Study on Optimizing of Ball Passing Strategy and Role Switching Mechanism for Robot Soccer

HAN Li-dong, FAN Shou-wen

School of Mechatronics Engineering, University of Electronics Scientific Technology of China Chengdu 610054 China

Abstract **A new ball passing strategy for robot soccer is proposed in this paper. With introduce of a new algorithm on ball passing, the optimum strategy is confirmed to be more efficient and exact when passing a ball. Questions of role switching in multi-intelligent agent cooperation in robot soccer are described based on Generalized Stochastic Petri-Net (GSPN). Results of computer simulation have confirmed the feasibility and efficiency of above Petri-net method.**

Key words **Petri-net; ball passing strategy; role switching; robot soccer; agent**

With the ever increase in number of robots in an industrial environment, scientists/technologists are often faced with issues on cooperation and coordination among different robots. This has led to the developments in multi-robot cooperative systems. The proponents of multi-robot systems need a model to test the theories being proposed, for their efficacy and efficiency. The platform of robot soccer is their best choice they can make. Robot soccer makes heavy demands in all the key areas such as: robot technology, mechanics, sensors and intelligent control, communication, image processing, mechatronics, artificial life, etc.

At present, most studies are based on the problems of cooperative strategy, path planning and relative topics [1-7]. A real time vector field based path planning for attack mode robot and a Petri-net state diagram approach for robot's role selection were proposed in Ref.[8]. Conception of running range of robot was proposed in Ref.[9], and it is very useful when shoot a ball. In Ref.[10], a motion control and the corresponded strategy to realize cyclic ball passing motion in robot soccer games were presented. The above mentioned proposals are proved to be successful in some ways. Considering the disadvantages of the previous researches, a new passing strategy in view of angle factor is proposed in this paper. The purpose of this proposal is to advance the probability of success when passing a ball. Considering the highly frequent cooperation among team members in robot soccer game, a new role switching mechanism is also proposed for all kinds of competitions. A classic example is described in detail based on Petri-net to demonstrate the feasibility and efficiency of the mechanism through computer simulation.

1 Research on Ball Passing Strategy

The action of pass is very important in robot soccer. Most previous studies on ball passing strategy ignore the influence of angle's factor which is very significant when passing a ball.

1.1 Several Theoretical Explorations

Considering the actual situations on court, the real translation velocity of the center of robot[9] can be abstracted into the following equation system:

$$v=\begin{cases} at, & 0\leqslant t<t_1 \\ v_{\max}, & t_1\leqslant t<t_2 \\ v_{\max}-a(t-t_2), & t_2\leqslant t\leqslant t_3 \end{cases} \tag{1}$$

The robot's initial velocity is zero, it reaches the maximum velocity when time goes on t_1, it begins to slow down when it reaches the time t_2, and its velocity will diminish to zero during the time interval of $t_3 - t_2$. The parameter a represents the translation acceleration of the center of robot.

The actual situations on court are so complex that they can not be simulated perfectly. In view of some experimental requirements, several felicitous assumptions are taken into account as below.

1) The damp of actual field is very little, and the ball hit by a robot will last its initial velocity v until it is cut (here we suppose the robot hit the ball at its most power). Since the field is taken for "pure rolling" and

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"non-slipping", the velocity of robot or ball will not slow down for the external factors.

2) The time consumed on translation of the center of the robot is only taken into account. The time expended on rotation of the center of the robot will be neglected.

3) The time interval between the initial velocity v_0 (here $v_0 = 0$) to the maximum velocity $v_{\max}$ is ignored.

According to the displacement formula of invariant velocity, the distance Δs passed in unit time Δt when robot moves at an invariant velocity (here is $v_{\max}$) is shown:

$$\Delta s = v_{\max} \Delta t \tag{2}$$

Fig.1 illustrates this process which is much like the spread of water wave.

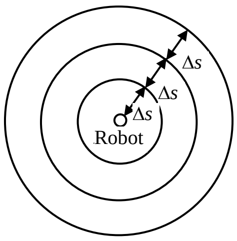


Fig.1 The sketch map of distance passed in a couple of time units when robot moves at an invariant velocity

1.2 Solutions of Angle When Passing a Ball

Based on the above analysis, a lot of situations can be solved easily. Fig.2 shows a classic role assignment of 3-vs-3 robot soccer at a certain time in the play. We can understand others situations once getting through this kind of situation by analogy. Here robot O_1 and O_2 of our team play the role of main attacker and assist, respectively. The opponent robot E_1 aims at intercepting the ball which passed to robot O_2 from O_1. Now pass angle θ_k must be determined appropriately so as to not only maximally save time but also avoid the block by enemy robot.

