ODENS 2010 Team Description

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Abstract. In this paper, the system of team ODENS, Osaka Electro-Communication University, Japan is introduced. Although the hardware of robot is designed and manufactured by a company, the software of controlling 4-wheeled omnidirectional mechanism is original. It is described in detail. The system outside of the field consists of a server PC and some client PCs. The server has newly removed the conventional image processing function and supported the SSL-Vision. The clients decides action of corresponding robots one by one based on the information received from the server. The method of placing defenders in the client program is newly improved.

1 Introduction

Team ODENS consists of members of Masutani Laboratory in Department of Computer Science, Faculty of Information Science and Arts, Osaka Electro-Communication University, Japan. ODENS has participated in RoboCup competition since RoboCup Japan Open 2007. The results in the Japanese competitions of ODENS were the 4th place in 2007, the 2nd place in 2008, and the 3rd place in 2009. Moreover, we won the 4th place in RoboCup 2009 Graz, which was the first experience of a world competition for ODENS.

In the Department of Computer Science, Exercise in Robot Programming is organized for the second grade students, which uses the actual robot system for RoboCup competition. Students learn basic programming of deciding action of soccer robots in the exercise. In the room for the exercise, full-size SSL field and two ceiling cameras are readied. Since ODENS develops robots and programs there, it can always do exercises and experiments on the assumption of regular game.

In this department, students belong to laboratories from the second semester of the second grade. Students who are interested in soccer robot through "Exercise in Robot Programming" wish to enter Masutani Laboratory. In Masutani Laboratory, projects for RoboCup are themes for pre-seminar before regular graduation thesis. Moreover some students study RoboCup as also theme of graduation thesis.

Since the department is in the field of computer science and technology, the second grade students focus on development of software for deciding action. The hardware of robot is designed and manufactured by a company. The software of controlling omnidirectional mechanism is improved by graduate students and higher grade students.

In the following sections, the hardware and software of robot is introduced first. After that the computer system outside of field, especially a method of deciding action, is described.

2 Overview of the system

The system of ODENS is a distributed and autonomous system, which consists of one server and some clients as shown in Fig.1. One client program corresponds to one robot. All client is independent of each other. The server receives coordinate information of objects in the field provided by SSL-Vision. They are transformed in appropriate format and sent to the clients. Signals from the referee box are also sent to them. Each client program decides the next action for the corresponding robot based on the information received from the server and sends a command back to the server. The server collects the commands from all clients and sends it to the robots in the field by wireless. The above cycle is executed 60 times in one second.

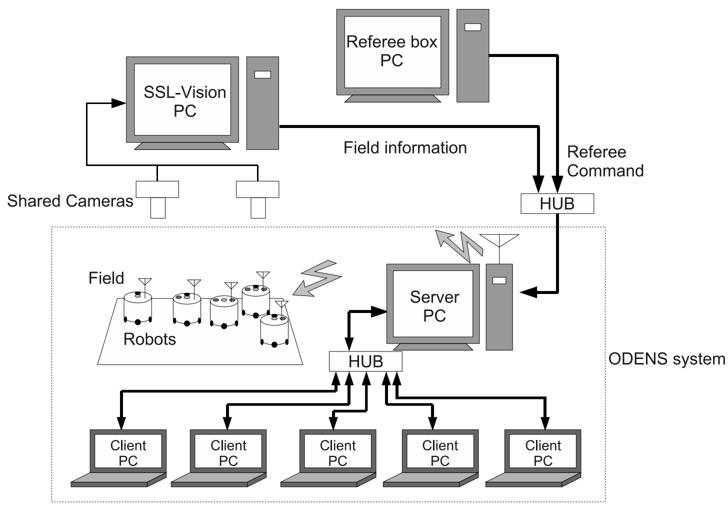


Fig. 1. Server and client system of Team ODENS

3 Robots

The mechanical and electrical hardwares of robots is designed and manufactured by SMATS Corp., which is very similar to RoboDragons' robot[1]. However, the onboard software for control is original.

3.1 Hardware

An appearance of the robot is shown in Fig.2. The main specification is shown in Table 1. The main dimensions of the robot with a cover is shown in Fig.3.

