Overview of RoboCup-99

S. Coradeschi[1], L. Karlsson[1], P. Stone[2], T. Balch[3], G. Kraetzschmar[4] and M. Asada[5]
[1] Örebro University, Örebro, Sweden
[2]AT&T Research
[3]The Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, US
[4]Neural Information Processing, University of Ulm, Oberer Eselsberg, 89069 Ulm, Germany
[5] Adaptive Machine Systems, Osaka University, Suita, Osaka 565-0871, Japan

Abstract

RoboCup is an initiative aimed to promote the full integration of AI and robotics research. Following the success of the first RoboCup-97 at Nagoya [Noda *et al.*, 1998] and the second RoboCup-98 in Paris [Asada, 1998; Asada *et al.*, 1999], the Third Robot World Cup Soccer Games and Conferences, RoboCup-99, was held at Stockholm during July 27th and August 4th, 1999 in conjunction with the Sixteenth International Joint Conference on Artificial Intelligence (IJCAI-99). There were four different leagues: the simulation league, the real robot small-size league, the real robot middle-size league, and the Sony legged robot league. The champion teams are CMUnited-99 (CMU, USA) for the simulation league, CS Sharif (Sharif University of Technology, Iran) for the middle-size league, The Big Red (Cornell University, USA) for the small-size league, and Les 3 Mousquetaires (Laboratorie de Robotique de Paris, France) for the legged robot league. The Scientific Challenge Award was given to three research groups Information Science Institute, University of Southern California (ISI/USC), USA, Electrotechnical Laboratory (ETL), Japan, and Chubu University, Japan for the development of automated and statistical game analysis systems and methodologies. RoboCup-2000, the fourth Robot World Cup Soccer Games and Conferences, will take place in Melbourne at the end of August, 2000.

1 Introduction

RoboCup-99, the Third Robot World Cup Soccer Games and Conferences, was held on July 27th - August 4th, 1999 at Stockholm. It was organized by Linköping University with the cooperation of Stockholm University, and it was sponsored by Sony Cooperation, Sun, Futurniture, First hotel, The Foundation for Knowledge and Competence Development, The Swedish Council for Planning and Coordination of Research, The Swedish Foundation for Strategic Research, NUTEK, and WITAS.

The purpose of RoboCup is to provide a common task for evaluation of different algorithms and their performance, theories, and robot architectures [Kitano *et al.*, 1997], and in this paper we report on the scientific progress made in RoboCup-99. However, as the game — soccer — is quite accessible to both experts and non-experts, RoboCup also provides an excellent opportunity to inform about and popularize research in AI and robotics. About 7000 spectators are estimated to have visited RoboCup-99, and it was covered by numerous media. A number of initiatives were taken to facilitate the popularization aspect of RoboCup-99, including commented finals, an exhibition, information leaflets distributed to visitors, and the RoboCup Jr event for children. For the benefit of an international audience, the games were web-casted by the Internet edition of the German magazine Der Spiegel (`http://www.spiegel.de`).

In the rest of this paper, we describe the different leagues: the winners, the advances, the trends and the challenges. More details can be found at the RoboCup home page (`http://www.robocup.org`), in the RoboCup workshop proceedings [Veloso *et al.*, 1999], and in the online team descriptions (`http://www.ida.liu.se/ext/robocup/`). In general, a significant increase of the quality of the games could be observed in all leagues, as well as a growing number of participants. And, no less important, the games were played in an atmosphere of great enthusiasm and sportsmanship. Figure 1 shows the award ceremony conducted at the intensive final day of the competition.

1.1 Leagues and results

RoboCup-99 had four different leagues, each one with its specific architectural constraints and challenges. During the preliminary round, each league was divided into a number of round robin groups of 4-7 teams. The top teams in each group qualified for the elimination round, in which the ultimate winners were decided. The different leagues and their winners are as follows.

