Proceedings of the 12th
KACC, October 1997

Development of Soccer-Playing Robots Using Visual Tracking

o Sung-Wook Park, Eun-Hee Kim, Do-Hyun Kim, Jun-Ho Oh

Mechanical Engineering Department, KAIST, 373-1, Kusong-dong, Yusong-gu,Taejeon, Republic of Korea
(Tel : +82-42-869-3263; Fax : +82-42-869-3095; Email :junhoh@ohzlab.kaist.ac.kr)

Abstract : We have built a robot soccer system to participate in MIROSOT97. This paper represents hardware specification of our system and our strategy. We select a centralized on-line system for a soccer game. The paper explains hardware specifications of our system for later development. Also, the paper explains our strategy from two viewpoints. From the viewpoint of cooperation, some heuristic ideas are implemented. From the viewpoint of path plan, Cubic spline is used with cost function which minimized time, radius of curvature for smoothness, and obstacle potential field. Direct comparison will be realized in MIROSOT97.

Keyword : Robot soccer, Path plan, MIROSOT, Visual tracking

1. Introduction

Multi-agent system is defined as the system composed of more than 2 robots[1] and performs the given task by cooperation. The characteristics of the system with respect to single robot are dynamic environment, cooperation, importance of appropriate architecture and so on[2]. In multi-agent system, the robots themselves constitute dynamic environment, since each robot recognize other robots as moving objects. Since the system performs given task by cooperation, it is necessary to make overall system plan for roles of robots. It is the most important characteristic of multi-agent systems, because the system achieves better performance with respect to single robot or performs tasks which cannot be done by single robot. The multi-agent system has many parts- for example, each robots, an supervisor, if any, communication part, sensors and so on. Since each part affects the overall system performance, it is necessary to adopt appropriate architecture.

Robot soccer is an interesting domain of multi-agent systems. It possesses characteristics of multi-agent systems. The robots play the game in dynamic environment - our robots, opponent's robots, and a ball. According to a situation, our robots must work together. It means a sort of cooperation. Also, according to a situation, our robots must decide which action they take - defense or offense, how they work and so on. In this viewpoint, the system needs real-time sensing, quick decision making and fast behaviors. It is related to system architecture and algorithms. Therefore, it is important to select an appropriate system architecture.

The robot soccer is studied by many researchers[2-5]. The researches of the robot soccer are promoted by some competitions. Direct competition is one of the advantages of robot soccer. We have participated in MIROSOT (Micro-Robot Soccer Tournament)[6-7]. MIROSOT makes some rules which describe precise specification for robot soccer[8]. The playground is rectangular with its length 130cm, its width 90cm. An orange golf ball is selected as the play ball. The size of a robot is restricted within 7.5*7.5*7.5cm. One team consists of three robots. We purpose to make soccer system with three robots.

We can categorize multi-agent systems based on two criteria. One criterion is Centralized / Decentralized system. The other is On-line / Off-line system. We select a centralized on-line system for the robot soccer[2]. We have been tried to improve the hardware system of our system - robots, communication, and vision system. This paper gives the specifications for later improvements. Developing path plans and the strategy for the cooperation is an important part of the robot soccer. This paper explains our path plan algorithms and strategy for winning the game.

The rest of the paper is organized as follows. Section 2 gives detailed descriptions of implemented hardware - robot itself, communication, and vision system. Section 3 gives our path plan algorithm and tracking control law. Section 4 gives our strategy for robot soccer. Section 5 gives conclusion of this paper and presents further works.

