Cooperative 3-Robot Passing and Shooting in the RoboCup Small Size League

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Abstract. This paper describes a method for cooperative play among 3 robots in order to score a goal in the RoboCup Small Size League. In RoboCup 2005 Osaka, our team introduced a new attacking play, where one robot kicks a ball and the other receives and immediately shoots the ball on goal. However, due to the relatively slow kicking speed of the robot, top opponent teams could prevent successful passing between robots. This motivates the need for more complex play, such as passing around to several robots to avoid the opponents' passing defense. In this paper we propose a method to realize such a play, i.e. a combination play among 3 robots. We discuss the technical issues to achieve this combination play, especially for a pass-and-shoot combination play. Experimental results on real robots are provided. They indicate that the success rate of the play depends strongly on the arrangement of the robots, and ranges from 20 % to 90 % in tests with an opponent goalkeeper which stands still.

1 Introduction

Year by year, the skill of the robot systems in the Small Size League is growing higher and higher. Cooperation between robots has become a necessary technology in the Small Size League. In these years, passing between two robots has become a stable technology[1]. Last year, in RoboCup 2005 Osaka, our team[2] performed a new attacking play, that is, one robot kicks a ball and the other receives and shoots the ball with no delay. It is an efficient play and is an interesting technique, but due to the rather slow kicking speed by our robot, top opponent teams could prevent the ball from passing between our robots. Kicking the ball faster makes it possible for a successful passing play, but the vision processing and physical robot limits bound the maximal speed of the ball for a reception to work. In order to prevent the opponent robots from stopping the play, a bit more complex play such as passing around between the robots is needed.

One method to achieve such a play is a combination play among 3 robots. In the other words, if a robot A tries to pass the ball to a robot B and an opponent robot intervenes on the pass line, then the robot A should pass it to

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a robot C, the robot C just kicks it to the robot B without holding it and the robot B shoots on the goal (or some other target). We call this a **1-2-3 shoot**. Cooperation between 3 robots has several technical issues, mainly the following:

– where should three robots position on the field?
– how is the second robot controlled?

In this paper, we discuss the above issues to achieve a successful 1-2-3 shoot play, and show with experimental results how the play can be carried out effectively with real robots.

2 Cooperation of Multiple Robots

2.1 Why Is Cooperation Necessary?

Humans can easily adapt themselves to suit the environment where they live, while a robot is typically vulnerable to changes in the environment due to its static policies. If a robot could gain the adaptation ability of a human, the robot could be used more often in situations of the human-robot cooperation. We feel that multiple robots cooperating in response to an external opponent is a useful step in that direction. So, in this paper, we discuss the cooperation among robots employed in the RoboCup Small Size League. More specifically, we discuss the methodology for achieving the goal of tight cooperation of three robots.

This situation occurs when a robot holding the ball has its direct shot on the goal blocked by opponent robots, making it difficult to achieve a goal on its own. The possible actions to do next are either moving somewhere else while dribbling the ball, or passing the ball to a teammate. According to the rules of the RoboCup Small Size League, it is not possible to move a long distance while dribbling the ball. Therefore, it is advantageous to achieve the goal with a combination play between robots that uses pass plays aggressively.

2.2 What Kind of Cooperation Do We Achieve?

A primary form of cooperation used in this paper is what we call a **direct play**, where the robot changes the direction of the ball's velocity without holding or dribbling the ball, but by kicking the ball in a new direction as soon as it arrives.

The direct play makes it possible to achieve continuous passing among teammate robots without stopping the ball's motion. This results in a situation where the opponent robots have a difficult time intercepting the ball and consistently defending the goal. Moreover, in a real game, since the opponent robots are likely to move in the direction of preventing the teammate robot holding the ball from shooting on the goal, the second teammate robot (receiving robot) can get the ball from the first robot and achieve the goal relatively easily.

The next kind of cooperation is a **1-2-3 shoot**, which we define as a play where three robots (A, B, C) cooperate and the robot A who is holding the ball kicks the ball toward robot B, and robot B kicks the ball toward robot C by a direct play and finally the robot C shoots on the goal. If successfully carried out, this play makes it possible to achieve a goal with high probability since the fast handling of the ball and direction changes make it difficult for the opponent robots to follow the ball.

