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The Development of a Micro Robot System for Robot Soccer Game

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Abstracts

In this paper, we present the design and the structure of our multiple micro-robot system, CENDORI, designed for playing a robot soccer game, MIROSOT. Robot soccer game is a very complex robot application that incorporates real-time vision, robot control, wireless communication and management of multiple robots. To build a robot system with high performance and reliability, we designed the system architecture with the centralized concept. The robot control relies largely upon the vision system and the host computer generating low level motion control words. The experimental results and the performance of the robot are discussed.

1. Introduction

Implementation of human-like intelligence in robots has been a perpetual challenge ever since researchers started to develop and utilize robots. In fact, the terminology of robot has long been symbolized for intelligent agent.

Many researchers have been studying the robotic intelligence in various research fields: robot control, motion and path planning, mobile robot navigation and others. Recently, multiple robot system has been drawing a lot of research interests in intelligent robot system.

Fukuda proposed Cellular Robotic System (CEBOT)[1], and has been working on distributed decision making[2], hierarchical control architecture[3] and cooperative path planning[4]. Y. Ishida et al.[5] worked on cooperation of multiple autonomous robots. Ferrari and Arai[6] proposed a method for motion planning of multiple robots. Ozaki et al.[7] worked on synchronized motion of multiple robots.

To encourage the research in multiple robot systems and robotic intelligence, a robotic soccer game was organized. The first international robot soccer game, MIROSOT '96 was held at KAIST, Taejon, Korea in November 9-12, 1996. This competition was a good challenge to implement and test various kinds of technologies in robotic intelligence and multiple robot system. Motivated by this reason, we have developed the micro robot system to participate in the game.

In this paper, we provide a detailed description of the design and structure of our multiple micro robot system, CENDORI, designed for the robot soccer game, MIROSOT. CENDORI system consists of micro robots, a vision system and a robot management system. We have tried to build a well-balanced system in the performance of each component to draw out the maximum overall performance.

2. Micro Robot Soccer Tournament (MIROSOT)

MIROSOT is an international robot soccer game organized to encourage the research in multiple robot systems and robotic intelligence. Its rules are similar to those of the real soccer game in many ways. Following is a brief introduction of the rule of the game[8].

The field of the game is 90cm wide and 130cm long with 5cm high wooden walls around the border. At the center of each goal line wall, the goal post is located. The field is like a Ping-Pong table and marked with white grid lines. A match is played by two teams, each consisting of 3 robots, one of who can be the goal keeper. The size of the robot is restricted to be within 7.5cm×7.5cm×7.5cm. The robots are allowed to be equipped with arms or legs, but they must meet the size restriction even with the appendages fully extended.

The participant is allowed to use a host computer and vision systems. Cameras or any other sensor systems should be located more than 2m high from the field floor at the centerline or in the team's own field area. The game is played for two half-periods of 5 minutes each with a 10 minutes' half time. There's a special defense zone located within 15cm from each goal line, where no more than one robot of each team excluding the defender's goal keeper can enter to defend or offend. The game has rules for fouls, a free kick and a penalty kick similarly to those of the real game, and a rule for a free ball called when the game becomes stalled.

3. Overall System Architecture

In implementing this kind of multiple robot system, we can categorize two types of basic design concept: 1) robot oriented (decentralized) design and 2) supervision oriented (centralized) design. Robot oriented design gives much weight on the autonomy of the robot. Thus, the

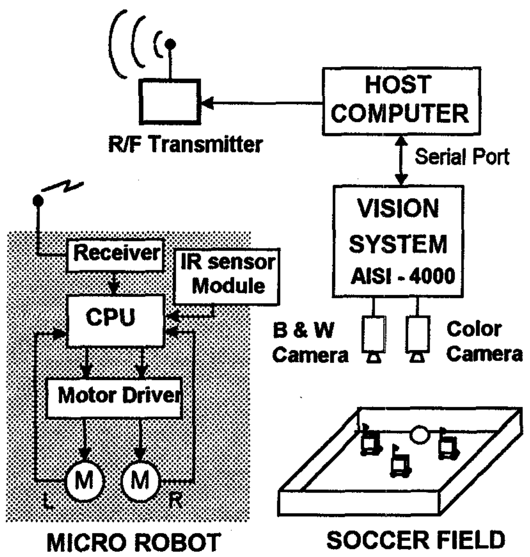

Fig. 1 Overall System Architecture

designer tries to build the robot as an entirely autonomous agent. People with this kind of design concept try to implement a lot of sensors, multiple way communication between each robot and host computer, and autonomous decision making functions to the robot itself. The host computer and vision system are then used as supplementary functions.

