Design of Automobile Anti-theft and Alarm System Based on MCU and Information Fusion

Zhang Feng
Dept. of Electronic Engineering, Sichuan University of Science & Engineering, Zigong, China
E-mail: zfzj@suse.edu.cn

Abstract—An automobile anti-theft and alarm system based on MCU and information fusion is introduced in this paper, in which multi sensors are used to collect the information about automobile’s situation firstly, and a MCU is used as the central processing and control center, the FCM and the neural network algorithms are adopted to fuse the multi-sensor information respectively, finally, the automobile’s safety information is sent to the mobile phones of automobile owners through the GSM network in order to achieve the real-time monitoring for automobiles.

Index Terms—Information Fusion, Neural Network, MCU, Anti-theft and Alarm

I. INTRODUCTION

At present, the anti-theft device on the market processes passively alarm signal in many cars. Generally, it determines safety state of automobile depending on a single signal from sensor, therefore it have some defects, such as less reliability, existing phenomenon of misreport and failing to report. These defects bring many unnecessary troubles to user. It is very difficult to identify precisely safety state of automobile using only a single sensor because automobile have many different information due to its unsafe situations (for example, illegal starting, being damaged, handing entire car and false failure phenomenon, etc.). We can precisely judge and describe state of automobile if we combine information from multi-sensors that are complement each other in space and time and redundant information according to a rule of optimization. An automobile anti-theft and alarm system is designed using MCU as control center of this system in this paper. In order to obtain precise automobile’s safety information all data from different sensors is fused in two levels by using the FCM and the neural network algorithms in this system. Deciding whether or not to start brake system is made depending on automobile’s safety information and finally, the automobile’s safety information is sent to the mobile phones of automobile owners through the GSM (Global System for Mobile Communications) network.

II. STRUCTURE OF ANTI-THEFT SYSTEM

A. Design of system structure

Modular structure is adopted in this anti-theft system, and in order to meet diverse demands for different customers the number of sensors or modules may be increased or decreased according to user’s requirement. This system consists of detection modules, CPU and control modules, alarm modules, auto ignition control modules and communication modules. The structure of system is shown fig.1.

Figure 1. The structure of the anti-theft and alarm system

The CPU and control modules consisted of MCU PIC18F448 and its external circuits is used to receive the information from all detection modules, fuse different information by a corresponding method, and then make a judgment on automobile’s safety condition on the basis of the result of information fusion. It can transmit different level alarm signals to alarm modules, executable modules and GSM modules, respectively. The auto ignition control module in the system can directly cut off automobile’s ignition circuit to enable automobile can’t work when automobile is being stolen. The detection module comprising many items (infrared sensor, vibration sensor, tilt sensor, fingerprint identification module and GPS module) is used to collect the automobile’s real-time safety state and then transmit these signals to CPU and control module. The alarm module is used to receive instruct from CPU and give acoustic and optical alarm signals. User can monitor and control his automobile due to the communication module. The system transmits the alarm signals to automobile owner via short message service (SMS) using GSM network and user also realizes remote control to his automobile by the same means.

B. Detecting automobile’s safety information

Situation due to automobile being stolen consists of illegal starting and being damaged and handing entire car. In these cases, the phenomena of vibration or leaning will occur in auto body and they will accompany some human biological information, for example, nocturnal radiation whose centre wavelength is from 9 to 10µm. In order to obtain an exact alarm signal, collecting information must be finished by a sensor corresponding to specific
phenomenon due to being stolen and be fused using a correct algorithm. The selection for the sensors complies with the following rules in this system to get enough information: selecting correctly and optimum integration sensors to meet low cost and high precision and robust, realizing the sharing and complement of information by exerting the advantage of different sensors, rational distribution of sensors on the board to eliminate detection dead area and increase the reliability of system. On the basis of these rules, the following detection modules of anti-theft system are chosen in this system to detect the real-time state of automobile:

1) Pyroelectric infrared sensor: Pyroelectric infrared sensor is sensitive only to the infrared radiation whose center wavelength is from 9 to 10µm and can find the radiation information from human body.

