Fuzzy Decision Method for Motion Deadlock Resolving in Robot Soccer Games

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Abstract. A new method of motion deadlock resolving by using fuzzy decision in robot soccer games is proposed in this paper. For the reasons of complex competition tasks and limited intelligence, soccer robots fall into motion deadlocks in many conditions, which is very difficult for robots to decide whether it is needed to retreat for finding new opportunities. Based on the analysis of human decision for dealing with these kinds of motion deadlocks, the fuzzy decision method is introduced in this paper. Then, fuzzy rules based deadlock resolving system is designed according to relative positions and orientations among robots and the ball in local regions. Lots of experiments by human experts and the fuzzy controller are implemented for comparison. Experimental results show that the method proposed is reasonable and efficient for motion deadlock resolving in most conditions for real soccer robot games.

Keywords: Fuzzy Decision, Soccer Robot, Deadlock Resolving.

1 Introduction

As important research and education platforms, robot soccer games are widely developed in many universities all over the world in the last decade. Although the games perform very exciting in many conditions, several problems, such as less robustness, sensitive for illuminations, poor real-time responding for autonomous robots, are open until now. Problems of game interruption are occurred frequently in not only practical robot soccer games, but also simulation ones. When host robots hold still for a long time, commonly more than 5 seconds, or both the host and the opponent robots refuse to move for a long time due to the disputing for the ball, the stalemates are defined as motion deadlocks of soccer robots, which are illustrated in the Fig.1 and Fig.2.

In many conditions, teams take no corresponding action to deal with the motion deadlocks but leave it alone. Then, it may result in several problems. First, potential chances may be lost. For example, in some situations, robots should utilize the deadlock-free strategy to initiate an occasion in favor of attacking or defending. Secondly, if the controller of a robot's wheels is comparatively frail, a deadlock would impose harm to the hardware when no deadlock resolving strategies were provided. Thirdly, audiences' delight for the competition will be reduced for the game interruption. Generally, 10 minutes game will cost about 40 minutes in many competitions due to about 10 times of deadlocks. Since many teams would break off to

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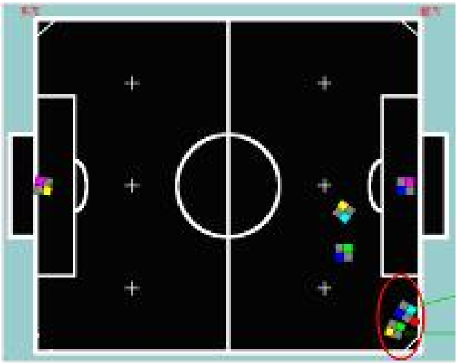


Fig. 1. Motion Deadlock Example I

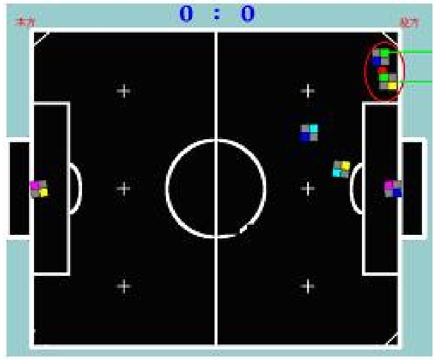


Fig. 2. Motion Deadlock Example II

change their robots and batteries, this not only wastes much time but also reduces the viewing delight of the game.

Motion deadlocks are mainly caused by following three factors. Firstly, dispute for the ball with opponent robots. In a robot soccer game, both sides create their strategies based on the position of the ball. A robot generally takes action when it is near the ball, and a problem will arise if the opponent robots adopt a similar strategy. Both teams are attempt to dispute for the ball at walls or the four corners in the playground. Secondly, when a host robot is attacking, one of the companions may try to disturb the opponent robots. Then, this robot can hardly break its current status away as tangled with the opponents, and there is also the problem of the limitation of the hardware, even subsequently its role is changed and the strategy system commands it to attack. Thirdly, under certain circumstances, the strategy system orders the main attacking robot to take the action “position”, and the robots’ velocity are determined by the velocities of robot’s left and right wheels. A halt of the main attacking robot is likely to occur when there are barriers nearby.

