Hiroaki Kitano*, Minoru Asada**, Itsuki Noda***, Hitoshi Matsubara***,

RoboCup: Robot World Cup

RoboCup is an attempt to foster intelligent robotics research by providing a standard problem where a wide range of technologies can be integrated and examined. The First Robot World Cup Soccer Games and Conferences (RoboCup-97) was held during IJCAI-97, Nagoya, with over 40 teams participating from throughout the world. RoboCup soccer is a task for a team of fast-moving robots in a dynamic, noisy environment. In order for a robot team to actually perform a soccer game, various technologies must be incorporated including: design principles of autonomous agents, multi-agent collaboration, strategy acquisition, real-time reasoning, robotics, and sensor-fusion. This article describes technical challenges involved in RoboCup, its official rules, a report of RoboCup-97, and future perspectives.
Keywords: robot soccer, Robot World Cup, RoboCup, landmark project

RoboCup (The Robot World Cup) is an attempt to promote intelligent robotics research by providing a common task for evaluation of various theories, algorithms, and agent architectures.[4,5] 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. 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 April 1998, RoboCup activity involves over 1,000 researchers from 22 countries. Further information is available from the web site: http://www.robocup.org/.

- **Competitions:** A RoboCup competition has a simulator league and one or more real robot leagues (with different technical specifications).
- **Conferences:** The main forum of technical exchange is often (though not always) associated with competitions. Currently, most RoboCup conferences take the form of a dedicated workshops at major international conferences, such as IJCAI, ICMAS, IROS, or PRICAI.
- **RoboCup Challenge:** A set of benchmark problems is defined for short-term research targets. The RoboCup Challenge is defined for both synthetic agents and physical agents. Benchmark tests quantify progress in robotics, which is difficult to measure under the competition environment.
- **Education:** A series of educational programs is in planning, including *RoboCup Jr.*, aimed at low-cost educational needs.
- **Infrastructure:** International joint work is underway to establish a software and hardware infrastructure, including a standard robot platform, a software repository, advanced simulator systems, and other resource sharing.
- **Secondary Domains:** While soccer is the central task at present, RoboCup Secondary Domains offer cross-domain validation of

*Sony Computer Science Laboratory, 3-14-13 Higashi-Gotanda, Shinagawa, Tokyo 141 Japan; **Dept. of Mechanical Engineering, Osaka University, Suita, Osaka 565 Japan; ***Electrotechnical Laboratory, 1-1-4 Umezono, Tsukuba, 305 Japan; E-mail RoboCup@csl.sony.co.jp; Web: http://www.robocup.org/

1070-9932/98/$10.00©1998 IEEE

developed technologies and concepts. Secondary domains are chosen so as to compensate for missing features in soccer, such as long-term strategy or logistics. These domains are also chosen from real world application domains; for example, search and rescue, or exploration in dangerous terrain.

Of the range of activities listed above, however, competition remains the 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.

Currently, RoboCup consists of three competition tracks. A **Real Robot League** uses physical robots to play soccer games. In RoboCup-97, the real robot league has two subcategories: the small-size league and the middle-size league. A *small-size league* consists of up to five robots per team played on a field the size of a ping-pong table. Each robot is about 15cm in diameter (under 180cm in area, with a maximum length of less than 18cm). An orange golf ball is used as the "soccer ball." A *middle-size league* uses up to five robots per team, and each robot is under 50cm in diameter, and no more than 2,000cm in area. A FIFA Size 4 Futsal ball is used. The field of play is equal to 9 ping-pong tables (arranged in a 3×3 array).

In a **Simulator League** software agents play soccer games in an official soccer simulation system. Each player program is connected via UDP/IP and receives only limited, noisy visual information from the vantage point of his the player on the field.

In **Exhibitions** adjunct demonstrations and competitions are held along with the main event. These are the *Expert Robot Competition*, competitions of robots which have special skills, but are not able to play a full soccer game; *Legged Robot Exhibition*, exhibition games using legged robots (premiering at RoboCup-98 Paris); and the *RoboCup Commentator Exhibition*, which is an exhibition of fully autonomous commentator for RoboCup Games (premiering at RoboCup-98 Paris).