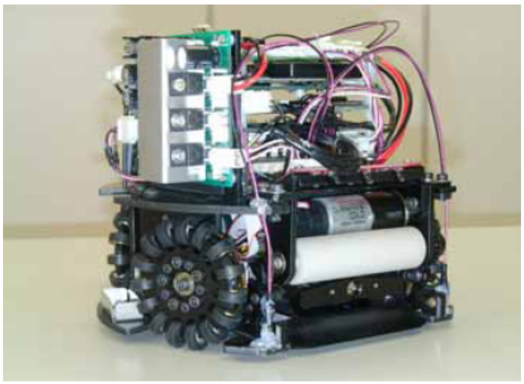
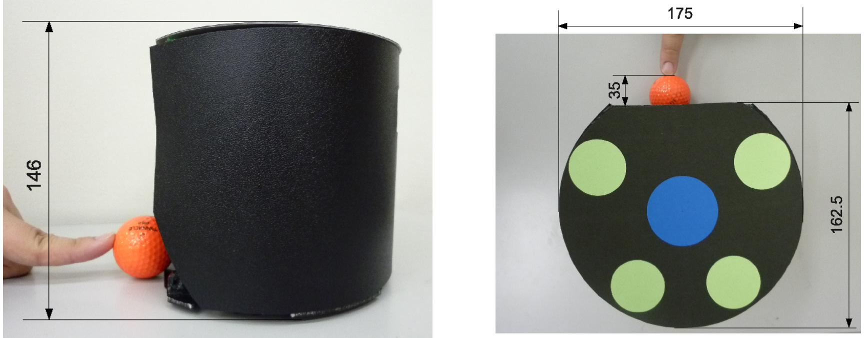


Fig. 2. ODENS robot



(a) Side view (b) Top view

Fig. 3. The main dimensions of the robot with a cover

Table 1. Specification of the robot

Dimension	length 162.5[mm], width 175[mm], height 146[mm]
Mass	2.2[kg]
Wheel	number 4, radius 30.5[mm], sub wheels 15
Motor	maxon RE-max23 222050, 11[W], reduction ratio 7.916
Kicking device	3 solenoids, 240[V]
Dribbling device	radius 10[mm], length 72[mm]
Ball sensor	LED and Photo-transistor, number 4
Gyro sensor	ADXRS610
Wireless modem	Futaba FRH-SD07T, 2.4[GHz]]
CPU	Renesas SH7045F(SH-2), clock 28[MHz]
Memory	SRAM 8[Mbit], Flash ROM 4[Mbit]
Battery	Li-Polymer 14.8[V]×1, 7.4[V]×1

3.2 Software for Robot Control

The program of CPU on the robot is developed with GNU C compiler. Three tasks are concurrently processed on the CPU. Task for feedback control is executed every 2[ms]. Task for communication receives a command from the outside via wireless modem every 16.7[ms]. The command consists of magnitude and direction of linear velocity, angular velocity, and on/off of dribbling device and kicking device.

Modeling As shown in Fig.4, a coordinates system is attached on the robot. Then numbers are assigned for wheels. Let α be angle of axes of front wheels from the front direction ($+X_r$), β be angle of axes of rear wheels from the rear direction ($-X_r$), and, L be distance between the center and the wheel. We define the vector $\boldsymbol{v} = [v_1, v_2, v_3, v_4]^T$ as set of velocities of wheels at contact point and $\boldsymbol{V} = [V_x, V_y, \Omega]^T$ as set of linear and angular velocities of the body in the robot coordinates system. Relation between two velocity vectors is obtained based on geometry as follows,

$$\boldsymbol{v} = A\boldsymbol{V} \tag{1}$$

$$A = \begin{pmatrix} -\sin\beta & -\cos\beta & L \\ \sin\alpha & \cos\alpha & L \\ -\sin\alpha & \cos\alpha & L \\ \sin\beta & \cos\beta & L \end{pmatrix} \tag{2}$$

Furthermore, we define the vector $\boldsymbol{f} = [f_1, f_2, f_3, f_4]^T$ as set of forces acting on the wheels at contact point and the vector $\boldsymbol{F} = [F_x, F_y, N]^T$ as set of resultant forces and moment acting on the body. Relation between two force vectors is obtained from the principle of virtual work as follows,

