Proceedings of the 12th
KACC, October 1997

Cell-Based Motion Control of Mobile Robots for Soccer Game

Seung-Min Baek, Woong-Gie Han and Tae-Yong Kuc
Intelligent Control and Dynamic Simulation Lab.
School of Electrical and Computer Eng., Sung Kyun Kwan University
Chunchun-dong 300, Changan-gu, Suwon, Kyungki-do 440-746, Korea
E-Mail : tykuc@yurim.skku.ac.kr

Abstract

This paper presents a cell-based motion control strategy for soccer playing mobile robots. In the central robot motion planner, the planar ground is divided into rectangular cells with variable sizes and motion indices to which direction the mobile robot should move. At every time the multiple objects-the goal gate, ball, and robots-detected, integer values of motion indices are assigned to the cells occupied by mobile robots. Once the indices being calculated, the most desirable state-action pair is chosen from the state and action sets to achieve successful soccer game strategy. The proposed strategy is computationally simple enough to be used for fast robotic soccer system.

1. Introduction

This paper develops a centralized but computationally simple approach to motion control of multiple mobile robots playing soccer game. The robotic soccer has recently been receiving considerable amount of attention not only as an interesting entertainment but also as a dynamic test bed for which many coordination techniques can be applied and evaluated in terms of feasibility and effectiveness. The robotic soccer systems and control schemes have been also studied by many researchers with various degree of application and success[2] [15][18][19][21].(For detailed description of the previous results on soccer playing robots, one may see the works of [13] and references therein.) However, most of the previous control strategies developed so far for robotic soccer system have been tested with only computer simulation due to high demand in real-time computational power or intense and heavy communication link which is beyond the reach of current technology. In this paper, we propose a motion control strategy for robotic soccer system which is computationally simple and hence can be implemented in real-time. The basic idea is to divide the planar workspace into cells with variable size and assign motion indices of integer values to occupied cells by the mobile robots. Based on the motion index for each degree of freedom(or each robot), the desirable state-action pair is chosen for cooperating motion control of robotic soccer game. That is, the multiple soccer robots is treated by the motion controller as a virtual composite system with the same degrees of freedom as the number of mobile robots. Hence, the proposed control approach falls into the category of centralized coordination methods. However, unlike most of centralized strategies, it requires no heavy computation to be performed in the configuration space of the virtual composite robot. The experimental results as well as computer simulation demonstrates the effectiveness and feasibility of the proposed motion control strategy.

2. The Robotic Soccer System

The robotic soccer system, Kinggo, developed in our lab consists of three $7.5 \times 7.5 \times 7.5cm$ micro robots fit to the MIROSOT specification[14], an external vision system with static configuration, and a PC station which supervises the robotic soccer game as the central coordinator. Fig.1 shows the schematic diagram of micro robotic soccer system.

2.1. The robots

Each robot shown in Fig.1 is driven by two independent DC motors and uses encoders for dead reckoning in local navigation, while the global coordination is guided by the supervising central coordinator with the external vision system. The micro mobile robot has on top 16 bit microprocessor Intel 80C196KC-20 to provide a fast PID servo loop for two DC motor driven wheels. For wireless communication in between the main computer and mobile robots, we prepare two sets of communication modules - an IR and a RF communication module - one of which can be used as a reliable communication link for robotic soccer game.

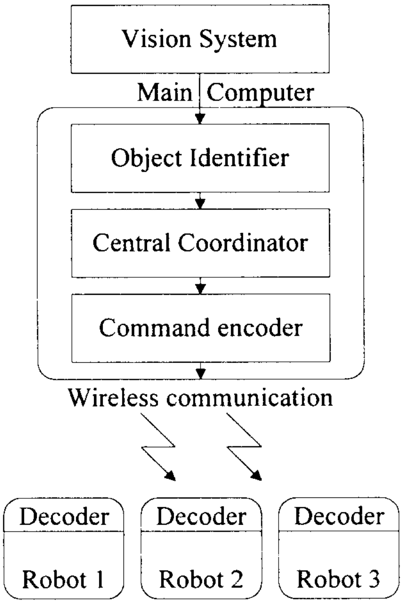

Figure 1: Schematic Diagram of Robotic Soccer System

2.2. The Vision System

An external color vision system is used to provide the raw data of planar ground for visual information extraction by the vision processing algorithm which developed for robotic soccer game. The vision system consists of a camcoder and frame grabber interfaced with the main computer. The camcoder provides NTSC signal output for the frame grabber to convert the raw data into the digital data at a maximum rate of 30 frames/sec. Each pixel in the 514 × 490 array of pixels in the image plane is assigned some RGB values of 8 bits data which are further processed by the vision data processing algorithm for object recognition.

