RoboCup as a Strategic Initiative to Advance Technologies

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ABSTRACT

RoboCup is an increasingly successful attempt to promote the full integration of AI and robotics research. The most prominent feature of RoboCup is that it provides the researchers with the opportunity to demonstrate their research results as a form of competition in a dynamically changing hostile environment, defined as the international standard game definition, in which the gamut of intelligent robotics research issues are naturally involved. In this article, first we shown an overview of the RoboCup initiative. Currently, we have four kinds of leagues: the real robot small, middle, and four legged ones, and the simulation league. While the practical issues have been mainly attacked in the real robot leagues, the more strategic issues in multiagent environments have been focused in the simulation league, such as teamwork among agents, agent modeling, and multi-agent learning which are argued in the rest of the paper. Finally, the future perspectives are given.

1 INTRODUCTION

RoboCup (The Robot World Cup Initiative) is an attempt to promote intelligent robotics research by providing a common task for evaluation of various theories, algorithms, and agent architectures [4]. RoboCup has currently chosen soccer as its standard task. In order for a robot (a physical robot or a software agent) to play a soccer game reasonably well, many technologies need to be integrated and a number of technical breakthroughs must be accomplished. The range of technologies spans the gamut of intelligent robotics research, including design principles for autonomous agents, multi-agent collaboration, strategy acquisition, real-time reasoning and planning, robot learning, and sensor-fusion.

The First Robot World Cup Soccer Games and Conferences (RoboCup-97) was held during the International Joint Conference on Artificial Intelligence (IJCAI-97) at Nagoya, Japan with 37 teams around the world, and the Second Robot World Cup Soccer Games and Conferences (RoboCup-98) was held on July 2-9, 1998 at La Cite des Sciences et de I'Industrie (La Cite) in Paris with 61 teams. RoboCup-99 Stockholm will be held in conjunction with IJCAI-99 participated in by about 100 teams. A series of technical workshops and competitions have been planned for the future. While the competition part of RoboCup is highlighted in the media, other important RoboCup activities include technical workshops, the RoboCup Challenge program (which defines a series of benchmark problems), education, and infrastructure development.

The rest of this article is structured as follows. First an overview of the RoboCup Initiative is explained. Then discussions on the research issues mainly focusing the simulation league are given. Finally, the future perspectives are shown.

2 WHAT'S ROBOCUP?

RoboCup has a series of activities such as competitions, conferences, RoboCup challenges, education, infrastructure, and secondary domain. Among them, however, competition remains most well-known component. We think competition has unique value in testing robots and software teams in environments outside of the laboratory. It also forces participants to build robot platforms which reliably perform the task, instead of showing superb performance once in a hundred times. And of course, competition is fun. It motivates students and appeals to spectators.

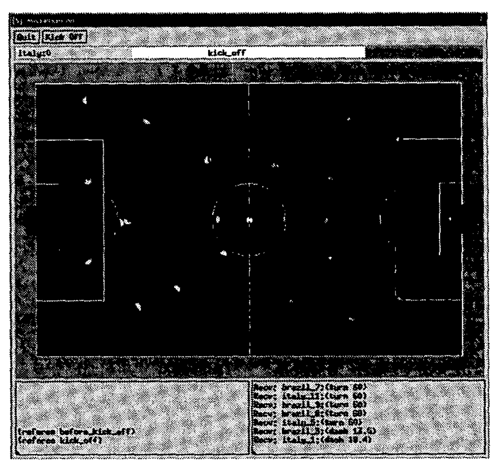

Figure 1: A screen of soccer server

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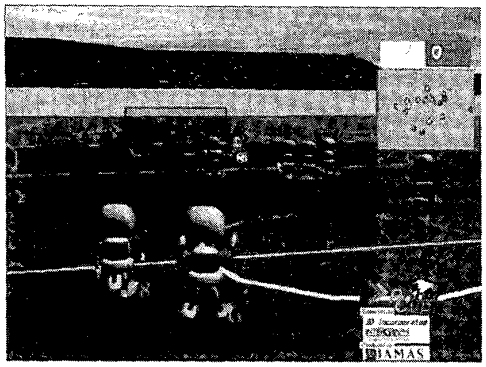