2) Tilt sensor: detecting whether or not to change between auto body and its initial position using Tilt sensor, we can make a conclusion that the automobile is being carried as a whole if this change appears with a certain frequency and reaches a presupposing value.

3) Vibration sensor and GPS module: The vibration sensor made from acceleration detection sensors can detect the tilt information of being stolen by carrying as a whole for automobile. The control center gets the automobile’s address via reading data from GPS system after obtaining the tilt information. Since the drift of GPS locator, the GPS module can be started and send the address to owner by SMS only when change value is greater than a threshold.

4) Fingerprint identification module: Fingerprint identification system will be triggered and identify the operator’s identity when the automobile’s engine is forced to be started. The anti-theft system can lock the engine by starting automatically the spark control system and send an alarm message to owner via GSM module if its operator can’t pass the fingerprint identification system.

III. MULTI-SENSOR INFORMATION FUSION

Multi-sensor information Fusion is actually an information processing paradigm that simulates the human brain to process a comprehensive matter. Its basic principle is to combine redundant information and data from different sensors, which are complement in time and space by an optimization algorithm, on basis of fully utilizing multi-sensor resources and correct using information, and then to get the consistency of interpretation and description about observed thing. In this paper, clustering and neural network algorithm are used to fuse the information from multi-sensors for feature level and decision-making level, respectively, to realize the real-time detection of automobile’s situation.

A. Feature level fusion

The infrared sensor, tilt sensor and vibration sensor are used to detect automobile’s state in time sequence and collect the feature information corresponding to different automobile’ state, and then all feature information is fused using three ART-2 neural networks by time-fusion method. The ART-2 neural network is a excellent data clustering approach and its structural chart is shown in fig.2.

1) Fuzzy C means clustering(FCM)

FCM is a data processing unsupervised algorithm. In FCM, objective function is iterated according to the weighted member in C classification center and all samples collected in order to get the optimal classification of data sets. The result of clustering is that the grades of membership between every sample and all classifications are obtained and their sum is 1. Assuming \( X = \{x_1, x_2, \ldots, x_n\} \) expresses n sets containing unclassified samples. Where \( x_i \in \mathbb{R}^p, i = 1,2, \ldots, n \), \( p \) is feature dimension of samples. FCM clustering approach can classification X into C subsets \((S_1, S_2, \ldots, S_C)\). If \( V_1, V_2, \ldots, V_C \) express clustering center of corresponding to set, respectively, and \( u_{ij} \) expresses grade of membership between \( x_i \) and \( S_j \), and \( U = \{u_{ij}\} \) is \( n \times C \) matrix, error sum of squares is employed as a objective function in FCM algorithm as follow:

\[
J(U,V) = \sum_{i=1}^{n} \sum_{j=1}^{C} u_{ij}^m d_{ij}^2
\]

Where: \( u_{ij} \) meets a constraint condition as follow:

\[
\sum_{j=1}^{C} u_{ij} = 1, 1 \leq i \leq n; u_{ij} \geq 0, 1 \leq i \leq n, 1 \leq j \leq C \; \text{i = 1,2,\ldots,C} \quad (2)
\]

\( m \in [1,\infty) \) is the fuzzy weighted index and is used to control the fuzzy degree of matrix U. The fuzzy degree will increase with m and the optimal range is from 1.5 to 2.5 (m=2 in this paper).