Several related items are defined as:

O_i, $(i = 1, 2)$: indicates home robots;

E_j, $(j = 1, 2)$: indicates opponent robots;

$X_i Y_j$, $(X, Y = O, E, T \vee i, j = 1, 2)$: indicates the distance between point X_i and Y_j;

D_{E_j}, $(j = 1, 2)$: indicates the time delay of opponent robot E_j;

θ_{opt} : indicates the optimum angle;

T_i, $(i = 1, 2)$: indicates intersection of robot and ball;

$t_{x_i \to T}$, $(x = E, O \vee i = 1, 2)$: indicates the time passed from point x_i to T.

Fig.2 (a) shows the situation on condition $L_1 > L_2$, concretely, we assume that

$$\left.\begin{aligned} & L_2 = 2a \\ & L_1 = a + b \quad (b > a) \\ & E_1 T_2 = b \\ & O_1 T_1 = O_2 T_2 = a = O_1 T_3 \end{aligned}\right\} \tag{3}$$

where a is the distance between O_1 and point T_1 which is the intersection of ball and robot O_2 after time interval t on condition that they move at the same velocity of $v_{\max}$ vis-a-vis, arc_2 is the circumference when radius equals to a. According to the law of cosines, we have the following equation

$$E_1 T_1^2 = a^2 + (a+b)^2 - 2a(a+b)\cos\alpha \tag{4}$$

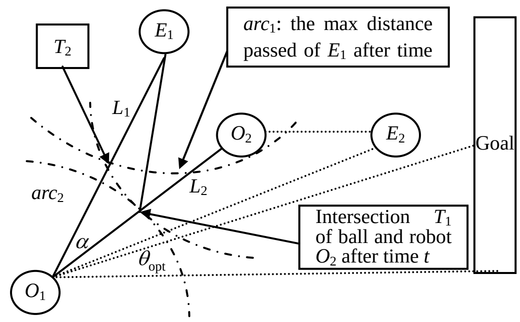
where α is the included angle between line L_1 and L_2. From the discussion above, we can obtain some conclusions as the follows

$$E_1 T_1 > b > a \tag{5}$$

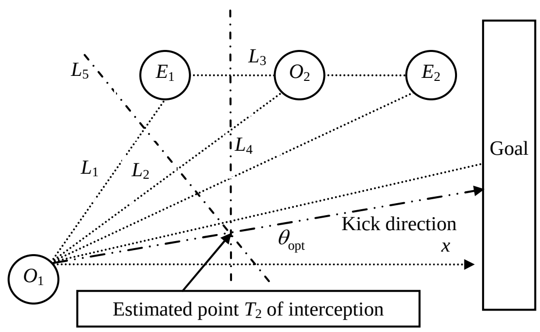
Fig.2 (b) shows the situation on condition that $L_1 \leqslant L_2$. Then we have the following conclusions:

$$O_1 T = O_2 T = E_1 T \tag{6}$$

$$t_{E_1 \to T} > t_{O_1 \to T} = t_{O_2 \to T} \tag{7}$$



(a) Situation on condition that $L_1 > L_2$



(b) Situation on condition that $L_1 \leqslant L_2$

Fig.2 A classic situation on field in robot soccer

Based on the above descriptions, the optimum algorithm on ball passing is proposed in Fig.3. This new ball passing strategy deals better with the interference and interception by opponent robot through introduce of optimum algorithm on pass angle. It not only enhances the probability of success when passing a ball but also saves time maximally in order to provide better condition for next cooperation.

