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What We Learned from RoboCup-97 and RoboCup-98

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Abstract

RoboCup is an increasingly successful attempt to promote the full integration of robotics and AI 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. This article describes what we have learned from the past RoboCup activities, and overview the future perspectives of RoboCup in the next century, mainly focusing the real robot leagues. Finally, we introduce the new leagues, one of which will have been held at RoboCup-99 in Stockholm.

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 [1]. 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 l'Industrie (La Cite) in Paris with 61 teams. RoboCup-99 Stockholm will be held in conjunction with IJCAI-99 participated in by over 120 teams. In Japan, a domestic competition called RoboCup Japan Open was held in 1998 and 1999. 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. 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/`

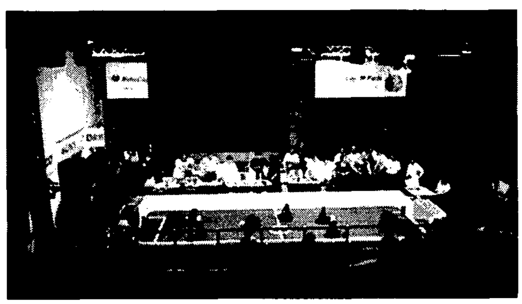

Figure 1: RoboCup-98 in Paris

RoboCup has currently three kinds of leagues: (1)the simulation league, (2) the real robot small-size league, and (3) the real robot middle-size league. (Please see Figure 1 for the real robot middle-size league competition site)

In this article, we review the challenge issues of real robot leagues and analyze the results of RoboCup-98 and Japan Open 1999. We compare the architectural differences between the leagues, and overview which research issues have been solved and how, and which have been left unsolved and remain as future issues.

2 Research Issues and Approaches

In this section, 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.

Currently, each league has its own architectural constraints, and therefore research issues are slightly different from each other. We have published proposal papers 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.

For the robotic agents in the real robot leagues, for both the small and middle-size ones, the following issues are considered:

- Efficient real-time global or distributed perception possibly from different sensing sources.
- Individual mechanical skills of the physical robots, in particular target aim and ball control.
- Strategic navigation and action to allow for robotic teamwork, by passing, receiving and intercepting the ball, and shooting at the goal.

More strategic issues are dealt in the simulation league and in the small-size real robot league while acquiring more primitive behaviors of each player is the main concern of the middle-size real robot league.

2.1 Architectural Analysis

There are two kinds of aspects in designing a robot team for RoboCup:

1. Physical structure of robots: actuators for mobility, kicking devices, perceptual (cameras, sonar, bumper sensor, laser range finder) and computational (CPUs, microprocessors) facilities.
2. Architectural structure of control software.

In the simulation league, both of the above issues are fixed, and therefore more strategical structure as a team has been considered. On the other hand, in the real robot leagues, individual teams have devised, built, and arranged their robots. Although the small league and the middle one have their own architectural constraints, there are variations of resource assignment and control structure of their robots. Table 1 shows the variations in architectural structure in terms of number of CPUs and cameras, and their arrangement.

Three types A, B, and C indicate a variation adopted in the real robot small-size league. Type A is a typical structure many teams used in this league: the centralized control of multiple bodies through a global vision. Type B is a kind of multiagent system in which decision making is distributed and independent from each other although they share the global vision. CMUnited-98 in the small-size league took this sort of architecture. Type C features sensor coordination of global and local views based on the centralized control with multiple bodies. I-space (a joint team of Utsunomiya Univ. and Univ. of Tokyo, Japan) in the small-size league adopted this type architecture. C' is a variation of C and a new trend in which each robot does its own decision making.

On the other hand, type E is a typical architecture adopted in both the simulation league and the real robot middle-size league: a completely distributed multiagent system. Type D used C. S. Freiburg team in the middle-size league adopted a combination of types A and E utilizing laser range finders mounted on players which make it possible to reconstruct the global view and to localize observed objects (teammates, opponents, and ball) in the field. That is, they changed the problem in the middle-size league into one in the small-size league.