$$\boldsymbol{F} = A^T\boldsymbol{f} \tag{3}$$

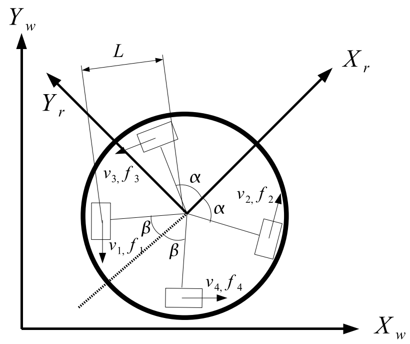


Fig. 4. robot model

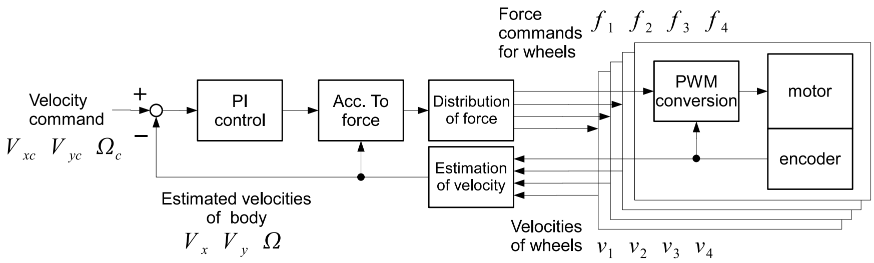


Fig. 5. Diagram of control law

Control law ODENS uses a control law based on dynamics model. Fig.5 shows its overview. For velocity command V_{xc}, V_{yc}, Ω_c given from the outside, method of computing the duty ratio of PWM motor drive is described in the following.

Letting ω_j be angular velocity of the j-th wheel, N be reduction ratio, and, r be radius of wheel, the velocity of wheel at contact point is represented as follows,

$$v_j = \frac{r}{N}\omega_j \tag{4}$$

The velocity of the body $\boldsymbol{V}$ is estimated from wheel velocities $\boldsymbol{v}$ based on an error minimum solution of Eq.(1).

$$\boldsymbol{V} = (A^T A)^{-1} A^T \boldsymbol{v} \tag{5}$$

The angular velocity Ω in $\boldsymbol{V}$ is replaced with measured value of gyro sensor to avoid error of estimation from wheel velocities.

Accelerations to be provided for the body are computed based on PI feedback.

$$a_x = k_{Px}(V_{xc} - V_x) + k_{Ix}\Delta t \sum (V_{xc} - V_x) \tag{6}$$

$$a_y = k_{Py}(V_{yc} - V_y) + k_{Iy}\Delta t \sum (V_{yc} - V_y) \tag{7}$$

$$\alpha = k_{P\theta}(\Omega_c - \Omega) + k_{I\theta}\Delta t \sum (\Omega_c - \Omega) \tag{8}$$

where k_{P*} is proportional gain and k_{I*} is integral gain. Forces acting on the body are computed based on equation of motion.

$$F_x = M(a_x - V_y\Omega) + \gamma_x \tag{9}$$

$$F_y = M(a_y + V_x\Omega) + \gamma_y \tag{10}$$

$$N = I\alpha + \gamma_\theta \tag{11}$$

where M and I are mass and inertia moment of the body respectively, γ_* is compensation of friction.

The wheel forces realizing this resultant force are computed as norm-minimizing solution of Eq.(3).

$$\boldsymbol{f} = A(A^T A)^{-1}\boldsymbol{F} \tag{12}$$

The current of the j-th motor i_j is given as follows,

$$i_j = \frac{r}{NK_t} f_j \tag{13}$$

where K_t is torque constant.

For PWM driven motor, current i can be represented as a function of the duty ratio p and the angular velocity ω, $i = g(p, \omega)$, based on model of electrical circuit. The program has numerical table of inverse of this function. For given current and angular velocity, duty ratio is decided by looking up the table.

$$p_j = g^{-1}(i_j, \omega_j) \tag{14}$$

4 Server

4.1 Hardware

PC The server PC is equipped with Intel Core2 Duo P8700 2.53[GHz] and 2[GB] RAM. It is connected to the SSL-Vision PCs, referee box PCs, and some client PCs through LAN. It also uses a USB-serial converter to connect the wireless modem.

Wireless communication Wireless modem Futaba Corp. FRH-SD3T is used to communicate with the robots in the field, whose communication rate is 38.4[kbps] and whose frequency is 2.4[GHz].

4.2 Software

OS for server PC is Microsoft Windows XP Professional SP3. Visual Studio 2008 C++ is used to develop the program. The server program has GUI and consists of multiple threads. These threads have functions respectively as follows.

Since field information is given by SSL-Vision from RoboCup 2010, we removed the process of the image processing from conventional ODENS server.[4] We use a conventional system about the other processes.

S-V watcher SSL-Vision Watcher is a thread to merge and manage the field informations divided into two that is given from SSL-Vision. It gives the merged field information to the "Position estimation" thread mentioned later.