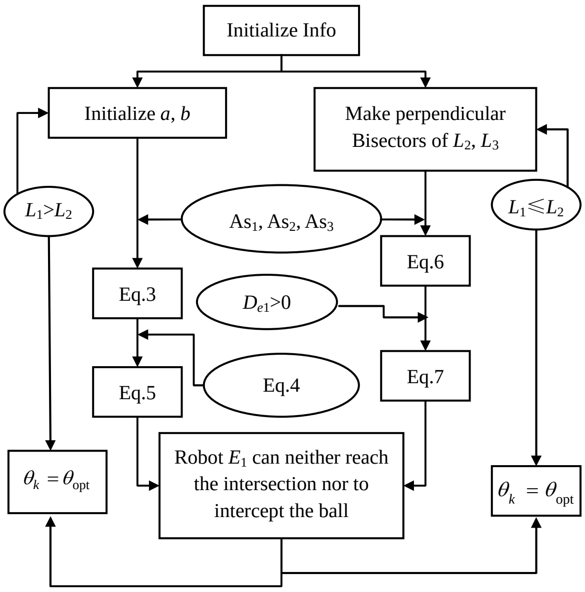


Fig.3 The optimum algorithm on ball passing

2 Mechanism of Role Switching

2.1 Condition on Role Switching

Situations on court are complicated and change fast. Role switching is much important in some circumstances such as: the former defender is in a good position to attack; the former main attacker is blocked by opponent or happens to be malfunction so that the ball is likely to lose, etc.

At present, some papers introduced strict conditions for role switching by considering some factors such as: distance between robot and ball, present orientation and position of robot, angle between coordination and the line that connects robot and destination, etc. There is a problem existing in the above proposal, that is, they missed the opponent's influence. Considering this problem, a new condition for role switching is proposed as follows.

$$C=\lambda_1\left|P_b-P_r\right|+\lambda_2\left|\theta_{br}\right|+\lambda_3 O+\lambda_4 P_o+\lambda_5 I \tag{8}$$

where P_b is the present position of ball, P_r is the present position of robot, θ_{br} is the angle of ball relative to the reference frame of robot, O expresses whether there is obstacle between robot and destination, P_o stands for whether the robot is between ball and goal, I represents the influence of opponent (mostly the factor of distance), and λ_1, λ_2, λ_3, λ_4, and λ_5 are the weight coefficients of distance, angle, obstacle, position and influence of the opponent, respectively.

The optimum algorithm on role switching is described below:

1) Host computer collects visual information on court and pretreats the collected data.

2) Compare index C. The host compares the last situation with the former one and makes decision whether or not to change role according to the value of index C.

3) Judgment of role switches. This step is the important premise of next cooperation. The situations in the field change all the time and it is hard to know the opponent intention, so a parameter used to measure the influence of opponent is introduced in Eq.8. Here we suppose robot2 is main attacker and robot1 is assistant attacker, if $C_1<C_2$, then switch the role between robot1 and robot2; otherwise go to step1).

2.2 Description of Role Switching Mechanism (ROSM) Based on GSPN

The above ROSM can be widely used in most types of robot soccer such as 3v3, 5v5 and 11v11. A concrete example of 3v3 is given below. It is assumed that the formation of team is type 1-1-1, that is to say, one attacker, one defender, and one goalie. Description of role switching between robots based on GSPN is given below:

Place: $P=\{P_1,P_2,\cdots,P_8\}$

Transition: $T=\{T_1,T_2,\cdots,T_8\}$

where P_1: robot1 defending and robot2 attacking, P_2: robot1 attacking and robot2 defending, P_3: robot1 attacking, P_4: robot1 defending, P_5: robot1 and robot2 defending, P_6: robot2 attacking, P_7: robot2 defending, P_8: robot1 and robot2 attacking, T_1: robot1's position is suit for attacking, T_2: robot2's position is suit for attacking, T_3: robot1 is defending now, but its position is suit for attacking, T_4: robot1 is attacking now, but it's position is suit for defending, T_5: robot2 is defending now, but its position is suit for attacking, T_6: robot2 is attacking now, but it's position is suit for defending, T_7: robot1 locates at backcourt, and it receives the order from robot2 to attack together, and T_8: robot2 locates at backcourt, and it receives the order from robot1 to attack together.

The state diagram can be modeled in simple GSPN as Fig.4. According to characters of GSPN, it's more suitable to simulate actual situations happened in play because of its randomicity of event-driven. ROSM controls the transition of roles according to actual circumstances on court, that is, the ROSM will spring randomly which is more similar to the event-driven processes in GSPN. To start with, there are three tokens in P_1, P_4 and P_6 which mean robot1 is defending and robot2 is attacking. In the following instant if transition T_1 is fired, token in P_1 moves to P_2, then T_6 is fired, and tokens in P_2 and P_6 move to P_2, P_5 and P_7. When T_4 fires, tokens in P_4 and P_5 move to P_3.

