Overview of RoboCup-98

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Abstract. RoboCup is an increasingly successful attempt to promote the full integration of AI and robotics research. Following the astonishing success of the first RoboCup-97 at Nagoya [1], the Second Robot World Cup Soccer Games and Conferences, RoboCup-98, was held at Paris during July 2nd and 9th, 1998 at the partly same place and period of the real world cup. There are three kinds of leagues: the simulation league, the real robot small-size league, and the real robot middle-size league. The champion teams are CMUnited-98 (CMU, USA) for both the simulation and the real robot small-size leagues, and CS-Freiburg (Freiburg, Germany) for the real robot middle-size league. The Scientific Challenge Award was given to three research groups (Electrotechnical Laboratory (ETL), Sony Computer Science Laboratories, Inc., and German Research Center for Artificial Intelligence GmbH (DFKI)) for their simultaneous development of fully automatic commentator systems for RoboCup simulator league. Over 15,000 spectators and 120 international media covered the competition worldwide. RoboCup-99, the third Robot World Cup Soccer Games and Conferences, will be held at Stockholm in conjunction with the Sixteenth International Joint Conference on Artificial Intelligence (IJCAI-99) at the beginning of August, 1999.

1 Introduction

RoboCup-98, the Second Robot World Cup Soccer Games and Conferences, was held on July 2-9, 1998 at La Cite des Sciences et de I'Industrie (La Cite) in Paris (See Figure 1)[1]. It was organized by University of Paris-VI and CNRS, and it was sponsored by Sony Corporation, NAMCO Limited, and SUNX Limited. The official balls for the middle-size league were supplied by Molten Corporation. Over 15,000 people watched the games and over 120 international media (such as CNN, ABC, NHK, TV-Aich, etc,..) as well as prominent scientific magazines covered them. The Second RoboCup Workshop was held [2].

[1] the same city where the real world cup finals were held almost the same period

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Fig. 1. RoboCup-98 in Paris

RoboCup-98 had three kinds of leagues: (1)the simulation league, (2) THE real robot small-size league, (Please see Figure 2 for the real robot small-size league competition site where a match between J-Star (Japan) and CMUnited-97 (USA) is taking place.) and (3) the real robot middle-size league. (Please see Figure 3 for the real robot middle-size league competition site where a semi-final between Osaka Trackies (Japan) and CS-Frieburg (Germany) is taking place.)

Although it was not an official RoboCup competition, Sony Legged Robot Competition and Demonstration have attracted many spectators, especially boys and girls, for its cute style and behaviors. Figure 4 shows a scene from their demonstrations. Three teams from Osaka University, CMU, and University of Paris-VI have show their exhibition games. In 1999, Sony Legged Robot league will be one of the RoboCup official competitions with more teams around the world [3]. Also, University of Aahus has built an exciting soccer stadium using Lego Mind Storm with many figures of supporters that could wave and give great cheers for the play.

Aside from the world championship award, the RoboCup Scientific Challenge Award is created as an equally or more prestigious award. This year, the Scientific Challenge Award was given to three research groups (Electrotechnical Laboratory (ETL), Sony Computer Science Laboratories, Inc., and German Research Center for Artificial Intelligence GmbH (DFKI)) for their simultaneous development of fully automatic commentator systems for RoboCup simulator league. Detailed information is given at *http://www.robocup.org/*. In this article, we review the challenge issues of each league and analyze the results of RoboCup-98. 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.

Fig. 2. Real robot small-size league competition site

2 Leagues and Approaches

RoboCup-98 had three kinds of leagues:

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 developed by Noda[2]. 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. off-sides). 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.

[2] for the details, please visit RoboCup web site

Fig. 3. Real robot middle-size league competition site

2. **Small-size real robot league:** The field is of the size and color of a ping-pong table 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, 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.

Each league has its own architectural constraints, and therefore research issues are slightly different from each other. We have published proposal papers [4,5] 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:

Fig. 4. Sony legged robot league competition site

- 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.

We held the first RoboCup competitions in August 1997, in Nagoya, in conjunction with IJCAI-97 [6]. There were 28, 4, and 5 participating teams in the simulation, small-size robot, and middle-size robot leagues, respectively.

The second RoboCup workshop and competitions took place in July 1998, in Paris [2] in conjunction with ICMAS-98 and AgentsWorld. The number of teams increased significantly from RoboCup-97 to 34, 11, and 16 participating teams in the simulation, small-size robot, and middle-size robot leagues respectively. More than twenty countries participated. Every team had its own features some of which have been exposed during their matches with different degrees of success.