\[
d_{ij}^2 = \|x_i - v_j\|^2 = (x_i - v_j)^T A (x_i - v_j)
\]

where \( A \) is a symmetric matrix and \( A = A^T \), which is used to control the degree of fuzzy. The optimal value of fuzzy degree is from 1.5 to 3.5 in this paper.
Where, \( d_{ij} \) is the distance between a sample and the clustering center, \( A \) is a symmetric matrix (\( A \) is a unit matrix in this paper). \( J(U,V) \) is the sum of squares of the weighted distance between samples in different classifications and the clustering center, the smaller \( J(U,V) \) means better clustering. FCM algorithm is an iterative process to minimize its objective function. By Lagrange multiplier method we can obtain

\[
J(U,V) = \sum_{i=1}^{n} \sum_{j=1}^{k} (u_{ij})^2 d_{ij}^2
\]

\[
u_j = \sum_{i=1}^{n} (u_{ij})^n x_i / \sum_{i=1}^{n} (u_{ij})^n
\]

\[
u_j = \sum_{i=1}^{n} (u_{ij})^n x_i / \sum_{i=1}^{n} (u_{ij})^n
\]

\[
u_j = \sum_{i=1}^{n} (u_{ij})^n x_i / \sum_{i=1}^{n} (u_{ij})^n
\]

\[
u_j = \sum_{i=1}^{n} (u_{ij})^n x_i / \sum_{i=1}^{n} (u_{ij})^n
\]

U and the elements of matrix V are modified until the minimum value of \( J(U,V) \) is obtained.

2) FCM-based feature-level information fusion

Window length of the sample model is set to 60s. The interval between two times sensor information collections is set to 3s. Therefore the number of data in a pattern window is 20. The information pattern features for infrared sensor, tilt sensor and vibration sensor are expressed as follows, respectively:

\[
X_1 = [T_1, T_2, ..., T_{20}]^T; \quad X_2 = [P_1, P_2, ..., P_{10}]^T; \quad X_3 = [H_1, H_2, ..., H_{10}]^T
\]

Because dimension of \( X_1 \) or \( X_2 \) or \( X_3 \) is 20 (\( N=20 \)), the number of input pin in ART2 network is also 20. In experiment, other parameters in ART2 network are set as follows: Contrast constant is 12 (\( a=b=12 \)), the adjustment subsystem constant \( c=0.25 \), field gain of output layer equal 1 (\( d=1 \)), filtering threshold is 1/200.5 (\( \theta = 1/N^{0.5} = 1/20^{0.5} \)), filter transformation function is expressed as following:

\[
f(x) = \begin{cases} 0, & 0 \leq x \leq \theta \\ x, & x > 0 \end{cases}
\]

Pattern vector \( X_1, X_2 \) and \( X_3 \) are written into ART2 network. The information from every sensor is clustered into four typical classifications, which is represented as follow using coding: 00(no risk), 01(smaller risk), 10(risky) and 11(alarm). After fusing, fusing space \( C \) for infrared sensors, tilt sensors and vibration sensors is obtained.

\[
C = [C_1, C_2, C_3, C_4, C_5, C_6]
\]

Where, \( C_1 \) and \( C_2 \), \( C_3 \) and \( C_4 \), \( C_5 \) and \( C_6 \) are the coding of information from infrared sensors, tilt sensors, and vibration sensors, respectively. GPS and GSM modules will be started and send the automobile’s address to owner via GSM network when the information from the vibration and tilt sensors is conformated to be “alarm” in order to avoid that the automobile is stolen by carrying whole body. On the other hand, fingerprint identification and spark control modules will be started when the information from the infrared sensors is conformated to be “alarm” to prohibit starting the engine.

B. Decision-making level fusion

Three-layer BP neural network based on BP is applied to this system to process the former fusing result, it can predict the probability of being stolen for automobile by integrating the information from different sensors. Input layer in BP neural network consists of 6 neurons corresponding to six messages from three sensors (infrared, tilt and vibration), namely, six variables in vector \( C \) (from \( C_1 \) to \( C_6 \)), on the other hand, out layer consists of only one neuron corresponding to a three-dimension vector \( B \) (\( b_1, b_2, b_3 \)). Element \( b_1 \) in \( B \) represents the safety situation of monitored automobile (0: normal, 1: alarm). The \( b_2 \) and \( b_3 \) combine to represent the working state of three sensors (00: normal, 01: abnormal infrared sensors, 10: abnormal tilt sensors, 11: abnormal vibration sensors). In addition, the selection of nodal points of hidden layer neuron network based on BP can be carried out through empirical formula as follow:

\[
r = (m + n)^{1/2} + (1 \sim 10)
\]