Figure 1: The award ceremony, with some of the winning teams in the center.

The simulation league: the game takes place in a software server, and the individual players are controlled by separate programs. 37 teams participated, and among these the following teams were awarded:

1st: CMUNITED-99, Carnegie Mellon University

2nd: MAGMAFREIBURG, Albert-Ludwigs-Universität, Freiburg

3rd: ESSEX WIZARDS, University of Essex

The small-size real robot league (F-180): small ($15cm^3$) robots play on a ping-pong-table sized field using global vision. 16 teams participated, and among these the following teams were awarded:

1st: BIG RED, Cornell University.

2nd: FU-FIGHTERS, Free University of Berlin.

3rd: LUCKY STAR, Ngee Ann Polytechnic.

The middle-size real robot league (F-2000): larger (50 cm diameter) robots, each with their own vision system play on a 9m $\times$ 5m field. 20 teams participated, and the winners are:

1st: SHARIF CE, Sharif University of Technology, Teheran.

2nd: AZZURRA ROBOT TEAM, RoboCup Italia.

3rd: CS FREIBURG, Albert-Ludwigs-Universität, Freiburg.

The legged robot league: the teams consist of legged robots provided by Sony. RoboCup-99 is the first time a full-scale legged robot league has been implemented (although RoboCup-98 in Paris featured an exhibition league with three teams.) 9 teams participated, and the winners are:

1st: LES 3 MOUSQUETAIRES, Laboratoire de Robotique de PARIS (LPR).

2nd: UNSW-UNITED, University of New South Wales.

3rd: CMTRIO-99, Carnegie Mellon University.

1.2 Other events

The following events also took place during RoboCup-99.

The RoboCup-99 workshop: one of the central activities of the event, where scientific results on issues pertaining to RoboCup are presented and discussed. This year 20 papers and 22 posters were presented [Veloso *et al.*, 1999].

The RoboCup-99 scientific challenge award: an award to people or groups that have made significant scientific contributions to RoboCup. This year, the award was given to three research groups Information Science Institute, University of Southern California (ISI/USC), USA, Electrotechnical Laboratory (ETL), Japan, and Chubu University, Japan for the development of automated and statistical game analysis systems and methodologies.

RoboCup Jr: RoboCup Jr. is an initiative to transfer knowledge about the latest artificial intelligence and adaptive robotic research to the general public. RoboCup Jr. allows children the get hands-on experience with advanced robotic topics. There were three parts of RoboCup Jr. An Israeli team showed the use of robot soccer in high school education with a penalty shooting robot developed by high school students (age approximately 16-17). Bandai showed a remote-control soccer game with two robots (each with a holding and a shooting device) on each team. LEGO Lab from University of Aarhus arranged open sessions for children (age 7-14) to develop their own robot soccer players and participate in the daily tournament.

2 Simulation League

The simulation league continues to be the most popular part of the RoboCup leagues, with 37 teams participating in RoboCup-99, which is a slight increase over the number of participants at RoboCup-98. As with RoboCup-97 and RoboCup-98, 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 (where a team has to lose twice to be eliminated) to determine the first three teams.

Research directions in the RoboCup simulation league are quite varied. Several contributions were made independently from teams that were entered in the competition. For example, onlookers were able to observe games via a variety of 3-dimensional visualization systems. They were also able to listen to computer-generated, real-time game commentaries. The commentaries not only described the play-by-play action, but also used statistical analysis techniques to evaluate the strengths and weaknesses of the participating teams. Statistical analysis techniques were also used to generate newspaper-style summaries of past games complete with hyperlinks to the highlights of relevant plays, and to make predictions regarding the scores of future matches.

With respect to the competition entrants themselves, there is concrete evidence that the overall level improved significantly over the previous year. The defending champion team, the CMUnited-98 simulator team was entered in the competition. Its code was left unaltered from that used at RoboCup-98 except for minor changes necessary to update from version 4 to version 5 of the soccer simulator. In 1998, this team won all of its matches and suffered no goals against. However, this year, after advancing to the elimination round, it won only one game before being eliminated.

