Science,Visvesvaraya National Institute of Technology (VNIT),Nagpur, Maharashtra, India 
Email: uad@vnitnagpur.ac.in

Abstract—A distributed algorithm based on Dynamic Itemset Counting (DIC) for generation of frequent itemsets is presented by us. DIC represents a paradigm shift from Apriori-based algorithms in the number of passes of the database hence reducing the total time taken to obtain the frequent itemsets. We exploit the advantage of Dynamic Itemset Counting in our algorithm- that of starting the counting of an itemset as early as possible at the different site as soon as they become frequent at at least one site. Hence, our algorithm shows remarkable improvement in the amount of time taken because of reduction in the number of passes of the database and comparatively lesser number of candidates generated. Distributed frequent itemset counting and association rule generation have basically used algorithms based on Apriori or Sampling. This is the first algorithm which is based on DIC.

Index Terms—Distributed Association Rule Mining, dynamic Itemset Counting (DIC), Optimistic Messaging DIC

I. INTRODUCTION

ARM has been used extensively for the classical problem of market basket analysis where it is required to find the buying habits of customers. Determining what products customers are likely to buy together can be very useful for planning and marketing. Association rules are used to show the relationships between these data items.

Many centralized algorithms exist for Association Rule Mining(ARM) [9], [10], [14], [15], [11]. Most of the algorithms depend on the discovery of frequent itemsets for generation of association rules. Since the total number of itemsets is exponential in terms of the number of items, it is not possible to count the frequencies of these sets by reading the database in just one pass.

Different algorithms for the discovery of association rules aim at reducing the number of passes by generating candidate sets, which are likely to be frequent itemsets. They attempt to eliminate infrequent sets as early as possible. Dynamic Itemset Counting (DIC) [1] is one such algorithm, which does not wait for a complete database pass to start counting the candidate itemsets. It therefore reduces the number of passes of the database and generates fewer number of candidate itemsets.

Why distributed ARM? With the presence of multinational companies at different geographical locations across the globe, the data they need for decision making is inherently distributed. It is necessary to analyse the data to allow company-wide activities such as planning, marketing and sales. Analyzing data locally is not enough. A straightforward solution is to transfer all data to a central site where data mining is done. However even when such a site is available, it may incur huge communication costs to transfer the local datasets because of their sizes. Sometimes the local data cannot be transferred because of the security or privacy of the datasets. Distributed Association Rule Mining (DARM) is an active field in which global association rules are formed for the distributed data. The performance affecting issues in a distributed environment are the disk I/O minimization, the time required for synchronization between the nodes and the message transmission over the network.

Almost all distributed ARM methods have been based on two sequential algorithmic paradigms: Apriori [3] and Sampling [9]. We have designed our algorithm Optimistic messaging DIC (OPT-DIC) on the Dynamic Itemset Counting (DIC) algorithm. OPT-DIC focusses on disk I/O minimization by reducing the number of database passes and has almost no issues of synchronization between the nodes. It generates far fewer candidate sets than Apriori-based, level-wise algorithms because the nodes start counting an itemset early and only if it is frequent at at least one node. This also reduces to a very large extent the number of bytes transmitted over the network.

Our algorithm does not send the data but the counts of itemsets over the network thus security and privacy of the datasets is preserved.

The rest of the paper is organized as follows. Section II discusses the existing centralized algorithms and DIC. Section III deals with the issues in Distributed Association Rule Mining and the work done in the field of Distributed Association Rule Mining. Section IV discusses the Optimistic Messaging DIC algorithm. Section V discusses the
results. We conclude with Section VI.

II. ASSOCIATION RULE MINING

Let \( I = \{i_1, i_2, \ldots, i_m\} \) be a set of items. Let \( D \) be a database of transactions, where each transaction \( T \) consists of a set of items such that \( T \subseteq I \). The support of an itemset \( X \) is the number of transactions in which the itemset occurs as a subset. An itemset is frequent or large if its support is more than some user defined minimum support threshold \( \delta \). Thus support is the number of transactions in the database that contain the itemset \( X \). An association rule is an implication of the form \( X \Rightarrow Y \) where \( X \subset I, Y \subset I \) and \( X \cap Y = \emptyset \). The rule \( X \Rightarrow Y \) holds in the transaction set \( D \) with confidence \( c \) if \( c\% \) of transactions in \( D \) that contain \( X \) also contain \( Y \). The rule \( X \Rightarrow Y \) has support \( s \) in the transaction set \( D \) if \( s\% \) of transactions in \( D \) contain \( X \cup Y \). The problem of mining association rules is to generate all association rules that have a certain user-defined minimum support and confidence.

Several centralized algorithms exist for Association Rule Mining. One of the first algorithms is Apriori. [2], [3] on which most of the parallel algorithms are based. Apriori is an iterative, level-wise algorithm which uses a bottom-up search starting with the counting of frequent 1-itemsets. It generates these itemsets after a complete scan of the database. It then uses a self-join to find the 2-itemsets from the frequent 1-itemsets. It then scans the database to find the frequent 2-itemsets and continues this process till the maximal itemsets are generated. The number of passes is equal to the size of the maximal n-itemset. It uses the large itemset property that any subset of a large itemset must be large. The large itemsets are also said to be downward closed because if an itemset satisfies the minimum support requirements so will its subsets. Hence, if we know that an itemset is small then we need not generate its supersets as candidates because they will also be small. The performance of Apriori directly depends on the length of the longest frequent itemset. A remarkable breakthrough in sequential algorithms was achieved by the Dynamic Itemset Counting (DIC) [1] algorithm which represents a shift in the method in which frequent itemsets are generated. Since Dynamic Itemset Counting (DIC) forms the basis of our distributed algorithm, we would discuss this algorithm in detail.

A. Dynamic Itemset Counting (DIC)

Dynamic Itemset Counting (DIC) [1] is an algorithm which reduces the number of passes made over the data while keeping the number of itemsets which are counted in any pass relatively low. In the first \( M \) transactions the algorithm starts counting the 1-itemsets. After \( M \) transactions for a given minimum support threshold, if any of the itemsets exceeds the minimum support threshold in those \( M \) transactions, then we start counting the 2-itemsets before waiting for a complete scan of the database. In this way, DIC starts counting the 1-itemsets and then quickly adds counters for the 2,3,4,...k-itemsets. We will define this \( M \) as a checkpoint. DIC uses these checkpoints \( M \) transactions apart. DIC counts the frequent itemsets and the minimal small itemsets. Minimal small itemsets are those itemsets which form the boundary between the frequent itemsets and the infrequent ones. Their subsets are frequent itemsets. For every itemset, the counting stops from the same point from where it started i.e after one complete database pass. Thus an itemset can be considered for counting at the next checkpoint instead of waiting until the end of the previous pass.

If the data is fairly homogeneous and for small values of \( M \), DIC takes very few passes. If the data is non-homogeneous or it is very correlated, it may not be realized that an itemset is actually large until it has been counted in most of the database. This effect can be reduced considerably with randomizing the order of the transactions. The most important issue in the performance of any ARM algorithm is the type of data structure used to keep track of the many itemsets generated. Particularly the data structure should support the addition of new itemsets, the incrementation of counters of those itemsets and maintaining the itemset states as those that are being counted or active and those which have been counted over the entire database. When itemsets become large the counting of the supersets should be started. The incrementation of the counters has to be done efficiently otherwise the performance of the entire algorithm may degrade.

The data structure used in DIC is a trie in which each itemset is sorted by its items. Every itemset that has to be counted or has been counted has a node associated with it as do all of its prefixes. The empty itemset is the root node and every itemset is attached to the root node. All itemsets are attached to their prefixes containing all but their last item. Every node stores the last item in the itemset it represents, a counter, as to where in the file its counting was started, its state and its branches if it is an interior node. The branches point to the supersets of the itemsets. These operations are performed at every checkpoint.

III. DISTRIBUTED ASSOCIATION RULE MINING

In centralized data mining the main concern for the efficiency of a data mining algorithm is its I/O and CPU time. The I/O time is the number of disk reads or the number of passes of the database made by the algorithm. In a distributed environment the communication cost is added which is determined by the network bandwidth and the number of messages that are sent across the network. Count Distribution, Data Distribution, Candidate Distribution [4], ODAM(An Optimized Distributed Association Rule Mining Algorithm) [5], [6], [7] are a few of the modified versions of Apriori. [8] is a distributed algorithm based on Sampling.

The Count Distribution (CD) algorithm focuses on minimizing communication. In the first pass, each processor dynamically generates its local candidate set depending
on the items actually present in its local data partition. Hence candidates counted by different processors may not be identical. Each processor exchanges local counts to develop global candidate counts. C_k is a set of candidate _k-itemsets or potentially frequent itemsets where 1 ≤ k ≤ N and N is the number of nodes in the distributed network. After each scan each processor broadcasts C_k and synchronization takes place at this step. L_k, a set of frequent _k-itemsets or itemsets with minimum support is now generated from C_k. Each processor then decides to terminate or continue to the next pass and as all processors have the same L_k, this decision will be identical. Thus every processor scans its local data asynchronously in parallel and synchronizes at the end of each pass to develop global counts.

In the Data Distribution algorithm, each processor counts mutually exclusive candidates. Thus as the number of processors is increased, a large number of candidates can be counted in one pass. On a _n-processor configuration, Data Distribution will be able to count in a single pass a candidate set that would require _n passes in CD. The first pass of the algorithm is the same as CD where all the candidate 1-itemsets are counted. For all passes greater than 1, processor _P_i, where 1 ≤ i ≤ _N generates C_k from _L_i(−1). _P_i retains only 1/ _N_th of the itemsets, that it will count. If candidate set C_k generated by _P_i is C_k then all such C_k are disjoint and their union is the original C_k. Processors exchange _L_k so that every processor has the complete L_k for generating the candidate itemset C_k+1 for the (k + 1)_th pass. The drawback of this algorithm is that every processor must broadcast its local data to all other processors in every pass.

The Candidate Distribution algorithm partitions the data and candidates in such a way that each processor may proceed independently. In some pass _l, where l can be determined heuristically, the frequent itemsets _L_l=−1 are divided between processors in such a way that a processor generates a unique candidate set irrespective of the other processors. Till pass _l, Candidate Distribution behaves similar to Count or Data Distribution. At the same time data is repartitioned so that a processor counts its candidate set independently. No communication of counts or data tuples is done except for pruning the local candidate set. This information is sent asynchronously and processors do not wait for complete information to arrive. Each processor opportunistically starts counting the candidate sets using whatever information has arrived. Experimentation involving Count Distribution, Data Distribution and Candidate Distribution [4] has shown that Count Distribution (CD) outperforms the other two. We have compared our algorithm against CD.

IV. OPTIMISTIC MESSAGING DIC

We present a distributed algorithm based on DIC namely Optimistic Messaging DIC (OPT-DIC). OPT-DIC runs DIC at each node. DIC reads _M transactions and performs all operations of incrementation of the counters and adding supersets of items which become frequent.

We call every _M (which may vary for each node, depending on the size of the database), in OPT-DIC, a checkpoint.