Communication between agents is possible in all of the leagues. The simulation league is the only that uses it except one team UTTORI in the middle-size league. In the following, we attempt to analyze the

Table 1: Variations in architectural structure

Type	CPU	Vision	issues	league
A	1	1 global	strategy	small-size
B	n	1 global	sharing of information	small-size
C	1	1 global + n local	sensor fusion; coordination	small-size
C'	1+n	1 global + n local	sensor fusion; coordination	small-size
D	1+n	n local	multiple robots	middle-size
E	n	n local	sensor fusion; teamwork	middle-size & simulation

achievements in RoboCup-97 and 98 in terms of each league.

3 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. In RoboCup-98, because of the offside rule introduced from 1998, most of matches are carried out in 'compact soccer' style like human soccer which provides two research issues closely related to each other: dynamic formation and opponent monitoring. This means the change from position based role assignment to context sensitive dynamic role assignment.

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 a game. The detailed analysis is given in the paper in [2].

The stage in RoboCup-98 is still in the preliminary level. For example, tactics to escape from offside traps was still passive even in champion teams. In future RoboCup, 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.

In the simulation league, the source code of agents participated in past competitions are available. Therefore, the skill of individual agents and the team is improved in every competition. In Japan Open 1999, many on-line learning method were tested.

4 Small-Size Real Robot League

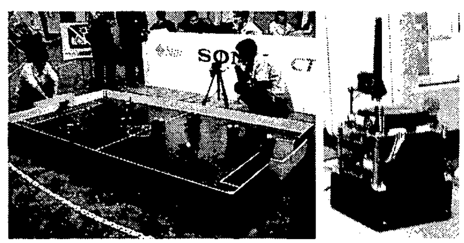

Figure 2: A scene of the small robot league in Japan Open 1999(left) and a new platform(right)

The environment in the small-size league is highly dynamic with robots and the ball moving at speeds between 1m/s and 2m/s. An interesting research issue consists of the prediction of the motion of the mobile objects to combine it with strategy. In the case of the CMUnited-98 team, prediction of the movement of the ball was successfully achieved and highly used for motion (e.g., ball interception) and strategic decisions (e.g., goaltender behavior and pass/shoot decisions).

We look forward to understanding better several issues, including the limitations imposed by the size restrictions on on-board capabilities; the robustness of global perception and radio communication; and strategic teamwork. One of the main interesting open questions is the development of algorithms for on-line learning of the strategy of the opponent team and for the real-time adaptation of one's strategy in response. Finally, similarly to the simulation and middle-size leagues, we want to abstract from our experience algorithms that will be applicable beyond the robotic soccer domain.

New hardware products which are designed and developed for a small size robot were shown in Japan Open 1999 (see Figure 2). Linked99 team was designed and developed an IC chip for vision processing. A private team, Fukui Football Club, was build up small autonomous robots with vision system and used only local vision on robots. In addition, a new off-the-shelf platform shown in Figure 2 was introduced by two teams Owrari-bit and Nagoya-RFC. It is an fully autonomous robot with CPU and radio communication, and can mount a camera and an image processor. It will be an experimental platform for cooperation of the global vision and local visions on each robot.

5 Middle-Size Real Robot League

The performance of robot behaviors in RoboCup-98 was better than in RoboCup-97 although the number of teams in the middle-size league drastically increased from 5 to 16, more than three times. However, the level of skills is under development, mainly putting more focus on individual behavior acquisition than cooperative teamwork. Engineering issues such as precise robot control and robust object detection are still main issues in this league.

The focus on colors to visibly distinguish objects exerts a strong bias for research in *color-based* vision methods. It is desirable to permit other approaches as well, such as using *edges*, *texture*, *shape*, *optical flow* etc., thereby widening the range of applicable vision research within RoboCup.

Another issue is the study of a better obstacle avoidance approaches. Currently, most robots except NAIST and a few cannot reliably detect collisions with walls or other robots. Solving the charging problem using a rich set of onboard sensors is another major field of future research for RoboCup teams.

Finally, the use of communication in the different leagues is also an active research topic. Communication allows interesting research in a variety of topics, including multi-robot sensor fusion and control. We want to explore limited communication environments and its relationship to agent autonomy, and learning of cooperative behavior.

In Japan Open 1999 (see Figure 3, individual skills of the robot were improved. Recognition of the ball and the goals was improved a lot even though a black logo was printed on the wall inside the field (see Figure 3. Until RoboCup-98 the wall inside the field was completely white without any log to simplify image processing for robots, however, black log will be printed from RoboCup-99. Another point is that obstacle avoidance was improved and number of collisions with opponent robots and the wall decreased.