One common research focus in the simulator league is the study of methods for generating action decisions under real-time constraints. For example, the eventual runner-up used an action-selection method based on extended behavior networks that generated decisions very quickly. This method was used primarily for times when an agent was in possession of the ball.

It is interesting to note that different techniques are generally used for agent control when the agents are not in possession of the ball. Many teams use the concept of flexible formations in which agents adjust their positions based on the ball's location. Some research is focussed on using machine learning or linear programming techniques to allow agents to adapt their positioning based on the locations of the opponent players during the course of a game.

An interesting improvement to the soccer simulator this year was the addition of an on-line coach. Each team was permitted to use a single agent with an overhead view of the field that could communicate with all teammates whenever play was stopped (i.e. the ball was out of bounds). At least one team took advantage of this feature to have the coach give advice to the team regarding the overall formation of the team, which could range from offensive to defensive, and "narrow" (concentrated near the middle of the field) to wide.

3 Small Size Real Robot League

The F-180, or "small-size" RoboCup league features five players on each team in matches on a field the size of a ping-pong table. Each robot can extend up to eighteen centimeters along any diagonal and occupy up to 180 square centimeters of the pitch. Coloring of the field, the robots and the ball help computerized vision systems locate team players, opponents, and the ball. The robots are often controlled remotely by a separate computer that processes an an image of the field provided by an overhead camera. A number of teams however are moving towards fully autonomous robots with their own on-board vision.

This year saw a substantial increase in the capabilities of robot soccer teams. In past years a majority of the teams were still wrestling with vision, localization and control issues. This year several teams seemed to have solved these problems entirely and were instead focusing on player skills and team coordination. One of the most interesting technical developments concerned ball kicking technologies. Nearly half of the participating teams utilized some sort of kicking device. One team (the FU-Fighters from Berlin) was able to propel the ball so fast that observers could barely track it. Another interesting development was a new spinning technique for removing stuck balls from along the wall or in corners. One team demonstrated this early in the tournament and several others quickly adopted it.

The core research issues faced by RoboCup F-180 researchers include the development of individual robot skills, reliability in dynamic, uncertain and adversarial environments, and importantly, cooperative team coordination. In the F-180 league these capabilities depend significantly on engineering challenges like reliable real-time vision and high-performance feedback control of small robots. Several teams demonstrated a mastery of the engineering challenges, but much remains to be accomplished in team coordination.

Rules for F-180 league robotic soccer continue to evolve. Of course the long term vision for RoboCup is participation in the real human World Cup, so our robots must eventually be capable of play according to FIFA (the World Cup rules-making body) regulations. For now, however, we adjust FIFA's rules to accommodate our robots. Examples of RoboCup adjustments to the rules include special markings to help with vision issues and walls around the pitch to keep the ball from departing the playing surface.

4 Middle-Size Real Robot League

The middle-size (F-2000) tournament went very smoothly. The new rule structure for the middle-size robot league, which is based upon the official FIFA rules, proved to be quite successful and helped to focus on real research issues instead of rule discussions.

Just as in real soccer, robotic soccer is good for lots of surprises! Already the preliminaries presented several of them: teams like ATTEMPTO! (University of Tübingen, 2nd in RoboCup-98), TRACKIES (Osaka University, 3rd in RoboCup-98 and co-champion in RoboCup-97) or USC DREAMTEAM (USC, co-champion in RoboCup-97) suffered unexpected losses, often against surprisingly strong newcomers like SHARIF CE (University of Teheran), CoPS STUTTGART, ALPHA++ (Ngee Ann Polytechnic, Singapore) or WISELY (Singapore Polytechnic), and did not survive the preliminary rounds. Another big surprise occurred in one of the semi-finals, when the Italian Team (ART) won over the then-undefeated champion of RoboCup-98, CS FREIBURG, in a match that required a penalty shootout and two technical challenge rounds to come up with a decision. In a very exciting final game, a crowd of several hundred spectators watched how the team from the University of Teheran, SHARIF CE, defeated ART by 3:1.