Figure 2: A new 3-D viewer for the simulation league (by courtesy of IAMAS)

Currently, RoboCup consists of four competition tracks:

1. **Simulation league:** Each team consists of eleven programs, each controlling separately each of eleven team members. The simulation is run using the Soccer Server (See Figure 1) developed by Noda et al. [8]. Each player has distributed sensing capabilities (vision and auditory) and motion energy both of which are resource bounded. Communication is available between players and strict rules of the soccer game are enforced (e.g. offsides). This league is mainly for researchers who may not have the resources for building real robots, but are highly interested in complex multiagent reasoning and learning issues. In addition to such research issues, commentary systems (ex., [7]) and 3-D viewer system [9] have been developed as completely different research issues that projected the new light onto the the conventional research topics. Fig. 2 shows an example from a sequence of images which was successfully generated in real-time and broadcasted through Internet Streaming (for more details, please visit `http://www.kaminari.org/robocup/`).

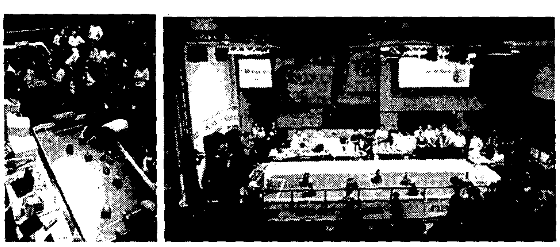

Figure 3: Real robot small (left) and middle (right) size league competition sites

2. **Small-size real robot league:** The field is of the size and color of a ping-pong table (See Figure 3), and up to five robots per team play a match with an orange golf ball. The robot size is limited to approximately 15cm^3. Typically robots are built by the participating teams and move at speeds of up to 2m/s. Global vision is allowed, offering the challenge of real-time vision-based tracking of five fast moving robots in each team and the ball.

3. **Middle-size real robot league:** The field size is of the size and color of three by three ping-pong tables (See Figure 3), and up to five robots per team play a match with a Futsal-4 ball. The size of the base of the robot is limited to approximately 50cm diameter. Global vision is not allowed. Goals are colored and the field is surrounded by walls to allow for possible distributed localization through robot sensing.

4. **Legged Robot League:** From this year, the legged robot league was introduced as a new league. One team consists of the three four-legged robots that are common robot platform provided by Sony [3]. Nine teams around the world selected by the committee attended RoboCup-99.

Technical details of teams represented in RoboCup-97 as well as related research results was published as the official publication [5], and those in RoboCup-98 will appear [1]. For the details of the results of all matches in RoboCup-97 and RoboCup-98, please visit the site: `http://www.robocup.org/` In the rest of this paper, we focus the research issues in the simulation league. Please refer to the related publications above for the information of the real robot leagues.

3 RESEARCH ISSUES IN THE SIMULATION LEAGUE

The simulation league continues to be the most popular part of the RoboCup leagues, with 34 teams participating in RoboCup-98, which is a slight increase over the number of participants at RoboCup-97. As with RoboCup-97, teams were divided into leagues. In the preliminary round, teams played within leagues in a round-robin fashion, and that was followed by a double-elimination round to determine the first three teams.

3.1 Research Issues in General

In this section, first we discuss several research issues involved in the development of real robots and software agents for RoboCup. One of the major reasons why RoboCup attracts so many researchers is that it requires the integration of a broad range of technologies into a team of complete agents, as opposed to a task-specific functional module. The following is a partial list of research areas which RoboCup covers:

- Agent architecture in general

- Combining reactive approaches and modeling/planning approaches
- Real-time recognition, planning, and reasoning
- Reasoning and action in a dynamic environment
- Sensor fusion
- Multi-agent systems in general
- Behavior learning for complex tasks
- Strategy acquisition
- Cognitive modeling in general

Currently, each league has its own architectural constraints, and therefore research issues are slightly different from each other. We have published proposal papers [6, 2] about research issues in RoboCup initiative. For the synthetic agent in the simulation league, the following issues are considered:

- Teamwork among agents, from low-level skills like passing the ball to a teammate, to higher level skills involving execution of team strategies.
- Agent modeling, from primitive skills like recognizing agents' intents to pass the ball, to complex plan recognition of high-level team strategies.
- Multi-agent learning, for on-line and off-line learning of simple soccer skills for passing and intercepting, as well as more complex strategy learning.