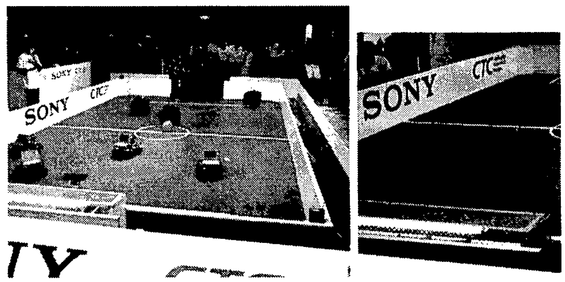

Figure 3: A scene of the middle robot league in Japan Open 1999(left) and a logo printed on the wall(right)

Figure 4: A scene from Sony legged robot demonstration(left) and the new platform(right)

6 New Leagues

6.1 Sony Legged Robot League

In RoboCup-98, Sony Legged Robot exhibition games and demonstration were held, and they attracted many spectators, especially boys and girls, for its cute style and behaviors. The four-legged robot has totally 16 DOFs (degrees of freedom): each leg has 3 joints, head has pan, tilt, and roll movements, and tail has one DOF [3].

Figure 4 shows a scene from their demonstrations. Three teams from Osaka University, CMU, and University of Paris-VI showed their exhibition games provided the fundamental behavior control library and software development environment [4]. In 1999, Sony Legged Robot league will be one of the RoboCup official competitions with nine teams around the world with a new platform shown in Figure 4. This is same hardware with AIBO sold in Japan and USA in July 1999.

6.2 Humanoid League

Currently, except for Sony Legged Robot League, games are played by wheel-based robots, soccer game by humanoid robot is the next major leap in the field which leads to the ultimate goal of the RoboCup [5].

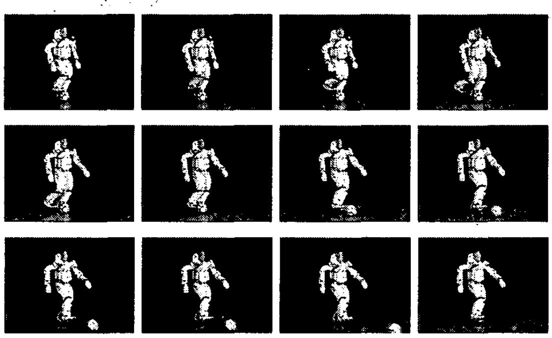

Figure 5: Shooting Play by Honda P3

We propose that the final goal to be the one of the grand challenges shared by robotics and AI community for next 50 years. This goal may sounds overly ambitious given the state of the art technology today. Nevertheless, we believe it is important that such a long range goal to be claimed and pursued. It took only 50 years from the Write Brother's first aircraft to Apollo mission to send man to the moon and safely return them to the earth. Also, it took only 50 years, from the invention of digital computer to the Deep Blue, which beat human world champion in chess. We recognize, however, that building humanoid soccer player requires equally long period and extensive efforts of broad range of researchers, and the goal will not be met in any near term.

Before, actually play soccer with human players, RoboCup organize humanoid leagues in following categories, and start Humanoid league competition from RoboCup-02 (2002). Fig. 5 shows the performances by Honda P3 in 1998, and they will show 3 by 3 humanoid games in RoboCup-2002, the year of World Cup in Japan and Korea.

Numbers of AI and robotics issues are involved in building humanoid robot for RoboCup, as pointed out by [5], some of them requirements fundamental innovation in integrated area of material, chemical, computer science, and robotics. At the same time, as seems from Honda Humanoid, initial set of technologies are already available.

7 RoboCup New Activities

7.1 RoboCup Jr.

The comprehensive nature of RoboCup makes it an ideal subject for project-oriented AI and robotics courses (ex., [6]). Already, a few undergraduate and graduate courses are now being planned using RoboCup. Further, an education infrastructure named **RoboCup Jr.** is proposed, reflecting the needs of educational institutions. RoboCup Jr. will use cheaper robots and a much simpler task domain, rather than the highly challenging arrangement seen in the current RoboCup competition. A prototype of platforms will make a debut in 2000 or 2001, and the official league RoboCup Jr. will start from 2002.