In this algorithm we also send and receive messages at this checkpoint. At each node at every checkpoint, messages in the incoming queue are checked for counts of itemsets which have become potentially frequent at other sites. If counting for those itemsets has not begun at that node, it begins counting for that itemset.

With this step we would like to mention that OPT-DIC starts counting only those itemsets which have become locally frequent at at least one node. This reduces the number of candidates which may ultimately not contribute to the frequent itemset generation.

The node sends messages at checkpoints regarding the counts of itemsets which can be potentially frequent without waiting for complete counting of that itemset. Because of this particular aspect of the algorithm, we describe the algorithm as an optimistic messaging distributed algorithm. This initiates early counting of that itemset at other sites. The main advantage of this algorithm is that it does not wait to synchronize with the other sites. It reports the potential candidate itemsets as soon as they turn potentially frequent at the next checkpoint. This leads to a significant reduction in the number of passes of the database as compared to CD.

A. Description of OPT-DIC

In OPT-DIC every site needs to maintain certain information with respect to every other site. To maintain this information, the messages used in OPT-DIC are:

1. _T_i - number of transactions present at node _N^i
2. _C_i_candidate - candidate itemset at node _N^i
3. _C_i_inter - candidate itemset with its intermediate local count at node _N^i
4. _C_i_final - candidate itemset with its final local count at node _N^i
5. _F_i - Final message at node _N^i, indicating completion of counting.

Initially each node broadcasts message _T_i, sending its number of transactions to every node. DIC is run locally at every node. Each node initiates counting of an itemset _I at the (n-1) other nodes, if that itemset looks potentially frequent at its site. It does so by broadcasting a message _C_i_candidate at the next checkpoint. After receiving the counts, it can locally decide whether _I is globally frequent or not. Each node _N^i maintains information associated with each itemset _I to indicate whether it is locally frequent or infrequent and globally frequent or infrequent or unknown. The messages to be broadcast are maintained in a message queue _Q_out and broadcast at the next checkpoint. All incoming messages are kept in an incoming message queue _Q_in. When a node _N^i counts the itemset _I over the entire database and if _I is locally or globally frequent, a message _C_i_final with the count of _I is generated at _N^i. If no itemsets are to be counted locally,
If messages are sent at every checkpoint and if there are l such checkpoints and if we are grouping messages for every checkpoint, then (n-1) such messages will be sent at every checkpoint by each site, if there are n such sites. The number of these checkpoints will also depend on the number of database scans i.e if we have l such checkpoints in one database scan and an average of p such scans and if $C^i_j$ are the average number of candidate sets generated at the $i^{th}$ checkpoint by site $j$ then the message complexity in the worst case will be:

At the $i^{th}$ checkpoint the number of messages are:

$$(n - 1) \times C^i_j$$

Total messages in one pass:

$$(n - 1) \times \sum_{i=1}^{l} C^i_j$$

It is not necessary that at every checkpoint a message is generated. We consider the worst case here, where we consider a message at every checkpoint and average candidate sets as $C^i_j$.

If $p$ (where $p$ can be a non-integer) is the number of database scans, the number of messages broadcast by each node in the worst case are:

$$p \times (n - 1) \times \sum_{i=1}^{l} C^i_j$$

C. The Algorithm

The basic essence of DIC lies in the fact that counting for itemsets starts very early. At every checkpoint, all itemsets which have become locally frequent are marked so. These have become frequent recently, they are not marked frequent by any other site (indicated by a message from any other site initiating counting for that itemset). Such itemsets are broadcast to the other sites to initiate counting at the other sites. Thus counting is initiated at all sites only if an itemset becomes frequent at at least one site.

The OPT-DIC algorithm retains the basic essence of DIC in the distributed version in terms of communicating the itemsets at the next checkpoint when they become likely candidates locally. This helps the other sites in starting the counting for those itemsets, if counting for them has not already been started. This is done at the next possible checkpoint. In the worst case the communication complexity is such that there is a message broadcast at every checkpoint. So if $D$ is the size of the database, $M$ is the interval which represents the number of transactions between two checkpoints, $D/M$ will represent the number of checkpoints. If $N$ is the number of nodes and $p$ is the number of passes the message complexity in the worst case will be $D \times (N-1) \times p/M$. To reduce the number of messages the interval between checkpoints (the value of $M$) can be increased but many a times this adversely affects the performance as there is a delay in conveying the candidate itemsets which are locally frequent.

The disadvantage of CD and many Apriori-based algorithms is that the number of bytes transmitted increases rapidly with the number of nodes. This is also because a lot of globally infrequent but locally frequent candidate itemsets are broadcast between nodes. This factor is reduced to a great extent in OPT-DIC as a node starts counting an itemset only if it is frequent at at least one site. Without communicating with the other nodes CD proceeds with its entire database pass and then broadcasts the itemsets generated. This may contain many itemsets which may not contribute towards the global frequent itemset generation.

V. EXPERIMENTATION AND ANALYSIS

We have compared OPT-DIC and CD using a Discrete Event-based Simulator. We have tested Optimistic Messaging DIC and CD on the benchmark datasets namely...
mushroom dataset \cite{12}, the retail dataset and two synthetic datasets T10I4D100K and T40I10D100K generated from \cite{13}. The mushroom dataset is a multivariate, dense dataset with 8124 transactions, 119 items and an average transaction size of 23. The retail dataset is sparse with 16,470 items, 88,162 transactions and average transaction size of 10. The datasets T10I4D100K and T40I10D100K are sparse with 1000 items and 1,00,000 transactions each and the average transaction size as 10 and 40 respectively. The performance metrics we have considered are the total time taken, number of passes, number of diskreads, number of bytes and the number of messages. The number of diskreads take into account the number of passes so we have not elaborated on the number of passes.

From the above datasets, for T10I4D100K, we have experimented on the value of minimum support $\delta$ as 1\% and $M$ as 100. For T40I10D100K, we have taken $\delta$ as 4\% and $M$ as 100. For the Retail dataset, $\delta$ has been taken as 10\% and $M$ as 100. Since Mushroom is a dense dataset, we have taken a higher value of $\delta$ as 50\% and $M$ as 100. We have packetized the messages generated at the end of each pass in CD and at a checkpoint in OPT-DIC with a MTU of 1500 bytes and a header of 20 bytes. To calculate the disk access time we have considered the seek time (3 msec), disk latency time (2 msec) and disk transfer rate (1000 Mbps). To calculate time for transmission across the network, latency time (15 msec) and bandwidth (1 Mbps) have been considered. We now discuss the performance of the algorithms according to the above performance metrics on equipartitions and on gaussian partitions.

A. Results for Equipartitions

We have tested the results of the algorithm by equipartitions and on gaussian partitioning, i.e. to check the results on variable paritions as well as for similar partitions.

1. Total time taken: Due to the huge size of the database and the disk and network latency, time taken is heavily dependent upon the maximum number of passes and the number of messages transmitted. In case of CD, sites synchronize at the end of every pass. This makes the sites with minimum records wait for the sites with maximum records to send their counts. In case of OPT-DIC, none of the sites try to synchronize. They send messages but as long as there is data to be mined locally, they do not wait for messages from other sites.

From Figure 1 we observe that the time required for OPT-DIC for T10I4D100K is around 52\% less than that required for CD and this reduction in time is almost constant for an increase in the number of nodes. The time required for OPT-DIC for T40I10D100K is around 32\% less than that required for CD and this reduction in time is almost constant for an increase in the number of nodes. We have observed that the rate of reduction in time required for OPT-DIC as compared to CD for Retail is almost constant between 60 to 70\%. We observe that the rate of
reduction in time required for OPT-DIC as compared to CD for Mushroom increases with the increase in number of nodes.

(2) Number of diskreads: The number of passes in OPT-DIC are much less than those in CD as seen in figures 5 and 6. Local counts of all itemsets is always maintained. As a result if n globally frequent itemsets are not locally frequent at the same site, they would never be used to generate a candidate at the next level. Not only does this reduce the number of candidates but it can save up to one extra pass. All these factors reduce the number of diskreads. We observe that the diskreads in OPT-DIC are around 50% less than those in CD. This is a major component of the time required.

(3) Number of Bytes transmitted:
The number of bytes transmitted by CD in the first pass is quite high as it sends the counts and names of all the frequent 1-itemsets. In subsequent passes, only counts of all candidates are transmitted. Please refer to figures 7 and 8. In the case of OPT-DIC the count and name of each itemset with cardinality more than 1 is transmitted. But the number of candidate itemsets generated in CD are far more than those in OPT-DIC.

(4) Number of messages transmitted: By messages here, we mean the number of packets transmitted over the network. In case of OPT-DIC, if some itemsets have turned potentially frequent, messages are generated at that checkpoint. In the worst case, a message is broadcast at every checkpoint. Hence the number of messages is higher in OPT-DIC compared to CD. But though the number of messages is higher, OPT-DIC fares much better than CD in the time taken.

B. Results for Gaussian Partitioning

We have partitioned the database using the gaussian distribution which represents the actual distribution of data at various sites in an actual distributed setup. Using similar performance metrics as applied to equipartitioning, we
Figure 10. Messages generated for mushroom for $\delta = 50\%$ and $M=100$

Figure 11. Time taken for gaussian distribution of T10I4D100K $\delta = 1\%$ and $M=100$

Figure 12. Messages generated for gaussian distribution of T10I4D100K for $\delta = 1\%$ and $M=100$

analyse the results for gaussian partitions.

(1) Time taken: We observe that with gaussian partitioning the performance gain in terms of reduction in the time required in OPT-DIC is much higher than that with equipartitioning.

(2) Bytes transmitted:
The total bytes transmitted in gaussian partitioning show much reduction than in equipartitioning

(4) Messages transmitted: There is definitely a reduction in the number of messages in gaussian distribution for both CD as well as OPT-DIC but the messages in OPT-DIC are more than those in CD.

The above results show that OPT-DIC outperforms CD with respect to the time taken, the maximum number of diskreads and the total number of bytes transmitted. It transmits larger number of messages than CD but since the total time required by OPT-DIC is much lower the other parameters offset the impact of larger number of messages.

VI. CONCLUSION

In this paper, we have presented an algorithm, OPT-DIC, based on Dynamic Itemset Counting which represents a different approach to frequent itemset generation in a distributed ARM environment. We have observed that compared to CD, OPT-DIC shows much higher performance gain on sparse as well as dense datasets.

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Preeti Paranjape-Voditel is currently a Ph.D. candidate at The Department of Computer Science and Engineering, Visvesvaraya National Institute of Technology (VNIT), Nagpur, Maharashtra, India. She received her MTech in Computer Science and Information Technology from the Indian Institute of Technology, Kharagpur, West Bengal, India and BE in Electronics from Walchand College of Engineering, Sangli, Maharashtra, India. She is presently working as an Assistant Professor in the Department of Computer Applications, Shri Ramdeobaba Kamla Nehru Engineering College, Nagpur, Maharashtra, India. Her research interests include Distributed Data Mining, Algorithms and Databases.