3 Achieving a Direct Play

The basis of the 1-2-3 shoot play is a direct play. This section describes an algorithm to achieve the direct play. The direct play is played by two robots (A, B); the robot A holding the ball kicks the ball toward the robot B, and the robot B kicks the coming ball toward in a different direction without holding it. An algorithm to achieve the direct play is as follows:

[Direct play algorithm]
Let A be a robot holding the ball and B be a cooperating robot.
Step 1. The robot B moves to an open location that has an open shooting line to the goal (or a pass line to another robot). That is, in the shoot line case, the robot B moves to a position where there are no opponent robots on the line that connects the robot B and the goal (see position B_{t1} in figure 1). If such a position doesn't exist, it looks for the next chance.
Step 2. The robot A kicks the ball toward the robot B. No opponents are assumed to be blocking the direction that the ball follows.
Step 3. Measuring the ball speed using the vision system, calculate the position and the time that the ball meets the robot B.
Step 4. The robot B moves to B_{t2} meeting at exactly time $t2$. (Figure 1)
Step 5. The proximity sensor of the robot B detects the moment that the ball touches to the robot B and kicks the ball at the moment.

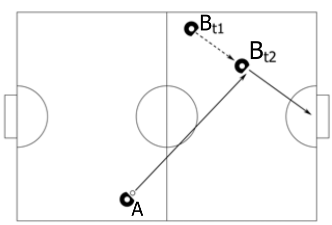

Fig. 1. Direct play

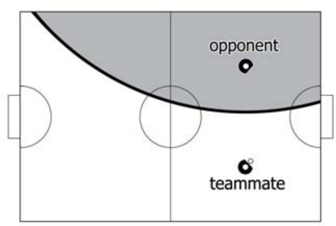

Fig. 2. An example dominant region

4 Achieving a 1-2-3 Shoot

To achieve a 1-2-3 shoot, the teammate robots should have an advantage that a pass is possible between them without being intervened by the opponents. The dominant region method [3] provides a method for calculating a solution to this problem.

4.1 Dominant Region Method

The dominant region method is a kind of Voronoi diagram. It is calculated with respect to two agents, one of which is a teammate and the other which is an opponent. The diagram divides the area of the soccer field into two regions, where one region is the one that the teammate can get to faster than the opponent, while the other is the one that the opponent can get to faster.

4.2 Calculation of the Dominant Region

Figure 2 shows an example of the dominant region. The shaded area is a dominant region for the teammate robot and the other is for the opponent. In the following, we show how to compute the dominant region.

Let v_1 and a_1 be an initial velocity and an acceleration of the teammate robot, and v_2 and a_2 be those of the opponent. Let (x_1, y_1) and (x_2, y_2) be the current positions of the teammate and opponent robot, respectively. Then, for given position (x, y), the distance between each robot and the given position and arrival time are given by the following

$$L_i = v_i t_i + \frac{1}{2} a_i t_i^2 = \sqrt{(x - x_i)^2 + (y - y_i)^2}, \tag{1}$$
$$i = 1(teammate), \quad i = 2(opponent)$$

Solving Eqs (1) with respect to $t_1$and t_2, respectively, we obtain,

$$t_i = \frac{-v_i + \sqrt{v_i^2 + 2a_i\sqrt{(x - x_i)^2 + (y - y_i)^2}}}{a_i}, \qquad i = 1, 2 \tag{2}$$

In case of zero initial velocity.

$$\begin{aligned}(a_2^2 - a_1^2)x^2 + (a_2^2 - a_1^2)y^2 + \\ 2(x_2 - x_1)x + 2(y_2 - y_1)y + x_1^2 + y_1^2 - x_2^2 - y_2^2 = 0\end{aligned} \tag{3}$$

Equation (3) expresses the border between the regions.

The dominant region can be generalized to multiple teammates and opponents. It is calculated by considering all pairs of teammates and opponents, and for each location the minimum time value is taken to construct the overall diagram.

4.3 Pass Play and Dominant Region

First, we discuss a direct play based on the dominant region method. Figure 3 is a typical case of such a situation.