3 RoboCup Architectural Approaches

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 strategic 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.

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
D	1+n	n local	multiple robots	middle-size
E	n	n local	sensor fusion; teamwork	middle-size & simulation

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 real robot middle-size league.

4 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. Appendix A shows the results of all matches including preliminary and final ones.

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 RoboCup Teamwork Challenge addresses issues of real-time planning, re-planning, and execution of multi-agent teamwork in a dynamic adversarial environment. A team should generate a strategic plan, and execute it in a coordinated fashion, monitoring for contingencies and select appropriate remedial actions. 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. 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. 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.

5 Small-Size Real Robot League

The RoboCup-98 small-size real robot league provides a very interesting framework to investigate the full integration of action, perception, and high-level reasoning in a team of multiple agents. Therefore, three main aspects need to be addressed in the development of a small-size RoboCup team: (i) hardware of physical robots; (ii) efficient perception; and (iii) individual and team strategy.

Although all of the eleven RoboCup-98 teams included distinguishing features at some of these three levels, it showed crucial to have a *complete* team with robust hardware, perception, and strategy, in order to perform overall well.

This was certainly the case for the four top teams in the competition, namely CMUnited-98 (USA), Roboroos (Australia), 5DPO (Portugal), and Cambridge (UK), who classified in first, second, third, and fourth place respectively.

Fig. 5. Real robot small-size final match

Figure 5 shows a scene from the final match between CMUnited-98 and Queensland Roboroos (Ausuralia). Appendix B shows the results of all matches including preliminary and final ones. We overview now the characteristics of the RoboCup-98 teams and the research issues addressed.

Hardware: All of the eleven RoboCup-98 participating teams consisted of robots built by each participating group. The actual construction of robots within the strict size limitations offered a real challenge, but gave rise to a series of interesting physical and mechanical devices. Remarkably, the robots exhibited sensor-activated kicking devices (iXs and J-Star, Japan, Paris-6, France, and CMUnited-98, USA), sophisticated ball holding and shooting tools for the goalie robot (Cambridge, UK), and impressive compact and robust designs (Roboroos, Australia, and UVB, Belgium). All of the robots were autonomously controlled through radio communication by off-board computers.

Perception: Ten out of the eleven teams used a single camera overlooking the complete field. The ISpace (Japan) team included one robot with an onboard vision camera.

Global perception simplifies the sharing of information among multiple agents. However global perception presents at the same time a real challenging research opportunity for reliable and real-time detection of the multiple mobile objects – the ball, and five robots on each team. In fact, both detection of robot position and orientation and robot tracking need to be very effective. The frame rate of the vision processing algorithms clearly impacted the performance of the team. Frame rates reached 30 frames/sec as in the CMUnited-98 team.

In addition to the team color (blue or yellow), most of the teams used a second color to mark their own robots and provide orientation information, hence only about their own robots. Robot identification was achieved in general by greedy data association between frames. The 5DPO (Portugal) and the Paris-6 (France) teams had a robust vision processing algorithm that used patterns to discriminate among the robots and to find their orientation.

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. It was not clear which teams actually developed prediction algorithms. In the particular 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).

Motion: In this RoboCup league, a foul should be called when robots push each other. This rule offers another interesting research problem, namely obstacle avoidance and path planning in a highly dynamic environment. The majority of the teams in RoboCup-98 successfully developed algorithms for such difficult obstacle avoidance and the semi final and final games showed smooth games that demonstrated impressive obstacle avoidance algorithms.

Strategy: Following up on several of the research solutions devised for RoboCup-97 both in simulation and in the small-size robots, at RoboCup-98, all of the small-size teams showed a role-based team structure. As expected, the goaltender played a very important role in each team. Similarly to the goaltender of CMUnited-97, the goaltender of most of the teams stayed parallel to the goal line and tried to stay aligned with or intercept the ball. The goaltender represented a very important and crucial role. To remark were the goaltenders of Roboroos, CMUnited-98, and Cambridge.

Apart for CMUnited-98 which had a single defender and three attackers, most of the other teams invested more heavily on defense, assigning two robots as defenders. In particular, defenders in the Belgium and in the Paris-8 teams occupied key positions in front of the goal making it difficult for other teams to path plan around them and to try to devise shots through the reduced open goal areas. Defending with polygonally-shaped robots proved to be hard, as the ball is not easily controlled at a fine grain. In fact a few goals for different teams were scored into their own goals due to small movements of the defenders or goaltender very close to the goal. It is clearly still an open research question how to control the ball more accurately.