Umesh Deshpande received his PhD in Computer Science and Engineering in 2005 from the Indian Institute of Technology, Kharagpur, West Bengal, India. He received his Masters from the Indian Institute of Technology, Bombay, Maharashtra, India and BE from Visvesvaraya National Institute of Technology (VNIT), Nagpur, Maharashtra, India. He is currently an Associate Professor in the Department of Computer Science and Engineering at Visvesvaraya National Institute of Technology (VNIT), Nagpur, Maharashtra, India. His current research interests include distributed systems, real-time operating systems, multi-agent systems and Data Mining.
A Constraint-based Test Suite Reduction Method for Conservative Regression Testing

Chang-ai Sun
School of Information Engineering, University of Science and Technology Beijing, Beijing 100083, China
Email: casun@ustb.edu.cn

Abstract—In regression testing, an important problem is how to select a smaller size of test set for execution. We present a novel constraint-oriented test suite reduction method for conservative regression testing by which we mean that all bugs discovered must be revealed by the reduced test suite. A test constraint for a bug is Boolean formulas defined over the input variables of program under test. The reduced test constraints for a pool of bugs are constructed using the subsumption relationship between test constraint conditions. Test case selection is based on the reduced test constraint set. A test case is selected into the test suite when and only when it satisfies one or more test constraints. The selection process is completed when all test constraint conditions are satisfied by the selected test cases. An empirical study is conducted and the experimental results show that our method can significantly save efforts for the conservative regression testing.

Index Terms—software testing, regression testing, test case reduction, test case selection

I. INTRODUCTION

In regression testing, one concern is to verify whether the detected bugs have been removed, and the other is to check whether new bugs are introduced during the modification [10]. This requires testers to re-execute a huge number of test cases developed in the previous stages. Software testing is a kind of an engineering activity, and must be conducted within the limited schedule, budget and human power, thus an important issue in regression testing is how to efficiently select test cases from a test set that have been developed using various test case generation strategies [13]. Lots of test suite reduction techniques have been developed, and they usually select test cases based on some criteria, such as control flow coverage [14], requirement coverage [3], dependency analysis [2] and so on [1], [10]–[13].

Conservative regression testing pays much attention to confirm that the reported bugs are removed. We describe a common scenario of conservative regression testing below. When a failure is detected, testers often record the inputs that cause the failure, the functional domain where the failure takes place, and the steps necessary for repeating this failure. With the reported information, programmers debug the relevant modules. This is an extremely challenging and time-consuming process, since the failure-causing input doses not reveal the true reason of the failure. Furthermore, more than one test case may trigger the same failure, programmers need to figure out all possible inputs that can trigger this failure even they have solved the failure with the reported inputs. In this situation, the problem arises that given a set of bugs reported by testers, how to select the minimum set of test cases that can trigger all of them. We view this as a kind of conservative regression testing, which is especially important for the hurry-up software release while the limited budget and schedule is allocated.

In this paper, we present a novel constraint-based test case reduction method for conservative regression testing. This method makes use of test constraint for test suite reduction. For a given bug of program $p$, a test constraint that is defined over input parameters of $p$ specifies the necessary conditions that the bug can be detected. In other words, to answer whether a test case can detect a specific bug, we only need to check whether the test case satisfies the test constraint of the bug. Test constraints can be derived through program analysis techniques. For a pool of bugs, we calculate the hierarchy of their test constraints and keep the stronger test constraints. Then the test case selection is based on the reduced constraint set. A test case is selected into the test suite when and only when it satisfies one or more test constraints. The selection process is completed when all constraint conditions are satisfied by the selected test cases. In this way, our method only selects a small subset of test suite for conservative regression testing. Our method does not need to run the program, because that a test constraint for a bug is derived through program analysis techniques; both test constraint reduction and test case selection for a constraint are conducted in the level of class rather than instance.

The main contributions of this work include:

- a method for deriving test constraint for a given bug,
- a test constraint oriented test case reduction strategy, and
- a case study on test suite reduction for a real life program using test constraint-oriented strategy.

The remaining of the paper is organized as follows. Section II presents the concept of test constraints and their construction. Section III discusses the construction of the test constraint hierarchy for a pool of bugs. Section IV
proposes to reduce test suite based on the test constraint hierarchy. Section V demonstrates the proposed method with a real-life program and reports the experimental results. Section VI discusses related work and compares our method with the exiting approaches. Section VII concludes the paper with pointing out future work.

II. TEST CONSTRAINTS AND THEIR CONSTRUCTION

All inputs of a program constitute the input domain of the program. If there is a bug with a program, it means there must be some inputs that can be used to detect the bug. These inputs are called failure-causing inputs and are part of the whole input domain. Then, how can we restrict the input domain into failure-causing inputs? We call such a restriction as a test constraint. A test constraint answers the question “why and how do the beginning statement influences the faulty statements, and why and how do the faulty statements influences to the statements which can produce different observable outputs”.

A. Test constraints

**Definition 1** (program under test). A program under test \( p \) is a three-tuple \( p = \langle I, O, S \rangle \) where \( I \) is a set of inputs, which can be represented by the parameter vector \( < V_1, V_2, \ldots, V_n > \), \( O \) is a set of operations, and \( S \) is a set of states. A state \( s \) of \( p \) is an instance of an input vector \( < v_1, v_2, \ldots, v_n > \) where \( v_1 \in V_1, v_2 \in V_2 \) and \( v_n \in V_n \). \( S_{init} \in S \) and \( S_{final} \subseteq S \) are initial state and final states of \( p \), respectively. An operation \( o \in O \) is the transformation between states \( s_i \in S \) and \( s_j \in S \), namely \( s_i \xrightarrow{o} s_j \). Note that a final state refers to the one that produces observable outputs, including returning a value or printing out a message.

**Definition 2** (faulty version) A mutant \( f \) of a program \( p \) is said to be a faulty version, when there exist inputs \( x \) s.t. \( x \in I^p \) and \( x \in I^f \) where \( I^p \) and \( I^f \) are the inputs of \( p \) and \( f \), such that \( S_{final}^p \neq S_{final}^f \) where \( S_{final}^p \) and \( S_{final}^f \) are the final states of \( p \) and \( f \), respectively.

An example of a faulty version is illustrated in Figure 1 where an operator fault occurs in line 4. For the program \( p \), its input consists of four parameters: the first two are of integer, while the last two are of bool. The operations of \( p \) are a set of assignment, logic and relation operations. The final state of \( p \) is represented by the output, i.e. the value of variable \( alt\_sep \). Obviously, not all test cases can reveal the bug illustrated in Figure 1. For example, when the test case \( < 1, 1, 1, 1 > \) is used as an input, both the original program and the faulty version produce an output of 0. The bug is not revealed because the faulty operation is not activated.

**Definition 3** (trigger-condition). The input set \( bti \subseteq I^f \) which can trigger the bug \( b \) is called bug-trigger inputs, and the condition which can restrict the whole inputs \( I^f \) to \( bti \) is called trigger-condition.

The trigger-condition for the bug shown in Figure 1 is “\( !\text{preflag} \)”, and its bug-trigger inputs can be expressed as \( \{ < x, y, 0, z > | x \in \text{all possible values of own_alt}, y \in \text{all possible values of other_alt}, z \in \{0, 1\} \} \). It intends to specify that \( \text{preflag} \) is restricted to be 0, and there are no constraints defined on \( \text{postflag} \), \( \text{own}_\text{alt} \) and \( \text{other}_\text{alt} \).

**Definition 4** (Propagation-Condition). The input set \( fpi \subseteq I^f \) which can guarantee different outputs for \( f \) and \( p \) after the bug \( b \) is triggered is called fault-propagation inputs, and the condition which can restrict the whole inputs \( I^f \) to \( fpi \) is called propagation-condition.

As to the bug shown in Figure 1, the propagation-condition for the bug is “\( \text{own}_\text{alt} == \text{other}_\text{alt} \)” and “\( \text{postflag} \)”. Its fault-propagation inputs are \( \{ < x, y, z, 1 > | x \in \text{all possible values of own}_\text{alt} \land y \in \text{all possible values of other}_\text{alt} \land x == y \land z \in \{0, 1\} \} \).

**Definition 5** (Test Constraint). Given a faulty version \( f \) of a program \( p \), i.e. a bug \( b \) is seeded into \( p \), the test constraint of \( b \) is a set of constraints that are used to identify all possible inputs that can guarantee the detection of the bug \( b \). The intersection of \( btpc(b) \) and \( fppc(b) \) is necessary part of test constraint of the bug \( b \). Here, \( btpc(b) \) and \( fppc(b) \) are the trigger-condition and propagation-condition of the bug \( b \), respectively.

The test constraint for the bug in Figure 1 is “\( !\text{preflag} \)”, “\( \text{own}_\text{alt} == \text{other}_\text{alt} \)” and “\( \text{postflag} \)”. The test suite satisfying the test constraint is \( \{ < x, x, 0, 1 > | x \in \text{all possible values of own}_\text{alt} \land \text{all possible values of other}_\text{alt} \}, < 5, 5, 0, 1 > \) is a test case that satisfies test constraint of the bug.

B. Constructing test constraints

We employ program analysis techniques, including slicing [16], chopping [6], and path condition [8], to obtain the trigger-conditions and propagation-conditions of a test constraint.
Definition 6 (Program Slicing). Given a statement $t$ in a program $p$, a set of statements slicing $(s) = \{s_1, s_2, \cdots, s_n\}$ is extracted to form the slice of the statement $t$, where $t$ is called the slicing criteria, $s_i$ is a sentence which potentially has an influence onto the statement $t$ (i.e. its execution affects the state $s_i^p$ of program $p$ at the statement $t$), denoted as $s_i \rightarrow t$.

The slices of statements $10$ and $14$ in the program in Figure 1 are slicing$(10) = \{2, 3, 4, 5, 6, 7, 9\}$ and slicing$(14) = \{2, 3, 4, 5, 6, 7, 9, 11, 13\}$, respectively. Note that the program slicing defined here is a kind of static slicing, and therefore the line number is used for reference to a statement.

Definition 7 (Program Chopping). Given a source criterion $s$ and target criterion $t$ in a program $p$, the chopping$(s, t) = \{s_i | s_i \in s \rightarrow t \land s \in p \land t \in p\}$, where $s \rightarrow t$ is referred to as the path from $s$ to $t$.

The choppings of statement $5$ to statements $10$ and $14$ in Figure 1 are chopping$(5, 10) = \{5, 6, 7, 9\}$ and chopping$(5, 14) = \{5, 6, 7, 9, 11, 13\}$, respectively. Statements in source criterion or target criterion are often replaced by criteria $(s, t)$, where $s \rightarrow t$ is referred to as the path from $s$ to $t$. Given a statement $5$ in a program with only one single faulty statement, we need to restrict the inputs to fall in the offset caused by the fault in terms of input domain, denoted as $Offset(b)$. Figure 2 illustrates such an offset. When $x < 3$ or $x \geq 5$, the variable $i$ is assigned to the same value in both the faulty version and the correct version. When $3 \leq x \leq 5$, the variable $i$ is assigned to $0$ in the faulty version, while $1$ in the correct version. Thus, the $offset(b)$ is $3 \leq x \leq 5$. As to the bug in 1, the upward is $0$ in the original program when $other\_alt$ is equal to $other\_alt$, while $1$ in the faulty version. $Offset(b)$ is that $other\_alt = own\_alt$ needs to be evaluated to be true.

