Intelligent Control of Autonomous Mobile Soccer Robot Adapting to Dynamical Environment

Nobuyuki Kurihara, Ryotaku Hayashi, Hikari Fujii,
Daiki Sakai, and Kazuo Yoshida

Yoshida Lab, System Design Engineering, Keio University
3-14-1, Hiyoshi, Kohoku-ku, Yokohama, Kanagawa 223-8522, Japan

Abstract. This paper deals with an intelligent control of an autonomous mobile robot, which can adapt to dynamical environments. RoboCup soccer robots are chosen as demonstration targets. An important issue in robotic soccer is how to respond to dynamical environment. This study presents an intelligent control method based on System-Life concept for the autonomous mobile robot system. In other words, it is presented how to design the activating controller, sensing element, processing element and so on. Furthermore, Kalman filter and Euler's method are applied to estimate the motion of the ball. First, the soccer robot system is developed based on System-Life concept. Second, the intelligent control method is applied to them. Finally the experiment is carried out on RoboCup Soccer field. It is demonstrated the field player succeeds in approaching moving ball and goalkeeper prevents moving ball from netting. The validity of the proposed method is verified.

1 Introduction

Recently, specialized robots have been installed in factories. It is expected that autonomous mobile robots will be used in dynamical environment. Although there have been considerably many researches on the design methods and adaptation to dynamical environment for autonomous mobile robots, the results of these researches have not necessarily been put into practice. In such classical planning methods as sense-model-plan-action framework, the environment was supposed to be static [1]. Working in dynamical environment is very hard for autonomous robots. For achieving intellectual action in dynamical environment, it is necessary to use such decision making based on sensory information as Subsumption Architecture [2] and [3]. However, these methods adapt an artificial system to the environment unilaterally and there is not a concept of symbiosis with natural systems. Natural systems include some information in gene. The information is influenced through the evolutionary process of adaptation to the environment. And in natural systems the information on their existences and evaluation is embedded. In the design of artifacts, the information of a system is not necessarily embedded, but it is possessed by the designer. It will be effective to embed this information into artificial systems. The above-mentioned concept was proposed as System-Life Concept (SLC) [4] and [5] which is applied to the design concept of the soccer robots system. In this concept, the System-Life Information (SLI) is provided for designing well-balanced artificial systems, so that an effective behavior control can be achieved.

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2 Design of Autonomous Soccer Robot System

2.1 Application of SLC

The soccer robot system is designed to play soccer game on the field of RoboCup MSL. The system consists of Sensing, Processing, Activating and Expression mechanisms. The sensing mechanism recognizes environment in real-time. The processing mechanism selects the most appropriate behavior with environmental information. The activating mechanism drives actuators. The expression mechanism is a communication system to realize cooperative behavior. SLI comprises environmental model, memory, estimated state, purpose, and self-evaluation. Figure 1 shows the scheme of the System-Life architecture, for the robot.

Section 2.2, 2.3, 2.4 and 2.5 describe the sensing mechanism, the processing mechanism, the activating mechanism and the expression mechanism, respectively.