One of currently available platform for RoboCup Jr., is LEGO MindStorms which is cheap and intellectual toys. In RoboCup-98 Paris, University of Aarhus has built an exciting soccer stadium using Lego MindStorms with many figures of supporters that could wave and give great cheers for the play [1]. In Japan Open 1999, a private group "LMind F.C." showed simple and various soccer robots made by LEGO MindStorms (see Figure 6). This is a good entrance for RoboCup world.

An exhibition match was demonstrated in Japan Open 1999 (see Figure 6). All robot was remote controlled by human, these robot will be a candidate of a platform of RoboCup Jr. and some of them will be demonstrated in RoboCup-99.

7.2 RoboCup Rescue

Disaster rescue is one of the most serious social issue which involves very large numbers of heterogeneous agents in the hostile environment. RoboCup-Rescue intends to promote research and development

[1]visit http://www.daimi.au.dk/~hhl

	Rescue	Soccer
Number of Agents	100 or more	11 per a team
Agents in the team	Heterogeneous	Homogeneous (except Goalee)
Logistics	Major Issue	No
Long-Term Planning	Major Issue	Less Emphasized
Emergent Collaboration	Major Issue	No
Hostility	Environment	Opponent Players
Environment	different for each time	Same (fixed play field)

Table 2: Features of Rescue and Soccer

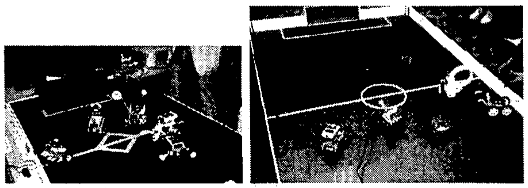

Figure 6: Soccer robots made by LEGO(left) and A scene from the exhibition match of RoboCup Jr.(right)

in this socially significant domain by creating a standard simulator and forum for researchers and practitioners. While the rescue domain intuitively appealing as large scale multi-agent domains, it has not yet given through analysis on its domain characteristics. RoboCup-Rescue targets search and rescue activities for large-scale disaster like Kobe earthquake in 1995.

We chose Urban Search and Rescue as a secondary domain for RoboCup, because (1) it is a socially significant real world domain, (2) numbers of features which are missing in soccer exist, and (3) there are certain commonalities between rescue and soccer, where the essence of autonomous multi-agent systems can be investigated through the use of two domains.

Features missing in soccer, but play important roles are long-term strategy planning, logistics, planning for heterogeneous agents, interaction with human agents, emergent collaborations, etc.

RoboCup Rescue consists of a simulator league and a real robot league. The simulator league focus on strategy planning and team coordination, whereas the focus of real robot league will be on capability of individual robots in rescue operation. We are planning to hold the first RoboCup Rescue Forum (exhibition matches and conferences) in Kobe, 2002, when the festival of recovery from the large earthquake in 1995 will be held.

8 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. Although we have addressed the issues in real robot league, RoboCup researchers face an unique opportunity to learn and share solutions in three different agent architectural platforms with its three leagues.

Acknowledgement

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References

[1] H. Kitano, M. Asada, Y. Kuniyoshi, I. Noda, E. Osawa, and H. Matsubara. "robocup: A challenge problem of ai". *AI Magazine*, 18:73–85, 1997.

[2] Hirokai Kitano and Minoru Asada. Special issue on robocup. *Artificial Intelligence*, 77:(to appear), 1999.

[3] Masahiro Fujita, Stephane Zrehen, and Hiroaki Kitano. A quardruped robot for robocup legged robot challenge. In *RoboCup-98:Proceedings of the second RoboCup Workshop*, pages 73–88, 1998.

[4] Manuela Veloso, William Uther, Masahiro Fujita, Minoru Asada, and Hiroaki Kitano. Playing soccer with legged robots. In *Proc. of IROS'98*, pages 437–442, 1998.

[5] Hiroaki Kitano and Minoru Asada. Robocup humanoid challenge: That's one small step for a robot, one giant leap for mankind. In *Proc. of IROS'98*, pages 419–424, 1998.

[6] Silvia Coradeschi and Jacek Malec. How to make a challenging ai course enjoyable using the robocup soccer simulation system. In *RoboCup-98:Proceedings of the second RoboCup Workshop*, pages 57–62, 1998.