Since the test constraint of a bug $b$ is the intersection of bug-triggering trigger-conditions and fault-propagation propagation-conditions, the test constraint $ts(b)$ of the bug $b$ is equivalently the combination of $Path\_Conditions(BS, s)$, $offset(b)$ and $path\_conditions(s, ES_i)$ $(i = 1..n)$, where $BS$ is the beginning statement of program $p$, $ES_i$ is one of the end statement set $ES$, $s$ is the statement where the bug $b$ occurs. In order to be efficient, the calculation of path conditions can be executed based on their slicings and choppings. Slicing$(s)$ indicates the statements which affect the execution of $s$. Chopping$(s, t)$ indicates the possible fault propagation paths from the source $s$. The test constraint for the bug in Figure 1 can be calculated using $path\_conditions(1, 3)$, $path\_conditions(5, 10)$ and $offset(b)$, and the result is $pre\_flag = false \land post\_flag = true \land other\_alt = own\_alt$.

We propose algorithm 1 in Figure 3 to construct test constraints. It makes use of slicing, chopping and path conditions in an integrated way. The algorithm assumes that the program under test is a $C$ program with only one single function and with only one single faulty statement, and consists of assignment, branch, goto and return statements. The algorithm first constructs a PDG of program $p$, where the entry statement, faulty statement and output statements can be mapped into different nodes; it then constructs bug trigger chopping (between entry statement and faulty statement) and fault propagation choppings (between faulty statement and output statements); finally, it calculates trigger-conditions and propagation-conditions. Since how to construct a PDG of a program $Construct\_PDG(p)$, program slices $Construct\_Slice(s, t)$, program chops $Construct\_Chopping(s, t)$ and path conditions $Construct\_PathConditions(s)$ are well discussed, we will not extensively discuss these issues. For details, the interested can refer to [6], [8], [13].

The procedure $get\_OffsetCondition(sc)$ as illustrated in Figure 4 returns the $Offset(sc)$ of a mutant $sc$ (i.e. a bug).
Algorithm 1 Test Constraint Construction for a Single Fault TS_Construction(p, sc, ts)

\{
    \textbf{INPUT} \\
    p: \{s_i|\text{type}(s_i) \in \{\text{assignment, branch, goto, return}\} \land \ 1 \leq i \leq n\}; \text{Note that type (s_i) is type of statement s_i;}
    sc: s_i \xrightarrow{\text{mutation}} s'_i, \text{where s_i \in p, s'_i is a mutated statement;}
    
    \textbf{OUTPUT} \\
    ts: \{s_j|\text{type}(s_j) \in \{\text{true, false}\} \land \text{vars}(s_j) \subseteq \text{paras}(p) \land \ 1 \leq j \leq m\}; \text{Note that var}(s_j) \text{denotes a set of variables in c_s_j; paras(p) denotes a set of input parameter variables of program p.}

\textbf{PROCEDURE} \\
1) Initialise ts to \emptyset, the beginning statement of p to \text{s}_{\text{init}}, the output statement set to \text{s}_{\text{final}}, the input parameter variables to paras(p).
2) Construct a PDG of p using the procedure \text{Construct_PDG}(p), where PDG = \{\text{Nodes, Edges}\},
   - Note that for each s_i \in p, there exists a node n_k \in \text{Nodes}. For s_i \in p \land s_j \in p \land s_i \rightarrow n_k \wedge s_j \rightarrow n_m \wedge n_k \neq n_m, if there exists an edge t \in \text{Edges} between n_k and n_m, then there exists dependency between s_i and s_j. When constructing the PDG of a program, the mutated statement s'_i should be included in a separate node.
3) Map \text{s}_{\text{init}}, \text{s}_i and \text{s}_{\text{final}} to the nodes \text{N}_{\text{init}}, \text{N}_{\text{mutant}} and \text{N}_{\text{final}} in PDG, where \text{N}_{\text{init}} \in \text{Nodes, N}_{\text{mutant}} \in \text{Nodes, and N}_{\text{final}} \subseteq \text{Nodes}.
4) Construct program slices slice using the procedure \text{Construct_Slice(N}_{\text{init}}, \text{N}_{\text{mutant}}), and ts \leftarrow ts \cap \text{Construct_PathsConditions(slice)}.
5) ts \leftarrow ts \cap \text{get_OffsetConditions(sc)}.
6) For each n_i \in \text{N}_{\text{final}}, construct chops using the procedure \text{Construct_Chop(N}_{\text{mutant}}, n_i) and ts \leftarrow ts \cap \text{Construct_PathsConditions(chops = \{s_i\}).
7) Return ts.
\}

Figure 3. A sketch of Algorithm 1

Here, ts(\text{vars, v_{s_i}, v_{s'_i}}) := |\text{var}| \rightarrow \text{v_{s_i} v_{s'_i}}, where \text{v_{s_i} and v_{s'_i}} satisfy \text{assume}(s(\text{v_{s_i}/}\text{var})) \oplus \text{assume}(s(\text{v_{s'_i}/}\text{var})). Note that \text{assume}(s(y/x)) is referred to as that all the occurrences of x in statement s are substituted by y which is a set of feasible values of variable x. \text{assume}(s) is defined as follows.
\begin{align*}
    \text{assume}(s) = \begin{cases}
        \text{var} \Rightarrow \text{exp}; & \text{if s is an assignment statement like vari = exp} \\
        \text{var op exp}; & \text{if s is a branch statement like if(\text{var op exp}) where} \\
    \end{cases}
\end{align*}

Algorithm 1 can apply to normal C programs through pre-processing. Like slicing execution [19], we can inline the function body at every function call site to get an equivalent C program with only one function, and use if and goto statements to rewrite all loops in C program.

Procedure get_OffsetConditions(sc)

\{
    \textbf{INPUT} \\
    sc: s_i \xrightarrow{\text{mutation}} s'_i.
    
    \textbf{OUTPUT} \\
    \text{dts:}\{s_j|\text{type}(s_j) \in \{\text{true, false}\} \land \text{vars}(s_j) \subseteq \text{paras}(p) \land \ 1 \leq j \leq m\};

    \textbf{PROCEDURE} \\
1) dts \leftarrow \emptyset.
2) foreach \text{var} in \text{vars}(s_i) \cap \text{paras}(p) \cap \text{vars}(s'_i), \text{where vars}(s_i) and vars(s'_i) are variables in statements s_i and s'_i, respectively, dts \leftarrow dts \cap \text{ts}(\text{var, v_{s_i}, v_{s'_i}}).
3) Return dts.
\}

Figure 4. The sketch of Procedure get_OffsetConditions.

After rewriting, the C program has only one function and is composed of assignment, branch, goto and return statements.

We assume the faulty version contains only one bug when the faulty version is compared with the original one, as illustrated in Figure 1. Actually, we can extend the test constraint of a single fault to the one containing multiple faults. A faulty version f of the program p contains bugs b_1, b_2, \ldots, b_n, t_{c_1}, t_{c_2}, \ldots, t_{c_n} is the test constraint of bugs b_1, b_2, \ldots, b_n, respectively. Each test constraint t_{c_i} for a single fault can be derived using Algorithm 1. Then test constraint for this faulty version (composite of bugs b_1, b_2, \ldots, b_n) is \bigcup_{i=1}^{n} t_{c_i}. Hereinafter test constraints may be referred to as test constraint for single or multiple faults unless otherwise indicated.

III. CONSTRUCTING TEST CONSTRAINT HIERARCHY

For a given bug of a program, we can obtain its test constraints using program slicing, chopping and path conditions as discussed in Section II. Repeatedly, we can obtain a set of test constraints for a pool of reported bugs. Each test constraint specifies the conditions that can guarantee the detection of the targeted bug in a program under test. In other words, test constraints restrict the selection of test cases to the particular area of input domain of the program. Sometimes, test cases a and b have overlapping in the input domain. This means that test constraints of different bugs may have hierarchical constraint conditions.

A test constraint is a Boolean formula. The operators between two constraint conditions in a test constraint are disjunctive (\lor), conjunctive (\land) and not (!) and parentheses. We can transform a test constraint ts in a general form to one ts' in disjunctive normal form (DNF) using the distributive law. Each term in the resulting test constraint ts' is a feasible test case schema, which is referred to as that a test case satisfying this schema must be able to detect the fault on which ts is constructed. Each literal in a term is an atomic constraint condition. For example,
the atomic constraints defined on input parameter \( x \) of program \( p \) may be \( x \geq a \) where \( a \) is a constant, or \( x \leq y \) where \( y \) is another variable or input parameter. If more than one literal is defined on the same input parameter \( x \), then these literals are the composite constraint condition for \( x \). For example, \( x \geq a \lor x \geq b \) and \( x \geq a \land x \leq b \) (\( a \) must be less than \( b \); otherwise, it is an unsatisfiable constraint) are two composite constraints for \( x \).

**Definition 9 (null constraint condition).** For an input parameter \( x \) of a program \( p \), if there does not exist a test constraint condition defined on \( x \), we say \( x \) has a null constraint.

**Definition 10 (stronger constraint condition).** \( c_1 \) and \( c_2 \) are two constraints defined on the input parameter \( x \), \( c_1 \) is said to be stronger than \( c_1 \) (denoted as \( c_1 \succ c_2 \), if and only if, any value \( v \) satisfying \( c_1 \) must satisfy \( c_2 \).

A null constrain is the weakest constraint. A stronger constraint restricts the qualified values to smaller scope. For example, \( x > 5 \) and \( x > 7 \) are two constraints on \( x \), then \( x > 7 \) is stronger than \( x > 5 \).

**Definition 11 (test constraint subsumption) \( ts_1, ts_2 \) are two test constraints of program \( p \), and \( V_1, V_2, \ldots, V_n \) is a set of input parameters of \( p \), for all \( V_i (1 \leq i \leq n) \), \( C(V_i) \) and \( C'(V_i) \) are constraints on input parameter \( V_i \) in test constraints \( ts_1 \) and \( ts_2 \), respectively. If \( C(V_i) = C'(V_i) \) or \( C(V_i) \succ C'(V_i) \), then we say \( ts_1 \) subsumes \( ts_2 \) (denoted as \( ts_1 \succ等于 ts_2 \)).

Based on the hierarchy among test constraints, we propose the following strategies for test constraint reduction.

1) **Strategy-I:** If constraint condition \( c_1 \) is stronger than constraint condition \( c_2 \) (i.e. \( c_1 \succ c_2 \)), \( c_1 \) will restrict input domain to a smaller input domain than \( c_2 \), \( c_1 \) is selected as the reduced constraint.

2) **Strategy-II:** If test case schema (a term in a test constraint) \( tcs_j \) subsumes test case schema \( tcs_2 \) (i.e. \( tcs_j \succ等于 \( tcs_2 \)), \( tcs_j \) is selected as the reduced test constraint.