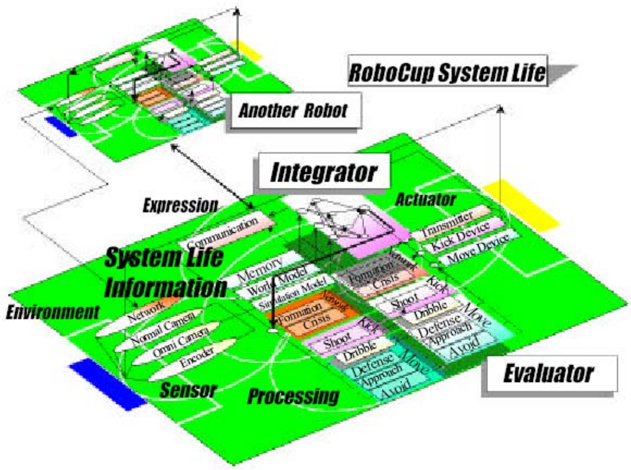

Fig. 1. System life concept on RoboCup soccer

2.2 Sensing Mechanism

The sensing mechanism is constructed by a normal color CCD camera, an Omni-directional vision system, encoders of DC motors and receiver of wireless LAN. The sensors for external environment are only cameras. Two image frames (256*220 pixels) from these normal and omni cameras are combined by field-mix circuit. The combined image (256*440 pixels) is shown in Fig.2. This combined image is the object of image processing. Robots recognize the distance (r) and the direction (θ) to the ball and two goals on polar coordinate shown in bottom half of Fig.2. In this paper, for decreasing image-processing time, only the image from the Omni-directional camera is used to recognize environment. Additionally, image-processing area $\mathbf{A}_{\mathbf{np}}$ is narrowed by G_{n-1} and A_{n-1} calculated by S_{n-1} when robots recognize S_n where

S_n : the state in some situation such as direction and distance to the ball and two goals
S_{n-1} : the state recognized 1 sampling time before S_n
$\mathbf{A_{np}}$: the processing area when robot recognizes S_n
G_{n-1} : the gravity point of each recognized object: ball and two goals
A_{n-1} : the area of each recognized object

This situation is shown in Fig.2. Each image-processing time is decreased to 40ms.

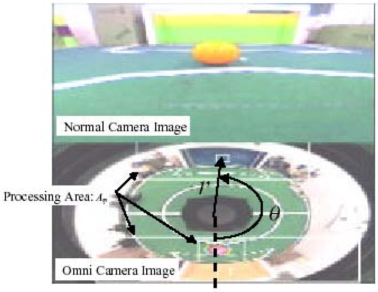

Fig. 2. Processing image

2.3 Processing Mechanism

Pentium II 450MHz CPU is used for the processing mechanism. This mechanism receives the environmental information obtained from the sensing mechanism, selects an action and outputs control signal. In this paper the following action modules are provided.

For field player

Ball approach, Dribble, Shoot and so on

For goalkeeper

Defense based on S_n, Defense based on the predicted state S_{n+j} and so on

These modules are allocated in the same level as shown in Fig.1, where the dribble module is selected. Robots can adapt to dynamical environment by selecting these modules in real-time.

2.4 Activating Mechanism

Activating mechanism is constructed by a kicking device and two DC motors to drive robot. The robot can run about 1.5m/s and kick the ball about 1.6m/s. The activating mechanism works according to the control signal from the processing mechanism.

2.5 Expressing Mechanism

The expressing mechanism is constructed by a wireless LAN. In this paper the *Info*(n) is sent and received to realize a cooperative behavior. The *Info*(n) is Ball-position, Self-position, Self-evaluating value and Degree of risk for loss.

3 Extended Kalman Filter for Predicting Ball-Position

Accurate information of the ball-position (X_B,Y_B) is necessary to estimate ball-position on the absolute coordinate (Σ_A). The ball-position on Σ_A is calculated by the self-position (X_R,Y_R) and the ball-position (r,θ) on the relative coordinate (Σ_R). However, the self-position and the ball-position on Σ_R obtained from camera image include errors. Therefore, a method for predicting ball-position with only the ball-position on Σ_R is considered.

3.1 Modeling of Ball Dynamics

The dynamics of a ball is formulated as Eq.(1) on the polar-coordinate shown in Fig.3.