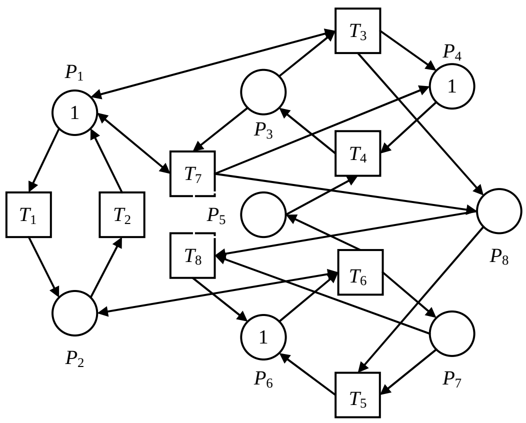


Fig.4 A classic kind of Petri-net model of ROSM

3 Simulation

A toolbox of Matlab is exploited to simulate the model of the given example based on GSPN. The purpose of this simulation is to testify some significant characteristics of Petri-net. Through the results of evaluated items, several characteristics of robot soccer system such as boundness, safeness, liveness and conservativeness can be analyzed. Fig.5 shows the reachable tree and the marking lists of GSPN model.

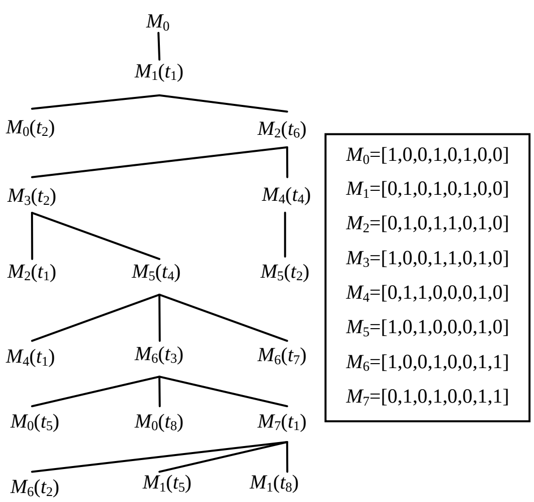


Fig.5 Reachable tree and its marking list of GSPN

According to the characters of reachable tree, some conclusions can be gained:

1) All the nodes of this net include 0 and 1 only, so the net is safe;

2) All the transitions appear in the reachable tree, so all of them are live. If all transitions of one net are live, then the net is live;

Fig.6 shows the incidence matrix $\boldsymbol{A}$, $\boldsymbol{P}$-invariants and $\boldsymbol{T}$-invariants of GSPN model respectively.

According to the characters of incidence matrix $\boldsymbol{A}$, P-invariants and T-invariants, we know:

1) Once exists a positive real number vector of (n×1) which can make $x^{\mathrm{T}}\boldsymbol{A} \leqslant 0$, the net is bounded. There exist 4 vectors of this kind in Fig.6, so this net is bounded;

2) Once exists a positive real number vector of (n×1) which can make $x^{\mathrm{T}}\boldsymbol{A} = 0$, the net is conservative. There exist 2 vectors of this kind in Fig.6, so this net is conservative;

$$\boldsymbol{A} = \begin{bmatrix} -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 & -1 \\ 0 & 0 & 0 & 0 & 1 & -1 & 1 & 0 \\ 0 & 0 & -1 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 & -1 \end{bmatrix}$$

$$\boldsymbol{P}: \begin{matrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{matrix} \qquad \boldsymbol{T}: \begin{matrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 \end{matrix}$$

Fig.6 Incidence matrix $\boldsymbol{A}$, $\boldsymbol{P}$-invariants and $\boldsymbol{T}$-invariants of GSPN model

We can tell that the net is bounded, safe, live and conservative based on the above analysis. Reflecting on the robot soccer system, the phenomenon like deadlock won't occur according to the role switching mechanism. Safety and liveness are also guaranteed in this net when role switches properly according to real situations of cooperation and role assignment.

Considering real-time control and influences of uncertainties, the roles will switch randomly on time. Tab.1 shows the results of a certain competition, and it describes the global transitional situations of places.