Although the realization of total autonomy may be the ultimate goal, this kind of design has a lot of technical limitations in practice due to the tight size regulation of the robot. Thus, we started the design of our system with the supervision oriented concept. In this concept, the vision system recognizes the environment, and the host computer decides the robot action based on the information from the vision system. In this case, the computational load on the on-board CPU can much be reduced, and results in a much faster robot reaction cycle. Thus, the overall system performance can be much improved.

Our micro robot system, CENDORI, consists of micro robots, a host computer and a vision system as shown in Fig. 1. A color camera and a vision system identify the ball and robots, and all the information is transferred to the host computer. The host computer decides each robot's action, plans robot paths and generates control words for all the robots. Control words are transmitted through the radio communication link, and the robot moves by controlling its motors according to the control words.

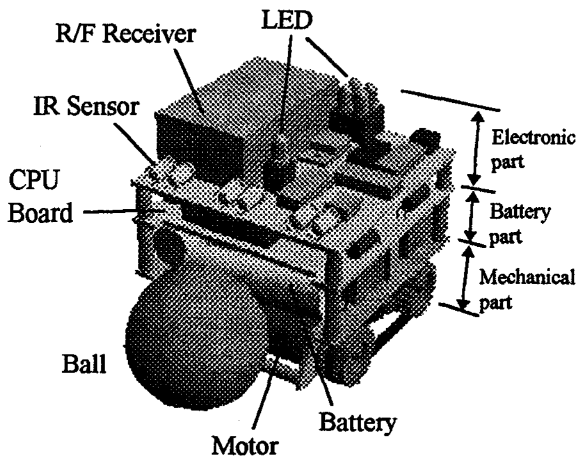

Fig. 2 Drawing of CENDORI Micro Robot

4. Micro Robots

4.1 Mechanical Design

Fig. 2 shows the 3D model of our robot. Our robot utilizes traction drive rather than wheel to achieve more stable traction. The robot has two traction drives in its right and left side, and steering is achieved by differencing the speed of each side. The traction drive utilizes toothed flexible timing belt and pulley mechanism. High power type belt with 3mm pitch is selected considering the load condition, and the effective wheel diameter is 20.1mm.

The frame supports all the components of the robot: drive train mechanisms, batteries and PCBs. It should be sturdy enough to prevent damage from a possible collision with other robots, though intentioned collision to the opponent robots is illegal. However, since heavy mechanism will make the robot slower in speed and response, the frame should be designed as light as possible.

Each traction drive train consists of a motor and a gear head, a driving pulley, a driven pulley, a belt and a belt tensioner. Two motors are located in front and rear in such a way to reduce the height of the mechanical part and balance the mass distribution.

The motor rating, the reduction ratio and the pulley size were selected through the iterative process of estimating total robot mass, calculating the required RMS torque of the motor and re-selecting the gear ratio. The motor selection method is well described in [9]. The selected motor is a DC brushed motor manufactured by Swiss Minimotor SA, with nominal voltage of 6 volts,

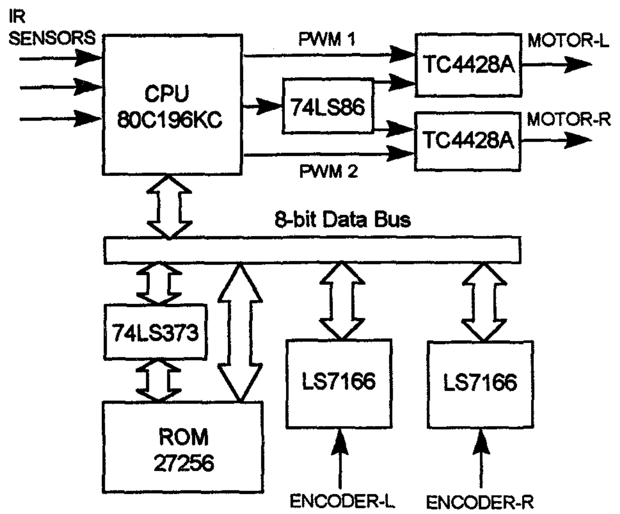

Fig. 3 Structure of the Robot Controller

maximum output of 0.38W[10]. A reduction gear head and a magnetic encoder come assembled together with the motor in the factory. The reduction ratio of the gear head is 1:22 and the pulse rate of the encoder is 16pulses/rev.