We propose Algorithm 2 in Figure 5 to reduce test constraints based on the above reduction strategies. The algorithm assumes that a set of test constraints of all known bugs has been derived in DNF. The body of the algorithm is composed of two passes: the first pass reduces each test constraint by the concept of stronger constraint, and the second pass reduces the set of test constraints by the concepts of test constraint subsumption. The algorithm returns a reduced test constraint set. Note that the algorithm cannot guarantee that the output is a smallest size of test constraints, \( constraint(v_k, t_j) \) denotes the constraint conditions of term \( t_j \) defined on the variable \( v_k \), \( t_j \)/(\( -c_2 \)) denotes all occurrences of \( c_2 \) in \( t_j \) are replaced by null.

**IV. TEST SUITE REDUCTION VIA CONSTRAINT HIERARCHY**

If there are common test constraints between two bugs, we can merge the test constraints. The test cases that satisfy the reduced test constraints can still guarantee the detection of the two bugs. In practice, a software bug

**Algorithm 2. Test Constraint Reduction TS_Reduction**

\( ts_0, ts_r \)

**INPUT**

\( ts_0 : \{ ts_i | ts_i \) is a test constraint in DNF \( \land 1 \leq i \leq n \}; \)

**OUTPUT**

\( ts_r : \{ ts'_i | ts'_i \) is a constraint in DNF \( \land 1 \leq j \leq m \}; \)

**PROCEDURE**

1) **foreach** test constraint \( ts_i \in ts_0 \) using Strategy-I.

   - **foreach** term \( t_j \in ts_i \) 
     - **foreach** variable \( v_k \) in \( paras(p) \) 
       - **foreach** constraints \( c_1 \in constraint(v_k, t_j) \land c_2 \in constraint(v_k, t_j) \land c_1 \neq c_2 \) 
         - If \( (c_1 \succ c_2) \)  
           - \( t_j \leftarrow t_j \) \( (-c_2) \).
         - \} 
     - **foreach** terms \( t_1 \in ts_i \) and \( t_2 \in ts_i \land t_1 \neq t_2 \) 
       - If \( (t_1 \prec t_2) \)  
         - \( ts_i \leftarrow ts_i \) \( (-/2) \).
   \} 

2) \( ts_r \leftarrow ts_0 \).

3) **foreach** term \( ts'_i \in ts_r \) and \( ts'_j \in ts_r \) 
   
   - If \( \exists t_1, t_2 \in ts'_i \land t_2 \in ts'_j \land t_1 \prec t_2 \) 
     - \( ts_r \leftarrow ts_r \) \( \{ ts'_j \} \).
   \} 

4) **Return** \( ts_r \).

**END**

**Figure 5. A sketch of Algorithm 2.**

library usually consists of a number of reported bugs and test cases. Ideally, all those test cases should be re-executed to verify whether all reported bugs are removed from the program under test. This is often impractical. Instead, we need to select test cases for execution from the pool of test cases that have been developed before regression testing.

We propose the following procedure to select test cases based on the reduced test constraint set \( ts_r \).

1) **Initialise** an empty test case set \( TestSuite \), and an empty satisfied test constraint set \( SatTC \).

2) For all test cases \( tc_i \) in the test case pool \( tcp \), figure out the number \( sts_i \) of test constraints \( ts'_i \) in \( ts_r \) which \( tc_i \) can satisfy.

3) Select the test case \( tc_m \) whose \( sts_m \) is the largest among the remaining test cases in \( tcp \). \( tcp \leftarrow tcp \) \( \{tc_m \}, TestSuite \leftarrow TestSuite \cup \{tc_m \}, SatTC \leftarrow SatTC \cup \{tc_m \} \)

   - Note that \( GetSatTC(tc_m) \) denotes the set of test constraints \( ts'_i \) in \( tcp \) which test case \( tc_m \) can satisfy.

4) **Repeat** Steps 2 and 3 until \( tcp \) is null or the size of \( SatTC \) does not increase any longer.

5) **Return** \( TestSuite \).
reported bugs are detected by the selected test cases; if latter, it means that new test cases need to be constructed to satisfy the remaining test constraints.

Although the proposed method is intended to reduce the size of test cases and selects test cases from a test case library, it can be also used to guide the generation of high-quality test cases for regression testing. This is totally different from those generating test cases from software code or specifications because our method generates test cases on the basis of test constraints. This is particularly useful to design test case for those hard-to-detect bugs provided that test constraint hierarchy exists.

V. CASE STUDY

In this section, we report a case study which is used to validate feasibility and efficiency of the proposed method.

A. Experiment Settings

Subject program. TCAS is an aircraft collision avoidance system developed by the researchers at Siemens. TCAS consists of 138 executable lines of C code in 9 modules. It has 12 input parameters: 5 of them are of Boolean type and 7 are of Integer. We select TCAS as subject program since it has been widely used for empirical study in several literature [5], [7], [9], [14], [15], [17].

Faulty versions. For TCAS, 41 faulty versions have been created by manually seeding "realistic" faults into the base program that is considered correct, and each fault involves single or multiple line changes when compared with the base program [5], [14].

Test suite. The test case pool has 1608 test cases which has been constructed with two steps: a test suite first generated by employing Category Partition Method, and then additional test cases are appended to the test suite to ensure that several kinds of unit coverage in the base program and faulty versions were exercised by at least 30 tests [5], [14].

B. Test suite reduction via test constraints

For each faulty version, we first locate the place where the fault is seeded, and then develop the test constraint using the proposed method in Section II. Finally, we obtain 41 test constraints.

As an illustration, faulty version 6 has an operator error in line 104 where the less than operator (i.e. “<”) is mistakenly replaced by the less than or equal to operator (i.e."\leq"). The corresponding test constraint is illustrated in Table I. Atomic constraint condition is represented by a Boolean literal, which usually defines a relationship over one or more input parameters. Composite constraint conditions are represented by a Boolean expression consisting of one or more atomic constraint conditions. The test constraint of faulty version 6 is composed of 4 atomic constraint conditions (i.e. No. 1, 4, 5 and 6 in Table I) and 3 composite constraint conditions (i.e. No. 2, 3 and 7 in Table I).

For the 41 faulty versions of TCAS, we achieved 17 atomic constraint conditions (such as No. 1, 4, 5 and 6 in Table I and 37 composite constraint conditions (such as No. 2, 3 and 7 in Table I), respectively. We further construct the test constraint hierarchy using the concept and strategy in Section III and then employ the test constraint reduction algorithm to reduce the size of test constraint set and obtain 26 reduced test constraints.

Among these 1608 test cases, 1076 valid test cases are accepted and processed by the program. We use the procedure discussed in Section IV to select 26 test cases from 1076 valid test cases. The selected test cases can satisfy the reduced test constraints. For each faulty version, at least one test case can detect the seeded fault. This means that if one wants to confirm whether all seed faults are removed, he just needs to execute these 26 test cases.

C. Results and threats

Experimental results are very exciting since only about 2 percent of test cases are selected for execution for the purpose of conservative regression testing. Besides the test suite reduction efficiency, we also discover that there exists test constraint hierarchy among these 41 seeded faults. For example, test constraints of the faulty version 6 subsume test constraints of the faulty versions 10, 11, and 31. In other words, it is more difficult to detect the bug in the faulty version 6 than in the faulty versions 10, 11 and 31. This preliminary empirical study has shown the feasibility and efficiency of the proposed method.

VI. RELATED WORK

Various test suite reduction methods have been developed [13]. Below, we describe several typical work and compare them with our method.

<table>
<thead>
<tr>
<th>No</th>
<th>Atomic/Composite constraint conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Other_Tracked_Alt = Own_Tracked_Alt</td>
</tr>
<tr>
<td>2</td>
<td>Down_Separation &lt; 400 ∧ All_Layer_Value = 0 ∨</td>
</tr>
<tr>
<td></td>
<td>Down_Separation &lt; 500 ∧ All_Layer_Value = 1 ∨</td>
</tr>
<tr>
<td></td>
<td>Down_Separation &lt; 640 ∧ All_Layer_Value = 2 ∨</td>
</tr>
<tr>
<td></td>
<td>Down_Separation &lt; 740 ∧ All_Layer_Value = 3</td>
</tr>
<tr>
<td>3</td>
<td>Climb_Inhibit = 1 ∧</td>
</tr>
<tr>
<td></td>
<td>Up_Separation + 100 &gt; Down_Separation ∨</td>
</tr>
<tr>
<td></td>
<td>Climb_Inhibit = 0 ∨</td>
</tr>
<tr>
<td></td>
<td>Up_Separation &gt; Down_Separation</td>
</tr>
<tr>
<td>4</td>
<td>High_Confidence = 1</td>
</tr>
<tr>
<td>5</td>
<td>Own_Tracked_Alt_Rate ≤ 600</td>
</tr>
<tr>
<td>6</td>
<td>Cur_Vertical_Sep &gt; 600</td>
</tr>
<tr>
<td>7</td>
<td>Other_Capacity! = 1 ∨ Other_Capacity == 1 ∧</td>
</tr>
<tr>
<td></td>
<td>Two_of_Three_Reports_Valid = 1 ∧ Other_RAC = 0</td>
</tr>
</tbody>
</table>
Program-based test suite reduction methods select a subset of test cases from original test set using some criteria on programs. Harrold and Rothermel [14] presented a test suite reduction technique using the control-flow coverage as selection criteria. Wu et al. [18] presented a regression testing technique that selects test cases by utilizing static information from the analysis of the program structure and dynamic information by tracing the function-calling sequences.

Specification-based test suite reduction methods use system requirements to select test cases for regression testing. Chittimalli and Harrold [3] presented a regression test selection approach using system requirements along with their associate test cases and their criticality. Paul et al. [12] presented a scenario-based functional regression testing technique.

Model-based test suite reduction methods first model programs or specifications and then select test cases for regression testing using some criteria over the model. Chen et al. [2] proposed a test suite reduction technique using extended dependency analysis. Ali et al. [1] developed a test case selection technique that is based on an extended concurrent control flow graph generated from UML class diagrams and sequence diagrams.

Architecture-based test suite reduction methods make use of architecture information to guide test case selection for regression testing. Muccini et al. [10] explore how regression testing can be systematically applied at the software architecture level in order to reduce the cost of retesting modified systems. A model differencing technique that is used to implement architecture-level regression testing is reported in [11].

The test suite reduction method presented in this paper belongs to the program-based category. However, our method is completely different from existing program-based test suite reduction approaches in that our method is based on test constraints that are Boolean formulas defined on the input parameters of a program; thus our method itself does not concern the structure or data flow of the program although calculating test constraints needs to analyze the program, our method does not need to run the program in order to select test cases for regression testing, and our method reduces test suite at the level of constraints instead of test case instances.