3.2 Changes of Regulations

For RoboCup-98, the regulation is changed as follows from RoboCup-97:

- *Offside* rule is introduced. Like human's soccer, offside players [1] can not receive the ball. By this rule, defending players can use strategic plays called 'offside trap', and offending players should take care such strategies of opponent teams.

  This rule causes 'compact soccer' in which most of players gather into relatively small area near of the ball. This condition requires more flexible teamwork. (See below.)

- A player in a team can become the *goalie* who can *catch* the ball in his penalty area. When the goalie catch the ball, the match restarts by a free-kick of the goalie's team from the catching position. On the other hand, other defending players are inhibited to stay in their own goal area. [2]

- The *ball speed* is reduced.
  In RoboCup-97, a player can kick the ball three times continuously and the ball gets so fast speed, so that a player can shoot the ball to the goal from the center line. Moreover, there are no way for defenders to stop such fast ball because the ball move so much during the delay between recognition and action of the defenders. In order to inhibit such nonsense plays, the limitation of the ball speed is introduced. By the limit, the ball can reach about half of the width of the field.

- The control of player's *stamina* is modified so that a player can not run continuously through a match. In RoboCup-97, stamina mechanism was already introduced, but the setup is not good so that a player can dash by full power through a match. By new stamina mechanism for 98, the stamina exhausts after about 50m dash of full power, and also, the speed of recovering the stamina decays when a player use stamina so much (long-term stamina control). The new mechanism forces participants to take care resource (stamina) management in the dynamic environment.

3.3 Changes of Strategies and Research Issues

3.3.1 Offside and compact soccer Because of the offside rule, most of matches are carried out in 'compact soccer' style like human soccer, in which most of players except goalies are placed in the narrow band whose width is about 30-40m. By the offside rule, the defenders use offside trap in which they go up toward the opponent side in order to let opponent offensive players offside. In order to avoid this trap, offensive players must go back to their own side if necessary. By such tactics, most of players are push into the narrow area near of the ball.

The compact soccer provides two research issues:

- Dynamic Formation: Since they are pushed into a narrow area which moves following the ball, the players must change their positions dynamically. In RoboCup-97, most of teams used the static formation strategy in which each player has his/her own home position in the field and stay there unless he/she is chasing the ball. In RoboCup-98, many players change their positions according to the status of a match. Because of the dynamic formation, the strategy of pass-work also changed. Under the static formation, the simplest way to pass the ball to one of the teammates is to kick the ball toward one of home positions of its teammates. Since the

[1] A player is offside when he/she is in the area that satisfied the following conditions are satisfied:

- between the opponent goal-line and the second opponent defender (include a goalie).
- between the opponent goal-line and the ball.
- between the opponent goal-line and the center line.

[2] The players can be in the goal area temporally. For example, a player can run into the goal area in order to chase the ball, but can not stay too long time in front of the goal in order to cover the goal intensively. This judgment is done by a human referee.

home positions do not change during a match, a player can kick the ball without checking the home position to where it would kick the ball. While, under the dynamic formation, the player needs to confirm where teammates are staying. Therefore, each team took care how to manage dynamic formation using communication and/or pre-defined team strategies that should be applied dynamically by each player independently.

- Opponent Monitoring: Due to tactics between setting offside-traps and avoiding them, it becomes more important to monitor the movements of the opponent players. In order to set an offside-trap, the defenders need to recognize the positions and the movements of the all opponent offenders. On the other hand, the offenders should pay their attention to the positions of all opponent defenders so that they may not be caught in the trap. Although the strategies of the opponent monitoring adopted in RoboCup-98 were very simple, it will become more sophisticated in future like arm-race.