4.2 Robot Controller

Each robot has to be made as an autonomous agent that can operate independently under the supervision of the management system. To achieve this goal, each robot should be equipped with its own CPU. The basic functions CPU has to perform within a sampling time are as follows: 1) decoding the command signal from the host computer, 2) controlling the positions and velocities of two DC motors, and 3) handling the on-board sensor signals. Among various CPUs, we decided to use an Intel 16-bit micro-controller, 80C196KC, which has 488 bytes of registers, an 8-bit A/D input, 3 PWM outputs, 2-hardware timer/counters and 4-software timer/counters, 48 I/O ports in a single package[11].

With this CPU, we could design our robot controller as described in Fig. 3. The software for robot control and communication is stored in ROM, which is connected to CPU by 8-bit data bus. CPU generates PWM output for motor control through its PWM port, and this signal is amplified by dual high-speed MOSFET driver, TC4428A. An XOR gate, 74LS83 is used in changing the direction of the motor rotation. Two multimode counters, LS7166, were used as the encoder counters of two motors.

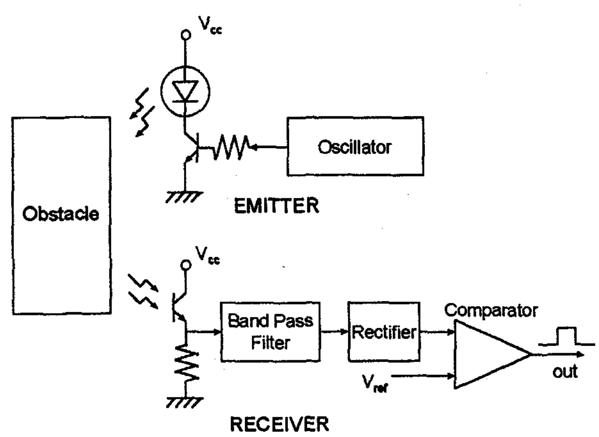

Fig. 4 IR Sensor Module

4.3 IR Sensor

One of the basic functions the robot should have is an obstacle avoidance. Colliding to the opposite team's robot is considered as a foul, and a free kick is called. Though we implement an obstacle avoidance algorithm in the host computer, there is a little time delay in the whole control cycle. Thus we need some on-board sensors to detect obstacles. When the robot senses an obstacle in front, it can stop and modify its paths to avoid the collision. Infrared sensor and ultrasonic sensor were considered for the possible use. Because the robot's size is so small and the required sensing range is short, we decided to use infrared sensor rather than ultrasonic sensor.

Infrared sensor has two modules: emitter and receiver. The emitter generates an oscillating light, and the receiver detects the reflected light. Because the opposite team may use IR sensors too, we should build a sensor module that can distinguish our own emitted light from other lights. Thus, we use an oscillating light of a specific frequency and a band-pass filter. The intensity of the light gets higher, as the obstacle comes closer to the sensor module. When the voltage level of the rectified output gets higher than the reference voltage, V_{ref}, the comparator output goes high level(+5V) from the low level(0V). The sensing range can be adjusted by changing V_{ref}.

Because we did not want to detect the ball with on-board sensors, we installed the sensors higher than 5cm from the ground. Currently, we installed three IR sensors only at the front side of the robot.

4.4 Communication Link

The rule of the soccer game regulates the data transmission between the host computer and the robots as a wireless communication. We can think of an infrared communication or a R/F(radio frequency) communication. Infrared enables simpler and smaller-size circuit compared to a R/F module. However, it is vulnerable to light noises such as from light sources for vision system. R/F communication has the merits that we don't have to align the transmitter and the receivers, and it's not affected to the noise in an ordinary environment.

We use a commercial R/C(radio control) transmitter and receivers of 72MHz band, which are commonly used in model airplanes. Because the radio controller uses a pulse modulation scheme, we could easily utilize it as a communication link between the host computer and the robots.

RS-232C communication protocol is used in our command transmission. Currently, a robot control word consists of 4 parts: header part, command part, data part and word terminator. The header part declares specific robot number to which the control word belongs. The command part specifies the mode of robot motions, and the data part specifies how far the robot should move or turn. The word terminator was included to eliminate communication noise. When a received control word string is not terminated with the specified code, the whole word is ignored.