**VII. CONCLUSIONS AND FUTURE WORK**

We have presented a test constraint-oriented test suite reduction method for selecting a smaller size of test suite for conservative regression testing. The method consists of construction of test constraints for each bug, reduction of test constraints according to their hierarchy for a pool of bugs, and selection of test cases based on the reduced test constraints. A test constraint can be derived via program slicing, chopping, path conditions and sensitive data analysis techniques. A test case is selected into the test suite only when it satisfies one or more reduced test constraints. In this way, our method doesn’t need the execution of program under test, and selects the smaller size of test suite for regression testing. A case study has been conducted and the experimental results show the feasibility and efficiency of the propose approach.

For future work, we will seek the latest results from the area of symbolic executions and dataflow analysis, and leverage them for more experiments. The test constraint method analyzes the source code of programs under test and its success relies heavily on tool support for slicing, chopping and path conditions analysis. Another interesting topic is to verify the effectiveness when the proposed method is applied to unrestricted regression testing.

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**REFERENCES**


Chang-Ai Sun was born at Jiangsu, China in 1974. He received his Ph.D. degree in Computer Software and Theory from Beihang University in 2002; a bachelor degree in Computer Science from University of Science and Technology Beijing in 1997. His research areas are software testing, software architecture and service-oriented computing.

He is currently an Associate Professor in School of Information Engineering, University of Science and Technology Beijing, China. Before he joined University of Science and Technology Beijing, he was an Assistant Professor in School of Computer and Information Technology, Beijing Jiaotong University. From 2003 to 2007, he was a postdoctoral research fellow at the Faculty of Information and Communication Technologies, Swinburne University of Technology, Australia, and at Faculty of Mathematics and Natural Sciences, the University of Groningen, the Netherlands, respectively. In 2003, he worked as a Research Associate at Department of Computing, Hong Kong Polytechnic University. He has published more than 40 referred journal or conference papers in software engineering and service-oriented computing.

Dr. Sun is a member of IEEE, a senior member of China Computer Federation (CCF), an IBM Academic Initiative Member, a member of YOCSEF committee of CCF, a member of Experts Panel of Beijing Haidian District Scientific Committee, an International Reader of Australian Research Council, a Program Chair of TrustCom 2008, and a Program Committee member of more than ten international conferences.
A Content-based Classified Hierarchical Vector Quantization Algorithm for Volume Compression

Li-Ping Zhao¹, Guang-Xue Yue¹,²,³, De-Gui Xiao², Xu Zhou¹, Xiang Yu¹
¹School of Mathematics and Information Engineering, Jiaxing University, Jiaxing, Zhejiang, China
²School of Computer and Communication Engineering, Hunan University, Changsha, Hunan, China
³Department of Computer Science and Technology, Huaihua University, Huaihua, China
Email: zhaoliping.jian@126.com

Fei Yu
Jiangsu Provincial Key Laboratory for Computer Information Processing Technology, Soochow University, Soochow, China
hunanyufei@126.com

Abstract—An improved volumetric compression algorithm is presented in this paper. Histogram technique is used for analyzing the trait of volume data. The volume data is then partitioned into volume bricks which will be classified into two groups, the blocks with meaningless information as one group(also called empty blocks), and those with meaningful information as the other group(also called object blocks). An efficient hierarchical VQ is applied to compress object blocks while for empty blocks, nothing is saved. Compare with analogous Volume Compression algorithm, experimental results demonstrate the proposed algorithm not only can improve the compression rate significantly on the premise of the good quality of reconstruction image, but also can obtain fast decoding speed.

Index Terms—Vector quantization, volume Classify, Object blocks, Volume compression, GPU

I. INTRODUCTION

The rapid development of commercial graphics hardware has made it a reality nowadays to render volumetric datasets both in ultra high quality and at interactive frame rates. However, real-time rendering of a large volumetric dataset is still challenging due to the limitations in memory capacity and communication bandwidth (and delay). In the foreseeable future, datasets of further increased scale will be produced from the burst of data acquisition devices and numerical simulations [1]. Neither the memory capacity nor the communication channel, unfortunately, is expected to improve to such a level that the bottlenecks can be cleared.

Accordingly, CVR (Compressed Volume Rendering) [1-7], with the principle of coupling compression to rendering, has been proposed and has shown to be a practical solution for the issue of real-time rendering. Considering that a volumetric dataset has noticeable redundant information, the dataset is firstly compressed before being put into the memory or a GPU (Graphics Processing Unit), and then decompression and rendering can be done simultaneously at the GPU because it is equipped with some computing components. For a GPU, its SIMD (Single Instruction Multiple Data) architecture and parallel execution model, nevertheless, constrain the compression method that can be applied in CVR.

VQ (Vector Quantization) [2-6] is an ideal choice as an asymmetric coding scheme for CVR. In spite of the fact that the encoding of VQ is complex, the decoding is simple as it is essentially a single table look-up procedure. VQ has first been adopted in volume rendering for the purpose of compression by [2]. In the recent years, various VQ approaches have been applied in CVR domain, including HVQ (Hierarchical VQ) [3], CVQ (Classified VQ) [1, 4-5], TVQ (Transform VQ) [4] and their combined algorithms, such as CTVQ ( Classified Transform VQ) [4]. However, most existing VQ for CVR are Pixel-based compression algorithm [1-5]. MEPG-4 firstly introduced the content-based video/image compression algorithm. The key idea of MEPG-4 is that a scene can be divided into different AVOs (Audio Visual Object), for example the foreground AVOs and background AVOs, and which of those AVOs use different encoding methods. In this way, the objective of high compression ratio can be obtained on the premise of good quality of reconstruction image.

Inspired by the ideas of MEPG-4, in this paper we present a content-based volumetric compression algorithm which uses classified hierarchical VQ, hereafter abbreviated to CCHVQ (Content-based Classified Hierarchical VQ). This work extends our previous FCHVQ [5]. Compared with FCHVQ, firstly the histogram technique is used for analyzing the traits of volume data; secondly the classification scheme is content-based, in other words, total blocks are divided into two classes, one is empty blocks class (background) and the other is object blocks class (foreground); at last, different classes have different coding strategies. Specifically, our algorithm has the following particular properties:

- Memory efficiency: Note that the empty blocks is the meaningless part of the volume data, we set a flag for those blocks and save nothing for reconstruction. Many experiments show that more than 60% of blocks are empty blocks. Object
blocks are then vector quantized to achieve higher compression rate.

- Decoding efficiency: Different classes decode its different ways. Our decode speed of volume data can be faster as we waste no time on empty blocks. When decoding and rendering in GPU in future work acceleration techniques for GPU-based volume rendering, for example, empty space leaping [8,9] can be well used.

- Fidelity efficiency: The ultimate aim to volume rendering is to gain some meaningful information about the dataset. Our classified strategy let us focus on the object blocks. So, more details of object blocks can be retained to get fidelity efficiency.

In the following, we present related work in the context of compression for volumetric datasets (Section 2) and provide a rather brief introduction in the improved classical hierarchical VQ methods in Section 3. In Section 4, we introduce the examined datasets and present our compression results and Comparison. Finally, we conclude our paper in Section 5.

II. RELATED WORKS

VQ maps every k-dimensional input vector \( x \) to some reproduction vector \( \hat{x} \) selected from a finite codebook of \( M \) candidate vectors (i.e., code words), and encodes \( x \) by the index \( i \) of \( \hat{x} \). If \( M \) is small, then each index only requires a few (i.e., \( \log_{2}M \)) bits, thereby achieving the goal of compression. Dividing the size of original data by the size of compressed data, the result gotten is called the compression rate. Note that the size of compressed data is comprised of two parts, the size of indices (denoted by \( C_{\text{index}} \)), and the size of a codebook (denoted by \( C_{\text{codebook}} \)).

For example, given a volumetric dataset of \( N \times M \times K \) points, assuming that each point holds \( B \) bytes, the compression rate of VQ can be calculated by Eq. (1).

\[
VQ\text{-Rate} = \frac{N \times M \times K \times B}{C_{\text{index}} + C_{\text{codebook}}} \quad (1)
\]

Existing works on VQ mainly focus on increasing the compression rate, reducing distortion, and reducing the algorithm complexity [10]. For most existing algorithms, improvement on the compression rate tends to result in worse quality of the reconstructed image. In other words, better reconstructed image is often at the cost of the compression rate [3] and the algorithm complexity [4]. Detailed literature studies on VQ will be presented in the following.

A. Hierarchical VQ

Hierarchical VQ was described by Schneider et al [3] to get better image reconstruction quality. Specifically, starting with the original scalar field, the data is initially partitioned into disjoint blocks of size \( 4^3 \). Each block is decomposed into a multi-resolution representation, which essentially splits the data into three different triadic frequency bands. Therefore, each block is down-sampled by a factor of two by averaging disjoint sets of \( 2^3 \) voxels each. The difference between the original data samples and the respective down-sampled value is stored in a 64-component vector. The same process is applied to the down-sampled version, producing one single value that represents the mean value of the entire block. The \( 2^3 \) difference values carrying the information that is lost when going from \( 2^3 \) mean values to the final one are stored in an 8-component vector. Finally, a 1-component vector stores the mean of the entire block. In performing this task, the data is decomposed into three vectors of length 64, 8, and 1, respectively, which hierarchically encode the data samples in one block. In this way, HVQ, can reach good fidelity, however, much lower compression rate because each block should store the mean value of the block and two indices in order to reconstruct the whole block value.

Also, consider a volume with \( N \times M \times K \) data points and each point holds \( B \) bytes. The block size is \( n \times n \times n \), and the down-sample block size is \( (n/2) \times (n/2) \times (n/2) \), the compression rate of HVQ can be computed by (2). Because the codebook capacity is the same in HVQ, FCHVQ and CHCHVQ, so we just note by \( C_{\text{codebook}} \). For compassion convenience, size of codebook is 256. So each index need 1 byte (\( \log_{2}256,8 \) bits).

\[
HVQ\text{-Rate} = \frac{N \times M \times K \times B}{3 \times N \times M \times K / (n \times n \times n) + C_{\text{codebook}}} \quad (2)
\]

B. Flag Based Classified Hierarchical VQ

Regarding image compression, it should be pointed out that some of the blocks contribute more to the visual quality of the final image, while the others make little contributions [4]. To address this issue, all the blocks need to be classified into different groups, with each group being quantized separately, thereby guaranteeing their presence in the code vector population. Classification of blocks is more important in the case of volumetric compression due to arbitrary nonlinear mapping of the transfer function. In addition, classification of blocks allows the encoder to adapt to a volumetric dataset containing various perceptually important features (e.g., surfaces, boundaries, etc.). Therefore, most literature works adopted the idea of classification for the goal of obtaining better performance [2,4].

