Task and Role Selection Strategy for Multi-robot Cooperation in Robot Soccer

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Abstract. Robot soccer is played in a dynamic environment. All robots in a team should select their task dynamically and adaptively in a cooperative manner. This paper proposes a framework for task and role selection strategy for distributed multi-robot coordination and its application to robot soccer. To deal with such a dynamic environment, context-based cooperation method is provided. The robot team has a task strategy and a task strategy ratio that can change the weight of the tasks, based on environmental changes. Using information on task strategy ratio and environmental changes, each robot in a team can effectively select its task and role. Computer simulations are carried out to demonstrate the effectiveness of the proposed framework for task and role selection for multi-robot cooperation.

1 Introduction

There are many complex problems such as such reconnaissance, hazardous cleanup, automated construction, exploration in outdoor environments, etc., which may not be solved by a single robot. Multi-robot coordination is one of solutions to solve such problems. Robot team can solve such problems more effectively and robustly with available redundant resources. For example, robot team can complete given tasks, even if one of the robots in the team malfunctions or goes out of order. Robot team can perform tasks more efficiently by utilizing the resources of each robot to meet specific mission capabilities.

To perform complex tasks, it is required for robot team to have robustness, scalability, information and resource sharing strategy and efficient task allocation method. The robot soccer is one of dynamical and adversarial applications in real world. The ball moves unpredictably and the opponent team robots act aggressively to catch and shoot the ball. In this adversarial and rapidly changing environment, planning and scheduling are less effective and they might lead the team to a worse situation. Therefore, in this domain, tasks and roles should be selected and performed dynamically in real time.

Considering this problem, in this paper, a framework for task and role selection strategy is proposed for multi-robot coordination. In this framework, there are two key modules such as multi-robot context module and environment context module. The former is used for sharing the information among robots in a team and the latter is provided to collect information on environmental changes.

The task strategy and its ratio are used to change the allocated number of robots for each task. The effectiveness of the proposed framework is demonstrated by computer simulations.

The remainder of this paper is organized as follows. Section 2 introduces the research related to multi-robot coordination. Section 3 defines the terms used in the multi-robot coordination and describes the perception, context module and task strategy. Section 4 presents the simulation results. Finally, conclusions follow in Section 5.

2 Related Research

There have been many researches about multi-robot coordination such as multi-robot architecture, resource sharing, task allocation, etc. ALLIANCE architecture is a behavior-based multi-robot architecture [1]. Each robot in the architecture has two internal states, impatience and acquiescence. If one robot performs a certain task poorly, the impatience of the other robots increases and if it goes over a certain threshold, the one which has the highest impatience takes over the task. In the same manner, if the robot recognizes that it can not perform a task well, its acquiescence increases and if it goes over a certain threshold, the robot abandons its task. Each behavior has behavior motivation and the robot selects the behavior which has the highest motivation. PAB (Port-Arbitrated Behavior) is extended versions of subsumption architecture for multi-robot coordination system [2]. PAB is a behavior-based architecture and consists of cross inhibition and cross suppression for behavior selection.

As research on multi-robot resource sharing, ASyMTRe (Automated Synthesis of Multi-robot Task solutions through software Reconfiguration) and the market-based approach were proposed. In ASyMTRe, each robot consists of different kind of schemas such as communication schema, motor schema and perceptual schema [3][4]. It coordinates those schemas for robots to perform a task with a tightly-coupled manner. In the market-based approach, any robot can call an auction for selling tasks and bid on the task [5]-[7]. Any robot can call an auction for selling tasks and bid on the task. Each robot calculates its bidding value based on its resources and state.

MCMRA (Motivation and Context-based Multi-Robot Architecture) is a multi-robot coordination architecture for dynamic task, role and behavior selections [8]. It employs the motivation of task, the utility of role, a probabilistic behavior selection and a team strategy for efficient multi-robot coordination. The proposed algorithm in this paper is based on MCMRA and applied to FIRA robot soccer [9].