Management of clients The clients can connect to the server and specify the robot number. After that it can disconnect and reconnect at any time. The information of clients connecting is displayed in the GUI window. Since the server can manage clients of two teams at same time, two team can play a game by using one server if all clients follow the protocol.

Position estimation The positions and velocities of objects are estimated by Kalman filter, whose observed values are the position of the objects given from S-V Watcher and whose model is a constant velocity motion. Furthermore, this function tackles exceptional situations by evaluating the difference between the observed value and the estimated value.

Wireless communication The server can deal with two modems. The commands to five robots are packed in one packet and transmitted in broadcast. The packet is 32[byte], which consists of a header of 2[byte] and five commands of 6[byte]. The command consists of ECC (Error Check and Correct) data of 2[byte], magnitude of linear velocity of 1[byte], its direction of 1[byte], angular velocity of 1[byte], and switches of dribbling device and kicking device of 1[byte].

Referee box Commands received from the referee box is sent to all clients in the prescribed format.

Communication among the robots Communication among the robots is represented as communication among the clients through the server program in the prescribed format.

5 Simulator

A simulator is indispensable for development of the program of deciding action. The ODENS simulator uses ODE[3] for physical computation. Since it supports

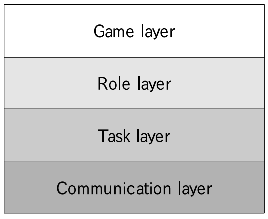


Fig. 6. Hierarchical structure of the client software

the same protocol as the server, the client program can connect to the simulator without changing its program. Moreover, it can deal with two or more clients and the referee box.

6 Client

PC executing the client program does not need special specification and performance, whose OS is not specified(We use both Windows and Linux). Only function of network communication is needed to connect to the server.

One client program corresponds to the one robot. Therefore, all clients program are executed independently of each other.

6.1 Structure of action decision

The structure of client program is separated into four layers as shown in Fig.6.

Game layer This layer is processed based on a state transition, whose state is switched mainly by command received from the referee box. There are five states, “Out of play”, “Pre set play”, “Set play”, “In play”, and “Halt”.

Role layer This layer decides role of each robot at each state. The role is assigned based on a role table mentioned below when the game state is “In play”. Otherwise, The role is assigned based on only distances between robots and ball in the team.

The role table is used to decide the role from the following four conditions.

- Rank: Rank of distance from the ball in the team (1...5)
- Relation: which team is near the ball? (not both, my team, opp. team, or both)
- Distance: distance from the ball (possessed, near, middle, or, far)
- Position: in which area is the ball as shown in Fig.7? (0...5)