Finally, it is interesting to note that one of the main features of the winning CMUnited-98 team is its ability to collaborate as a team. Attacking robots continuously evaluate (30 times per second) their actions, namely either to pass the ball to another attacking teammate or to shoot directly at the goal. A decision-theoretic algorithm is used to assign the heuristic and probabilistic based values to the different possible actions. The action with the maximum value is selected. Furthermore, in the CMUnited-98 team, a robot who was not the one actively pursuing the ball is not merely passive. Instead each attacking robot *anticipates* the needs of the team and it positions itself in the location that maximizes the probability of a successful pass. CMUnited-98 uses a multiple-objective optimization algorithm with constraints to determine this strategic positioning. The objective functions maximize repulsion from other robots and minimize attraction the ball and to the attacking goal.

6 Middle-Size Real Robot League

RoboCup-98 League Statistics and Results: The middle-size league this year had 18 entries, but the Deakin Black Knights (Deakin Univ., Andrew Price, Australia) had a fatal machine trouble, and the Iranian team could not attend the official games because of their late arrival due to the visa problem [3]. 16 teams were divided into four groups each of which consisted of four teams considering regional distribution, and preliminary games were took place in each group. Then, the best two teams from each group advanced to the final tournaments. Figure 6 shows a quarter final match between Osaka Trackies and NAIST.

Excitement both among participants and spectators reached new heights in the semi-finals, both of which were matches of Japanese against German teams (Appendix C shows the results of all matches including preliminary and final ones.). In the first semi-final, University of Freiburg won 3:0 against Osaka University. The second semi-final between Uttori United and University of Tübingen ended with a draw after regular time. Penalty shootouts did not produce a decision either, and a so-called technical challenge had to decide. In the technical challenge, a goal to shoot at is selected and the ball is placed in the middle of the field. A single robot is positioned on the field in the middle between the goal and the ball, heading towards the goal. The task is to find the ball, move it towards the goal, and finally shoot it into the goal. The time a robot takes to complete the task is taken as decision criterion. Tübingen won the technical challenge and proceeded to the finals. The finals itself were convincingly won 3:0 by University of Freiburg. This game also saw the nicest goal shot in the whole tournament, when the Freiburg robot took the ball from its “left hand” onto its “right hand” and scored.

Team Development Report: A very encouraging result from Paris is that all except two scheduled games could actually be played. Considering the large

[3] however, they played several exhibition games.

Fig. 6. A match from real robot middle-size

number of new teams, which were built within the nine months since Nagoya, this is a considerable achievement for most groups. Teams can use their technological base to investigate open problems, engineer new solutions, and conduct interesting experiments (see [7,8,9,10]).

Technological State-of-the-Art Report: All participants agreed that the overall level of play improved dramatically since Nagoya. What are the major technological innovations that contributed to this improvement?

1. Many of the new teams used off-the-shelf platforms, such as Activmedia's Pioneer-1 and Pioneer-AT robots (used by six teams) or Nomadics' Scout robot (used by one team). These platforms are not perfect, therefore many teams substantially modified the robot and added additional equipment like vision systems, kicking devices, communication devices, and embedded PCs for onboard computation.

2. Many teams seem to have now available vision systems that work reasonably well, at least much better than what we saw in Nagoya. However, there are still many problems with the perceptual capabilities of the robots, especially detecting other agents, and vision will remain a central research topic in RoboCup.
3. A number of teams featured kicking mechanisms on their robots. A simple, yet powerful approach were pneumatic kickers. Other robots used a solenoid-based activation device. The kicking devices produced much higher ball accelerations than the robots could achieve by simply pushing the ball. One robot even scored a goal directly after kickoff. Overall, with kicking devices robots could move the ball significantly better, which is one of the research issues in the mid-size robot league.
4. Several teams attached passive devices such as shaped metal sheets or springs (nicknamed "fingers" or "hands") to their robots, thereby creating a concave surface for improved ball handling (moving, receiving, passing). With hands, robots could better move and turn with the ball, and often could retrieve the ball once it was stuck against the walls and bring the ball back into play although the use of such "hands" is still under discussion.

Despite of the architectural structure shown in Table 1, many teams used some kinds of radio communications to control their robots. However, frequency conflicts, noise produced by mobile phones and equipment used by film teams and the press often caused serious problems to communication. The less dependency on physical communication line is expected in future.