The teammate B has an open line from teammate A, as well as an open line to the goal. Teammate A can thus pass the ball to teammate B. The dominant

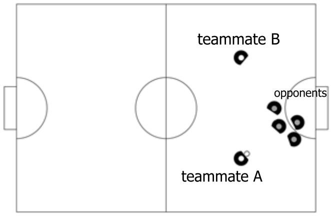

Fig. 3. Typical attack positioning

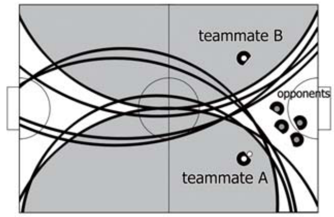

Fig. 4. Dominant region of figure 3

region of the figure 3 is given by the figure 4. In the Figure, each solid curve shows a dominant boundary between one of the teammate robots and one of the opponent robots. Shaded area is the dominant region for the teammates. It is clear from the figure 4 that the opponent can easily intercept the ball if the teammate A kicks the ball to the teammate B too slowly for the direct play.

On the other hand, as shown in figure 5, three teammates make a dominant region which can pass around the opponent robots in as shown in the dominant region.

The dominant region method is useful as a criterion for whether a pass should be done or not. In a real game, we might weaken this criterion slightly. However, we feel it can still act as a good criterion for judging whether to a direct play should be done or not.

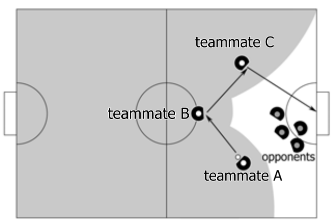

Fig. 5. Example of cooperation among 3 robots

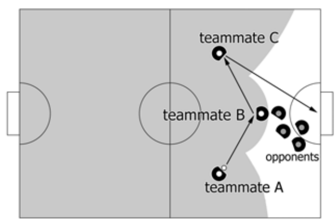

Fig. 6. 1-2-3 shoot position

4.4 Algorithm for the 1-2-3 Shoot

When should we play a 1-2-3 shoot? The following is a basic procedure to select the 1-2-3 shoot play.

[Selection procedure of action]

Let A be a robot holding ball, and let B and C be cooperating robots.

```
if (Robot A have a shoot line)
 { Robot A shoots.} else {
  Search open space which is able to make shoot line.
  Robot C moves to the open space.
  Calculate dominant region.
```

```
if (Pass line is in the dominant region of the teammate)
  {Direct play between robots A and C.} else {
    Robot B moves to the appropriate position.
    1-2-3 shoot play among robots A, B and C.
  }
}
```

When the 1-2-3 shoot play is selected, the following algorithm is executed.

[**1-2-3 Shoot algorithm**]
Let A be a robot holding the ball, and B and C be cooperating robots.
Assume that the positions of the robots are shown in figure 5.

Step 1. The robot C moves to the open space that has a shoot line to the goal. (The same movement as Step 1 in the direct play algorithm)

Step 2. If the pass line crosses the opponent dominant region, the robot B moves to the vertex of the near equilateral triangle as shown in figure 6. As a result, a pass line is made in the teammate dominant region. (If this is not the case, a re-schedule should be done.) The robot B turns to the robot C.

Step 3. The robot A kicks the ball to the robot B, then the robot B kicks it to the robot C according to the direct play algorithm.

Step 4. The robot C kicks the ball toward the goal mouth.

5 Empirical Study

We implemented the 1-2-3 shoot algorithm in our system and measured the success rate of the 1-2-3 shoot under the condition that an opponent goalkeeper stands still, as a first step toward usage in a real game.

5.1 Experimental Environment

Figure 7 shows the robots (with and without cover) we employed in the experiment. The robot consists of 4 omnidirectional wheels with diameter 60mm, 4 motors to drive the wheels, Hitachi's SH2 control processor and its peripheral circuits, dribbling and kicking devices, infrared proximity sensor and radio communication device. The robot moves at the maximal speed of $150cm/sec$. During these experiments the robot is limited to a speed of $100cm/sec$.

The host processor system consists of the Athlon64 3500+ CPU running at 2.2 GHz, 512 MB memory and Debian Linux as the operating system. The host processor system controls the robots by sending commands using the radio communication system. We developed a 1-2-3 shoot program on the system.

5.2 Experimental Results

It is difficult for the robot to kick a moving ball from a direction perpendicular to the initial velocity of the ball while it is rather easy to kick it from the parallel direction to the ball line. So we have tested two cases shown in Figures 8 and 9.

For each case, we ran 20 trials. The success rate of the 1-2-3 shoot is shown in the Table 1.