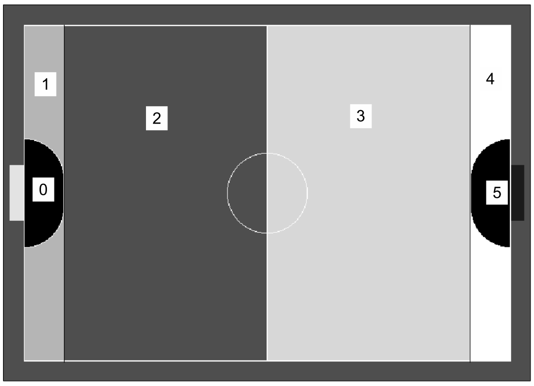


Fig. 7. Six areas in the field

Table 2. Role table

Rank	Relation	both teams are far						my team is near						opponent team is near						both teams are near					
	Position / Distance	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
1	possessed	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1	AT1
	near	BG	AT1	AT1	AT1	AT1	AT1	BG	AT1	AT1	AT1	AT1	AT1	BG	BG	BG	BG	BG	BG	BG	BG	BG	BG	BG	BG
	middle	BG	BG	BG	BG	BG	AT1	BG	BG	BG	BG	BG	AT1	BG	BG	BG	BG	BG	BG	BG	BG	BG	BG	BG	BG
	far	BG	BG	BG	BG	BG	AT1	BG	BG	BG	BG	BG	AT1	BG	BG	BG	BG	BG	BG	BG	BG	BG	BG	BG	BG
2	possessed	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	GD	GD	AT2	AT2	AT2	AT2
	near	PC	PC	PC	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	GD	PC	AT2	AT2	AT2	AT2	GD	GD	AT2	AT2	AT2	AT2
	middle	GD	GD	PC	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	GD	GD	GD	AT2	AT2	AT2	GD	GD	GD	AT2	AT2	AT2
	far	GD	GD	GD	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	AT2	GD	GD	GD	AT2	AT2	AT2	GD	GD	GD	AT2	AT2	AT2
3	possessed	GD	GD	GD	GD	PW2	PC	GD	GD	GD	GD	PW2	PC	GD	GD	GD	GD	PC	PC	GD	GD	GD	GD	PW2	PC
	near	GD	GD	GD	GD	PW2	PC	GD	GD	GD	GD	PW2	PC	GD	GD	GD	GD	PC	PC	GD	GD	GD	GD	PW2	PC
	middle	GD	GD	GD	GD	PW2	PC	GD	GD	GD	GD	PW2	PC	GD	GD	GD	GD	PC	PC	GD	GD	GD	GD	PW2	PC
	far	GD	GD	GD	GD	PW2	PC	GD	GD	GD	GD	PW2	PC	GD	GD	GD	GD	PC	PC	GD	GD	GD	GD	PW2	PC
4	possessed	PW2	PW1	GD	GD	GD	GD	PW2	PW1	PW2	GD	GD	GD	PW2	GD	GD	GD	GD	GD	PW2	GD	GD	GD	GD	GD
	near	PW2	PW1	PW2	GD	GD	GD	PW2	PW1	PW2	GD	GD	GD	PW2	GD	GD	GD	GD	GD	PW2	GD	GD	GD	GD	GD
	middle	PW2	PW1	PW2	GD	GD	GD	PW2	PW1	PW2	GD	GD	GD	PW2	PC	GD	GD	GD	GD	PW2	PW1	PW2	GD	GD	GD
	far	PW2	PW1	PW2	GD	GD	GD	PW2	PW1	PW2	GD	GD	GD	PW2	PC	GD	GD	GD	GD	PW2	PW1	PW2	GD	GD	GD
5	possessed	PW2	PW2	PW2	GD	GD	GD	PW2	PW2	PW2	GD	GD	GD	PW2	PW2	PW2	GD	GD	GD	PW2	GD	GD	GD	GD	GD
	near	PW2	PW2	PW2	GD	GD	GD	PW2	PW2	PW2	GD	GD	GD	PW2	PW2	PW2	GD	GD	GD	PW2	GD	GD	GD	GD	GD
	middle	PW2	PW2	PW2	GD	GD	GD	PW2	PW2	PW2	GD	GD	GD	PW2	PW2	PW2	GD	GD	GD	PW2	PW2	PW2	GD	GD	GD
	far	PW2	PW2	PW2	GD	GD	GD	PW2	PW2	PW2	GD	GD	GD	PW2	PW2	PW2	GD	GD	GD	PW2	PW2	PW2	GD	GD	GD

AT1: Attacker1 PC: PassCutter PW1: PassWaiter1
AT2: Attacker2 GD: GoalDefender PW2: PassWaiter2
BG: BallGetter

An example of the table shown in Table 2. Symbols in the table means roles as follows.

- Keeper: to defend goal in penalty area
- GoalDefender: to defend goal outside of penalty area
- PassCutter: to cut passing as for opponent team's ball
- BallGetter: to get opponent team's ball
- Attacker1: to shot at the opponent team's goal
- Attacker2: to assist Attacker1 or Attacker3
- Attacker3: to attack by passing
- PassWaiter: to wait for ball at specific position

Task layer This layer execute concrete actions of the robot. For example, "Turn to the ball", "Move to specified coordinates while avoiding obstacles " and so on.

It does not have state transition model internally. Therefore, when a destination to move and information of the field are given, the output action is uniquely decided. “Reflective kick” in the next sub-section is defined in the layer.

Communication layer This layer has functions for communication.

6.2 A Method of Placing Defenders

The defenders (including the goalkeeper) of ODENS were poor at positioning. The fact is proven by some called games in the competitions that we participated in 2009. In order to overcome the problem, a new algorithm of placing defender is introduced. Moreover the placing goalkeeper is improved.

Value of danger To decide positions were defenders should defend, we defin “value of danger”. It assesses of possibility to be aimed by opponents for a point on the own goal line. We consider two possibilities in case that a ball owner shoot directly (named direct shot) and in case that a friend who get a pass from a ball owner shoots (named indirect shot).

