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Design, Development and Investigation on an Embedded System based Control for Networking Mobile Robots

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***Abstract* – In today's hi-tech and hi-precision world, robot finds its application in many areas to carryout operations that are either routine, highly complex and critical, hazardous or of high-precision nature. Robots when networked offer many benefits such as increased maneuverability and efficiency. This paper makes a survey on the present developmental status and details the design features of networking mobile robots using embedded system based control. It is intended to use this work as basis for future research work in the area of cooperative behavior of mobile robots.**

***Index Terms* – Mobile Robot, Embedded System, Control, Network, Microcontroller, Vision system**

I. Introduction

Practical application is an important component of any scientific and engineering research and more so in the field of robotics. The applications of robot in day-to-day activities for industrial and time critical fail-safe operations are increasing. Some of the broader examples are agriculture, automotive manufacturing, construction, entertainment, health-care, laboratories, security and surveillance, military, mining, warehouse operations etc. Robot for industrial applications include critical and complex assembly operations which are of repetitive nature, performing routine operations such as pick-and-place, process control operations in nuclear and robotic arm in space to perform time-critical and fail-safe operations with minimum human intervention. Applications such as walking robot for human health care of elderly or handicapped people and for recreational activities are also on the increase.

Robot is a device employing sensors, electronics, computing and control features to carry out certain intended functions and falls in the realm of mechatronics. Cognition and artificial intelligence techniques are implemented in robot to make it think and act in the way humans do.

The use of multiple robots enables networking, resulting in various industrial applications viz., material handling, material transfer, machine loading and unloading, spot welding, spray coating, assembly operations and inspection. They also find applications in micro-surgery areas in performing time-critical and life-saving operations.

The science of robot encompasses three main engineering fields; electrical, mechanical and computing. While mechanical involves mechanisms and multi-body dynamics, electrical pertains to sensing and controlling, computing interfaces the above two fields in the form of hardware and software, also called embedded systems.

While conceiving a single robot for carrying out a specific operation, such as a robot arm could be less complex, yet it has to have in itself the computing capability. An embedded system bridges this gap which is a special-purpose computer system designed to perform one or more dedicated functions, often with real-time computing environment. It is usually embedded as part of a complete device including hardware, software and mechanical parts. The advantage of an embedded system is that it can be programmed according to the application in hand, 'application specific' providing reconfiguration of the same robot for different operations.

The main objective of this paper is to provide an overview of an embedded system based control for networking mobile robots in order to understand and carryout the following:

- Design and development of an embedded system for robot experiments and training scenarios related to the operation, programming, and control.
- Investigation and focus on the basic principles of networked intelligent mobile robots and further emphasis on features such as robotic arm manipulators, grippers or the vision system capability.
- Perform theoretical and experimental evaluation on the networking methodologies and control logic, in order to develop a comprehensive understanding between the robots.

II. Literature Survey

The basic principle and design of various components of robot such as manipulators, end effectors are dealt with in detail in textbooks [1][2][3]. Intelligent autonomous robots find its application in many areas as explained in Sec. I. Justin [4] discusses the mobile robot/sensor networks that have emerged as tools for environmental monitoring, search and rescue, exploration and mapping, evaluation of civil infrastructure and military operations. Shibata *et al.* [5] describes the realization of a modular distributed control architecture specifically designed to control locally intelligent robot agents. On the vision algorithms, Jose & Giulio [6] discusses the implementation of a set of visually based behaviors for navigation. More specifically, Thierry *et al.* [7] has presented the idea of using 3D visual cues when tracking a visual target, in order to recover some of the 3D characteristics of robots such as depth, size and kinematic information. The basic requirements for such a 3D vision module to be embedded on a robotic head are discussed.

A number of papers discuss on the communication network and control techniques. R.M Kuppan Chetty *et al.* [8] discusses a layered reconfigurable distributed planning and control strategy for multiple mobile robots in a leader-follower formation framework that combines formation planning, navigation and active obstacle avoidance.Firmansyah [9] has developed a prototype of modular networked robot for autonomous monitoring with full control over web through wireless connection. The robot is equipped with a particular set of built-in analyzing tools and appropriate sensors to enable independent and real-time data acquisition and processing. The paper focusses on the microcontroller-based system to realize the modularity. Ricardo Carelli *et al.* [10] proposed an autonomous tracking control system and a control structure to combine autonomous and teleoperation commands in a bicycle-type mobile robot. Teleoperation with visual access to the robot's workspace is integrated via a joystick with the autonomous operation of the robot. Behrokh Khoslmevis *et al*. [11] discuss the development ideas and merits of a single centralized station to provide supervision, sensing, control, intelligence and perhaps power to a colony of robots, organized for the performance of specific tasks. The consequence of such an approach is that each robot can be less complex, smaller in size and economical, as no on-board sensing, control and intelligence are required. Ollero *et al*. [12] presented the Navigation and Operation System (NOS) for a multipurpose industrial autonomous mobile robot for both indoor and outdoor environments. All processes in the NOS have been integrated in a distributed hierarchical architecture considering the real-time constraints. Alberto Elfes [13] discusses a distributed control system that provides scheduling and coordination of multiple concurrent activities on a mobile robot.