3 Task and Role Selection Strategy

3.1 Definition

This section introduces the terms used in this paper. Robot team can perform different kinds of tasks, where each task consists of different types of roles. In robot soccer, robot can select either an offense task ($task_1$) or a defense task ($task_2$). The roles for $task_1$ and the role for $task_2$ are defined as

$$\begin{aligned} Roles\ for\ task_1 &= \{Striker, Fwd, Centerwing,\\ &\quad Leftwing, Rightwing\}\\ Roles\ for\ task_2 &= \{Goalkeeper, Sweeper, Centerback,\\ &\quad Leftback, Rightback\}. \end{aligned}$$

Resources represent hardware features of robots. Based on the resources, each robot has different preferences for tasks. In robot soccer, a robot team is comprised of offensive and defensive robots, which have high preference on offense and defense, respectively. The resources of the robots are defined as

$$Res = [res_1, res_2, res_3], \qquad (0 \leq res_i \leq 1)$$

where res_1, res_2 and res_3 represent the normalized maximum velocity, maximum torque and frame size, respectively. The preference of robots is defined as

$$Pref = [pref_1, pref_2], \qquad (0 \leq pref_i \leq 1)$$

where $pref_1$ and $pref_2$ represent the preference of the robot on $task_1$ and $task_2$, respectively. For example, the resources of the offensive and defensive robots are respectively defined as

$$\text{Resource of the offensive robot}: Res = [0.7, 0.4, 0.4]$$
$$\text{Resource of the defensive robot}: Res = [0.4, 0.7, 0.7].$$

Using this, preference for each task is described as follow:

$$\text{Preference of the offensive robot for tasks}:$$
$$Pref = [0.7, 0.3]$$
$$\text{Preference of the offensive robot for tasks}:$$
$$Pref = [0.3, 0.7].$$

3.2 Environment Context Module

Environment context module is used to detect environmental events or particular conditions. In robot soccer, fifteen environment contexts are defined as in Table 1. For example, $e_{c8}(t)$ is defined as score difference between the home team and the opponent team is divided by maximum allowable score difference, as follows:

$$e_{c8}(t) = \frac{S_D}{S_{DMax}} \tag{1}$$

with

$$S_D = \begin{cases} S_H - S_O & \text{if } |S_H - S_O| < S_{DMax} \\ S_{DMax} & \text{if } |S_H - S_O| < S_{DMax} \\ -S_{DMax} & \text{otherwise.} \end{cases} \tag{2}$$

where S_H and S_O are scores of the home team and the opponent team, and S_{DMax} is the maximum allowable score difference which is set to 3 in this paper. If the home team is winning, $e_{c8}(t)$ is a positive value and otherwise, it is a negative value or zero.

$E_C(t)$	Meaning
$e_{c1}(t)$	The home team possesses the ball
$e_{c2}(t)$	The opponent team possesses the ball
$e_{c3}(t)$	The robot possesses the ball oneself
$e_{c4}(t)$	There is a home team robot aside
$e_{c5}(t)$	There is a opponent team robot aside
$e_{c6}(t)$	Approaching goal post of the opponent team
$e_{c7}(t)$	Time ratio $(0 \leq e_{c7}(t) \leq 1)$
$e_{c8}(t)$	Score difference ratio $(-1 \leq e_{c8}(t) \leq 1)$
$e_{c9}(t)$	$e_{c5}(t) = 1 \cap e_{c6}(t) = 0$
$e_{c10}(t)$	$e_{c1}(t) = 0 \cap e_{c2}(t) = 0$
$e_{c11}(t)$	$e_{c1}(t) = 1 \cap e_{c3}(t) = 0$
$e_{c12}(t)$	$e_{c3}(t) = 1 \cap e_{c4}(t) = 0 \cap e_{c5}(t) = 1$
$e_{c13}(t)$	$e_{c3}(t) = 1 \cap e_{c4}(t) = -1 \cap e_{c5}(t) = 1$
$e_{c14}(t)$	$e_{c3}(t) = 1 \cap e_{c5}(t) = 0$
$e_{c15}(t)$	$e_{c9}(t) = 1$ is maintained for a certain period of time

Table 1. Environmental context.

3.3 Multi-Robot Context Module

Each robot broadcasts its preference, position and conditions to the others. Therefore, all robots in a team have identical information in their multi-robot context module. The multi-robot context module of i-th robot for robot soccer is defined in Fig. 1. In the figure, 'Ball distance' is the distance between the robot and the ball and 'Ball possession' represents which team possesses the ball. 'Abandon' is broadcast when the robot cannot perform task any more and 'Help' is broadcast when the robot needs a help.