Research Results: One observation from the games in Paris is that creating a good goalie can dramatically improve overall team performance, but is somewhat simpler to build than a good field player. Several teams used omnidirectional vision systems that allowed their robots both to track their position in front of the goal as well as ball position [9,8] since Osaka used it in the first RoboCup in Nagoya. USC's Ullanta used a fast B14 base as goalie, together with a rotating "hand" and a Cognachrome vision system; it did not allow a single goal. Probably the most successful goalie was the one by University of Tübingen, which did not allow a single goal, not even in penalty shootouts, until the final game and was the main reason why Tübingen made it to the finals.

Two Japanese teams, Uttori United[11] and Osaka University, demonstrated excellent ball handling capabilities. The Uttori robots feature a sophisticated omnidirectional drive system that allowed their robots to closely circle around the ball once they found it without visually loosing track of the ball (which happened often to other teams) until the robot's kicking paddle is heading towards the ball and the goal. Then the robot starts to move slowly towards the goal. The kicking device is designed such that the robot can push the ball across the floor without the ball starting to roll, thereby reducing the risk to loose the ball. Near the goal, the kicking paddle gives the ball a sufficiently strong kick to roll it away about half a meter. The robot then turns in order to head two fans towards the ball, activates the fans and blows the ball into the goal.

The new robots by Osaka University also exhibited very strong ball handling. Once it found the ball it could move across the field in fast pace, guiding the ball closely to the base, all the way into the opponents goal. The main advantage over Uttori's approach is the higher speed they could achieve.

The winning strategy applied by Freiburg[12] was a combination of issues. The distinguishing feature of their robots was the use of a laser range finder, which provides fast and accurate range data, on each of their five Pioneer-1 robots. Freiburg applied their extensive work in laser-based self-localization to outperform teams using just vision systems. By matching the laser scan data against the known walls surrounding the field, they could not only determine their own position and orientation on the field, but also the position of the other robots. Via radio LAN the robots exchanged messages with a central server, which integrated all individual world models. By asking each of their robots about its own position, they could distinguish between teammates and opponents. The server in turn sent out a global, integrated world model to the robots, which was used to determine actions and to plan paths. The world model was precise enough to allow robots to choose and aim at the corner of the goal into which they would kick, or to give a pass to a teammate. However, team play would beverly suffer or be impossible in this case. As a result, their approach seems to be much more based on global positioning by LRF and centralized control (Type D in Table 1) although each player has its own CPU to detect a ball and to control its body than type E in Table 1 which is a typical architecture in the middle size league.

7 Future Issues

Simulation League

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 frexible team plays. However, the stage in RoboCup-98 is still in the preliminal level. For example, tactics to escape from off-side 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.

While the research displayed in the RoboCup simulation league is encouraging, it is fair to remark that it has been difficult for researchers to extract general lessons learned and to communicate such lessons to a wider audience in multi-agents or AI. To facilitate such generalization, a new domain, *RoboCup rescue* is being designed. In RoboCup rescue, the focus will be on rescuing people stranded in a disaster area (where the disaster may be earthquake, fire, floods, or some combination of these events). This domain will not only emphasize the research issues of teamwork, agent modeling and learning, but in addition, raise novel issues in conflict resolution and negotiation. This domain will enable researchers to test the generality of their ideas and test their effectiveness in two separate domains.

Real Robot Small-Size League

The small-size RoboCup league provides a very rich framework for the development of multiagent real robotic systems. 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.

Real Robot Middle-Size League

Despite the encouraging development of the middle-size league, we have to carefully review our current testbed and slowly adapt it to foster research in new directions and new areas. In most cases, this will require a slow evolution of rules.

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 [10] and a few cannot reliably detect collisions with walls or other robots. Solving the charging problem using a rich set of on-board 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[11] 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.

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. With its three leagues, RoboCup researchers face an unique opportunity to learn and share solutions in three different agent architectural platforms.

RoboCup-99, the third Robot World Cup Soccer Games and Conferences, will be held at Stockholm in conjunction with the Sixteenth International Joint Conference on Artificial Intelligence (IJCAI-99) at the beginning of August,

1999. In addition to the existing leagues, a new league, Sony legged robot league will be introduced as an official RoboCup competitions with more teams than 1998 exhibition games and demonstrations.