$$
\begin{aligned}
&\begin{pmatrix} r \\ \dot{r} \\ \theta \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & -\dfrac{c}{m} & 0 & r\dot{\theta} \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & -\left(\dfrac{2\dot{r}}{r}+\dfrac{c}{m}\right) \end{pmatrix} \begin{pmatrix} r \\ \dot{r} \\ \theta \\ \dot{\theta} \end{pmatrix} + \begin{pmatrix} 0 \\ -c/m \\ 0 \\ -c/m \end{pmatrix} w \\
&\begin{pmatrix} r \\ \theta \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} r \\ \dot{r} \\ \theta \\ \dot{\theta} \end{pmatrix} + v
\end{aligned}
\tag{1}
$$

where

m: mass of a ball c: damping coefficient w,v: uncorrelated noise each other

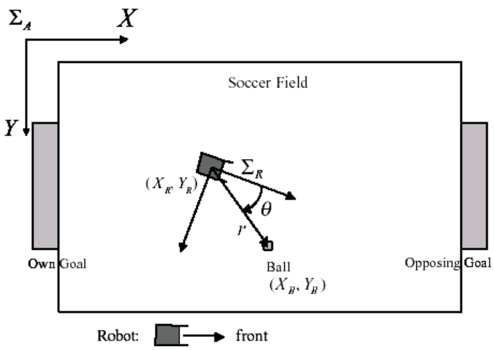

Fig. 3. Prediction coordinate

3.2 Predicting Ball-Position

In order to estimate and predict the ball-position an extended Kalman filter and Euler's method are used. Equation (3) indicates the algorithm of the extended Kalman filter for Eq. (2). By applying Euler's method to the estimated state, the ball-position in the future is predicted. To predict ball-position at intervals of Δt, Eq.(4) is used.

$$\begin{aligned} x_{t+1} &= f_t(x_t) + G_t w_t \\ y_t &= h_t(x_t) + v_t \end{aligned} \quad (2)$$

$$\begin{aligned} &\hat{x}_{t+1/t} = f_t(\hat{x}_{t/t}) \\ &\hat{x}_{t/t} = \hat{x}_{t/t-1} + K_t\left[y_t - h_t(\hat{x}_{t/t-1})\right], \quad \hat{x}_{0/-1} = \overline{x}_0 \\ &K_t = P_{t/t-1}\hat{H}_t^T\left[\hat{H}_t P_{t/t-1}\hat{H}_t^T + R_t\right]^{-1} \\ &P_{t+1/t} = \hat{F}_t P_{t/t}\hat{F}_t^T + Q_t, \quad P_{0/-1} = \Sigma_0 \\ &P_{t/t} = P_{t/t-1} - P_{t/t-1}\hat{H}_t^T\left[\hat{H}_t P_{t/t-1}\hat{H}_t^T + R_t\right]^{-1}\hat{H}_t P_{t/t-1} \quad \hat{F}_t = \left(\frac{\partial f_t}{\partial x_t}\right)_{x=\hat{x}_{t/t}} \quad \hat{H}_t = \left(\frac{\partial h_t}{\partial x_t}\right)_{x=\hat{x}_{t/t-1}} \end{aligned} \quad (3)$$

$$\begin{pmatrix} r \\ \dot{r} \\ \theta \\ \dot{\theta} \end{pmatrix}_{t+\Delta t} = \begin{pmatrix} 1 & \Delta t & 0 & 0 \\ 0 & 1-\frac{c}{m}\cdot\Delta t & 0 & r\dot{\theta}\cdot\Delta t \\ 0 & 0 & 1 & \Delta t \\ 0 & 0 & 0 & 1-\left(\frac{2\dot{r}}{r}+\frac{c}{m}\right)\cdot\Delta t \end{pmatrix} \begin{pmatrix} r \\ \dot{r} \\ \theta \\ \dot{\theta} \end{pmatrix}_t \quad (4)$$

4 Control Method

This section describes the method for action selection as shown in Fig.1. The method is divided into 6 steps. Figure 4 shows the action selection concept.

Step1 : *Info*(n) obtained from the sensing mechanism is sent to the processing mechanism.

Step2 : S_n is recognized and S_{n+j} is predicted with the method mentioned in section 3.2. S_{n+j}, S_n, S_{n-i} (i=1,2,…,10), the satisfaction values of system objective and E_n: self-evaluation value are elements of SLI. In this paper the objective is to carry the ball to the opposing goal and to defend the own goal.