3.3.2 Man marking Strong teams, especially CMUnited-98, adopted the defending strategy of explicit man-marking. In RoboCup-97, most of teams used the space-marking defense, in which, each defender is assigned a role to cover a certain space in its own side of the field. In other words, the formation and the position of defenders were affected by the positions of the opponent players during a match. On the other hand, in RoboCup-98, each defender of CMUnited-98 is assigned a role to mark one of the opponent forward players, or a role of sweeper [3] . Therefore, two or three defenders are completely following the movement of the opponent offenders.

Same as the compact soccer described above, the man-marking strategy is a starting point of the research of opponent-monitoring and opponent-modeling. While defenders were just following the opponents' movements in RoboCup-98, this strategy is easily extended to predict the movements and to infer the policy of the opponents.

3.3.3 Variation of plays The variation of plays of ball-players increased. Especially, the followings are new styles of plays in 98.

- Short-range Pass: Due to the limitation of the ball speed, the reach of pass is shortened. As a result, a team should perform systematic pass-works in short-range in order to break a defense line of the opponent team.

- Dribbling and Pass: Due to the same reason as the above, dribbling became one of effective plays in 98. In addition to it, the "offside" rule forbids forward players to be in front of the opponent goal. Therefore, it became more reasonable for mid-fielders to dribble rather than to pass the ball to the forward players directly.

- Through Pass and Back Pass: The compact soccer often causes the situation that a ball player can not find any suitable pass-receiver in front of it. In such cases, strong teams in RoboCup-98 perform back-passes or through passes, which result in success if the ball player can precisely predict the motions of the teammates. In the case of through pass, the ball player should expect the receiver to run to "no man's land" to where the ball should be kicked. In the case of back pass, the ball player should be aware that the receiver standing behind of it can receive the ball freely and find suitable receivers of the next pass. Otherwise, such plays result in good chances for the opponent team.

Dribble and other pass works can provide the players with variations of plays they can select. For example, a mid-fielder can select one of pass to a forward player, dribbling, back-pass to other mid-fielder, and through pass to a forward player. Owing to these variations, the research issue of dynamic, and real-time decision making in multi-agent systems becomes more realistic.

3.4 RoboCup Challenge in Simulation

Teams in the RoboCup simulation league are faced with three strategic research challenges: multi-agent learning, teamwork and agent modeling. All three are fundamental issues in multi-agent interactions. The learning challenge has been categorized into on-line and off-line learning both by individuals and by teams (i.e., collaborative learning). One example of off-line individual learning is learning to intercept the ball, while an example of on-line collaborative learning is to adaptively change player positions and formations based on experience in the game.

The RoboCup Teamwork Challenge addresses issues of real-time planning, re-planning, and execution of multi-agent teamwork in a dynamic adversary environment. A team should generate a strategic plan, and execute it in a coordinated fashion, monitoring for contingencies and select appropriate remedial actions. Stone and Veloso introduced a concept of periodic team synchronization (hereafter, PTS) to emphasize this domain characteristics and proposed a general team member architecture suitable in PTS domain (for the details, see [10]).

The teamwork challenge interacts also with the third challenge in the RoboCup simulation league, that of agent modeling. Agent modeling refers to modeling and reasoning about other agent's goals, plans, knowledge, capabilities, or emotions. The RoboCup opponent modeling challenge calls for research on modeling a team of opponents in a dynamic, multi-agent domain.

[3] A sweeper is a free player placing behind of other defenders and covers their fails of defense.

Such modeling can be done on-line to recognize a specific opponent's actions, as well as off-line for a review by an expert agent.

At least some researchers have taken these research challenges to heart, so that teams at RoboCup97 and RoboCup98 have addressed at least some of the above challenges. In particular, out of the three challenges outlined, researchers have attacked the challenge of on-line and off-line learning (at least by individual agents). Thus, in some teams, skills such as intercept, and passing are learned off-line. The two final teams, namely CMUnited simulation (USA) as winner of the first place and AT-Humboldt-98 (Germany) as runner-up, included an impressive combination of individual agent skills and strategic teamwork.