Appendix A: Final resuluts for the simulation league

Preliminary Results

Group A

A1	Andhill,Japan	A2	UBU, Sweden
A3	Windmillwanderers, Netherlands	A4	Delphine, Germany
A5	UFSC, Brazil		

VS	A1	A2	A3	A4	A5	W/L	Pnt	Rank
A1	-	22-0	0-1	21-0	11-0	3/1	9	2
A2	0-22	-	0-16	0-5	12-0	1/3	3	4
A3	1-0	16-0	-	9-0	11-0	4/0	12	1
A4	0-21	5-0	0-9	-	6-0	2/2	6	3
A5	0-11	0-12	0-11	0-6	-	0/4	0	5

Group B

B	AT-Humboldt'97, Germany	B2	Louvains, Belgium
B3	pippo, France	B4	Hicpobs, Iran

VS	B1	B2	B3	B4	W/L	Pnt	Rank
B1	-	8-0	5-0	8-0	3/0	9	1
B2	0-8	-	1-0	0-3	1/2	3	3
B3	0-5	0-1	-	0-1	0/3	0	4
B4	0-8	3-0	1-0	-	2/1	6	2

Group C

C1	AT-Humboldt'98, Germany	C2	TU-Cluj, Romania
C3	AIACS, Netherlands	C4	ERIKA, Japan
C5	Darbotics, USA		

VS	C1	C2	C3	C4	C5	W/L	Pnt	Rank
C1	-	23-0	6-0	17-0	13-0	4/0	12	1
C2	0-23	-	0-7	7-0	1-0	2/2	6	3
C3	0-6	7-0	-	17-0	16-0	3/1	9	2
C4	0-17	0-7	0-17	-	0-2	0/4	0	5
C5	0-13	0-1	0-16	2-0	-	1/3	3	4

Group D

D1 Gemini, Japan D2 Cosmoz, Germany
D3 Footux, France D4 Texas, USA

VS	D1	D2	D3	D4	W/L	Pnt	Rank
D1	-	6-0	21-0	11-0	3/0	9	1
D2	0-6	-	16-0	12-0	2/1	6	2
D3	0-21	0-16	-	2-0	1/2	3	3
D4	0-11	0-12	0-2	-	0/3	0	4

Group E

E1 PasoTeam, Italy E2 Ulm-Sparrow, Germany
E3 Miya2, Japan E4 DarwinUnited, USA

VS	E1	E2	E3	E4	W/L	Pnt	Rank
E1	-	6-2	0-1	5-0	2/1	6	2
E2	2-6	-	0-3	0-1	0/3	0	4
E3	1-0	3-0	-	0-0	2/0	7	1
E4	0-5	1-0	0-0	-	1/1	4	3

Group F

F1 CAT-Finland, Finland F2 MainzRollingBrains, Germany
F3 NIT-Stone, Japan F4 Dynamo98, Canada

VS	F1	F2	F3	F4	W/L	Pnt	Rank
F1	-	0-4	7-0	1-0	2/1	6	2
F2	4-0	-	10-1	0-0	2/0	7	1
F3	0-7	1-10	-	1-4	0/3	0	4
F4	0-1	0-0	4-1	-	1/1	4	3

Group G

G1 USCI, USA G2 Brainstorms, Germany
G3 LinkopingLizards, Sweden G4 kappa, Japan

VS	G1	G2	G3	G4	W/L	Pnt	Rank
G1	-	12-0	2-0	5-0	3/0	9	1
G2	0-12	-	0-4	0-4	0/3	0	4
G3	0-2	4-0	-	4-0	2/1	6	2
G4	0-5	4-0	0-4	-	1/2	3	3

Group H

H1 CMUnited, USA H2 UU, Netherlands
H3 TUM, Germany H4 Kasugabito-II, Japan

VS	H1	H2	H3	H4	W/L	Pnt	Rank
H1	-	22-0	2-0	5-0	3/0	9	1
H2	0-22	-	0-16	0-8	0/3	0	4
H3	0-2	16-0	-	9-1	2/1	6	2
H4	0-5	8-0	1-9	-	1/2	3	3

Appendix B: Final resuluts for the real robot small-size league

Preliminary Results

Group A

A1 Univ. Vrij Brussel (UVB), Belgique A2 Paris-6, France
A3 Univ. Western Australia (UWA), Australia