On the learning aspects of a robot, Nagata *et al*. [14] describe the reason and instinct networks; and pseudo impedance control, together with a training process in which they gave ten mobile robots with variety of habits and had them play a cops-and-robbers game. Through training, the robots learned habits such as capture and escape.

Obstacles, motion control, logic and estimation are dealt in detail by the following authors. Yang Tian-Tian *et al*. [15] considered the problem of formation control and obstacle avoidance for a group of nonholonomic mobile robots. On the basis of suboptimal model predictive control, two control algorithms were proposed. Liu Shi-Cai *et a7*. [16] proposed the formation control and obstacle avoidance problems that dealt with a unified control algorithm, which allowed the follower to avoid obstacle while maintaining desired relative bearing or relative distance from the leader. The leader-follower robot formation was modeled and controlled in terms of the relative motion states between the leader and follower robots. Ralph P. Sobek *et al.* [17] presents a distributed hierarchical planning and execution monitoring system and its implementation on an actual mobile robot. The planning system was a distributed hierarchical domain independent system called Flexible Planning System (FPS). It is a rule based plan generation system with planning specific and domain specific rules. Luca Consolini *et al.* [18] dealt with leader–follower formations of nonholonomic mobile robots, introducing a formation control strategy alternative to those existing in the literature.

Pertaining to robot intelligence, Volker Turau [19] presented a model for a robot control system that is under development for use in a manufacturing cell, which consists of various assembly stations and a material storage system. KAMRO robot will be able to analyze failures and to recover in an intelligent manner. S.G. Tzafestas *et al.* [20] study the problem of control and motion planning in the presence of uncertainty for a mobile robot subject to state and actuator constraints, which travels along a predetermined path inside a terrain with moving obstacles. Hemami *et al.* [21] proposed an optimal control law which was derived for path tracking control of a class of Wheeled Mobile Robots (WMR) or Automated Guided Vehicles (AGV's) with front steering wheel. K.C.Koh *et al.* [22] describe a path tracking control system developed for autonomous mobile robots driven by wheels. Y. Mori *et al*. [23] uses a robot vision system which finds a target object and focuses on it from a specified distance. A neural network is used as a decision maker which determines how to move the robot to reach the target object, on the basis of the image acquired through the camera. Dayal Ramakrushna Parhi *et al*. [24] address an intelligent path planning of multiple mobile robots. Gordon Wells *et al*. [25] provide a comparative survey of existing visual robot positioning methods and present a new technique based on neural learning and global image descriptors which overcomes many of the limitations. A.F.T. Winfield *et al*. [27] describe a communications and control infrastructure for distributed mobile robotics, which makes use of Wireless Local Area Network (WLAN) and Internet Protocols (IPs).

S.H Somashekhar *et al.* [27] present the precision machining used to drill microholes wherein various manufactuing processes are controlled manually which when replaced by an embedded system based control, will improve the process quality and accuracy. B.Gokul *et al.* [28] present some of the preliminary results of embedded system based industrial fault diagnoser.

III. EMBEDDED SYSTEM BASED CONTROL FOR NETWORKING MOBILE ROBOTS - DESIGN ASPECTS

The technical design aspects and methods planned to develop the proposed Embedded system based Control for Networking mobile Robots (ECNR) is described in this section. Fig. 1 shows the block representation of a mobile robot.