2.3. The Communication Link

The IR communication module or RF module can be used in transmitting the continuous stream of information data from the centralized coordinator to each robot playing soccer game. In the current robotic soccer system, only the uni-directional communication link is implemented meaning the transmitter is used by the main computer and the receiver is onboard mobile robot. In case of using IR module, the information from the central coordinator and address along with synchronization signals are coded into serial data and sent by the transmitter using a modulating carrier signal of frequency 37.9kHz. The received serial data are demodulated by the receiver and decoded and interpreted by the microprocessor onboard mobile robot.

3. Identification of Objects

Using an external color vision system with static camera configuration, all the objects in the planar work space are recognized in real-time. The camera is fixed at a location whose single view covers the whole work space with a scale factor k between the real workspace and image plane.

$$k = \frac{l_r}{l_i} \tag{1}$$

where l_r and l_i are respectively the lengths of real workspace and image plane in the same direction. Each robot and whose position and orientation are identified by using color markings on top of mobile robots as shown in Fig.2.

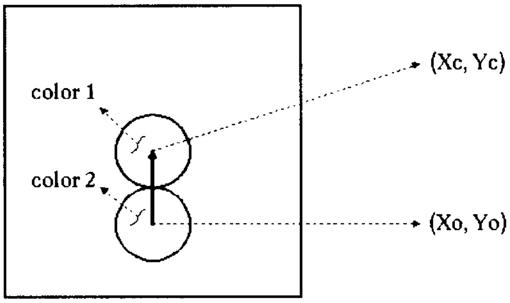

Figure 2: The Top View of Mobile Robot

In Fig.2, the color marking 1 located at the center of top of the robot is used to find the location of robot and the color marking 2 to find the orientation. To reduce the processing time of visual data in finding and identifying objects, we use the simple binary level centroid method[8]. The binary level centroid (X, Y) of robot is given by

$$X = \frac{\sum_{i=0}^{n} x_i}{n}, \quad Y = \frac{\sum_{i=0}^{n} y_i}{n} \tag{2}$$

where x_i and y_i are the x-coordinate and the y-coordinate of pixel, and n is the number of pixels. Then, the position of robot in the real workspace is computed as

$$Xr = kX, \quad Yr = kY \tag{3}$$

where k is the scale factor given in (1). Similarly, the orientation of robot can be obtained by first finding the binary level centroid of the color marking 2 and then calculating the direction vector from the center of color marking 2 to the center of the color marking 1.

In addition, by using the scanline method in [16], the computation time for visual data processing can be reduced by not scaning all the image plane. In our case, since the color marking is not a line but a color pattern, we can further accelerate the speed of visual data processing by using the simplified scanline method, i.e., *the*

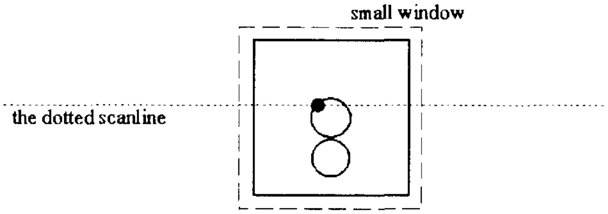

Figure 3: The Dotted Scanline Method For Fast Tracking

dotted scanline method[10] as shown in Fig.3. Once the color marking 1 is found in Fig.3, a small window is generated around the robot to handle the image data efficiently while preventing the interference of other objects. The identification of each robot is also achieved efficiently by calculating the area of color marking 2 which is assigned in advance for each robot.