Step3 : the integrator shown in Fig.4 selects an action module by S_{n-i}, S_n and S_{n+j} .

Step4 : the processing mechanism outputs control signal to the activating and the expression mechanisms.

Step5 : the activating mechanism executes the action based on the control signal which the processing mechanism outputs.

Step6 : the self-evaluating value is fed back to the integrator. Each action module has the self-evaluator as shown in Fig.1. If the self-evaluation value is satisfactory, the action is carried over without the decision by the integrator. Otherwise, the action is stopped and the integrator selects another action module.

By repeating Steps 1 to 6, it is possible to select an action module adapting to the environment.

The feature of this control method is to use the integrator and the self-evaluator. Additionally, it also has characteristics of the robustness against lacking image information from the sensing mechanism, which is achieved by using S_{n-i}, S_{n+j} and so on.

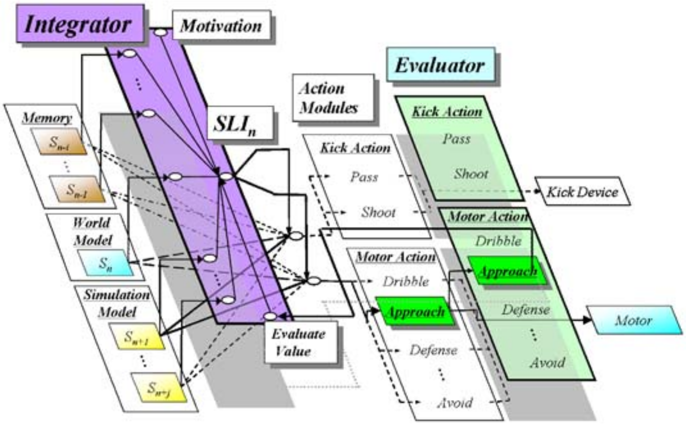

Fig. 4. Action selection scheme

5 Experimental Results

5.1 Experiment of Prediction

The precision of the prediction method is examined. The experiment is performed under the condition that a ball is rolled at the speed about 500 mm/s, and the ball-positions after 1 second and 3 seconds are predicted. In the experiment, the position of the robot is not changed. The prediction result is shown in Fig.5. The average and the maximum errors of r and θ after 1 second are shown in Table.1. These errors are mainly caused by the errors of the ball-position estimated from camera image. In Table.1, the error of r is large, while the error of θ is small. Therefore, the prediction result is accurate enough for the robots, since they are designed to behave using mainly θ information.

5.2 Experiment of Behavior Control

Experiment is carried out to compare two kinds of the behavior control methods using only S_n the present environmental information and using predictive information. The initial positions of the ball and the robot are shown in Figs. 6 and 7. Where the unit is [mm]. The initial position of the ball is (6000, 3500) in the experiment using field player and the initial position of ball is (3000, 500) in the experiment using goalkeeper, and the ball is rolled toward the left side of the own goal at initial velocity, 1.6 m/s and 2.0 m/s, respectively. The ball and robot are started at the same time. The experimental results are shown in Figs. 8 to 11. The goals in these figures are own goal.

In the experiment using a field player, the ball goes through the front of the robot and then the robot follows the ball, in the case of only using S_n. On the contrary, in the case of using SLI, the robot can shoot directly by predicting the path of the ball.

In the experiment using a goalkeeper, the robot moves right to defend own goal, and then moves left after goal is scored, in the case of using S_n. On the other hand, in the case of using SLI, the robot moves left immediately and a defensive action is achieved. Furthermore, a ball clearing action is achieved and the action selection is also smooth.

These experimental results show that the behavior control adapting to the dynamical environment is realized by selecting an appropriate action module with SLI.