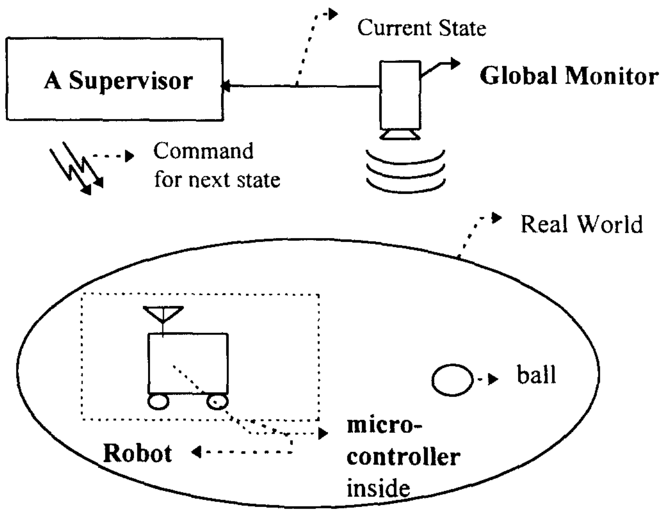

Figure 1. The constitution of our soccer robot system

2. System implementation

System is composed of three parts - a supervisor, vision system and 3 robots. A supervisor is a PC - pentium processor - which makes plans in real time, and vision system detects positions of the ball and robots. A robot has a CPU, communication module, motors, etc. These three parts are related one another. Figure 1 shows the overall system architecture of our system. Detailed descriptions are given in following chapters.

2.1 Configuration of individual robot

A robot is consisted of mechanical part, CPU board, and communication(receiver) module. Its size is within 7.5*7.5*7.5 cm.

2.1.1 Mechanical part

Mechanical part of a robot is consisted of two motors, encoders, gearheads, wheels, a ball caster, and a frame. The frame is designed for light, easy, compact and hardy integration. Motors and gearheads are selected in consideration for operating voltage, internal resistance, mechanical time constant. Its operating voltage is 6V. Reduction ratio of gearhead is 1:41. A diameter of a wheel is 32 mm. The no-load speed of a motor is 15200 rev/min. So, no-load speed of robots can be calculated as about 62 cm/sec. In real robots, we measure the maximum speed of a robot. The result is about 50cm/sec. Two motors are controlled by a CPU in main board independently. The encoder generates 16 pulses per revolution.

2.1.2 CPU board and sensor board

In CPU board, data processing and motor control are carried out. CPU board consists of two PCBs - same size of 7.5cm*6.0cm. We choose 80C196KC as robot's CPU. Its basic operation is to control motors according to the data from a supervisor via communication module. 80C196KC has three PWM generators which are used to control motors and 8 channel A/D converters which are used to receive the data from its own sensors. Motor driver is TC 4428 - dual high speed MOSFET driver. For compact spacing, we use EPLD(Erasable Programmable Logic Device) which can perform encoder counting, address decoding, and some logic functions.

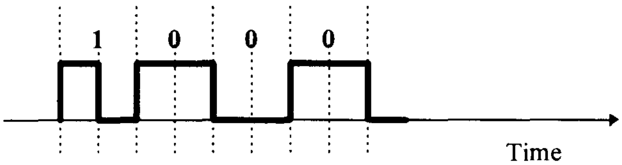

Figure 2. The shape of digitally coded data

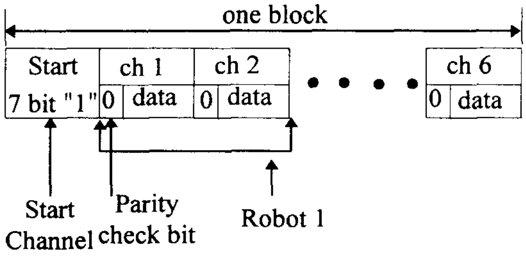

Figure 3. The constitution of communication signals

2.2 Communication

We choose unidirectional communication - from a supervisor to robots. Generally, to share more information, bi-directional communication is better. But, it needs more space and increases the complexity of tasks which robots and a supervisor carry out. In our system, we use vision system as a global monitor. So, it is not necessary for a robot to transmit its data to a supervisor. Therefore, we adopt unidirectional communication.

There are two prevalent communication methods - IR and R/F. IR communication has a problem such that it is affected by light. So, in real competition, it may malfunction. Therefore, we modify the commercial R/F communication module and introduce a digital method for high precision and good reliability of information transfer. We set the carrier frequency as 4kHz. Two sections make one digital data. If there is a state change between two sections in the digital data, this digital data means "1" bit. If no state change occurs, it means "0" bit. Between digital data, a state change always takes place. This is described in Figure 2. So, Data transfer ratio is 2000bit/sec. We define a channel as a basic unit and a channel has 7 bits - one bit is parity check bit and the other 6 bits are data bits. Since supervisor sends velocity commands for two motors, one robot needs 2 channels. We define a block as a basic command unit. As in Figure 3, one block consists of 7 channels because each of three robots needs 2 channels and there are a start channel. So, the transfer rate is about 41 block per second. It means that a supervisor can transfer information to five robots 41 times per second.