5. Off-Board Systems

5.1 Vision System

To play a soccer game, the robot management system has to be able to overview what's happening in the field with vision system or other sensor system. In the MIROSOT, the location of the camera is restricted to be higher than 2m above the field at the center of the entire field or in the area of the team's own field. After some experiments in the playing environments, we decided to use a vision system with two cameras: one in color and the other in black-and-white. The color camera is to identify the ball and opponent robots and the black-and-white is to identify our robots from LED lights on top the robot.

Because our system is a supervision oriented system, building a reliable and high speed vision system is very important. We are using a high speed stand-alone type vision system, AISI-4000, which has 64 parallel processing elements for image processing and a MC6800 CPU for supervisory control. It has memory capacity of 32 frames of 512×512 image. The vision system

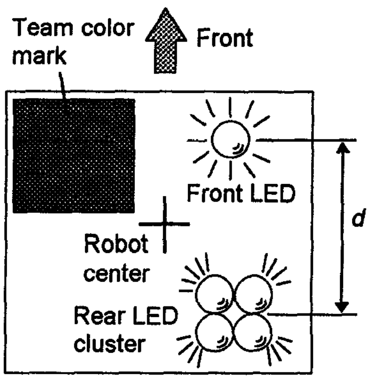

Fig. 5 LED Pattern On Top of The Robot for Recognition of Position, Orientation and Player Number

identifies the position of the ball, the positions and orientations of our robots and the positions of the opponent robots (orientations are not so important for opponents). Then it sends all the information to the host computer using a parallel communication port.

The color of the official ball is orange. The ball can be easily recognized from the intensity level of red and blue frame, and its center can be calculated from the mass center of thresholded image.

According to the rule, each robot must bear its team color mark (yellow or blue, according to the side the team belongs to) of a size larger than the specified size (3.5cm×3.5cm) on top. By comparing the intensity levels of RGB images of an object with previously taught levels, we can identify the opponent's color mark and calculate the positions of opponent robots.

To establish a reliable and efficient way to distinguish each of our robots and calculate its position and orientation, we developed our own robot recognition scheme. While the RGB intensity of ordinary color mark varies widely depending on the illumination condition, our pattern is more robust and less dependent to the change of surrounding environments, because LEDs are independent lightsources. The designed top mark is shown in Fig. 5. It consists of a single LED in the front side and a cluster of 4-LEDs in the rear side. Because the LED cluster looks like a larger single object when viewed in a 2m high distance, these two LED marks can be easily distinguished by comparing the areas. By changing the distance between the single LED and the cluster, we can distinguish each of our robots.

5.2 Host Computer

MIROSOT permits only one host computer to be used. Therefore, acquiring high computational speed is critical in the performance of the whole system. A Pentium-155MHz personal computer is used as our host computer. The host computer gets the positional information of the ball and the robots from the vision system through a serial communication port. Then, it performs all the required calculations and inferences of the management system and generates control words for each robot in the field. The control words are sent to the R/C transmitter through another RS-232C serial communication port.

5.3 Robot Management System

To manage a team of robots in a soccer game, we need to deploy some strategies. Like a real soccer game, there may be several different strategies depending on a few factors: who's getting the ball, current score, opponent's formation and other factors. These strategies are the highest level of robotic intelligence we should try to construct throughout the game. The robot manager may be able to select a certain formation of robots as an offense and defense strategy according to the game situation. We have built a rule-based robot management system. Depending on the position of the ball and the robots, a strategy is activated, and according to the strategy, a path of each robot is planned, which is a series of commanding orders.

At every sampling time, the robot manager gets position information of the ball and robots, calculates possible lines of attack and selects the most probable one. Then it should recognize the situation is to offend or to defend. When it's to offend, it orders the nearest robot to the ball to chase or shoot the ball according to the current situation. At that time, it orders the other field player robot to form a certain offense formation or move into the open space to prepare for a rebound. How to position these two field players is decided according to the strategy. Similar process is done for a defense case.

Then the multi-robot path planner generates a collision avoidance path for each field player. The planner also adjusts each robot's path to avoid the situation two field players enter the opponent's goal area at the same time, which is against the game rule.

In the mean time, the goal keeper algorithm orders the goal keeper robot to move back and forth according to the ball position, thus it may block the incoming ball. However, it is programmed not to let the goal keeper leave the goal area.