WHY ROBOCUP?

It is obvious that building a robot to play a soccer game is an immense challenge; readers might therefore wonder why even bother to propose RoboCup. It is our intention to use RoboCup as a vehicle to promote robotics and AI research, by offering a publicly appealing but formidable challenge. The idea of using soccer for robotics research is not new. In 1993, Alan Mackworth proposed[6] that soccer can be a good testbed of robotics and AI research. Independently, several researchers have been working on the soccer domain. These efforts merged into RoboCup.

A unique feature of RoboCup is that it is a systematic attempt to promote research using a common domain, mainly, soccer. Also, it is perhaps the first to explicitly claim that the ultimate goal is to defeat the human World Cup champion team. One effective way to promote engineering research, apart from specific application developments, is to set a significant long-term goal. When the accomplishment of such a goal has significant social impact, we call this kind of goal a *grand challenge project*. Building a robot to play soccer is not such a project. But its accomplishment would certainly considered as a major achievement in the field of robotics. We call this kind of project a *landmark project*. RoboCup is a landmark project as well as a standard problem.

A successful landmark project sets very attractive and broadly appealing goals to be accomplished. Certainly the most famous successful example is the Apollo space program. In the case of the Apollo project, the U.S. committed the goal of "landing a man on the moon and returning him safely to earth."[2] The accomplishment of this goal was a landmark in the history of mankind. Although the direct economic impact of landing a man on the moon was slim, technologies developed to achieve this goal contributed greatly to the powerful technological foundations of modern American industry. The important issue for a landmark project is to set a goal high enough so that a series of technical breakthroughs is necessary to accomplish the task; furthermore, a set of technologies should form the foundation of a next generation of industries. And of course, the goal also needs to be widely appealing and exciting.

In the case of RoboCup, the ultimate goal is: "By the mid-21st century, a team of autonomous humanoid robots shall beat the human World Cup champion team under the official regulations of FIFA." (A more modest goal is "to develop a robot soccer team which plays like a human player.") Needless to say, the accomplishment of the ultimate goal will take decades of effort, if not centuries. It is not feasible with current technologies to accomplish this goal in any near term. However, this goal can easily create a series of well-directed subgoals. Such an approach is common is any ambitious, or overly ambitious, project. In the case of the American space program, the Mercury project and the Gemini project (manned orbital missions) were two precursors to the Apollo mission. The first subgoal to be accomplished in RoboCup is "to build real and software robot soccer teams which play reasonably good soccer with modified rules." Accomplishing even this goal will undoubtedly generate technologies which impact a broad range of industries.

Another way to look at RoboCup is as a "standard problem" so that various theories, algorithms, and architectures can be evaluated. Computer chess is a typical example of a standard problem. Various search algorithms were evaluated and developed using this domain. With the recent accomplishment of the Deep Blue team, which beat Kasparov, a human grand master, using the official rules, the challenge of computer chess is close to over. A major reason for the success of computer chess as a standard problem is that the evaluation of progress was clearly defined. The progress of research can be evaluated as the strength of the system, which is indicated as a U.S. chess rating. However, as computer chess is about to complete its original goal, we need a new challenge. The challenge needs to foster a set of technologies for the next generation of industries. We think that RoboCup fulfills such a demand. Table 1 illustrates the difference between the domain characteristics of computer chess and RoboCup.

RoboCup is designed to require the handling of real world complexities, though in a limited world, while maintaining an

Table 1: Comparison of Chess and RoboCup

	Chess	RoboCup
Environment	Static	Dynamic
Information accessibility	Complete	Incomplete
Sensor Readings	Symbolic	Non-symbolic
Control	Central	Distributed

affordable problem size and research cost. RoboCup offers an integrated research task covering broad areas of intelligent robotics. Such areas include: real-time sensor fusion, reactive behavior, strategy acquisition, learning, real-time planning, multi-agent systems, context recognition, vision, strategic decision-making, motor control, intelligent robot control, and many more.