VS	A1	A2	A3	W/L	Pnt	Rank
A1	-	2-3	-	0/1	0	2
A2	3-2	-	-	1/0	3	1
A3	-	-	-	-	-	3

Group B

B1 5DPO/FEUP B2 iXs, Japan
B3 CMUnited98, USA

VS	B1	B2	B3	W/L	Pnt	Rank
B1	-	7-0	2-0	2/0	6	1
B2	0-7	-	2-16	0/2	0	3
B3	0-2	16-2	-	1/1	3	2

Group C

C1 Cambridge Univ., UK
C2 I-Space, Univ. Tokyo, Utsunomiya Univ,
C3 Roboroos, Univ. Queensland, Australia
and Shibaura Inst. Tech., Japan

VS	C1	C2	C3	W/L	Pnt	Rank
C1	-	6-2	5-4	2/0	6	1
C2	2-6	-	4-6	0/2	0	3
C3	4-5	16-2	-	1/1	3	2

Group D

D1 Paris-8, France D2 J-Star, Japan
D3 CMUnited97, CMU, USA

VS	D1	D2	D3	W/L	Pnt	Rank
D1	-	Cncld	forfeitO	-	-	3
D2	Cncld	-	3-2	1/0	3	1
D3	forfeitX	2-3	-	0/1	0	2

Appendix C: Final resuluts for the real robot middle-size league

Preliminary Results

Group A

A1 ISocRob, Portugal A2 Osaka Univ., Japan
A3 Ullanta Performance Robotics, USA A4 Ulm Sparrows, Germany

VS	A1	A2	A3	A4	W/L	Pnt	Rank
A1	-	0-0	0-0	1-1	0/0	3	2
A2	0-0	-	0-0	4-1	1/0	5	1
A3	0-0	0-0	-	0-0	0/0	3	3
A4	1-1	1-4	0-0	-	0/1	2	4

Group B

B1 CS-Freiburg, Germany B2 NAIST, Japan
B3 Dreamteam, ISI/USC, USA B4 Real Magicol, France-Columbia

VS	B1	B2	B3	B4	W/L	Pnt	Rank
B1	-	1-1	1-0	3-0	2/0	7	1
B2	1-1	-	1-1	2-0	1/0	5	2
B3	0-1	1-1	-	Cncl	0/1	4	3
B4	0-3	0-2	cncl	-	0/2	0	4

Group C

C1 GMD, Germany C4 LRP-Paris-6, France
C2 Uttori United, Utsunomiya Univ, Toyo Univ, and Riken, Japan
C3 Yale Univ., USA

VS	C1	C2	C3	C4	W/L	Pnt	Rank
C1	-	0-5	0-1	3-1	1/2	3	3
C2	5-0	-	1-0	2-0	3/0	9	1
C3	1-0	0-1	-	Cncl	1/1	6	2
C4	1-3	0-2	cncl	-	0/3	0	4

Group D

D1 Tubingen Univ., Germany D2 RMIT, Australia
D3 Munich Univ., Germany D4 RoboCup-Italy, Italy

VS	D1	D2	D3	D4	W/L	Pnt	Rank
D1	-	2-0	0-0	0-0	1/0	5	1
D2	0-2	-	1-2	0-0	0/2	1	4
D3	0-0	2-0	-	0-0 PK0-1	2/0	4	3
D4	0-0	0-0	0-0 PK1-0	-	1/0	5	2