FCHVQ (Flag based classified hierarchical VQ) [5] was described by us to get higher compression rate and faster decoding speed in addition to good fidelity. In particular, the volume data set is first divided into smaller regular blocks and then divided into two classes according to whether its average gradient value is zero or not. We focus on the Classification strategy of FCHVQ algorithm. Clearly, if the block with data that they have the same values, it will belongs to the zero average gradient class. While the block with data that they have much different value, it will belongs to the non-zero average gradient class. Suppose the block size is \( 2 \times 2 \times 2 \), then there are 8 data values in a block. See Fig.1 for an illustration of the classification strategy.
Many experiments show that the gradient values of non-zero blocks always occupy a more significant portion of the total blocks. Accordingly, suppose the number of blocks that hold the non-zero gradient value notes $N_{g\neq0}$, and the number of blocks that hold the zero gradient value notes $N_{g=0}$, so in Fig. I, the area of $N_{g=0}$ is larger than that of $N_{g\neq0}$. With the same preconditions as HVQ, suppose a volume with $N\times M \times K$ data points and each point holds $B$ bytes. The block size is $n\times n\times n$, the down-sample block size is $(n/2)\times(n/2)\times(n/2)$, the compression rate of FCHVQ can be computed by (3).

$$FCHVQ\_Rate_{\text{comp}} = \frac{N \times M \times K \times B}{9 \times N \times M \times K (2n \times 2n \times 2n) + 2 \times N_{g=0} + C_{\text{codebook}}}$$

In the context of FCHVQ, different compression methods to different classes were then introduced in order to make FCHVQ algorithm efficient. However, noticing that the blocks that hold the zero gradient value have two situation: one is the blocks that hold the same value $a(a\neq0)$, the other is the blocks that hold the same value of 0. So, FCHVQ is also Pixel-based compression algorithm. What’s more, another limitation was, Pixel-based compression algorithm would not be coupled to the acceleration techniques of rendering In GPU because of its SIMD architecture. In the light of this, CCHVQ will be introduced in detail in next section.

### III. CONTENT-BASED CLASSICAL HIERARCHICAL VQ

CVR, generally speaking, can be divided into three classes of methods based on the location of decompression and rendering, respectively software CVR, hardware CVR and hybrid CVR[4]. For software CVR, Ning and Hesselink [2] argued that the decompression should allow fast, direct, random access to voxels. For hardware CVR, Foua and Ma[4] recognized two more desired traits: one is compact, separable decompression; the other is uniform decompression. These demands only focus on the rendering speed, for the decompression is coupled to rendering in CVR domain. However, one more important idea should keep in mind is that volume rendering is a method of extracting meaningful information from volumetric data[11]. In addition to the decompression restrict, the characteristics of the volumetric data should be coupled to the compression and rendering. This is even more important when we take the classical VQ for a solution of compression as classification can identify the characteristics of the volumetric data. So, we recognize three more desired traits that specifically target classified VQ.

1. Classified method should be directly relating to the common traits of the volume data. For the object of the compression is to save more meaningful information about the volume data using less bits.
2. Different classes can held their own compression scheme. With the efficiently of today’s GPU, bits allocation can be more flexibility, different classes can held their own compression scheme so that leave more codewords to express the detail of the reconstruction image.
3. Classification scheme should be coupled to the acceleration techniques of rendering: The final goal of CVR are faster rendering speed and better image fidelity. To get that goal, Classification scheme should be considered with the acceleration techniques of rendering, for example empty space leaping.

These above constraints associated with these objectives put more emphasis on the relations among the volumetric data characteristics, compression algorithm and rendering, not only the relations between compression algorithm and rendering. That’s to say, before compression, we may extract the meaningful information using certain scheme. By this way, we can get higher compression rate for that the blocks with useless information will be discarded and better reconstruction image quality for that total codewords will leave to save the detail of the image. Under this background, this paper presents an content-based volume data compression algorithm. The procedure of the algorithm is as follows: During the data pre-process stage, statistic the characteristics of the data itself using histogram technique; From the histogram info, classify the blocks which divided from total volume data into two groups, the blocks with meaningless information as one group(also called empty blocks), and those with meaningful information as the other(also called object blocks); Only object blocks are decomposed into a three hierarchical representation manner and vector quantized in order to leave more details of the reconstructed image [3,5]. The overall algorithm is illustrated in Fig.II.
A. Trait of volume data

Volume rendering [11] is the process of projecting a volumetric three-dimensional dataset onto a two-dimensional image plane in order to gain some meaningful information about the dataset. A volumetric data set is typically a set $V$ of samples $(x,y,z,v)$, also called voxels, representing the value $v$ of the some property of the data, at a 3D location $(x,y,z)$. If the value is simply a 0 or an integer $i$ within a set $I$, with a value of 0 indicating background and the value of $i$ indicating the presence of an object $o_i$, then the data is referred to as binary data[11]. So, before using classification scheme, to investigate the characteristic of the volume data is needed. Histogram Info, a simple but useful way, to be used by us to get the distribution of the volume data. Taking the large size of the volume data into account, we firstly resample the volume data(uniformly resample from $x,y,z$ direction) in order to reduce the algorithm complexity. If the resample data is high dynamic range, for conventional, the volume datasets should be normalized to 0~255 according by (4) firstly. Here $v'_i$ is the volume data value after normalization. $V'_i$ presents the resample volume value. $V_{min}$ holds the minimum value of the resample data, while $V_{max}$ holds the maximum value.

$$V'_i = \frac{V_i - V_{min}}{V_{max}} \times 255 \quad (4)$$

For compassion convenience, the datasets used for experiments are the same as that used in FCHVQ, which list in TABLE I. Noting that bigger datasets can be divided into smaller $256 \times 256 \times 256$ volume[4] firstly, and then composite them to the whole datasets by certain rules.

For all datasets, the resample data size is $64 \times 64 \times 64$. Figure III shows the histogram info of the volume data. Here, the x-axis of histogram is the data value, while the y-axis is frequency of each value(0~255) in the normalization resample volume data set.

<table>
<thead>
<tr>
<th>Volume data</th>
<th>Bits</th>
<th>Resolution</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonsai</td>
<td>8</td>
<td>$256 \times 256 \times 256$</td>
<td>16MB</td>
</tr>
<tr>
<td>foot</td>
<td>8</td>
<td>$256 \times 256 \times 256$</td>
<td>16MB</td>
</tr>
<tr>
<td>aneurism</td>
<td>8</td>
<td>$256 \times 256 \times 256$</td>
<td>16MB</td>
</tr>
</tbody>
</table>

Notice that the frequency of value 0 scale to 0.01 in figure III. So, from the histogram info of the resample volume data, we can see the distribution of the volume data. Here, at least two traits of the volume data can be concluded. One is that different volume data have different data distribution, while the other is that different volume data have the same phenomenon which is different volume data holds a lots of value of 0 that indicating background.
Those traits of the volume data will provide the prior information for compression. The volume data is then partitioned into volume bricks \((4 \times 4 \times 4)\) \([3,4,5]\) which will be classified into two groups and different groups take different compression scheme.

\[ B. \text{Content-based Classification} \]

An important conclusion of the volume data characteristic is that the useful object information just occupy a little proportion of the volume data while the background proportion takes more proportion. It is not unique, \([8]\) presented that the volumetric data set can be divided into two classes: one class with the empty blocks and the other class with the object blocks. And empty blocks made no contribution to the final image, so empty space leaping can be used for acceleration of rendering but do not influence the image fidelity. We also take this classification method before compression.

Two advantages can be concluded when take this classification scheme: Firstly, the scheme for compression that the most of capacity for keeping empty blocks should be saved. We just set a flag to the empty blocks. Secondly, the compressed volume data rendering can take the advantage of the empty space leaping acceleration technique. We then give the brief specification of our classification scheme, and the differences of the classification scheme between FCHVQ and CCHVQ.

For classification, we firstly get the mean value of each block \(\text{Mean}(B_i)\). Here \(n\) is the block size and \(V(x,y,z)\) is the value of volume data in location \((x,y,z)\).

\[
\text{Mean}(B_i) = \frac{1}{n \times n \times n} \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} V(x,y,z)
\]

\[ (5) \]

Our Classification scheme is very easy: if the \(\text{Mean}(B_i)\) equals 0, then the block belongs to empty block (noted as \(B_{\text{empty}}\)), otherwise the block belongs to object block (noted as \(B_{\text{object}}\)).

\[ \text{C. Object blocks encoding} \]

From Fig.I and Fig. IV, the differences of the classification strategy of the two algorithms illustrate clearly. Noting the white area in Fig.I is bigger than that in Fig.IV, which can be proved by Lemma 1. Suppose \(N_{\text{empty}}\) is the number of empty blocks while \(N_{\text{object}}\) is the number of object blocks. \(N_{\text{empty}} + N_{\text{object}}\) is the total number of blocks of volume dataset.

\[ \text{Lemma 1. When Using the same block size of the same volume data in CCHVQ and FCHVQ, } N_{g=0} > N_{\text{empty}}. \]

\[ \text{Proof.} \]

Note that \(N_{g=0}\) is the number of blocks that hold the zero average gradient value \([5]\). The block that has the zero average gradient value, in other words, the data in one block have the same value, just as illustrated in Fig.I. Those blocks can be classified into two classes: one class is that the same value is 0 (also called empty block), and the other is the same value a(1~255). That’s to say, empty blocks are part of blocks those hold zero average gradient value. So, \(N_{g=0} > N_{\text{empty}}\).

\[ \text{Proved.} \]

We list the detail classification results of the classification strategy among different volume data in TABLE II, including \(N_{g=0}, N_{\text{empty}}, N_{g=0}, N_{g=0}\) and the proportion of \(N_{\text{empty}}\) of total blocks, which can be computed by \(N_{\text{empty}}/(N_{\text{empty}} + N_{\text{object}})\). From table II, we can see \(N_{\text{empty}}\) takes the most proportion of the total blocks, in particular for aneurism volume dataset, there are \(97.03\%\) blocks are empty blocks. One more fact is that for the testing volume datasets, the difference between \(N_{g=0}\) and \(N_{\text{empty}}\) is very small. The compression method of \(N_{g=0}\) is just to save the mean value in FCHVQ for reconstruction, while in CCHVQ, higher compression rate can be obtained because we just focus on the object blocks while for empty blocks, nothing is saved.

\[ \text{TABLE II. COMPARISON OF THE CLASSIFICATION STRATEGY} \]

\[ \begin{array}{|c|c|c|c|c|c|}
\hline
\text{volume data} & \text{CCHVQ} & \text{FCHVQ} \\
\text{空} & \text{N_{empty}} & \text{N_{object}} & \text{N_{empty}/(N_{empty}+N_{object})} & \text{N_{g=0}} & \text{N_{g=0}} \\
\hline
\text{bonsai} & 185154 & 76990 & 70.63\% & 187831 & 74313 \\
\text{aneurism} & 254361 & 17783 & 97.03\% & 255800 & 6344 \\
\text{foot} & 179883 & 82261 & 68.62\% & 180291 & 81853 \\
\hline
\end{array} \]

\[ \text{C. Object blocks encoding} \]

As mentioned above, the compression scheme of our proposed algorithm is to take different ways to different classes. For object blocks, an efficient hierarchical VQ is applied in order to get higher compression rate on the premise of the good quality of reconstruction image. Specifically, object blocks are decomposed into a three hierarchical representation manner like the way used in \([3,5]\) and then the vectors of different hierarchical use vector quantization to compress.