RESEARCH ISSUES OF ROBOCUP

In this section, we discuss several research issues involved in the development of real robots and software agents for RoboCup. A major reason 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

In addition to these technologies, providing a network-based soccer server with high quality 3D graphics capability requires an advancement in technologies for the real time animation of simulated soccer players, and in developing a network-based, interactive, multi-user environment. These happen to be the key technologies for network-based services in coming years.

A brief look at some of research issues will illustrate the breadth and depth of the challenges in RoboCup. Issues in the design of agent architectures for multi-agent systems constitute one obvious topic. But there are many other areas which can use the RoboCup framework. One such emergent research issue can be illustrated by considering how "learning" needs to be done in RoboCup. To be successful in RoboCup, an individual player needs to learn player skills, a team needs to learn teamwork, and a coach (a trainer program) may need to learn better coaching ability.

Individual player skills include basic skills such as shooting and passing, and also the ability to determine when to shoot and when to pass. Also, teamwork is categorized into two types: local teamwork, such as passing a ball between players; and global teamwork, that is, team formation (strategy). Currently, the real robot league focuses mainly on an individual player's skill while the softbot league focuses on teamwork issues. In addition to these levels of learning, teaching is also another important research issue with a wide range of direct-teaching or indirect-teaching possibilities. Modeling learners' capabilities from the coach's perspective can make learning issues even more pronounced.

The issue of how to scale up individual learning to teamwork learning is a new and innovative research topic. Learning needs to be done before the match, during the match, and after the match. Before competition, players may spend effectively as much time as they need to learn skills. However, if a team wants to adapt to opponent strategy, they must learn during the match itself, which must be done within 5-10 minutes. The learned results from this match must (hopefully) be applicable to the next match, whether against the same opponent or new ones. In addition, since strategy needs to be altered if a player on either team was is involved in an accident and is not able to continue in the match anymore, so the system must learn to detect anomalies and determine how strategy should be changed.

This example from RoboCup makes it clear that there are multiple aspects in learning when we try to build an integrated system for a comprehensive task. While RoboCup itself restricts its context to soccer games, it still presents many aspects of learning with which the naive use of current learning theories cannot cope. Variations and constraints imposed on learning in various situations have not been systematically investigated in the past. A thorough investigation of all aspects of learning would be a possible first step toward truly autonomous agents.

Other areas of research involve collaboration among agents/robots and contingency planning. It is essential that each player understands his basic role in the team, and can faithfully execute his mission. Defining roles in the team itself is a challenge. To make matters worse, the role of each player often changes with a new situation. When a player in the team gets hurt and cannot play, someone has to fill in the damaged player's role, or it is necessary to modify overall team strategy so that the damage does not lead to catastrophic inconsistencies in the team. Thus each player to must recognize abnormalities in other players, assess the situation, dynamically re-plan strategy, and generate a new teamwork plan. Progress in any of these areas would certainly benefit AI and mobile collective robotics.

APPLICATIONS OF ROBOCUP TECHNOLOGIES

Due to the breadth of technologies involved, and the characteristics of the soccer task, various applications can be envisioned in the future. Obviously, most military operations share similar features. A more futuristic but on-going effort is NASA's Deep Space exploration initiative in the New Millennium Project.[7] In the Deep Space missions, fully autonomous space craft will be used for space exploration. In future missions it is expected that multiple space crafts will carry out scientific observations working as a team. The ultimate goal of the New Millennium project is the creation of the New Millennium Network, which consists of a large number of small spacecraft orbiting in formation. Similar applications are possible for a Mars probe where multiple small robots may be delivered to the surface of Mars for scientific inquiry.

The Search and Rescue missions provide more immediate and socially significant application opportunities of RoboCup technologies. Imagine a major earthquake hitting Los Angeles or Tokyo. Lessons from Kobe and other disaster rescues indicate that highly intelligent and robust systems need to be developed if autonomous robots are to be deployed. Characteristics for a rescue mission coincide with those of soccer games in many aspects. In a major disaster, only partial information, many much of it false, is available. As the situation unfolds, more information will be provided, but still much of it may be incorrect. The field is hostile and dynamic. It is highly likely that some of the robots deployed will be damaged, and thus it will be necessary to reformulate team strategy in real time. Robots need to work in a team to rescue victims. For example, one robot may lift a fallen wall, while others find victims contained deeply inside the collapsed building. Additional robots may actually rescue the discovered victims. This requires high levels of teamwork.