What has been discussed above demonstrates the necessity of solving this problem. However, how to solve it? The key to solve motion deadlock is determining whether to retreat or not. And once be decided, it becomes easier to consider how to retreat. Let’s put ourselves into the status of the robot in a deadlock for better understanding the situation. In the deadlock, considering that ‘I’ were in the opponents’ half field and there were teammates defending behind. Meanwhile, the decision to retreat would not harm ‘myself’ but be helpful to the fluency of the occasion and protection of hardware, to retreat may be advisable. That is to say, human consciousnesses play an important role in solving a deadlock. Therefore, it is reasonable to adopt fuzzy logic controller to solve this problem similar to human beings. Based on fuzzy mathematics, the information expression of the fuzzy rules and fuzzy logic reasoning, fuzzy control system simulates the human thinking to control the complicated situation, and it is called fuzzy logic controller when it is used to control.

Because of the characteristics discussed above, the fuzzy decision system is sufficiently used in the robot soccer game. M. J. Jung brings forward a fuzzy logic controller about shooting [1], while H .L. Sng gives a good solution for the dynamic role assignment problem using the fuzzy logic [2], and C. C. Wong advances the fuzzy logic controller about obstacle-avoidance [3]. The fuzzy logic could also be used in the game strategy and the path planning [4-7]. There are three problems should be solved to construct the fuzzy control system: the generation of the fuzzy rules, the fuzzy rule explosion conduced by militarization, and the definition of the membership function. There are three methods to generate the fuzzy rules: the Wang-Mendel method [8], the neural-network-based fuzzy logic control [9], and the genetic-based fuzzy control system [10]. The multivariable fuzzy rule explosion could be solved by the hierarchical fuzzy controller [11]. It mostly includes the following categories: the set that divides the multivariable structure of fuzzy control systems into single variable rule [12-15]; the multistage fuzzy reasoning [16]; two layered hierarchical fuzzy system [17]. The triangle member function is used for the membership function. The Wang-Mendel method is developed to generate fuzzy rules while 2-layered hierarchical fuzzy system is used to solve the rule explosion problem in multi-input fuzzy logic system. So far, there is no special work on motion deadlock resolving by using fuzzy decision method, although it is very important for soccer robot games.

2 Fuzzy Rules for Motion Deadlock Resolving

2.1 Definition of Input and Output Variables

In order to deal with motion deadlock problems completely, 8 input variables are defined as follows: the distance between the deadlock robot and the ball —"*DistToBall*", the ball's position—"*Ballx,Bally*", the distance between the nearest teammate (except the host goal) and the ball—"*DistToTeam*", the distance between the nearest opponent robot and the ball—"*DistToNOpp*", the angle between the deadlock robot and the ball—"*Arb*", the angle between the nearest teammate(except the host goal) and the ball—"*Aot*", the angle between the nearest opponent robot and the ball—"*Aro*". Then, two layered output variables are constructed. When the first output is 0, there is no need to solve the motion deadlock. On the contrary, motion deadlock should be unlocked when the number is 1. When the value is about 0.5, the second fuzzy controller is taken and its output is only 0 or 1.

2.2 Dividing Input and Output Spaces into Fuzzy Regions

Assume that the domain intervals of each input variables are [a, b], and N_i fuzzy sets are A_i^j. The complete fuzzy sets in $[\alpha_i, \beta_l]$ are defined in this interval. The shape of each membership function is triangular, which is frequently used. Similarly, N_y fuzzy sets B^l, which are complete fuzzy sets in $[\alpha_x, \beta_y]$, are defined, too. The domain intervals of *DistToBall*, *DistToNOpp* and *DistToTeam* are [0, 200], in which three fuzzy sets are defined as "near by", "middling" and "far away", shown in Fig.3. The domain intervals of *Arb* and *Aro* are [-180,180], in which four fuzzy sets are defined as A_1, A_2, A_3, A_4, while the domain interval of *Aot* is [-180,180], in which two fuzzy sets are defined as “back” and “front”. Fig.4 and Fig.5 show the division and the membership functions.

In order to reduce the fuzzy rules, the division of the input variables is based on the principle of “the less, the better” and its availability is validated in experiments. Therefore, the domain intervals of *Ballx* and *Bally* are [0,150] and [0,130], in which *Ballx*’s two fuzzy sets are “safe” and “dangerous” while *Bally*’s two fuzzy sets are “left” and “right”, shown in Fig.6 and Fig.7.

For the first controller out, three regions are divided, which are “retreat”, “uncertainty” and “no retreat”, while for the second controller out, two regions are divided, which are “retreat” and “no retreat”, showed in Fig.8.