For instance, place P_1 is given to show the detailed information included in Tab.1. Fig.7 shows the relationship of time and duration between two successive instants when tokens arrive in place P_1. The solid line represents the current durations. The dashed line represents the global durations, whose values at the end of time are equal to the corresponding quantum in Tab.1. It is obvious that robot O_1 and O_2 cooperate with each other in two types mostly. Type one: Robot O_1 attacks, and robot O_2 defends; type two: robot O_1 defends, and robot O_2 attacks. But it lasts few times with these two types. On the other hand, cooperation in some other types is very frequent and relatively lasting according to ROSM. Along with the process of time, the ROSM will control the robots properly and take the competition more likely to win.

Tab.1 Global transitional situations of places

Place Name	Arrival Sum	Arrival Rate	Arrival Dist.	Throughput Sum	Throughput Rate	Throughput Dist.	Waiting Time	Queue Length
p1	197	0.65491	1.5269	197	0.65491	1.5269	1.5269	1.00000
p2	197	0.65491	1.5269	197	0.65491	1.5269	1.5269	0.99976
p3	48	0.15957	6.2667	48	0.15957	6.2667	6.2667	1.00000
p4	48	0.15957	6.2667	48	0.15957	6.2667	6.2667	1.00000
p5	48	0.15957	6.2667	48	0.15957	6.2667	6.1678	0.98421
p6	48	0.15625	6.4001	48	0.15957	6.2667	6.1425	0.98018
p7	48	0.15957	6.2667	48	0.15957	6.2667	6.2667	1.00000
p8	48	0.15957	6.2667	48	0.15957	6.2667	6.2667	1.00000

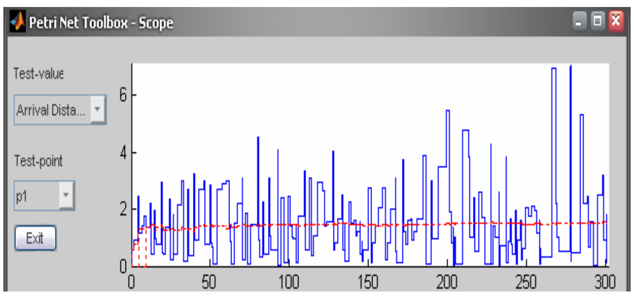


Fig.7 Transitional situations of place P_1

4 Conclusions

In this paper, significance of angle's factor in robot soccer gets recognition through optimizing the ball passing angle. Considering the influences such as real-time control and uncertainty, the propositional ROSM will switch the roles of robots depending on the situation and get better results in the game. Computer simulations are made to testify the safety and liveness of given example based on GSPN and conform ROSM's effectiveness indirectly. Possible conflicts in decision-making have been maximally avoided by using GSPN method compared with other means. Results of simulation have confirmed the feasibility and efficiency of GSPN method. Further study is needed to go deep into conditions on role switching. Cooperation of robots with full duplex communication is another issue to be looked into.

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Brief Introduction to Author(s)

HAN Li-dong (韩立东) was born in Liaoning Province, China, in 1980. He received the B.S. degree from University of Electronic Science and Technology of China (UESTC), Chengdu, in 2003. He is currently a graduate student with UESTC. His interests include intelligent robot, intelligent mechatronics systems, petri-net theory.

FAN Shou-wen (范守文) was born in Hubei Province, in 1968. He received his M.S. and Ph.D. degrees from Sichuan University, Chengdu, in 1992 and in 2002, respectively. He has obtained 7 patent rights for inventions-creations and published more than 50 academic papers. He is currently an assistant professor of UESTC and is a commissioner of Academic Committee of School of Mechatronics Engineering, UESTC. His research interests include robotics, design automation.

(Continued from page 79)

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Brief Introduction to Author(s)

WANG Zhong-sheng (王中生) received the M.S. degree in mathematics from The Northwest University in 1990. He is an associate professor with Zhongyuan University of Technology, Henan Province. He received the Ph.D. degree from Huazhong University of Science and Technology, Wuhan. He has published more than 30 papers. His research interests include nonlinear control systems, time-delay system control and artificial neural networks.

CHEN Jin-huan (陈金环) was born in 1964. She is an associate professor with Zhongyuan University of Technology, Henan Province. Her research interests include numerical analysis.

LIAO Xiao-xin (廖晓昕) was born in 1938. He is a professor with the Department of Control Science and Engineering, Huazhong University of Science and Technology, Wuhan. He has published more than 120 papers and 3 monographs in Chinese, 1 monograph in English and 1 translated book. His research interests include the stability of dynamical systems, nonlinear control systems, and the dynamics behavior of artificial neural networks.