The method of computing the value of danger is as follows. First, the own goal mouth is equally divided into eight parts. Let $i (i = 0, 1, 2, \ldots, 8)$ be the i-th dividing point. Next, Shoot lines for i are defined. For the direct shot, the shoot line is defined as the line which links the i-th point to the ball. For the indirect shot, the shoot line is defined as the lines which links the i-th to each opponents (except the ball owner). If the line intersects to a range of the goalkeeper, the value of danger is defined as zero. The range that the goalkeeper can prevent is the range that the goalkeeper can move during before the ball arriving at the goalkeeper. Let (x_b, y_b) be coordinates of the ball, (x, y) be coordinates of the goalkeeper, $(x_n, y_n) (n = 1, 2, 3, 4, 5)$ be coordinates of the n-th opponents. The range is computed by Eq.(15) for the direct shot, or by Eq.(16) for the indirect shot.

$$t_D = \frac{\sqrt{(x - x_b)^2 + (y - y_b)^2}}{v_{b_{max}}} - t_{delay}$$

$$r_D = \frac{a{t_D}^2}{2} \tag{15}$$

$$t_{I_n} = \frac{\sqrt{(x_b - x_n)^2 + (y_b - y_n)^2}}{v_{b_{pass}}} + \frac{\sqrt{(x_n - x)^2 + (y_n - y)^2}}{v_{b_{max}}} - t_{delay}$$

$$r_{I_n} = \frac{a{t_{I_n}}^2}{2} \tag{16}$$

The parameters in Eqs.(15) and (16) we use are shown in Table 3. If the line cannot be prevented by the goalkeeper, the value of danger is computed by Eq.(17) for the direct shot, or by Eq.(18) for the indirect shot.

$$\alpha_i = p \frac{1}{\sqrt{(x_b - x_{g_i})^2 + (y_b - y_{g_i})^2}}, (i = 0, 1, 2, \ldots, 8) \tag{17}$$

Table 3. Parameters for the value of danger

a	t_{delay}	$v_{b_{max}}$	$v_{b_{pass}}$
acceleration	time delay	shoot velocity	pass velocity
2627[mm/s^2]	0.149[s]	10[m/s]	5[m/s]

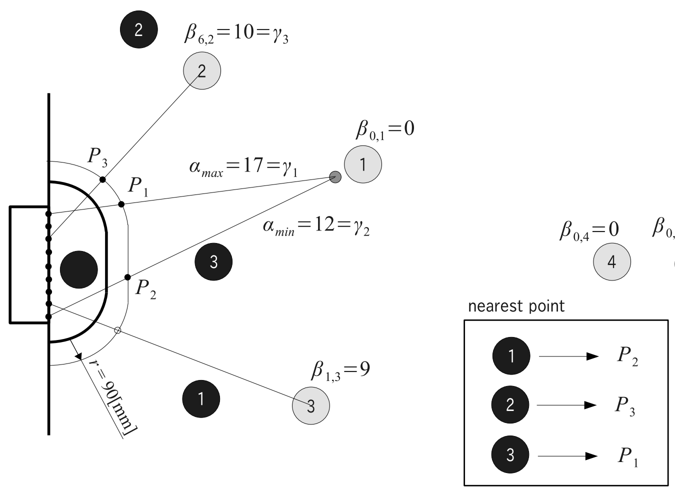


Fig. 8. An example of the method of placing defenders

$$\beta_{i,n} = q\frac{1}{\sqrt{(x_n - x_{g_i})^2 + (y_n - y_{g_i})^2}}, (i = 0, 1, 2, \ldots, 8) \tag{18}$$

where p and q are appropriate weight coefficients.

Placement based on value of danger Among the values of danger computed above, the following seven values are selected; the maximum and minimum values of α_i for the direct shot and the median values of $\beta_{i,n}$ for the indirect shot from every n-th opponent. Let γ_k be the k-th values of the selected values. Moreover m higher values are selected from γ_k , where m is the number of defenders decided by the role layer.

The defence place corresponding to the value γ_k is the point of intersection with the line where 90[mm] just extended an own penalty area line and the shoot lines of the k. At the point with the highest value, the defender nearest to it is placed. At the other points, the nearest defender is placed among the defenders whose places are not decided. An example of the method of placing defenders based on the value of dangers is shown in Fig. 7.

7 Conclusion

As mentioned above, the part of deciding action is perfectly separated from image processing and robot control in the system. Owing to this feature, this system became useful platforms for both education and research. For the purpose of education, many students learned robot programing by using it. On the other hand, ODENS won the 4th in the RoboCup 2009 Graz by using the same system.

Although under the SSL regulation it is possible to make centralized system, in the system of ODENS, the program for each robot is independent of others. In the future, following this policy we will study robot system and participate in competitions.

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