As for any VQ, the process generally can be divided into three aspects: code book design, codeword search, indexed allocation \([10]\). Among these steps, code book design plays an important role in the performance of the algorithm. LBG-algorithm developed one of the earliest vector quantization algorithms suitable for practical
applications[12]. Because of the sensitivity to the initial codebook in LBG, so far many optimized algorithms [13,14] have been proposed to improve the codebook design.

For compassion convenience, the improved VQ used in this work(see Figure V) also takes the splitting scheme based on a principal component analysis[14,15,16]. Specifically, a splitting scheme based on a principal component analysis (PCA) is used by us to find an initial codebook which is then refined by LBG algorithm, finally, we restrict the search to the k-neighborhood of the initial cell in the quantization stage. The difference between VQ based on PCA split used in HVQ and FCHVQ should be pointed out is that only the small part of object blocks are trained in VQ. Thus, we do not only save a large amount of computation, but also can get better reconstruction image quantity because of leaving the whole code words to the object blocks.

![Figure V. VQ base on PCA split](image)

**D. Compression rate and Comparison**

After compression of object blocks, the original volume dataset can be reconstructed by the codebooks, indexes, mean value of the object blocks and the flags of each block which are used for identifying the different classes. So, considering a volume of $N \times M \times K$ data points, each point holds $B$ bytes, the block size of is $n \times n \times n$ and the down-sample block size of hierarchical representation is $(n/2) \times (n/2) \times n/2$. The compression rate of CCHVQ can be computed by (6).

$$CCHVQ\_Rate_{\text{comp}} = \frac{N \times M \times K \times B}{N \times M \times K/(2n \times 2n \times 2n) + 3 \times N_{\text{object}} + C_{\text{codebook}}}$$

Here, $N \times M \times K/(n \times n \times n)$ is the capacity of the flags. And $C_{\text{codebook}}$ presents the capacity of the codebook.

As for each object block, we should store the mean value, the indexes in the highest level and the second level, so $3 \times N_{\text{object}}$ are needed.

**Lemma 2.** When the number of empty blocks is more than 4.17 percent of the total number of blocks, in other words, $N_{\text{empty}}/(N_{\text{object}} + N_{\text{empty}}) > 1/24$.

$$CCHVQ\_Rate_{\text{comp}} > HVQ\_Rate_{\text{comp}}.$$ 

**Proof.**

If $CCHVQ\_Rate_{\text{comp}} > HVQ\_Rate_{\text{comp}}$, then $N \times M \times K/(2n \times 2n \times 2n) + 3 \times N_{\text{object}}$ should be less than $3 \times N \times M \times K/(n \times n \times n)$.

Then $N_{\text{object}} < 23 \times (N \times M \times K)/24 \times (n \times n \times n)$, add $N_{\text{empty}}$ on both sides of the equation, get:

$$N_{\text{object}} + N_{\text{empty}} < N_{\text{empty}} + 23 \times N \times M \times K/24 \times (n \times n \times n).$$

Because $N_{\text{object}} + N_{\text{empty}} = N \times M \times K / n \times n \times n$,

So $N_{\text{empty}} > N \times M \times K / (24 \times n \times n \times n)$.

Then $N_{\text{empty}} / (N_{\text{object}} + N_{\text{empty}}) > 1/24$.

So, if $N_{\text{empty}} / (N_{\text{object}} + N_{\text{empty}}) > 1/24$,

then $CCHVQ\_Rate_{\text{comp}} > HVQ\_Rate_{\text{comp}}$.

Proved.

Considering empty blocks in the volumetric data always occupies a certain percentage, many experiments show that empty blocks is much more than 4.17 percent of the total number of blocks. See $N_{\text{empty}}$ in the above table II, there are more than 60 percent of the blocks are empty blocks, that’s the key point why our algorithm can be more memory efficient than that of HVQ.

**Lemma 3.** If $N_{\text{empty}} \approx N_{\text{object}}$, then

$$CCHVQ\_Rate_{\text{comp}} > FCHVQ\_Rate_{\text{comp}}.$$ 

**Proof.**

If $CCHVQ\_Rate_{\text{comp}} > FCHVQ\_Rate_{\text{comp}}$, then $3 \times N_{\text{object}}$ should less than $N \times M \times K / n \times n \times n + 2 \times N_{g=0}$.

Because $(N_{g=0} + N_{g=0}) = N \times M \times K / n \times n \times n$

and $(N_{\text{empty}} + N_{\text{object}}) = N \times M \times K / n \times n \times n$

So , $3N_{\text{empty}} - 2N_{g=0} > 0$

Here, if $N_{g=0} \approx N_{\text{empty}}$, so $2(N_{g=0} - N_{\text{empty}})$ is small,

So, $N_{\text{empty}} - 2(N_{g=0} - N_{\text{empty}}) > 0$.

Then $CCHVQ\_Rate_{\text{comp}} > FCHVQ\_Rate_{\text{comp}}$.

Proved.

From Lemma 2 and Lemma 3, we demonstrate the memory efficient of CCHVQ. We will show the detail compression performance(include concrete compression rate, the reconstructed image quality, the encode and decode complexity) of CCHVQ, HVQ and FCHVQ in next section, results and comparison.
E. Decoding

The decoding algorithm is similar like FCHVQ which to use the saved compressed information to reconstruct the image block by block. Firstly, get the flag of the reconstructed block. If the flag is zero, we just skip that blocks. If not, we should first get the mean value of the block, and then get the difference between the mean value of the block and data in the down-sample block according to the index of second level, finally, get the difference between each data in the block and that in down-sample block according to the index of highest level. The sum of the value got in the previous steps is the reconstructed value in the object block.

Different from decoding of FCHVQ, for empty blocks, we just skip that blocks. While in FCHVQ for those blocks whose average gradient values are zero, we need replace their whole block data with their mean values. Evidently, our method is faster than FCHVQ. What’s more, when decompress in GPU, for empty blocks, we just discard that blocks for that these blocks make no contribute to the final reconstructed image. So, acceleration techniques for GPU-based volume rendering [9], for example, empty space leaping can be well used.

IV. RESULTS AND COMPARISON

The performance of VQ is usually measured by the compression rate, the reconstructed image quality and the encode and decode complexity. In this work, the compression rate is measured by equation (1), while the reconstructed image quality is evaluated by the peak signal to noise ratio (PSNR) [10]. Considering a volume of \( N \times M \times K \) data points, the value of the raw data is \( x_{ijk} \). \( L \) is the maximum of the volume data, usually is 255. And the value of the reconstructed data is \( y_{ijk} \). Here \( 0 \leq i \leq N - 1, 0 \leq j \leq M - 1, 0 \leq k \leq K - 1 \), then MSE and the PSNR can be defined as follows.

\[
MSE = \frac{\sum_{i=0}^{N-1} \sum_{j=0}^{M-1} \sum_{k=0}^{K-1} (x_{ijk} - y_{ijk})^2}{M \times N \times N}
\]

\[
PSNR = 10 \times \log_{10} \frac{L^2}{MSE} \text{ db}
\]

For comparison, the encode and decode complexity is simply using the running time. All the experiments results have been obtained by programming with C++/VS2005 on 2.0GHz Inter(R) core2 Duo CPU with 2GB main memory under Window XP.

A. Encoding results and comparison

In order to provide a context for the evaluation of our work, we compare our approach (CCHVQ) with analogous implementations of FCHVQ and HVQ.

The comparison of the compression rate and reconstructed image quality of CCHVQ, FCHVQ and HVQ among different volume data illustrates in Fig.VII and Fig.VIII. Here, the number of codeword in the codebook is 256.

From Fig.VII, CCHVQ algorithm can get much higher compression rate than that obtained from HVQ and FCHVQ. Especially for aneurism volume data, the compression rate of CCHVQ is almost 9 times more than that of HVQ and almost 3 times more than that of FCHVQ. And for bonsai and foot, the compression of CCHVQ is nearly 2 times more than that of HVQ. Our memory efficient is not at the cost of the reconstructed image quality, on the contrary, the PSNR obtained from CCHVQ (see Fig. VIII) is about 0.1-0.2 higher than that of FCHVQ and 0.2-0.4 higher than that of HVQ.

For the same volume data, take aneurism for example, we use different codebook sizes, CCHVQ also can obtain efficient memory and better reconstructed image quality than other algorithms. For example, when the codebook size is 128, the compression rate and the PSNR obtained from CCHVQ, FCHVQ and HVQ are respectively 268.80, 53.22, 22.69. While the PSNR obtained from CCHVQ, HVQ and FCHVQ are respectively 35.46db, 35.36db and 35.34db.

B. Decoding time and encoding time comparison

At the same time, our decode algorithm runs faster than that of FCHVQ and HVQ. Noting the we skip the empty blocks, so no time waste on those blocks. See Figure VI for the detail comparison of the decode times among different volume datasets and different algorithm.

However, our proposed algorithm is a little more time-consuming than that of HVQ and FCHVQ. But exclude the getting histogram info process, the encode time is a little lower than FCHVQ, but also higher than HVQ. But in the CVR domain, compression can be slow since it is performed only once offline[4].

V. CONCLUSIONS AND FUTURE WORKS

We have devised a content-based classified hierarchical VQ to obtain memory efficiency, better reconstructed image quality and faster decoding. Since volume rendering is the process of gaining some meaningful information about a dataset, our content-based classification scheme before compression can classify which blocks is the meaningless information (i.e., empty blocks), hence no space and no time will be wasted on these blocks. While for the object blocks, a three hierarchical representation manner and a PCA-based split would be considered.
VQ have been employed in order to get better reconstructed image quality.

We then compare our approach (CCHVQ) with analogous implementations of FCHVQ and HVQ. The experimental results also demonstrate the improvement of compression rate, reconstructed image quality and decoding speed. Compression rate, reconstructed image quality and decoding speed are the the principal causes in CVR domain.

Although we have not done decoding and rendering on GPU, our classification scheme should be coupled to the acceleration techniques of rendering, such as empty space leaping. In the future, we are planning to investigate the relations between classified VQ and the transfer function and choose more advanced rendering algorithms to make volume rendering more meaningful and faster.

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Li-ping Zhao was born in 1984, HuNan, China. She obtained her master in Hunan University. Her main research interests include data compression, volume data visualization and multimedia.

Guangxue Yue was born in 1963, Guizhou, China. He obtained his master in Hunan University. Professor, the College of Mathematics & Information Engineering, jiaxing University, China. His main research interests include Biological Information, Distributed Computing & Network, and Hybrid & Embedded Systems.
De-Gui Xiao was born in 1972, HuNan, China. He obtained his doctor's degree in Huazhong University of Science and Technology. Associate professor, the school of computer science and communication, HuNan University. His main research interests include visualization in scientific computing, intelligent visual monitoring surveillance, video processing.

Zhou Xu was born in 1983, Jiangshu, China. She obtained his master in Hunan University. Her main research interests include Biological information, DNA Computing and Parallel Computing.

Xiang Yu was born in 1983. He obtained master's degree in computer science and engineering from State University of New York at Buffalo, USA. His main research interests are design and evaluation of future networks and distributed systems.
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