This procedure is repeated for all the mobile robots and, after identifying all the robots as well as the ball and goal position, the rest of which is considered as obstacles.

4. The Motion Control Strategy

As a supervising controller, the centralized coordinator for robotic soccer system plays a major role in making the soccer robots work and collaborate for successful soccer game. In the centralized coordinator, the soccer robots are considered as one virtual composite robot with three degrees of freedom. That is, each robot corresponds to one degree of freedom in the three dimensional configuration space. Therefore, the motion control problem can be converted into the problem of controlling each degree of freedom in a cooperating way to achieve the desired state in the three dimensional configuration space, the goal position.

4.1. Perception Level Control for The Team Strategy

In this section, we provide a simple control strategy for robotic soccer game which overcomes the general drawback of heavy computational burden in using the centralized coordination approach for multiple mobile robots. The basic idea in accelerating the speed of computation is to choose only a small number of discrete states from the configuration space and let only one degree of freedom to change the state at a time with the rest two degrees of freedom fixed. At each time a desirable degree of freedom being chosen which is the fittest one for reaching the possible goal position, the motion index assigned to each workspace cell occupied by the chosen degree of freedom determines an action command from the action set defined in the direction that the action selected results in the desirable next state for soccer game.

4.1.1 The State Sets: Assume that all the objects in the planar workspace are identified which include the ball, robots, and the goal post. Further, assume that the planar workspace is partitioned into cells of variable sizes.

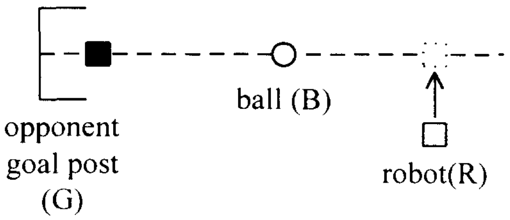

Figure 4: The Positive State(GBR)

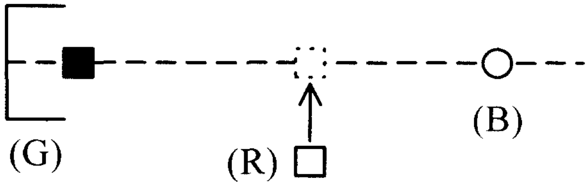

Figure 5: The Negative State(GRB)

In defining the states for each mobile robot or each degree of freedom in the configuration space, we consider the following two configurations based on the relative position of robot to the positions of opponent goal post and ball : *positive(desirable) and negative(undesirable) configurations*. In Fig.4, the positive or desirable configuration is defined as the configuration of robot such that the projection of robot to the extended straight line from the opponent goal post to the ball lines up in the order of the goal post-ball-robot(GBR). On the other hand, Fig.5 shows the negative or undesirable configuration in which the projection of robot to the linear line in between the opponent goal post and the ball makes line-up in the order of the goal-robot-ball(GRB). Note that the positive configuration means that the robot is demanded to move forward directly to the ball to make the ball closer to the opponent goal position, while the negative configuration is not. Based on the two configurations considered, we define the symbolic representation of positive states, negative states, and the singular states for each degree of freedom of a virtual composite robot system as follows :

$$\begin{aligned} S_P &= \{GBRc, GBRr, GBRl\} \\ S_N &= \{GRBc, GRBr, GRBl\} \\ S_S &= \{GB = Rr, GB = Rl\} \end{aligned}$$

where S_P, S_N, S_S represent the set of positive states, negative states, and the singular states. As shown in Fig.6

- Fig.8, the discriminating suffixes c, r, and l stands for the robot on the center, right plane, and left plane of the straight line between the goal post and the ball in the direction the ball facing the goal post.