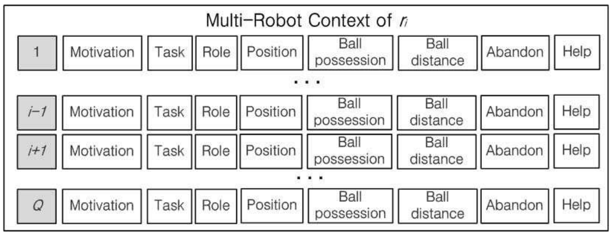

Fig. 1. Multi-robot context module.

3.4 Task Strategy and Task Strategy Ratio

Task strategy represents relative importance of each task and can be changed by user's decision when robot team is performing a task. Task strategy ratio adjusts the required number of robots in each task according to external conditions and task strategy. In other words, when tasks are performed at the same time, team members select each task according to the task strategy ratio. The i-th task strategy, s_i is defined as

$$s_i = [w_1, w_2], \qquad w_1 + w_2 = 1 \tag{3}$$

where w_1 and w_2 are the weights of offense and defense tasks, respectively. In robot soccer, three task strategies are defined as

$$\begin{aligned} s_1 &= [0.5, 0.5], \\ s_2 &= [0.7, 0.3], \\ s_3 &= [0.3, 0.7] \end{aligned} \tag{4}$$

where s_1, s_2 and s_3 represent normal strategy, offensive strategy and defensive strategy, respectively. Informations from task strategy and environmental context module are considered to determine the task strategy ratio which is defined as

$$\begin{aligned} v_1 &= \begin{cases} 0.5 & \text{if } s_1 \cup (e_{c1} = 0 \cap e_{c2} = 0) \\ w - \frac{e_{c7}(t) \cdot e_{c8}(t)}{2} & \text{otherwise,} \end{cases} \\ v_2 &= 1 - v_1 \end{aligned} \tag{5}$$

where v_1 and v_2 represent the task strategy ratio of offense and defense tasks, respectively, and w is defined in Table 2.

The team possessing the ball	The normal strategy	The offensive strategy	The defensive strategy
The home team	0.5	0.55	0.45
The opponent team	0.3	0.45	0.15

Table 2. Setting of w according to conditions.

As e_{c7} increases, e_{c8} effects more on task strategy ratio. For example, one score difference in the second half has a bigger effect than one score difference in the first half. In other words, the strength of offensive attribute increases with the increase of negative score difference and the decrease of the remaining time. Since w is dependent on strategy, the degree of attribute is changed depending on it.

On task selection, if v_1 is less than 0.5, more robots are allocated to the defensive task. In normal strategy and free ball situation, v_1 is 0.5 and the same number of robots are allocated into each task. This is shown in Table 3, where N_R is the total number of robots.

To allocate the same number of robots into each task except *Goalkeeper* which is always in goal area, one more robot is allocated to the defensive task when v_1 is 0.5. Moreover, if the number of total robots is even number, $\frac{N_R - 1}{2}$ value is rounded down. In this case, one remained robot is allocated to a task according to its preference. For example. when there are three offensive robots

Offense task strategy ratio	Number of allocated robots on $task_1$	Number of allocated robots on $task_2$
$v_1 < 0.5$	1	$N_R - 1$
$v_1 = 0.5$	$\frac{N_R-1}{2} - 1$	$\frac{N_R-1}{2} + 1$
$v_1 > 0.5$	$N_R - 1$	1

Table 3. Robot allocation according to offensive task strategy ratio.

and three defensive robots in normal strategy, two robots are allocated to $task_1$, three robots are allocated to $task_2$ and one remained robot is allocated to $task_1$ because of offensive attribute.

4 Experiments

This experiment is to demonstrate the effectiveness of task and role allocations according to the normal strategy, the offensive strategy and the defensive strategy. The normal strategy allocates the same number of robots to both the offense task and the defense task. The offensive strategy allocates more robots to the offensive task than the defensive task. On the contrary, the defensive strategy allocates more robots into defensive task. Moreover, every strategy adjusts weight of each task depending on task strategy ratio changed by the game situation such as score difference and remaining time. In this experiment, robot team was composed of three offensive robots and three defensive robots. Changing predefined conditions of each robot such as strategy, ball possession and score difference during the game, task and role of each robot were compared with those of the others.

$e_{c7}(t)$, time ratio, was increased from 0 to 1 during the game. Condition of the ball was changed as Free ball ⇒ Home team ball ⇒ Free ball ⇒ Opponent team ball, periodically. Score difference was also changed as 0:0 ⇒ 0:1 ⇒ 0:2 ⇒ 1:2 ⇒ 2 : 2 ⇒ 3:2.