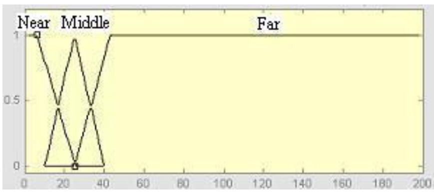


Fig. 3. The membership functions of *DistToBall*

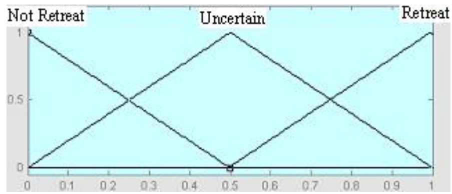


Fig. 4. The membership function of *DistToNOpp* and *DistToTeam*

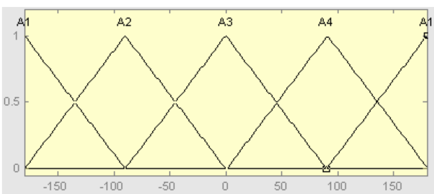


Fig. 5. Memberships functions of *Arb* and *Aro*

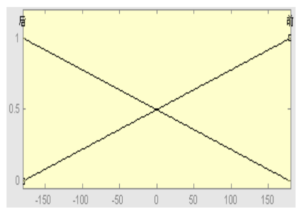


Fig. 6. Membership functions of *Aot*

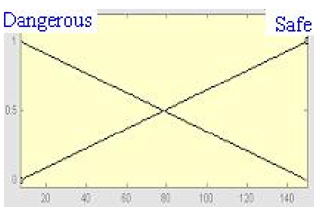


Fig. 7. Membership functions of *Ballx*

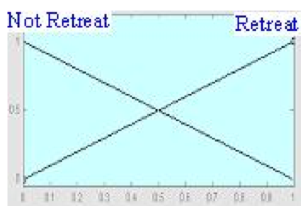


Fig. 8. Membership functions of *Out*

2.3 Fuzzy Rules Construction

The input and output data can be got from deadlock detecting in the competition record files using our data analysis system [18]. The selected input and output data pair $(x_{01}^p,\cdots,x_{0n}^p;y_0^p)$ determines the weights of given x_{0i}^p $(i=1,2,\cdots,N_i)$ which belongs to the fuzzy sets $A_i^j(j=1,2,\cdots,N_i)$. The weights of given y_0^p which belongs to the fuzzy set B^l $(l=1,2,\cdots,N_y)$, all of which are equal to calculate $\mu_{A_i^j}(x_{0i}^p)(j=1,2,\cdots,N_i,i=1,2,\cdots,n)$ and $\mu_{B^l}(y_0^p)$.

The following example will be help to understand the above method. Assume that the input is (11,13,45), in which *DistToBall* = 13, the rate of "near by" is 0.9, while the rate of "middling" is 0.1. Secondly, *DistToNOpp* = 13, the rate of "near by" is 0.8, while the rate of "middling" is 0.2. Finally, *DistToTeam* = 45, the rate of "middling" is 0.4, while the rate of "far away" is 0.6. For output *y*, the rate of "retreat" is 0.2, while the rate of "no retreat" is 0.8. Then, define each input variable $x_i(i=1,2,\cdots,n)$ to make sure that x_{0i}^p is the fuzzy set with the maximum rate.

Similarly, B^{l*} is obtained: $\mu_{B^{l*}}(y_0^p)\geq\mu_{B^l}(y_0^p)(l=1,2,\cdots,N_y)$. From the example above, we can get $A^{j*}{}_1$ = *near,* $A^j{}_2$ = *near,* $A^{j*}{}_3$ =*far,* B^{l*} =*uncertainty.* Finally, fuzzy IF-THEN rule is obtained: if x_1= $A^{j*}{}_1$, and $x_n = A^{j*}{}_n$, then $y = B^{l*}$. From the example above, a rule is got as follows: IF x_1 is near, x_2 is near and x_3 is far, THEN *y* is not sure. Therefore, the second layer control is used for decision making.

3 Fuzzy Decision System

3.1 Weighted Rules

The amount of input and output data is generally very large, and each pair of them corresponds to a rule, so there may be some conflict rules. To settle this problem, weights can be introduced on each rule. As a result, there will only be one rule with the biggest weight in a conflict group. With this method, not only the conflict problem is settled, but also the number of rules can be reduced a lot.