We believe that RoboCup opens new avenues of innovative research issues and applications.

ROBOCUP-97 NAGOYA

The First Robot World Cup Soccer Games and Conferences [3] was held during IJCAI-97 Nagoya, August 23-29, 1997. Over 40 teams throughout the world participated in the competition: thirty-two teams (Europe=8, North America=8, Australia=2, Japan=14) participated in the simulator league, four teams [Carnegie Mellon University (USA), Paris-VI (France), University of Girona (Spain), and Nara Advanced Institute of Science and Technology (Japan)] participated in the small-size robot league, and five teams [ISI/USC (USA), Osaka University (Japan), Ullanta Performance Robotics (USA), RMIT (Australia), Uttori United—A joint team of Riken, Tokyo Univ., and Utsunomiya Univ. (Japan)] participated in the middle-size league. Prior to the competition a two-day technical workshop was held with 30 technical papers and a poster session with all participating teams.

The simulation league used a round-robin system to select the top sixteen teams. Eight groups of four teams were created, and the top two teams from each group advanced to a single-elimination ladder competition. The winner of the simulation league was AT-Humbolt from the Humbolt University, Germany, who beat the AndHill team from the Tokyo Institute of Technology in the final. Third place went to ISI Synthetics (ISIS) from ISI/USC, which defeated CMUnited from Carnegie Mellon in the third-place play-off.

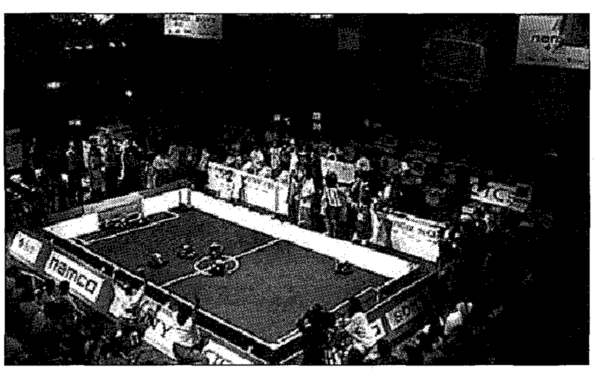


Figure 1. RoboCup-97. (Copyright, 1997 Plailly/Eurelios. All rights reserved.)

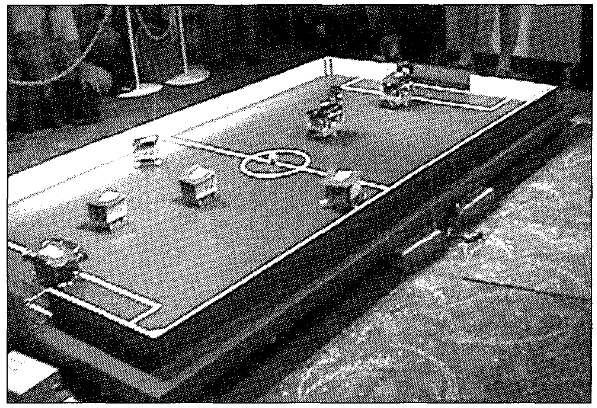


Figure 2. A match of the small robot league.

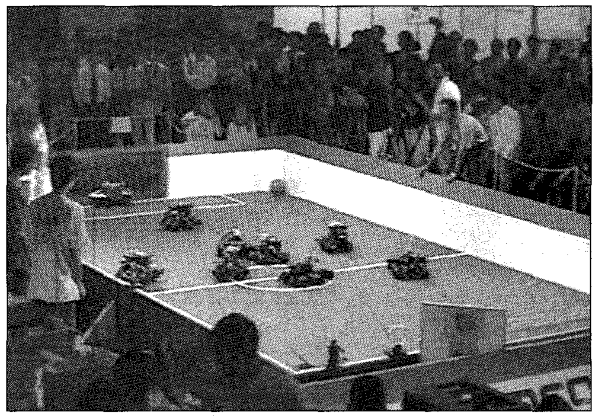


Figure 3. A match of the middle robot league.