2.3 Vision system

It is very important to recognize the positions of robots and the ball in real-time. We use commercial camcorder and multimedia PC board - MediaCamp7 produced by Dooin Company. It can detect positions and rotations of our robots by color patches placed above the robots. MIROSOT make it a rule to have a solid 3.5cm*3.5cm patch of its team color visible on top. Figure 5 shows our color patch pattern. As for opponent's robots, vision system detects opponents team color. In our experiment, our vision system can detect a ball and six robots 25 times per a second.

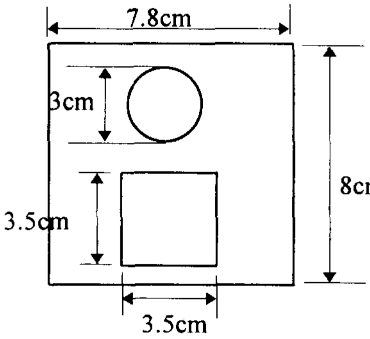

Figure 5. Our Color patch pattern

3. Path plan algorithm and tracking control for robot soccer game

Among many works of the system, the most improtant thing is the motion of each robot. Because each robot is free-ranging mobile robot, it is necessary to make the path. In our system, these are executed by a supervisor. In the path planning, we suggest a cost function which consists of two terms. One is the smoothness of the path, another is to minimize the total distance or time. To minimize the cost function, we choose the parametric cubic spline and update the coefficients in real time. The cubic spline is chosen in consideration for several points - simplicity for implementation, real-time calculation, continuous tracking aimed at a moving object. The path plan algorithm is made as same as that in [9].

After the path of a robot is generated, the tracking control is applied. We propose a globally asymptotically stable tracking control law. Figure 6 shows the mobile robot posture.

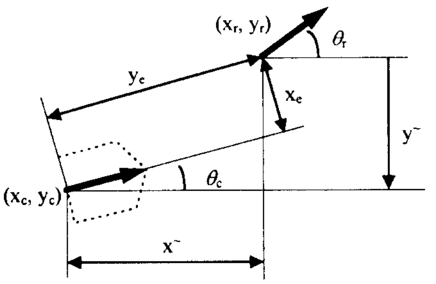

Figure 6. Mobile robot posture

Error state equations are derived as follows;

$$\mathbf{P}_e = \begin{bmatrix} x_e \\ y_e \\ \theta_e \end{bmatrix} = \begin{bmatrix} \cos\theta_c & \sin\theta_c & 0 \\ -\sin\theta_c & \cos\theta_c & 0 \\ 0 & 0 & 1 \end{bmatrix} (\mathbf{P}_r - \mathbf{P}_c) = \mathbf{T}_e \mathbf{P}^{\sim}$$

$$\begin{aligned} \dot{x}_c &= \cos\theta_c \, v & \dot{x}_e &= y_e\omega - v + v_r\cos\theta_e \\ \dot{y}_c &= \sin\theta_c \, v & \dot{y}_e &= -x_e\omega + v_r\sin\theta_e \\ \dot{\theta}_c &= \omega & \dot{\theta}_e &= \omega_r - \omega \end{aligned} \qquad (1)$$

where v is forward velocity, ω is angular velocity, x_e, y_e, θ_e are error states, v_r, ω_r are reference forward velocity and angular velocity, and L is distance of mobile robot. The following lemma represents the tracking control algorithm.

Lemma1. If we apply the following tracking control law to system (1)

$$v = K_x x_e + v_r \cos\theta_e - K_\theta \theta_e \omega$$

$$\omega = \omega_r + v_r/2 \,\{ K_y(y_e + K_\theta\theta_e) + 1/K_\theta \sin\theta_e \} \qquad (2)$$

then the Lyapunov function candidate

$$V(x_e) = 1/2\, x_e^2 + 1/2\,(y_e + K_\theta\theta_e)^2 + (1-\cos\theta_e)/K_y \ \geq 0 \qquad (3)$$

is nonincreasing, and all error states, x_e, y_e, θ_e, globally asymptotically converge to zero. where, K_x, K_y, K_θ, v_r is positive.