The weighted rules can be defined as follows: assume that formula (1) is the result of input-output data $(x_0^p;y_0^p)$, a weighted rule is given as follows:

$$D(rule)=\prod_{i=1}^{n}\mu_{A_i^{j*}}(x_{0i}^p)\mu_{B^{l*}}(y_0^p) \tag{1}$$

If the input-output data has different dependability, and it can be evaluated, this information should be combined into the regular weights. Assume that the dependability of input-output data is μ^p, weighted rules can be defined as follows:

$$D(rule)=\prod_{i=1}^{n}\mu_{A_i^{j*}}(x_{0i}^p)\mu_{B^{l*}}(y_0^p)\mu^p \tag{2}$$

If the number of the input-output data is small, the dependable rate can be evaluated by experts in practice. If the differences of the input-output data are not known, make $\mu^p=1$ simply.

Then, the Fuzzy rule based system consists of three sets can be given as follows:

(1) The rules are constructed above, which doesn't happen with other rules;
(2) The rules with the biggest weights in a conflict group, in which rules of conflict groups are those with the same IF and different THEN.

(3) Language rules coming from experts (mainly means the experts' Explicit Knowledge)

(4) The ultimate rule system for unlocking is composed of Explicit Knowledge and Tacit Knowledge.

3.2 Fuzzy Decision System Construction

Here, for designing a fuzzy decision system, single valued fuzzy engine, center average defuzzifier and triangle member function are chosen. According to the concepts of single valued fuzzy engine and center average defuzzifier, the ultimate format of fuzzy system can be give as follows:

$$f(x) = \frac{\sum_{l=1}^{M} \bar{y}^l (\prod_{i=1}^{n} \mu_{A_i^l}(x_i))}{\sum_{i=1}^{M} (\prod_{i=1}^{n} \mu_{A_i^l}(x_i))} \tag{3}$$

After structure of the fuzzy controller is introduced, the problem is how to construct bi-layer fuzzy controller. The main idea of bi-layer fuzzy controller is to build the first layer by the most important set of variables from various input variables, and the rest for the second layer controller. Considering the importance of distance when dealing with deadlock problems, three variables are set on the first layer.

The distance from deadlock robot to the ball is marked as *DistToBall*, the distance from the nearest player to the ball is marked as *DisToTeam* (excluding goalkeeper). The shortest distance from the player in the opposite team to the ball is marked as *DistToNOpp* and the angle between the deadlock robot and ball is marked as *Arb*, as shown in Fig 9. The five variables left are introduced to the second layer controller, as shown in Fig.10.

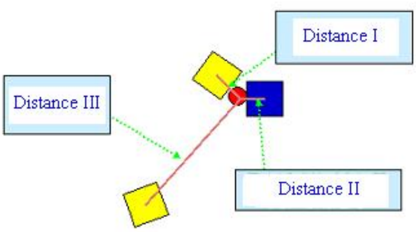


Fig. 9. Variables of the first level controller

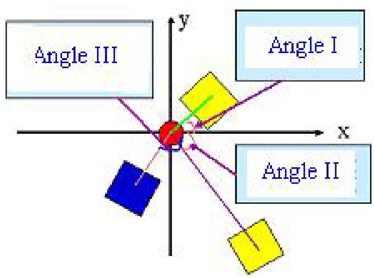


Fig. 10. Variables of the second level controller

Afterwards, fuzzy rules can be got based on the input-output data. Output data is analyzed by the data analysis system [18] when deadlock is obtained in deadlock situations. Then, output is obtained by voting when they are viewable. Fuzzy rule system can be built as soon as the input-output data is obtained. Finally, a fuzzy controller for deadlock problems can be constructed.

4 Experiments and Discussions

In order to evaluate our fuzzy controller, two kinds of experiments are implemented. One is off-line experiment based on global visual feedback data analysis system for robot soccer games, the other is online experiment based on Simulations. Data of 10 games are obtained, including 102 deadlock situations. The competitions are from several important robot soccer games, such as the National Robotic Competitions and invited games with other universities. Online experiments based on simulations are implemented to evaluate the proposed methods. First, the identical game strategy is given to these two teams, and then fuzzy control strategy is used by the first team. 250 experiments are implemented.