The small-size league World Champion was awarded to CMUnited from Carnegie Mellon University which won over Nara Advanced Institute of Science and Technology, Japan by a 3-0 score in the final.

The middle-size league final resulted in draw (0-0) between DreamTeam of ISI/USC and Trackies of Osaka University. Their score in the preliminary was also a 2-2 draw. The committee decided to award both teams first place.

In addition to the awards to the league winners, RoboCup awards the Scientific Challenge Award and Engineering Challenge Award for the teams that make major challenges with some success. This award was established to foster challenging scientific and engineering research in RoboCup. In general, the safest approach to winning the competition is to use conventional and reliable technologies well-tuned for the specific domain. The RoboCup domain is sufficiently challenging enough so that any successful team must use some challenging technologies. However, these special awards are given for truly high-risk and high-impact design.

In RoboCup-97, the Scientific Challenge Award was given to Sean Luke of the University of Maryland for demonstrating the utility of evolutionary computation by evolving soccer teams. Sean Luke used Genetic Programming to evolve soc-

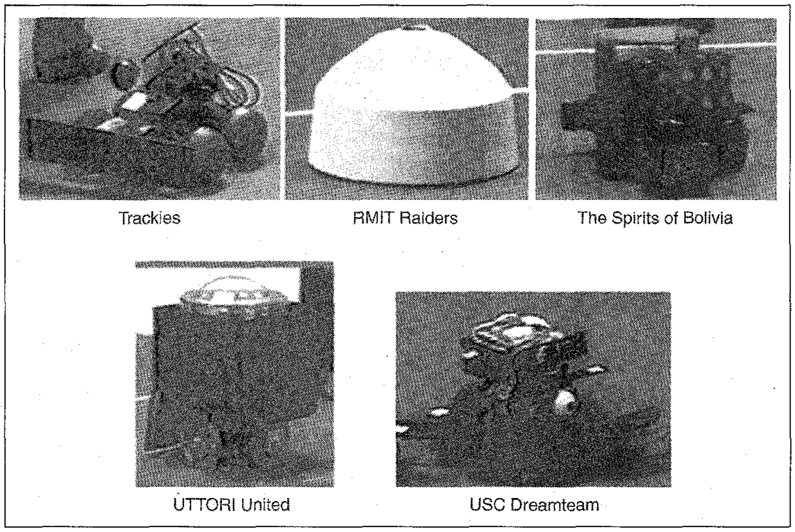


Figure 4. Participating robots.

cer players trained on the RoboCup simulator in a massively parallel machine for a few months. The evolved team beat two hand-coded teams and survived the round robin round to advance to the single-elimination round.

Two engineering challenge awards were given to Uttori-United and RMIT, for designing novel omnidirectional driving mechanisms. These teams designed new robot driving mechanisms which use special wheels (Uttori) and balls (RMIT) to enable robots to move in any direction without rotation (giving them, in effect, holonomic movement). Such mechanisms significantly improve a robot's maneuverability and simplify its control system, and their potential impact is far reaching.

Technical details of teams represented in RoboCup-97, as well as related research results were published as the official publication .[3]

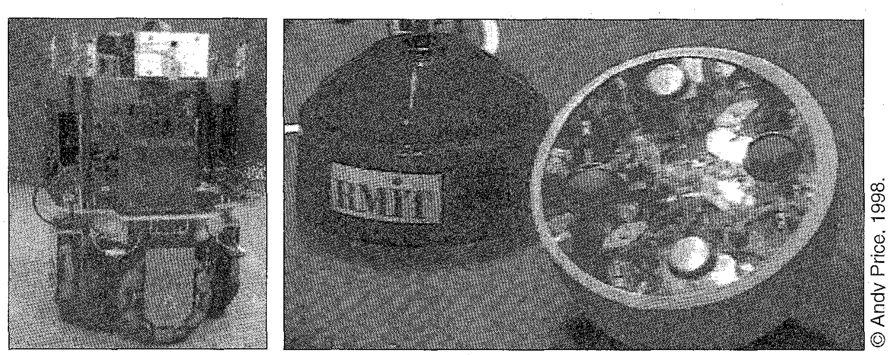
Over 5,000 general spectators watched the games during RoboCup, and the event was covered by over 70 world media organizations, including CNN, ABC, NHK, BBC, Sky Channels, *Le Monde*, *Der Spigel*, *Le Figaro*, *Wired*, and *Business Week*.