References

1. Itsuki Noda, Shoji Suzuki, Hitoshi Matsubara, Minoru Asada, and Hiroaki Kitano. Overview of robocup-97. In Hiroaki Kitano, editor, *RoboCup-97: Robot Soccer World Cup I*, pages 20-41. Springer, Lecture Notes in Artificial Intelligence 1395, 1998. 1
2. M. Asada, editor. *Proc. of the second RoboCup Workshop*. The RoboCup Federation, 1998. 1, 5
3. 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. 2
4. Hiroaki Kitano, Milind Tambe, Peter Stone, Manuela Veloso, Silvia Coradeschi, Eiichi Osawa, Hitoshi Matsubara, Itsuki Noda, and Minoru Asada. The robocup synthetic agent challenge 97. In Hiroaki Kitano, editor, *RoboCup-97: Robot Soccer World Cup I*, pages 62-73. Springer, Lecture Notes in Artificial Intelligence 1395, 1998. 4
5. Minoru Asada, Peter Stone, Hiroaki Kitano, Aalexis Drogoul, Dominique Duhaut, Manuela Veloso, Hajime Asama, and Shoji Suzuki. The robocup physical agent challenge: Goals and protocols for phase i. In Hiroaki Kitano, editor, *RoboCup-97: Robot Soccer World Cup I*, pages 41-61. Springer, Lecture Notes in Artificial Intelligence 1395, 1998. 4
6. Hiroaki Kitano, editor. *RoboCup-97: Robot Soccer World Cup I*. Springer, Lecture Notes in Artificial Intelligence 1395, 1998. 5
7. Wei Min Shen, Jafar Adibi, Rogelio Adobbati, Srini Lanksham, Hadi Moradi Benham Salemi, and Sheila Tejada. Integrated reactive soccer agents. In *RoboCup-98: Proceedings of the second RoboCup Workshop*, pages 251-264, 1998. 11
8. Andrew Price. Orsan: Omnidirectional radial signature analysis network. In *RoboCup-98: Proceedings of the second RoboCup Workshop*, pages 265-280, 1998. 11, 12
9. Shóji Suzuki, Tatsunori Katoh, and Minoru Asada. An application of vision-based learning for a real robot in robocup learning of goal keeping behaviour for a mobile robot with omnidirectional vision and embeded servoing. In *RoboCup-98: Proceedings of the second RoboCup Workshop*, pages 281-290, 1998. 11, 12
10. T. Nakamura, K. Terada, A. Shibata, J. Morimoto, H. Adachi, and H. Tadeka. The robocup-naist: A cheap multisensor-based mobile robot with on-line visual learning capability. In *RoboCup-98: Proceedings of the second RoboCup Workshop*, pages 291-304, 1998. 11, 14
11. K.Yokota, K. Ozaki, N. Watanabe, A. Matsumoto, D. Koyama, T. Ishikawa, K. Kawabata, H. Kaetsu, and H. Asama. Cooperative team play based on communication. In *RoboCup-98: Proceedings of the second RoboCup Workshop*, pages 491-496, 1998. 12, 14
12. Steffen Gutmann and Bernhard Nebel. The cs freiburg team. In *RoboCup-98: Proceedings of the second RoboCup Workshop*, pages 451-458, 1998. 13