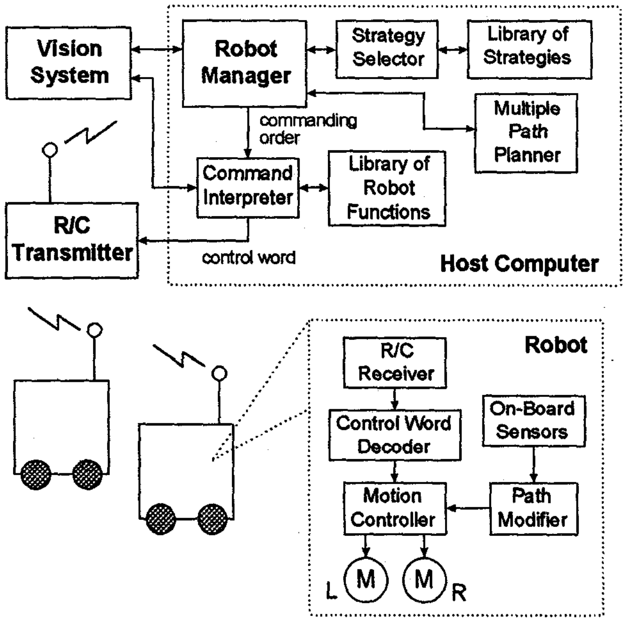

Fig. 6 Hierarchical Structure and Information Flow of the Robot Management System

6. Experimental Results and Discussion

All the components of the system have been integrated and tested. Because of the large voltage drop due to very low impedance of the selected motor, we have to add two more battery cells into the original 4 cells(4.8V) design. The mass of a robot turned out to be approximately 500g, and about a third of the entire mass was contributed to the batteries.

The belt traction shows a stable traction as expected, but the loss of power is a little large and the long contact area generates additional load when it turns. Thus, the robot doesn't show a good performance in low speeds. Currently, the robot has only four types of movement: forward, backward, left turn, and right turn.

With the R/F transmission, reliable communication was achievable up to 2400 BPS. After several optimizations of the vision algorithm, we could get 6 frames/s(167ms) of the vision sampling rate. Most of the required processing time was due to the image acquisition time, which is 90ms for the color camera and 30ms for the monochrome camera.

The whole system worked quite well for a static situation. However, because of the slow vision rate and the time delay in the vision and the managing algorithm, it doesn't show a satisfactory performance for a ball and robots continuously moving, though we implemented a ball position estimator.

About the robot managing algorithm, building an effective rule base required a lot of trial and error. In the future, various techniques in computational intelligence like neural network, fuzzy theory and genetic algorithms can be applied in constructing the robot manager, the strategy selector and the library of strategies.

7. Conclusions

In this paper, we provided a detailed description of our micro robot system for robot soccer game. We have tried to build a well-balanced system in overall performance. In November 1996, we have competed in the MIROSOT game, in which 23 teams participated, and qualified to the quarter final. From the experience of the game, we could see that fast frame rate and reliability of the vision system are one of the most crucial matter in making a high performance system. This system has been designed for the MIROSOT game. However, we expect to use it as a useful test bed for future researches in multiple robot system. We are going to study cooperation and collaboration of multiple robots and multiple robot navigation problem.

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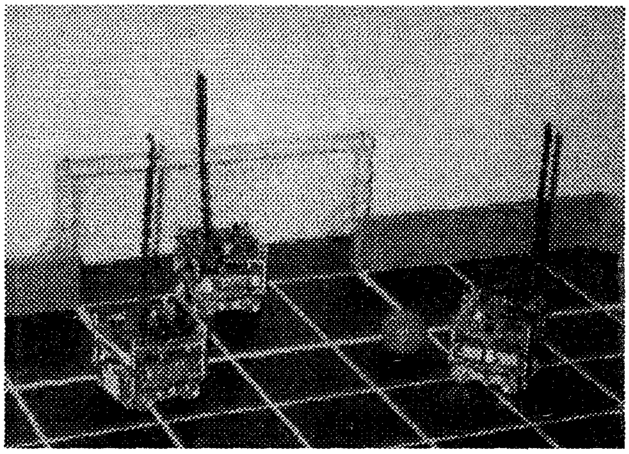

Fig. 7 Actual Robots and the Soccer Field