One thing one can learn from the tournament is that hardware alone does not buy you success. Both in 98 and 99, the team from GMD ROBOTS in Bonn had very interesting robots, but its performance did not yet benefit from its technical capabilities. Also, the 98 runner-up ATTEMPTO! this year had the probably most complete robot design, including both directional and omnidirectional cameras, but did not get past the preliminaries. Complex hardware requires substantial time to develop adequate software that can actually exploit the hardware features. On the other hand, hardware innovation can be the foundation for success. The 1999 champion, SHARIF CE, benefitted substantially from the agility of their robots, which arose from a combination of clever drive design and speed. Overall, systems that manage to exhibit relatively few behaviors in a very robust and reliable manner seem to be more successful than more complex, but less reliable systems.

The research efforts of teams in the middle-size robot league clearly indicate several focal points: vision, localization, and behavior engineering. In the vision area, methods for fast color image segmentation have been developed. Several groups use omnidirectional cameras and develop methods for processing the respective images, in particular for self-localization and object recognition. Another interesting direction investigates approaches to vision-based self-localization, which usually extend model-based methods developed for use with other sensor modalities (laser range finders, sonars) to work with features extracted from camera images.

Perceiving the relevant objects and knowing where you are are important prerequisites for generating successful soccer playing behavior, which makes up the other major thread of research. Several teams presented methods for designing behaviors for a single player, without giving particular attention to cooperative play. A few teams already started to seriously investigate methods for generating *cooperative* playing skills.

Overall, the league is in good shape. Worldwide, well over 20 teams are working on building and improving a middle-size robot team. Provided that the rules and the playing field remain reasonably stable for the near future, we can expect significantly enhanced vision capabilities, much improved ball control, smoother individual behaviors, and increasingly more cooperative playing behaviors. It will be a lot of fun to watch the RoboCup-2000 and -2001 tournaments!

5 Conclusion

RoboCup is growing and expanding in many respects. The number of participants is increasing, and so is the complexity of the arrangements. A new league (legged robot) has been introduced this year. The performance of the teams is clearly increasing; in

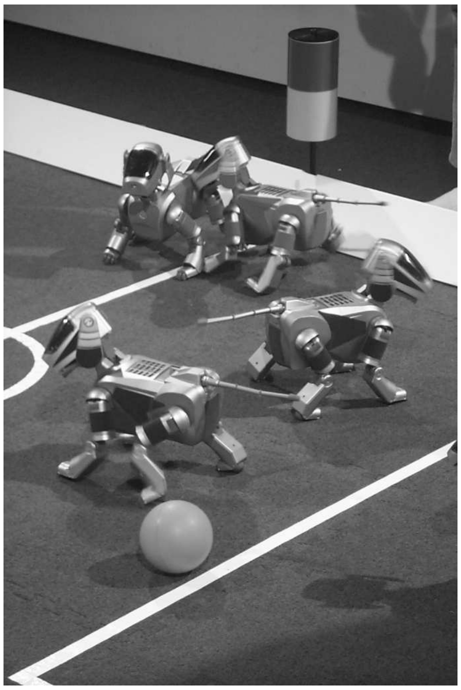

Figure 2: The legged robot league.

many cases the progress made can only be described as very impressing. Once more, RoboCup has proved its capacity to attract the interest of the general public and of newspapers, television and other media. Finally, and perhaps most important of all, RoboCup continues to stimulate and generate research of a high standard in artificial intelligence and robotics.

In 2000, RoboCup is played in Melbourne, Australia, in connection with the Sixth Pacific Rim International Conference on Artificial Intelligence (PRICAI-2000). There is also a European competition, RoboCup Euro-2000 in Amsterdam.