proof) We find the error state feedback system from (1),(2) as follows;

$$\begin{aligned} \dot{x}_e &= -K_x x_e + (y_e + K_\theta\theta_e)\left[\omega_r + \frac{v_r}{2}\left\{K_y(y_e + K_\theta\theta_e) + \frac{1}{K_\theta}\sin\theta_e\right\}\right] \\ \dot{y}_e &= -x_e\left[\omega_r + \frac{v_r}{2}\left\{K_y(y_e + K_\theta\theta_e) + \frac{1}{K_\theta}\sin\theta_e\right\}\right] + v_r \sin\theta_e \\ \dot{\theta}_e &= -\frac{v_r}{2}\left\{K_y(y_e + K_\theta\theta_e) + \frac{1}{K_\theta}\sin\theta_e\right\} \end{aligned} \qquad (4)$$

and we easily obtain $\dot{\mathbf{V}}$ as follows;

$$\dot{\mathbf{V}} = -K_x x_e^2 - 1/2 K_y v_r (y_e + K_\theta\theta_e)^2 - 1/2\, v_r \sin^2\theta_e / K_y \ \leq 0 .$$

i.e, $V(\mathbf{x}_e)$ is positive definite, and $\dot{\mathbf{V}}$ is negative definite.

Therefore, the equilibrium point, $\mathbf{x}_e=0$, is globally asymptotically stable.

■

4. Strategy for robot soccer game

In MIROSOT, three robots are permitted to play game. Therefore, we make algorithms considering three robots as a multi-agent system. From the viewpoint of cooperation, one robot is a goal keeper, the others take the roles according to the strategy. In this stage, many heuristic methods can be applied. Basically, we use divide-and-conquer heuristics. Figure 7 shows 4 modes. We divide the playground into two areas, assign each areas to two robots. Each robot takes the role according to the assigned area. Dividing area solves robots' getting entangled situation effectively. Mode (a) and (b) are natural division of the playground. Mode (c) has wide attack zone. Mode (d) is that two robots are all-round players. These modes are changed against opponent's strategy. We are testing established modes and developing more effective modes. Until now, we modify mode (a). The roles of robots are changed flexibly near the boundary.

It is because roles of each robot are assigned according to the geometrical relations of a ball and three robots. The geometrical relations can be classified as several cases. The transition from one case to another case is a event. Therefore, the robot soccer game can be considered as event-oriented system. There are some modeling tools in the research area of discrete-event system, for example, state automata, Petri-Nets. The Petri-Nets has more modeling power than automata.[10] Therefore, we try to develop whole system model using Petri-Nets. We try to investigate the possibility of adjustment of Petri-Nets as modeling tool of robot soccer system.

The goal keeper moves into three districts interchangably. Figure 8 (a) show these districts. According to ball position, the goal keeper moves three-divided goal area. The ball position and desired goal keeper position are matched like these : (1)-(1'), (2)-(2'), (3)-(3'). The Petri-Net modeling is represented in Fig. 8 (b). {p1,p2,p3} represent goal keeper position {(1'), (2'), (3')} as in Fig. 8 (a) and {p4,p5,p6} represent ball position {(1),(2),(3)} as in Fig. 8 (a). By vision sampling, a token is assigned to one of the places {p4,p5,p6}. Then one of the transitions {t1,t2,t3,t4,t5,t6} may fire to move the goal keeper to the desired position.