In the experiment, robot team consisted of six robots including *Striker* and *Goalkeeper*. $Robot_2$ and $Robot_3$ were the defensive robots and $Robot_4$ and $Robot_5$ were the offensive robots. Since $Robot_2$ and $Robot_3$ had a strong defensive attribute, they mainly carried out defensive tasks and occasionally carried out the offensive task according to the score difference and the remaining time. In the same manner, $Robot_4$ and $Robot_5$ performed the offensive tasks and occasionally performed the defensive task according to the situation.

As shown in the graphs of Fig. 2 and Fig. 3, the offensive attribute became stronger as the remaining time decreased because the home team was losing the game. This is clearly shown in the offensive strategy of Fig. 2. Fig. 3 was also shown that the defensive robot was performing the offensive task when the team was losing the game for about 20 seconds. After about 30 seconds, since the robot team turns the game around and there was not much time left, the defensive attribute became stronger.

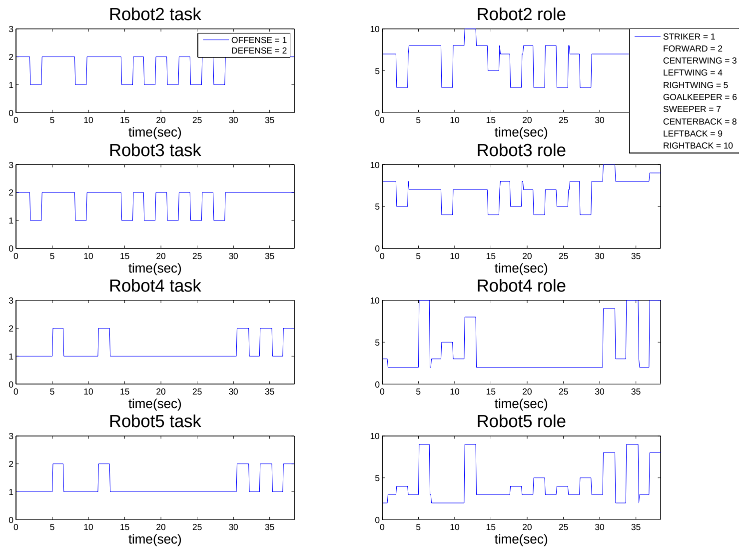

Fig. 2. Task allocation according to the offensive strategy.

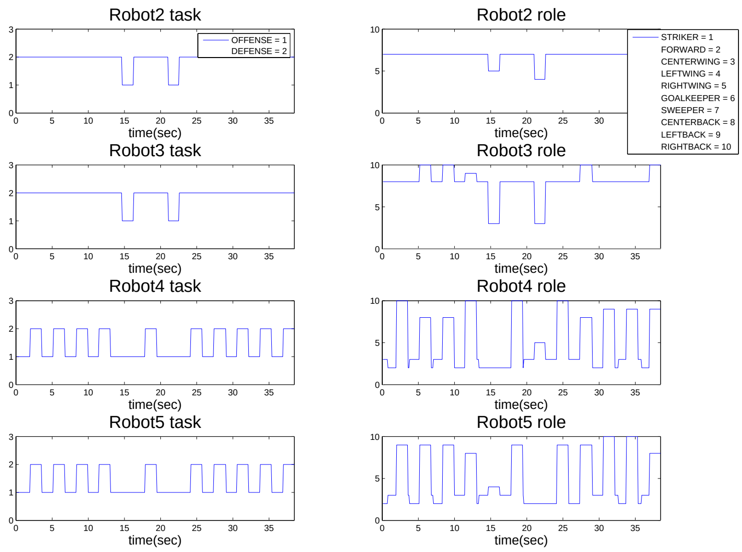

Fig. 3. Task allocation according to the defensive strategy.

5 Conclusions

This paper proposed task and role selection strategy for multi-robot coordination in robot soccer. Each robot had preference for different tasks depending on its own resources. The number of robots for each task was allocated considering their preferences on tasks, environment context, multi-robot context, and task strategy. The simulation results showed that robots were able to select task and role considering their preference, score difference, remaining time, task strategy and task strategy ratio. When offensive strategy was used, they tend to select offense task and roles in the offense task. When defensive strategy was used, on the other hand, they showed the tendency of defense rather than offense.

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