6 Sony Legged Robot League

Sony Legged Robot League is a new official RoboCup league since RoboCup-99. Four-legged autonomous robots compete in three-on-three soccer matches (Figure 2). The robot platform used for is almost the same as the famous Sony AIBO entertainment robot which was introduced into a general consumer's market last July, and 5000 sets were immediately sold out (3000 sets in Japan in 20 minutes, and 2000 sets in US in four days). The main difference from the commercial version is that all participating teams can develop their own programs to control the robots. Since hardware modifications are not allowed, the games are decided by who has developed the best software.

Exhibition games were shown at RoboCup-98 in Paris, where the prototype of "AIBO" was used by three teams, Osaka University BabyTigers (Japan), Carnegie-Mellon University CM-Trio98 (USA),and Laboratoire de Robotique de PARIS (LRP) Les 3 Mousquetaires (France). In addition to these three seeded teams, we had six more teams this year, Team Sweden from a group of Swedish universities, from Humboldt University (Germany), University of Tokyo (Japan), University of New South Wales (Australia), University of Pennsylvania (USA), and McGill University (Canada).

There were three groups in the round robin turn, each of which consists of three teams including one seeded team. The all three seeded teams advanced to the final league as expected since new teams had only two months to develop and debug their programs. The wild card for the fourth participant in the semi-finals was decided by the RoboCup Challenge among the teams that failed to advance in the round robins. Each team had one try in three different situations to score a goal, although none of the teams scored successfully, UNSW secured the wild card spot with their steady performance.

Since the robot easily loses sight of the ball due to the limited visual angle of the CCD camera attached at the nose, the robots spend most of their time looking for the ball. Therefore, the winning teams were those that had developed the image processing programs for robust color detection better than others.

Most teams used the walking programs provided by Sony due to the limited time available for walking program development and/or because they preferred to focus the tactics of the game plays. A few teams developed their own walking programs, for instance LRP which developed a stable and robust walking program, and Osaka which developed a trot walking to increase the speed of walking. These two points are highly significant when it comes to show a good performance during the match, and therefore the newcomers seem to have been disadvantaged. Since all developed programs are planned to be publicly accessible, the teams attending next year may be able to use these resources, and improve them. Twelve teams are expected to attend in Melbourne in 2000.

7 Conclusion

RoboCup is growing and expanding in many respects. The number of participants is increasing, and so is the complexity of the arrangements. A new league (legged robot) has been introduced this year. The performance of the teams is clearly increasing; in many cases the progress made can only be described as very impressing. Once more, RoboCup has proved its capacity to attract the interest of the general public and of newspapers, television and other media. Finally, and perhaps most important of all, RoboCup continues to stimulate and generate research of a high standard in artificial intelligence and robotics.

In 2000, RoboCup is played in Melbourne, Australia, in connection with the Sixth Pacific Rim International Conference on Artificial Intelligence (PRICAI-2000). There is also a European competition, RoboCup Euro-2000 in Amsterdam.

References

[Asada, 1998] M. Asada, editor. *RoboCup-98: Robot Soccer World Cup II.* The RoboCup Federation, 1998.

[Asada *et al.*, 1999] M. Asada, M. Veloso, M. Tambe, I. Noda, H. Kitano, G. Kraetzschmar Overview of robocup-98. In AI Magazine ?(?), 1999.

[Kitano *et al.*, 1997] 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 *Proceedings of the Fifteenth International Joint Conference on Artificial Intelligence*, 1997.

[Noda *et al.*, 1998] 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 Note in Artificial Intelligence 1395, 1998.

[Veloso *et al.*, 1999] Manuela Veloso, editor. *RoboCup-99: Robot Soccer World Cup III.* Springer, Lecture Note in Artificial Intelligence, 1999. To appear.