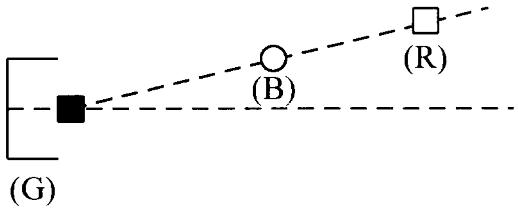

Figure 6: The Positive State(GBRc)

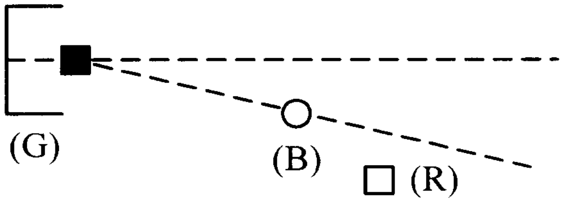

Figure 7: The Positive State(GBRl)

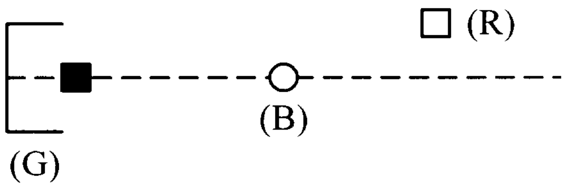

Figure 8: The Positive State(GBRr)

In the singular set, $GB = R$ means the projection of robot to the $G - B$ line meets the ball. Note that the singular states are the states which do not belong to the sets S_P or S_N. To provide obstacle avoidance action for mobile robot when necessary, the obstacle avoidance state can be defined by simply inserting an obstacle(O) in between the ball(B) and robot(R) as in Fig.9. That is, the sets of obstacle avoidance states S_{PO}, S_{NO}, S_{SO} are given as

$$\begin{aligned} S_{PO} &= \{GBORc, GBORr, GBORl\} \\ S_{NO} &= \{GROBc, GROBr, GROBl\} \\ S_{SO} &= \{GB = O = Rr, GB = O = Rl\} \end{aligned}$$

Therefore, all the states sum into 16 which is quite a small number of states for the centralized coordinator. Note also that if n-dof or n-robots need to be coordinated simultaneously, the centralized coordinator have to treat 16n states in the state search space, where in our case of robotic soccer system n equals 3.

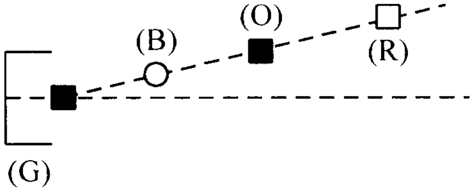

Figure 9: The Obstacle Avoidance State(GBORc)

4.1.2 The Motion Index: At every time all the object being identified, the coordinator can determine which robot is in which state and which robot should change its state to a more desirable state for successful soccer game. To facilitate the selection of action for state change, we assign the motion index of integer to each occupied cell in the workspace. The procedure for assignment of motion indices(d's) are as follows :
i) For unoccupied cells, assign 0.($d = 0$)
ii) For each robot, identify the state of the robot.
iii) For each cell occupied by the robot, with the positive(or negative) state assign the motion index which is defined as the number of cells if filled with the smallest cells in between the center of the ball and the robot multiplied by +1(or -1). Similarly, we assign for each cell occupied by the robot in the singular state(or obstacle avoidance state) the motion index defined as in the negative state case(or the positive state case except the ball being replaced with the obstacle.). With the motion index assigned for each state of mobile robot, an action is chosen for the current state in the direction that the resultant state is more preferable for successful soccer game, e.g., the ball is closer to the opponent goal post than the previous state. In addition, note that the precision of robot motion control increases as the size of cells gets smaller while the computation time also increases as the number of cells gets larger.

4.1.3 The Action Set: Since the cell based motion index dictates a desirable direction of movement for each robot, the actions can be chosen for each state from the action set defined. In deriving an action set for the state set of mobile robot, the robot motion is confined with only the following actions for simplicity : turn(T), move forward(F), move backward(B), and stop(or block)(S). Hence, the action set(S_A) is defined as

$$S_A = \{Tl(\theta > 0), Tr(\theta < 0), F(d > 0), B(d < 0), S\}$$

A command for mobile robot is composed of the actions from the action set. Two examples of commands are given as follows.

$$\begin{aligned} TrF &= TurnRight + Forward = Tr(\theta) + F(d) \\ TlB &= TurnLeft + Backward = Tl(\theta) + B(d) \end{aligned}$$

These commands can be assigned to each robot as a state-action command pair like as $\{(s, a)\} = \{(GBRc, F), (GBRr, TlF), \cdots\}$, where $(s, a) = (state, action)$. Fig.10 and 11 illustrate the control strategy.