ROBOCUP RESEARCH PROGRAM

In order to provide a forum for high-quality and high-impact research, RoboCup provides a set of programs to foster research and development in robotics and AI.

Competitions and Workshops

The main forum to support RoboCup research is the RoboCup competition and the workshop associated with each competition. The first RoboCup (RoboCup97 at Nagoya, Japan) had both a competition and a workshop; a series of future RoboCup competitions and workshops will be held including RoboCup-98 Paris, RoboCup-98 Victoria, and RoboCup-99 Stockholm.



(a) UTTORI (b) RMIT.

Figure 5. The omnidirectional driving mechanism.

The RoboCup Challenge

The RoboCup Challenge is a series of short-term technical challenges, which are designed to ensure steady and focused research progress. Current challenges are the RoboCup Synthetic Agent Challenge and the RoboCup Physical Agent Challenge. While the competition environment is suitable for evaluating comprehensive strength of the approach, there are needs for a precise evaluation scheme so that specific technical aspects can be examined. The RoboCup Synthetic Agent Challenge and RoboCup Physical Agent Challenge are designed for such an evaluation.

The RoboCup Synthetic Agent Challenge

The RoboCup Synthetic Agent Challenge 97 was selected as the IJCAI Challenge program.[5] It offers three specific challenges: a learning challenge, a teamwork challenge, and an opponent modeling challenge. The teamwork challenge, for example, spontaneously disables one of the players during the game, and examines how the team can cope with unexpected events. This challenge requires both detection of abnormality and reformulation of teamwork.

The RoboCup Physical Agent Challenge

The RoboCup Physical Agent Challenge Phase-I[1] consists of three tasks; ball moving, ball receiving, and ball passing. The ball moving task examines a robot's ability to approach a ball and to move the ball to the desired place through dribbling or kicking. The task is performed under three conditions: no obstacles, stationary obstacles, and moving obstacles. The ball receiving challenge is similar, except it deals with intercepting and receiving a ball. After these two tasks have been reasonably accomplished, the third task of passing the ball can be challenged.

RoboCup Natural Language Challenge

One interesting aspect of the RoboCup challenge is that it also involves the non-robotics community. In RoboCup Natural Language Challenge, researchers will develop RoboCup Automatic Commentator, which automatically generates natural language commentary. This is a new area of natural language research, and RoboCup provides rich domain for these researchers.

ROBOCUP INFRASTRUCTURE

RoboCup Simulator Development Group

A group of institutions and researchers are developing the RoboCup simulator and add-on software. The RoboCup Soccer Server is the official simulator for RoboCup simulator league, developed at Electrotechnical Laboratory in Japan. A Windows-95 version was developed at the University of Paris-VI, and a Java-version soccer simulator was developed at the Georgia Institute of Technology. A 3D visualization system for the soccer server has been developed jointly by Softopia Japan, the International Academy of Media and Science (IAMAS), and Electrotechnical Laboratory. We welcome the participation of various institutions to provide novel applications for RoboCup, as well as being a member of the joint development teams.

The RoboCup Advanced Simulator is now being planned, which simulates the details of physical properties of robots, instead of an abstract model of agents. The intent of the advanced simulator development is to create a detailed model of a robot's physical property as well as sensory inputs. The ultimate goal is for software developed on the advanced simulator to be able to be downloaded to a real robot and work well with little modification.