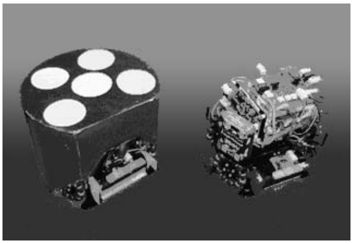

Fig. 7. Appearance of the robot

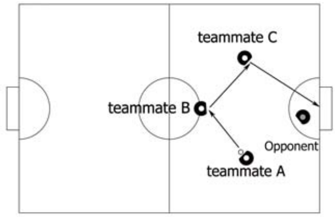

Fig. 8. Experiment 1

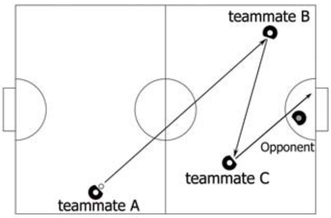

Fig. 9. Experiment 2

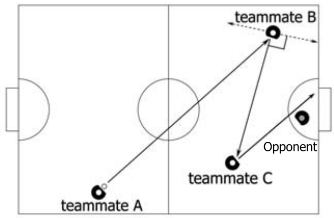

Fig. 10. Improvement of control of robot B

Table 1. Success rate of the 1-2-3 shoot play

	success	fail	rate of success (%)
experiment 1 (figure 8)	4	16	20
experiment 2 (figure 9)	12	8	60
experiment 3 (figure 10)	18	2	90

5.3 Discussion

In addition to the direction between the line on which the ball moves and the kicking direction, the distance between two robots that pass through are important factor to raise the success rate, since the longer the distance the easier the control of the robot becomes. This is because the receiving robot has time to move to the point where the ball comes, compared to a short distance pass. However, the longer distance also gives the opponents a better chance for an interception. Therefore, the positioning shown in figure 6 with long distance should be searched for. Such a strategy is an interesting future research topic.

In the previous implementation, the robot B (in Figures 8 and 9) moves on the pass line back and forth and adjust the kick line to the robot C. However, the success rate did not rise. We improved the control of the robot B as we let the robot move left and right on the line perpendicular to the kick line to the robot C as shown in figure 10. The success rate raised 90 % by this improvement. The reason why the improvement is achieved is that, by the left and right movement, we can keep the distance long enough and form V-shaped kicking lines.

6 Concluding Remarks

We have developed a cooperative skill involving 3 robots, called 1-2-3 shoot, to perform a pair of passes and a goal shot, which is based on the direct play from our previous system and the dominant region for aiding in decisions. This is a highly cooperative play and one of the useful skills for the future of the RoboCup Small Size League, since the goal block skills of opponent robots makes it difficult to achieve a goal by a single robot alone.

Experimental results show that the success rate of the play ranges from 20 % to 90 % depending on the positioning of the robots. Though the success rate varies in wide depending on the positioning, it is important to have shown the continuous cooperation among 3 robots. A successful 1-2-3 shoot play could have a much higher scoring probability than a direct shot, making it worthwhile even if the play is not successfully executed on every attempt. From the experiment, the varying success rate raises the next problem of how best positioning can be achieved. Moreover, a way of effective selection among many skills must not be found by analyzing a game, choosing between plays such as a direct shot, a direct passing play, and the 1-2-3 shoot play.

References

1. Murakami, K., Hibino, S., Kodama, Y., Iida, T., Kato, K., Naruse, T.: Cooperative Soccer Play by Real Small-Size Robot. In: Polani, D., Browning, B., Bonarini, A., Yoshida, K. (eds.) RoboCup 2003. LNCS (LNAI), vol. 3020, pp. 410–421. Springer, Heidelberg (2004)
2. Bruce, J., Hibino, S., Murakami, K., Naruse, T., Veloso, M.: CMRoboDragons 2005 Team Description. In: Bredenfeld, A., Jacoff, A., Noda, I., Takahashi, Y. (eds.) RoboCup 2005. LNCS (LNAI), vol. 4020, Springer, Heidelberg (2006)
3. Taki, T., Hasegawa, J.: Dominant Region: A Basic Feature for Group Motion Analysis and Its Application to Teamwork Evaluation in Soccer Games. In: Proc. SPIE Conference on Videometrics VI, vol. 3641, pp. 48–57 (1999)