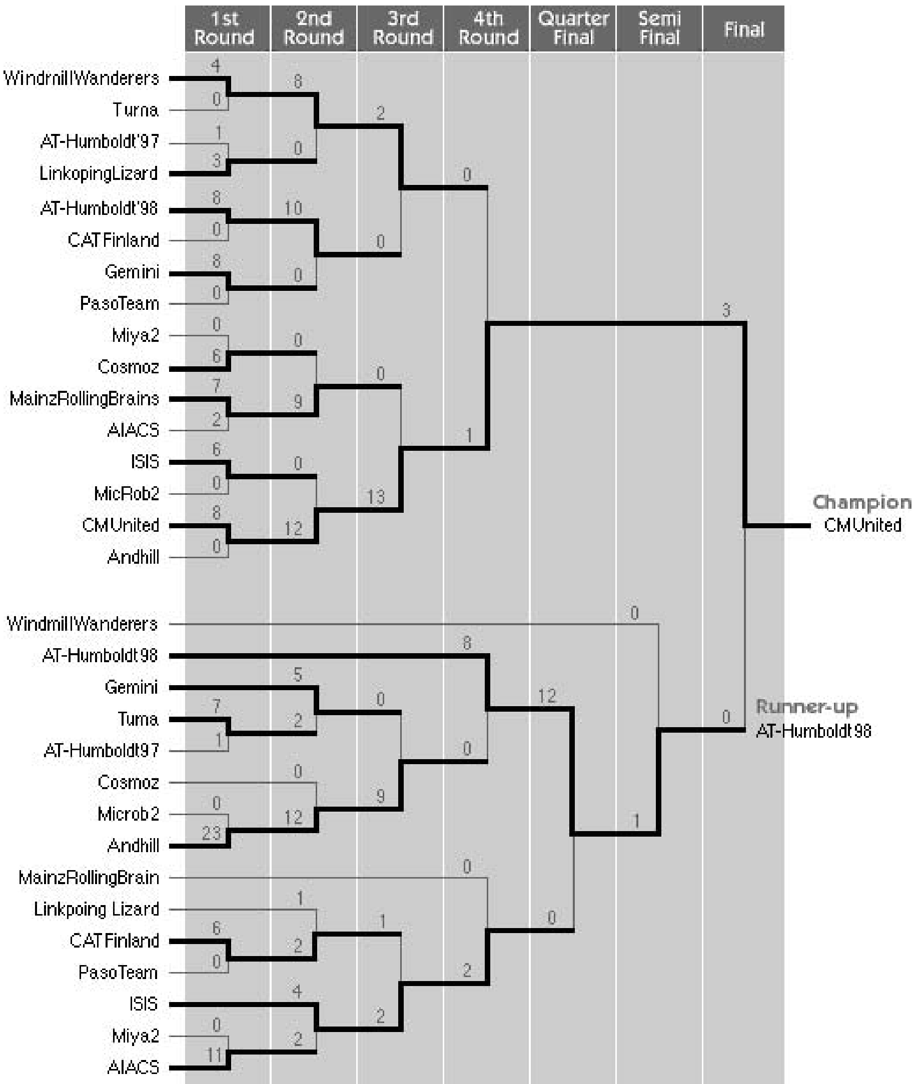

Fig. 7. Final tournament of the simulation league

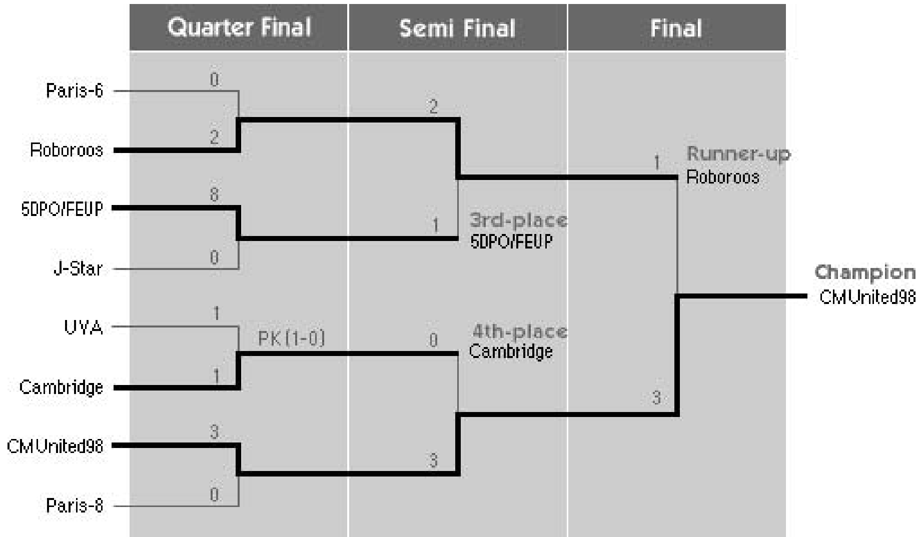

Fig. 8. Final tournament of the small-size league

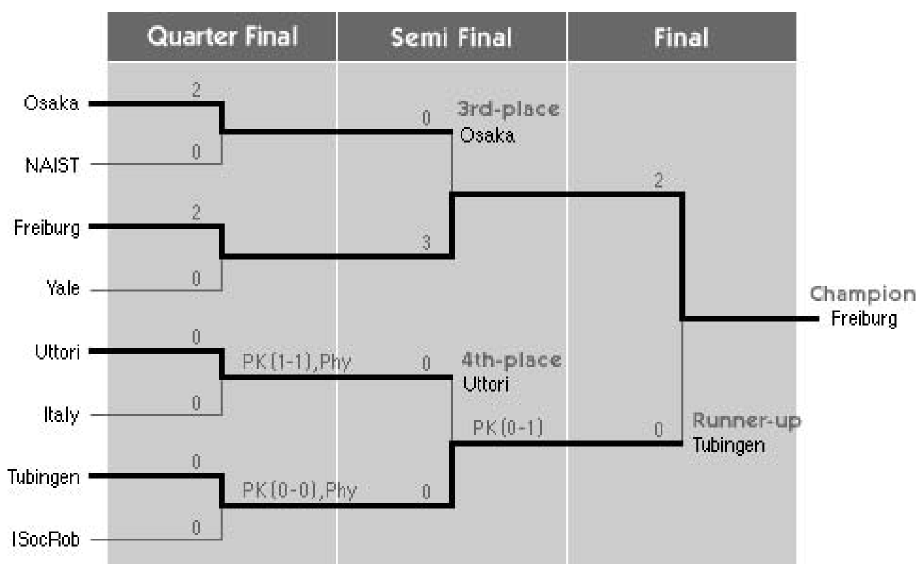

Fig. 9. Final tournament of the middle-size league