Research in teamwork has provided concepts such as exhibiting reusability of domain-independent teamwork skills (i.e., skills that can be transferred to domains beyond RoboCup), about roles and role reorganization in teamwork. Tambe et al. proposed a teamwork modeling and learning method and have shown some results based on the proposed method (for the details, see [11]). RoboCup opponent modeling, in terms of tracking opponents' mental state, has however not received significant attention by researchers. There are however some novel commentator agents that have used statistical and geometric techniques to understand the spatial pattern of play.

3.5 Evaluation Session

While competitions are held to determine winners, we carry out *evaluation sessions* with every competitions from RoboCup98 in order to evaluate teams performance from the view points of each research issues.

In the evaluation sessions, the committee prepares a couple of protocols to evaluate each team. Each team play a match with a fixed opponent. A committee member manipulate some conditions of the match according to the protocol.

Here are a couple of possible protocols:

- **Changing Field Conditions:** The evaluator changes some field parameters that controls movements of objects. This tests the performance of on-line learning/adaptation of agents. For example, the evaluator can change a decay parameter of ball's movement, so that the distance the ball moves by kick commands changes. Each player should adapts this change and changes the strategy of planning of pass-work.
- **Disabling Players:** The evaluator disable a couple of players of a team. This tests the performance of team-work of multi-agent systems. For example, the evaluator can disable a midfielder, then other teammates must re-form systems of the team to cover the lack of the disabled player.
- **Limited Sensing:** The evaluator limit the sensor information. This tests the performance of agent-modeling. For example, the evaluator can limit identification information of players in visual information. In this case, the server does not send team-color and uniform number of the players. Then, each player must guess who are teammates by behavior of the players.

In RoboCup98, we carried out a test of 'disabling players'. The protocol of the test is as follows:

1. An evaluated team plays a match with the fixed opponent, AT-Humboldt97 that is the previous champion team. A match consists of 4 halves (3000 simulation cycles).
2. In the first half, the team plays with 11 players.
3. The evaluator disable a player selected randomly. Then the team plays with 10 players in the second half.
4. The evaluator disable a goalie. Then the team plays with 9 players in the third half.
5. The evaluator disable another player selected randomly. Then the team plays with 8 players in the fourth half.

Generally, the total performance of a team depends on the number of players. So, the performance of each half in the above protocol will decrease according to the number of players. However if the evaluated team plays really cooperatively, they can cover the lack of performance of disabled players, so that the decrease of the total performance will be reduced.

Now, we are analyzing log files of the evaluation session. Unfortunately, we found that the number of goals does not reflects the total performance. Some teams can get more goals in 10 players than in 11 players. So, we are trying to find alternative measure of total performance by investigating detailed plays.

In RoboCup99, we are planning to have two kind of evaluations. One is the same evaluation of RoboCup98. Another evaluation is kept secret to the participants. We will keep this scheme in the future, that is, we will have two evaluation, one is open and another is secret. This is because researchers can focus on improvement of performance evaluated by the open test, and also the evaluator can test the performance of teams in the unexpected viewpoint by the secret test.

4 FUTURE ISSUES

The major progress from RoboCup-97 to RoboCup-98 has been shown in the aspect of more dynamic and systematic teamworks. Especially, introduction of offside rule and improvement of individual plays force flexible team plays. However, the stage in RoboCup-98 is still in the preliminary level. For example, tactics to escape from off-side traps was still passive even in champion teams. In future RoboCups, such tactics will require recognition of intention of opponent players/teams. In this stage, opponent modeling and management of team strategies would become more important. Similarly, on-line learning will become more important, because team strategies should be changed during a match according to strategies of opponent teams.

5 CONCLUSION

As a grand challenge, RoboCup is definitely stimulating a wide variety of approaches, and has produced rapid advances in key technologies. With a growing number of participants RoboCup is set to continue this rapid expansion. With its four leagues, RoboCup researchers face an unique opportunity to learn and share solutions in four different agent architectural platforms.

We hope that RoboCup activity promotes AI and robotics research, and to be a source of innovation for the 21 century. As of December 1998, RoboCup activity involves thousands of researchers from over 36 countries. Further information is available from the web site: `http://www.robocup.org/`

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