RoboCup Practice Server

The Royal Melbourne Institute of Technology (RMIT) started the RoboCup Practice Server in May 1997. The purpose of the practice server is to provide opportunities for simulator-based RoboCup researchers to carry out practice rounds against other teams which are registered on the practice server.

RoboCup Secondary Domains

To validate whether the technologies developed through robot soccer can be applied to other practical domains, a set of secondary domains is being prepared. The domains will be taken from real application problems, and will emphasize features missing in the soccer game, such as middle- and long-term strategy, logistics, and collaboration between teams. Two domains likely to be used are search and rescue, and (space) exploration. The RoboCup Rescue domain will simulate various disaster rescue missions and evaluate how a group of agents can accomplish a rescue task, as well as test how two groups of agents, encountering each other for the first time, can establish a collaborative relationship.

These secondary domains compensate for obvious missing features of soccer games, and combine with the RoboCup soccer domain to establish a solid testbed for autonomous agent and robotics technologies.

RoboCup Education Program

The comprehensive nature of RoboCup makes it an ideal subject for project-oriented AI and robotics courses. Already, a few undergraduate and graduate courses are now being planned using RoboCup. Further, an education infrastructure named *RoboCup Jr.* is now being planned, 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.

RoboCup Common Platform Program

In order to concentrate on high-level control and planning aspects of multi-agent research without spending too much time and energy on low-level hardware issues, a reliable robot platform is essential. The trade-off of using such a platform is that it may not be fully optimal for the particular task; nonetheless, it is necessary to provide versatility and (especially) reliability. One such standard may be the OpenR autonomous robotics standard. One important reason to define such a common platform is that it has immediate impact on an education program using RoboCup.

As the need for the real world application of AI increases, the use of robots and systems that actually interact with the physical real world as AI research platforms will be more and more important. However, the lack of standard components which can be purchased at affordable costs prevents many researchers from venturing into physical, real world domains. RoboCup hopes to foster a collective effort to define a standard for reliable, flexible, scaleable, and affordable physical robot components. Such a component set would provide a mother board with a real-time operating system, and a basic development environment.

Industrial Sector Programs

Several robotics companies have expressed interest in supporting RoboCup activities by establishing a robot loan program, a team support program, and by developing robots specifically for RoboCup.

New Leagues

New categories will be introduced as technology progresses. In RoboCup-98 Paris, exhibition games will be scheduled to be held using legged robot teams. Each robot has four legs and a head. It is expected that such a robot will have about 15 degrees of freedom. It is a challenging task to control such a robot in real-time to play a soccer game. The legged robot league will turn into an official league after the Paris competition.

Also, a new Full-Set Small Size League will use eleven players per team, and will be played on the middle-size field. The increase in the number of robots drastically increases the complexity of the task.

In the future, we are planning to organize a humanoid robot league. It will be subdivided into two categories: a fully autonomous league and a teleoperated league. With the emergence of bi-pedal humanoid robots such as the Honda Humanoid Robot, a soccer league of this kind is no longer just a Sci-Fi dream. It is certainly within the scope of serious research goals. Such a humanoid robot is expected to be almost the same size as a human being, and is expected to play in a real soccer stadium some day in the future.

RoboCup has a dream and a challenge. It is one of the fastest-growing areas of intelligent robotics research today. The community is expanding, and is sharing of extensive knowledge and resources towards this common vision.

CONCLUSION

As described in this article, RoboCup offers an opportunities for intelligent robotics and AI research by providing an attractive but formidable challenge. It also provides a range of challenging programs which are designed to evaluate specific technical issues. The challenge programs will be updated and new challenges will be offered as technology progresses. Along with other programs such as the education program, RoboCup offers a comprehensive research program which promotes AI and robotics.

REFERENCES

[1] Asada, M., et al., RoboCup Physical Agent Challenge: Phase-I. *Applied Artificial Intelligence*, 1998.

[2] Kennedy, J.F., Urgent National Needs. Speech to a Joint Session of Congress. *Congressional Record — House*, 25 May 1961, p. 8276.

[3] Kitano, H. (Ed.), *RoboCup-97: World Cup Robot Soccer I*, LNAI, Springer-Verlag, 1998.