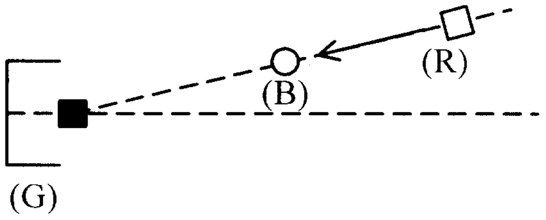

Figure 10: The State-Action Pair (s,a)=(GBRc,F)

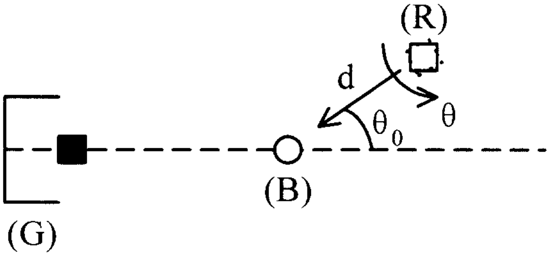

Figure 11: The State-Action Pair (s,a)=(GBRr,TlF)

4.1.4 The State Transition Model: In order to transit the current state to the most desirable next state for successful soccer game, the centralized coordinator should determine to which state the current state transferred and which robot to move. The simple criteria which can be used in selecting the next state are as follows:

i) transit the negative, singular, and obstacle avoidance states to one of positive states.

ii) in selecting one positive state, choose the most similar state to the current state in terms of moving distance and angle by one degree of freedom(robot).

iii) choose the most desirable state in terms of the distance and angle of approach to the ball.

iv) choose the most desirable state with robot with the minimal deviation from the $G - B$ line.

4.2. Servo Level Control for The Individual Action Strategy

Once the command from the central coordinator received and interpreted which consists of turning angle and distance to move, the mobile robot converts the data into motor inputs for two independent motors. The equations for conversion of turning angle and distance into motor angles are as follows.

Since the mobility of robot is critical for successful soccer game, we use the bang-bang control strategy in servoing the mobile robot to maximize the mobility of each mobile robot. That is, if the maximum speed of DC motor is V_0 and the command angle is θ_d, the reference velocity profile is determined as in Fig.12.

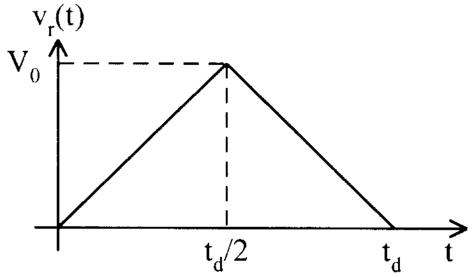

Figure 12: The Bang-Bang Control Strategy

$$v_r(t) = \begin{cases} \left(\frac{2}{t_d} V_0\right) t & (0 \le t \le \frac{t_d}{2}) \\ -\left(\frac{2}{t_d}\right) t + 2V_0 & (\frac{t_d}{2} \le t \le t_d) \end{cases}$$

where $t_d = \frac{2\theta_d}{V_0}$.

5. The Learning Strategy

Since the precise turning angle which result in a desirable state transition can not be precisely calculated in advance, the action parameter θ is to be learned by using a learning method. Moreover, the learning strategy enhances the robustness of robot motion control to various uncertainties such as in the weight of the ball, the friction coefficient of ground, kinematics and dynamics of robot, etc.. The action parameter in the learning process is assumed to be a function of the distance and angle of the robot to the ball.

$$\theta = f(\theta_0, d),$$

where θ_0 and d are defined as in Fig.11. The unknown function is learned by using a set of experimental data applied to a universal function approximator of radial function basis NN. Then, the uncovered region in the training phase is interpolated by the NN.

6. Discussion and Further Works

In formulating the control strategy for robotic soccer players, we implicitly have assumed the opponent plays the soccer game reasonably well and can move as fast as our robot. Simulation and experimental test is going on to validate the computationally simple strategy by training the robotic soccer system with the proposed learning scheme.

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