The main step of the first kind of experiments is to test several deadlock data from data analysis system for robot soccer games based on global visual feedback. After obtaining deadlock data, it is saved in a record file. Then, decisions are made for the motion deadlock in the file with our fuzzy controller. The results are saved in another file for unlock results. To evaluate the deadlock controller, voting methods are used and five members engaged in robot soccer game research are invited. Then, data from the deadlock file are made visible based on the data-analysis system. After finding deadlock situations, make a decision by using the fuzzy controller.

Experimental Results in the first experiment have 65 situations to retreat, 37 cases are not. 97 situations are reasonable based on voting, and the reasonable rate is 95.1%. Some examples are given in figures 11-14. Table I shows the voting result of motion deadlock situations. The first column is for deadlock situations, the second one is the number of voting for unreasonable retreat, the third one is the number of voting for reasonable retreat, and the fourth one is the result of voting. The fifth one is the decision result of fuzzy controller. It can be observed that all the results are reasonable except the complicated situations of Test 3.

There are 189 retreats and 61 not retreats situations in the second group of results, and the reasonable rate is 95.6%, based on decisions of ten periods after retreat. Several experimental results are given in Fig.15-20. The results of fuzzy controller for deadlock scene in Fig.15 is not unlocked and it is beneficial for defending if retreat. The results of

Table 1. Comparison between Vote Results and Fuzzy Decision

Deadlock Situation	Number of not retreat	Number of retreat	Results by expert vote	Results by Fuzzy decision	Same as experts?
Situation 1	4	1	Not Retreat	Not Retreat	Yes
Situation 2	0	5	Retreat	Retreat	Yes
Situation 3	3	2	Not Retreat	Retreat	No
Situation 4	1	4	Retreat	Retreat	Yes
Situation 5	5	0	Not Retreat	Not Retreat	Yes
Situation 6	2	3	Retreat	Retreat	Yes
Situation 7	0	5	Retreat	Retreat	Yes
Situation 8	0	5	Retreat	Retreat	Yes
Situation 9	2	3	Retreat	Retreat	Yes
Situation10	0	5	Retreat	Retreat	Yes

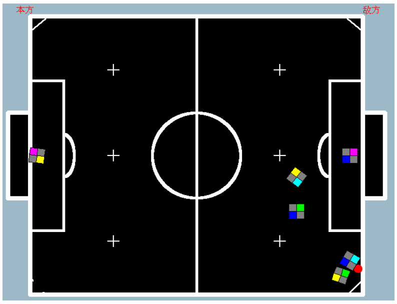


Fig. 11. Do not retreat

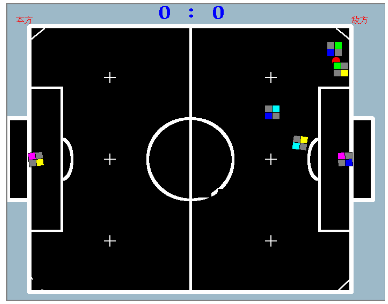
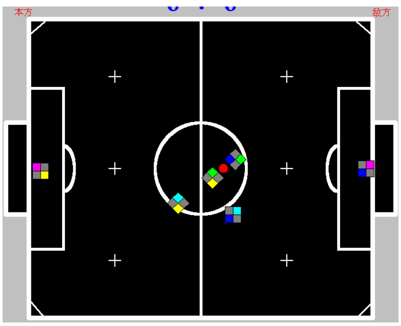