[4] Kitano, H., et al., RoboCup: A Challenge AI Problem. *AI Magazine*, Spring, 1997.

[5] Kitano, H., et al., RoboCup Synthetic Agent Challenge 97. *Proc. of IJCAI-97*, 1997.

[6] Mackworth, A., On Seeing Robots. *Computer Vision: Systems, Theory, and Applications*, World Scientific Press, Singapore, 1993.

[7] Pell, B., Bernard, D., Chien, S., Gat, E., Muscettola, N., Nayak, P., Wagner, M., and Williams, B., An Autonomous Spacecraft Agent Prototype. *Proc. Agent-97*, ACM Press, 1997. Also, see http://jpl-nmp.arc.nasa.gov/nmp/Vision/index.html.

Hiroaki Kitano is a senior researcher at Sony Computer Science Laboratories. He received the B.S. in physics from the International Christian University and the Ph.D. in Computer Science from Kyoto University. He was a visiting researcher from 1987 to 1993 at the Center for Machine Translation, Carnegie Mellon University. He is President of the RoboCup Federation, adjunct professor at the National Institute of Genetics and Medical Research Institute of Tokyo Medical and Dental University. He is also an editor of the *Artificial Life Journal* (MIT Press).

Minoru Asada is a professor of the department of Adaptive Machine Systems, Graduate School of Engineering, Osaka University. He received the B.E., M.Sc., and Ph.D. degrees in control engineering from Osaka University, Osaka, Japan in 1977, 1979, and 1982, respectively. He was a general chair of IEEE/RSJ 1996 International Conference on Intelligent Robots and Systems (IROS96). Since early 1990, he has been involved in RoboCup activities and his team is the first champion team with the USC team in the middle-size league of the first RoboCup, held in conjunction with IJCAI-97, Nagoya, Japan.

Itsuki Noda is a Senior Researcher at ETL, Japan. He received the B.E., M.E. and Ph.D. degrees in electrical engineering from Kyoto University, Kyoto, Japan in 1987, 1989, and 1995, respectively. Since 1993 he started to develop soccer simulators, and released the first version of Soccer Server in 1995. Soccer Server became the official simulator for the RoboCup simulation league.

Hitoshi Matsubara is a senior researcher at the Electrotechnical Laboratory (ETL), Ministry of International Trade and Industry, Japan. He received his Ph.D. in computer science from the University of Tokyo in 1986. He is group leader of the Complex Games Laboratory in ETL. The Complex Game Laboratory studies game programming including computer Shogi (Japanese chess), Go, Bridge and Soccer. His current research interests include multiagent systems, machine learning and game programming.

ROBOCUP-98 PARIS

During the final tournament of the human World Cup Championship Games, la Cité des Sciences et de l'Industrie, Paris became the venue for the Second Robot World Cup Soccer Games and Conferences, July 4-8.

The dramatic increase in the number of participating teams for RoboCup-98 Paris signified the excitement of the community. RoboCup-98 Paris had over 80 teams (nearly 40 simulator teams, 12 small-size robot teams, 16 middle-size robot teams, 3 legged robot teams) and many other related exhibitions and technical presentations (nearly 70 papers were presented). Public interest was massive as it attracted 15,000 spectaters and 150 world media representatives during the competition.

This year there is an exhibition of RoboCup-related technologies that are not directly related to competing teams. For example, the RoboCup Commentator Exhibition demonstrated a number of systems which automatically generate soccer commentary for simulation league games. They understand what is going on in the game, analyze the performance of each player, create hypotheses on interesting topics on which to provide comments, and generate fluent commentary in different languages.

Sony's legged robots and Honda's humanoid robot could also be seen at RoboCup. Sony organized a special demonstration with their legged robot as a part of RoboCup Technical Exhibition Program. Honda showed a video presentation of their ground-breaking humanoid robot, which was first demonstrated in 1997, is now able to kick a soccer ball, and Honda declared that they will have humaniod soccer game by RoboCup-2002.

RoboCup-99 will be held in Stockholm in conjunction with IJCAI-99. For more details, please visit web site: http://www.robocup.org/