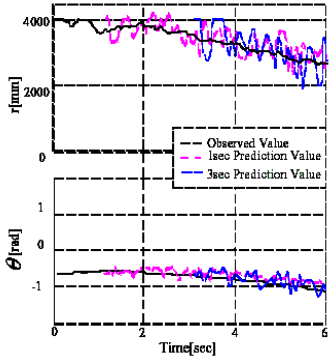

Fig. 5. Result of predicted ball-position

Table 1. Errors of predicted Ball-position

Average Error of r	[mm]	280
Max Error of r	[mm]	752
Average Error of θ	[rad]	0.12
Max Error of θ	[rad]	0.23

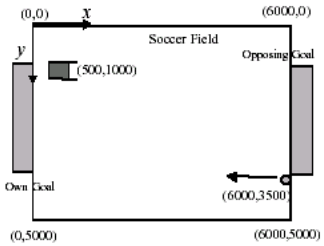

Fig. 6. Field player starting position

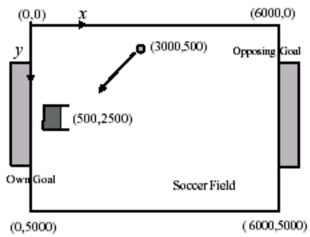

Fig. 7. Goalkeeper starting position

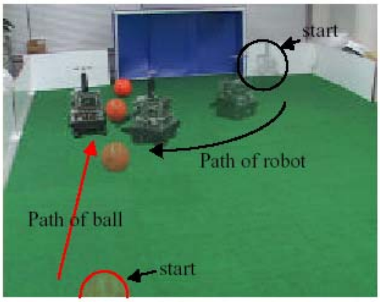

Fig. 8. Result of experiment without SLI (Field player)

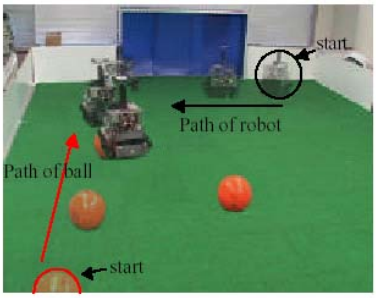

Fig. 9. Result of experiment with SLI (Field player)

6 Conclusion

In this paper, the purpose was the realization of intelligent control for autonomous mobile robots in the dynamical environment. The object of this research was the soc-

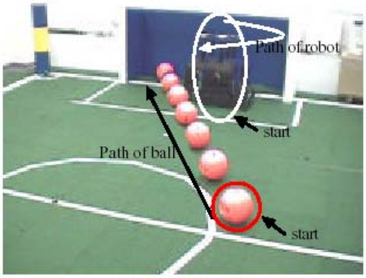

Fig. 10. Result of experiment without SLI (Goalkeeper)

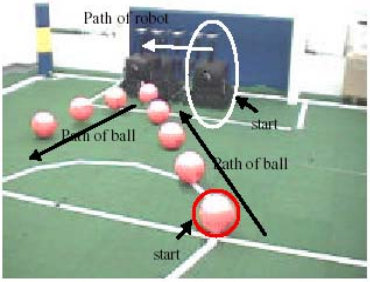

Fig. 11. Result of experiment with SLI (Goalkeeper)

cer robot of RoboCup middle size robot league. The robots were designed based on the System-Life Concept where there are sensing, activating, processing, expression mechanisms and system life information. The behavior control method was applied to action module selection using an integrator. The experiments demonstrate that field players and goalkeeper can cope with the dynamical environment and the proposed method is effective. The proposed method was applied to soccer robots at RoboCup 2002 in Fukuoka and the validity of this method in dynamical environment was demonstrated.

This concept leads to the design methodology such that the system itself possesses explicitly the information on its objective and evaluation with respect to action control and decision-making. The design methodology is expected to cope with unpredicted situation and will be applied to various fields as an intelligent control methodology.

Future works are decrease of designing difficulty, emersion of new action adapted to environment and realization of self-repairing and self-organization.

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