A. Mobile Robot Description

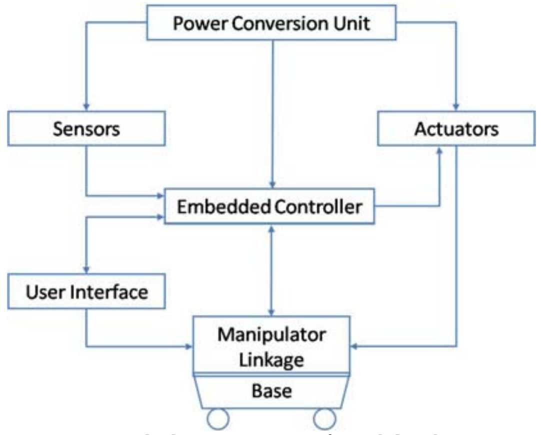

Fig.1 Block representation of a mobile robot

Embedded Controller is the brain of the mobile robot and is responsible for all actions. According to the function planning, the system hardware constitutes the following basic elements such as Sensors, Processor, Controller, Actuators, Communication (user interface) and Power supply. Processor unit is responsible for processing the signal received from other modules and to send proper error signals back to them. Motor stepper driver (controller) magnifies the pulse width modulation from the processor to drive the motors. Sensors viz., magnetic, gyros, accelerometer, tactile, force and vision sensor etc are commonly used to sense the various signals and send them to the processor. The core of control system is either a DSP processor or microcontroller.

B. Embedded System for a Networked Robot

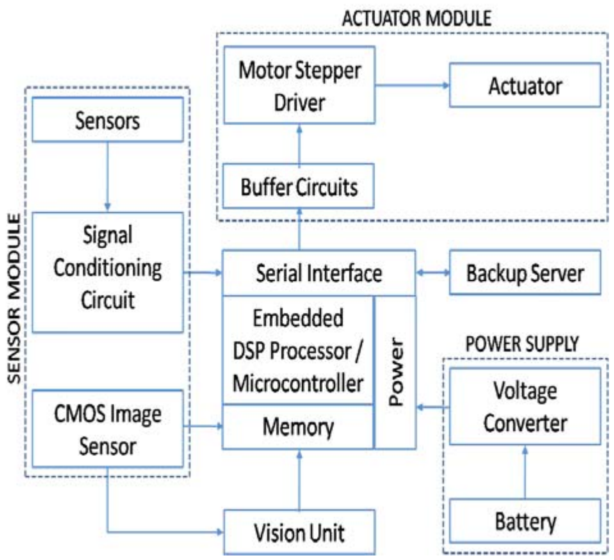

Fig.2 Embedded system based control schematic for networked mobile robot

Embedded system configuration for a networked mobile robot is shown in Fig. 2 below. It is configured around a server with a backup in order to provide the required fail-safe functioning during critical operations. The server basically takes-off the load of the individual robots and all the main functions are deposited and controlled from the main server while the backup functions as redundant or hot-standby. The configuration and various elements are described in the para above.

C. Choice of Mobile Robots

Some of the known mobile robots, viz., E-Puck and Amigobots provide necessary knowledge on motion planning and control strategies and suitable for usage in development of an ECNR. The E-Puck mobile robot is preferred because of its miniature size and availability of multiple sensors and actuators matching the requirements of ECNR. While the Amigobot is expensive, it has the range capability for indoor as well as outdoor operations and has a built-in wireless.

D. Software Architecture of Embedded System

Typical software system architecture of an ECNR is shown in Fig. 3 below.

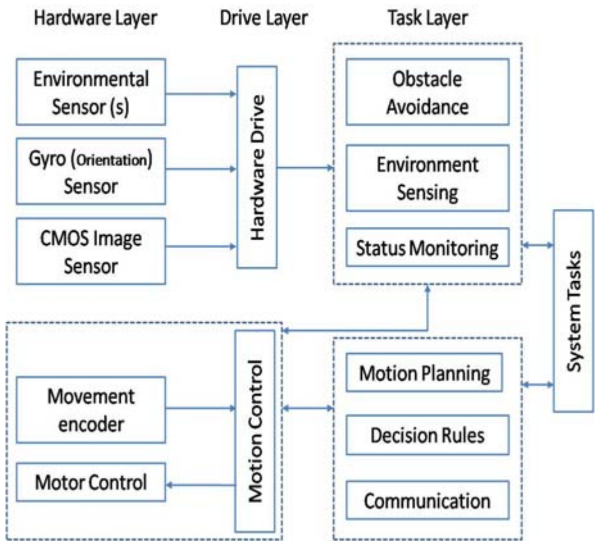

Fig.3 Software system architecture

The drive layer interfaces the hardware and task layer. The hardware layer consists of various sensors for detecting the environment, path constraints, motion, speed etc; gyro sensor provides the orientation and the CMOS image sensor, the vision capability that is basic to mobile robots.

The sensor information is processed by the various modules of the task layer, viz., in motion planning, rule based decisions and generating the correction/commands for communication to the motor control.