Where, \( r \), \( m \) and \( n \) represent the number of the neuron in hidden layer, input layer and output layer, respectively. In this system, \( r \) is equal to 12 so that it can meet to the requirement of detecting precise of vehicle condition and the training time of network. Its network structure chat is shown in fig.3.

C. Simulating results

If the transfer functions between two layers in three-layer BP neural network is Gaussian function, then

\[
Y_j = \sum_{i=1}^{12} W_{ij} Z_i + b_j \quad (j = 1, 2, 3)
\]

\[
Z_i = \exp[-d_i(X, C_i, B)]
\]

Figure 3. BP neural network structure
\[ d_i(X,C_i,B) = (C_i - X)^T B (C_i - X) \] (11)

Where, \( Y_j \) is the output of neuron j in the output layer, \( W_{ij} \) is a weighted value from neuron i in the hidden layer to neuron j in the output layer, \( b_j \) is the offset of neuron j in the output layer, \( Z_i \) is the output of neuron i in the hidden layer, \( d_i \) is the Euclidean distance between the input vector \( X \) and the vector \( C_i \) corresponding to neuron i in the hidden layer, \( B \) is the diagonal matrix of RBF (Radial Basis Function) bandwidth. According to formula (9), (10) and (11), we can obtain:

\[ Y_j = \sum_{i=1}^{12} W_{ij} \exp\left(- (C_i - X)^T B (C_i - X)\right) + b_j \] (12)

The ultimate purpose for us training the neural network is to modify its weighted value and then minimize the error sum of squares of network output, namely,

\[ J = \min \sum \left\| y_j - y_j^m \right\|^2 \] (13)

Where, \( y_j^m \) is the output of the neural network, \( y_j \) is the desired output. Simulation samples and the results of training are shown in the following table:

<table>
<thead>
<tr>
<th>samples</th>
<th>infrared (mm)</th>
<th>tilt (degree)</th>
<th>Vibration (mm)</th>
<th>network output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>1</td>
<td>0.1</td>
<td>000</td>
</tr>
<tr>
<td>2</td>
<td>55</td>
<td>1.5</td>
<td>0.9</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>49</td>
<td>4</td>
<td>14.5</td>
<td>111</td>
</tr>
<tr>
<td>4</td>
<td>58</td>
<td>6</td>
<td>1.1</td>
<td>110</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
<td>0.8</td>
<td>0.25</td>
<td>101</td>
</tr>
</tbody>
</table>

In table 1, sample 1 represents that the automobile is safe and three sensors are normal, sample 2 represents the automobile is to be risky and all sensors are normal, sample 3, 4 and 5 represent the automobile is still to be risky as well, the difference is that sample 3, 4 and 5 mean the abnormal phenomenon of the vibration sensor, tilt sensor and infrared sensor, respectively.

IV. CONCLUSIONS

An automobile anti-theft and alarm system based on MCU and information fusion is designed in this paper and we can realize the full-view monitoring of the automobile’s safety state by using it. The comprehensive analysis for many kinds of vehicle condition from the different sensors is accomplished on basis of the fully utilizing the differences and complementarities of functions for different sensors, the accuracy of alarm is improved, since the system can identify actively and reliably the automobile’s safety state by taking advantage of two-level information fusing on basis of FCM clustering and neural network. Compared with the traditional anti-theft system including only a one sensor, this system has some advantages as follows: low cost, high precision, expandability, real time and good robust, etc.

ACKNOWLEDGMENT

The research is supported by science and technology research project of Sichuan University of Science & Engineering (No.2007ZR004).

REFERENCES