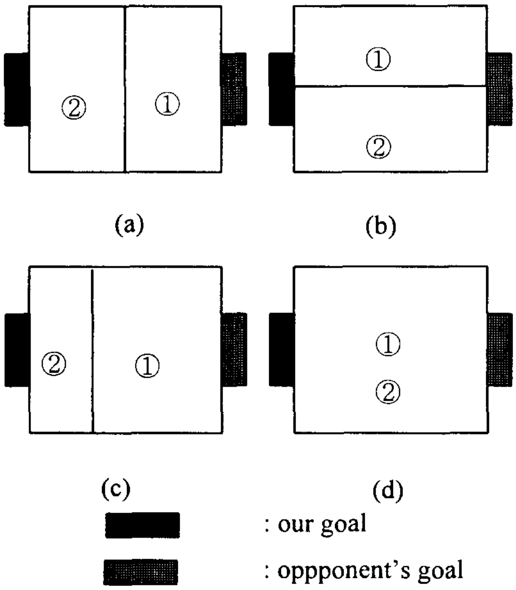

Figure 7. The 4 tested modes

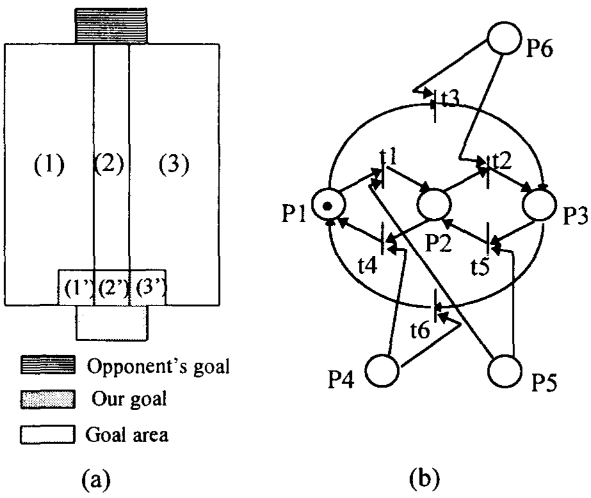

Figure 8. (a) three-divided area
(b) Petri-Net modeling of a goal keeper

The modeling for other two robots is complicated. It contains the strategy. We try to establish the complete modeling of robot soccer game. But, it has so many case that we cannot establish the whole modeling. We continue to develop the modeling.

The Petri-Net modeling will be helpful to make a simulation kit. The simulation kit is strongly needed in developing the strategy.

5. Conclusions and further works

In this paper, we provide specifications of implemented hardware. Detailed description of our system is helpful to those who plans to participate in soccer game and someone who want to make similar system. The supervisor makes path plans of robots using cubic spline for several reasons. This paper suggests globally asymptotically stable tracking control law and provides the proof.

We plan to improve sampling speed of vision system. It is very important factor to affect the performance of overall system. Also, we plan to improve communication speed to transmit more information to robots in restricted time. In addition, we are going to develop more effective algorithms to win soccer games.

References

[1] T.Arai and J.Ota, "Motion planning of multiple mobile robots", *IEEE Proc. Int. Conf. on Intelligent Robots and Systems, 1761-1768,1992.*

[2] Sung-Wook Park, Jung-Han Kim, Eun-Hee Kim, Jun-Ho Oh, "Development of multi-agent system for robot soccer game", *IEEE Int. Conf. On Robotics and Automation, pp.626-631, 1997.*

[3] Michael K. Sahota, "Real-Time Intelligent Behaviour in Dynamic Environments : Soccer-playing Robots", *University of British Columbia, MS Thesis, 1994.*

[4] Kyung-Hoon Kim, Kuk-Won Ko, Joo-Gon Kim, Su-Ho Lee, Hyung-Suck Cho, "The Development of a Micro tobot System for Robot Soccer Game", *IEEE Int. Conf. On Robotics and Automation, pp.644-649, 1997.*

[5] Arvin Agah, kazuo Tanie, "Robots Playing to win : Evolutionary Soccer strategies", *IEEE Int. Conf. On Robotics and Automation, pp.632-637, 1997.*

[6] Sung-Wook Park, Jin-Woo Lee, Do-Hyun Kim, Jung-Han Kim, Jun-Ho Oh, "Development of micro-robots and basic strategy for micro-robot soccer tournament", *Proc. of MIROST, pp39-46, May 1996.*

[7] Sung-Wook Park, Jung-Han Kim, Eun-Hee Kim, Jun-Ho Oh, " A Study on the Development of Micro-Robots and Basic Strategy for Micro-Robot Soccer Tournament", *Proc. of Micro-Robot World Cup Soccer tournament, pp.105-109, Nov. 1996.*

[8] Jong-Hwan Kim, The call for participation : Micro robot world cup soccer tournament (MIROSOT97).

[9] Eun-Hee Kim, "A Study on Real-time Path planning and Visual Tracking of Micro Mobile Robot", *M.S Thesis, Korea Advanced Institute of Science and Technology, 1997.*

[10] James L. Peterson, "Perti Net theory and The modeling of System.", Prentice-Hall, 1981.