E. Vision Unit

Vision being the complex of all the sensors, a brief description on the typical features is discussed in this section. This unit consists of a CMOS image sensor, dual-port RAM and necessary real-time features for communication with DSP. The sensor will have a normal sampling rate of 30-50 frames per second. This sensor has features for implementing the white equilibrium, exposure control, saturation and tonality control. The image captured and stored in the RAM is used by the DSP during every sampling period. The processing involves reading of a static image at the target position and processing. Thus the system can make a judgment through the sampled data of several lines. Since the memory requirement for image storage is not very large, a high speed dual-port RAM is adapted.

F. Visual Algorithm

CMOS Image sensor provides RGB data. The hefts of RGB own a strong relation amongst each other and make it difficult to process. HSI model is used for the object identification algorithm. It separates the intensity data from the colour information. Considering the system storage capacity associated with such operations, an evenly distributed line sampling detection needs to be implemented. The result is expected to give definite information about the block's position and its rotation angle in the horizontal direction. HSI model uses H heft as the main partition parameter. The basic image processing algorithm to obtain HSI parameters from RGB input are shown below.

$$I = \frac{1}{3}(R + G + B) \qquad (1)$$

$$S = 1 - \frac{3}{R + G + B}[\min(R, G, B)] \qquad (2)$$

$$H = \arccos\left\{\frac{[(R - G) + (R - B)]/2}{[(R - G)^2 + (R - B)(G - B)]^{1/2}}\right\} \qquad (3)$$

The processing algorithm should be simple enough to occupy less memory and fast enough but at the same time, capture the image features within the real time period.

IV. Robot Kinematics

Robots movement involves both kinematics as well as dynamics. While details on these are considered out of scope of this paper, a small brief is provided here.

Robot movement consists of translation as well as rotation and these have to be calculated with reference to a fixed reference coordinate system in order to estimate the movement of every single robot. In a robot, each link and parent joint form their own local coordinate system. Rotation, translation and other transforms can be performed through matrix multiplication as depicted below.

Translation (D):

$$\begin{pmatrix} 1 & 0 & 0 & T_X \\ 0 & 1 & 0 & T_Y \\ 0 & 0 & 1 & T_Z \\ 0 & 0 & 0 & 1 \end{pmatrix} \qquad (4)$$

Rotation about x (Rx), y (Ry), and z (Rz) axes:

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \qquad (5)$$

A. Locomotion of Wheeled Robots

The locomotion of wheeled robots may be carried out in any of the following four standard methods:

- Differential Drive, eg – Pioneer 2-DX
- Car Drive (Ackermann Steering)
- Synchronous drive, eg – B21
- Mecanum wheels, eg – XR 4000

B. Position Estimation

The position estimation can be carried out by the 'Dead Reckoning' method as explained in Fig. 4 below.

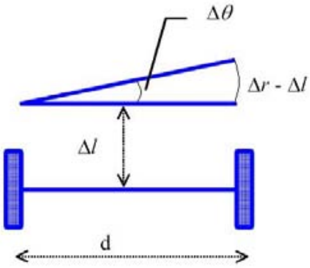

Fig. 4 Position estimation using dead reckoning method

$$\Delta\theta = \frac{\Delta r - \Delta l}{d} \qquad (6)$$

$$\Delta S = \frac{\Delta r + \Delta l}{2} \qquad (7)$$

V. ECNR Development Methodology

The ECNR development can be planned in phases as described below. Initially system modelling could be done, followed by control law design. Verification by simulation is carried out at each and every stage. Next, the embedded control system is implemented and finally the complete system is realized after validation and testing by experiments.

A. Phase – I

- Conceptual design and modeling of embedded systems and robotics experiments
- Graphical user interface design for the experiments
- Integration of mobile robots with the embedded control and vision systems

B. Phase – II

- Realization of the Embedded Control for Networking Robots and integration of the systems
- Experimental investigation and verification of user interface systems through LAN

VI. Experimental Verification

The following sets of broad level experiments need to be planned to evaluate the total system performance.

- Direct and inverse kinematics problems
- Study of different controllers and the effects of control parameters on individual mobile robots
- Robot motion planning in different control modes, in different coordinate systems etc
- Experiments on path planning, trajectory tracking for each of the individual mobile robots
- Experiments on obstacle avoidance, localization, goal seeking and other features that are applicable
- Experiments on Mobile robot applications such as search & surveillance, navigation and Multi robot coordination
- Experiments on networking with the Vision system

VII. Conclusion

ECNR when implemented can provide an easier access to the available hardware and software facilities that helps to practice realistic robot networking using the functionalities and programming capabilities of the real robots for developing various industrial applications. Thus, an attempt is made in this paper to provide an over view for a researcher interested this field with the status, and a broad survey of available lieterature and an introduction on the basic module functionalities.

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