Fig. 12. Retreat for attacking



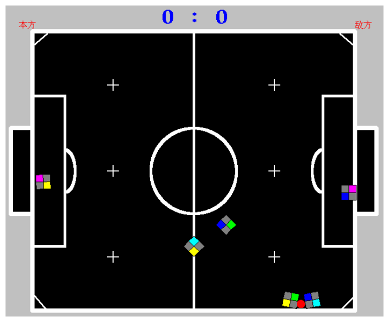


Fig. 13 and 14. Retreat for smooth competition

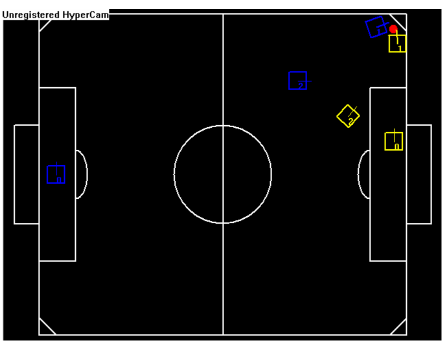


Fig. 15. Motion deadlock at T moment

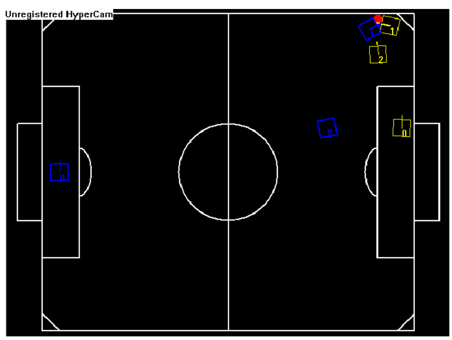


Fig. 16. Do not retreat

deadlock situation are in Fig.17 is retreat, the situation after 30 periods are shown in Fig 18. Conclusions can be got that the result of unlock is beneficial for defense. The results of deadlock controller in Fig.19 is retreat, situation after 10 periods is shown in Fig.20, in which unlock is beneficial for further aggression.

The first layer needs 27 rules, the second needs 128 ones, and all the fuzzy controller needs 155 rules. If traditional method is used, 3456 rules are needed, and an input will make 256 rules activity, which is difficult for designing fuzzy controller. Besides, many situations only need 8 rules in experiments. The main reason for some situations invalid

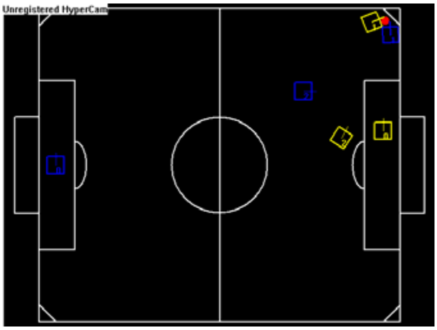


Fig. 17. Motion deadlock at T moment

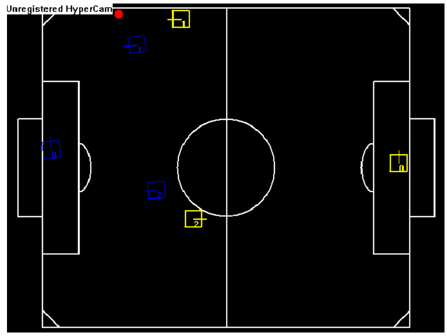


Fig. 18. After solving the motion deadlock

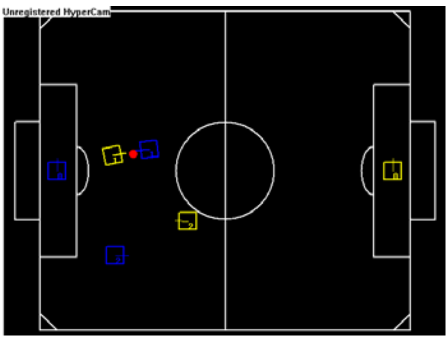


Fig. 19. Motion deadlock at T moment

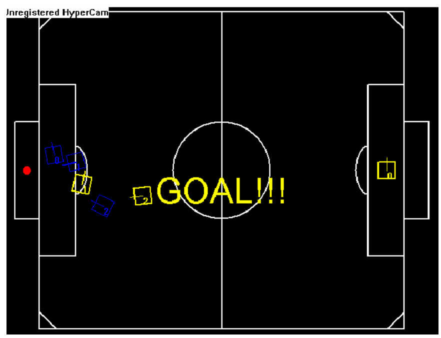


Fig. 20. After solving the motion deadlock

for unlock is the simplicity of fuzzy rules, the division of fuzzy sets are so simple that some deadlock situations are not dealt with reasonably. However, for motion deadlock situations in these games, the validated rate of unlock controllers is about 95% on average. Lots of experiments show that the proposed fuzzy based motion deadlock resolving method are reasonable and efficient for real and simulation soccer robot games.

5 Conclusions

In this paper, the problem of soccer robot motion deadlock, which generally emerges in competitions, is resolved by using fuzzy decision method. First, motion deadlock of soccer robots in practical and simulation games are defined and analyzed. Secondly, a new method based on fuzzy decision is proposed to resolve the deadlock. Finally, bi-layer fuzzy controller for deadlock resolving is proposed based on the Wang-Mendel methods. Experiments show that the proposed method is efficient for practical and simulation soccer robot competitions.

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