RoboCup 2004 Competitions and Symposium: A Small Kick for Robots, a Giant Score for Science

Pedro Lima[1], Luis Custódio[1], Levent Akin[2], Adam Jacoff[3], Gerhard Kraetzschmar[4], Beng Kiat Ng[5], Oliver Obst[6], Thomas Röfer[7], Yasutake Takahashi[8], Changjiu Zhou[9]

Abstract

RoboCup is an international initiative with the main goals of fostering research and education in Artificial Intelligence and Robotics, as well as of promoting science and technology to world citizens. The idea is to provide a standard problem where a wide range of technologies can be integrated and examined, as well as being used for project-oriented education, and to organize annual events open to the general public, where different solutions to the problem are compared. The 8th annual of RoboCup – RoboCup2004 – was held in Lisbon, Portugal, from 27 June to 5 July. In this paper a general description of RoboCup2004, namely summaries concerning teams, participants, distribution per leagues, main research advances, as well as detailed descriptions for each league, are presented.

1. Introduction

The RoboCup Federation stated the ultimate goal of the RoboCup initiative as follows: ``By 2050, a team of fully autonomous humanoid robot soccer players shall win a soccer game, complying with the official FIFA rules, against the winner of the most recent world cup of human soccer." (Kitano *et al*, 1997). This main challenge lead robotic soccer matches to be the main part of RoboCup events, from 1997 to 2000. However, since 2000, the competitions include search and rescue robots as well, so as to show the application of cooperative robotics and multiagent systems to problems of social relevance (Kitano *et al*, 1999). RoboCupJunior was also introduced in 2000, and has now become a large part of any RoboCup event. It aims at introducing robotics to children attending primary and secondary schools, including undergraduates who do not have the resources yet to take part in RoboCup senior leagues (Lund and Pagliarini, 1999).

RoboCup2004 was held in Lisbon, Portugal, from 27 June to 5 July. As in past years, RoboCup2004 consisted of the 8th RoboCup Symposium and of the competitions. The competitions took place at Pavilion 4 of Lisbon International Fair (FIL), an exhibition hall of approximately 10000 m^2, located at the former site of the EXPO98 world exhibition. The symposium was held at the congress center of the Instituto Superior Técnico (IST), Lisbon Technical University. Together with the competitions, two

1 Instituto de Sistemas e Robótica, Instituto Superior Técnico, Av. Rovisco Pais, 1, 1049-001 Lisboa, Portugal
2 Bogaziçi University, Department of Computer Engineering, 34342, Bebek, Istanbul, Turkey
3 Intelligent Systems Division of the National Institute of Standards and Technology (NIST), USA
4 University of Ulm, Neuroinformatics, 89069 Ulm, Germany
5 Alpha Centre, Ngee Ann Polytechnic, Singapore
6 AI Research Group, Universität Koblenz-Landau, Universitätsstr. 1, 56070 Koblenz, Germany
7 Center of Computing Technology, Universität Bremen, Germany
8 Adaptive Machine Systems, Graduate School of Engineering, Osaka University, Japan
9 School of Electrical and Electronic Engineering, Singapore Polytechnic, 500 Dover Road, Singapore 139651, Singapore

regular demonstrations took place on a daily basis: SegWay soccer, by a team from Carnegie-Mellon University, and SONY QRIO robot, by a team from SONY Japan.

Portugal was chosen as the host of the 2004 edition due to its significant representation in RoboCup committees, competitions and conferences, as a result of the effort of the country in recent years to attract young people to science and technology. Also, because EURO2004™, the 2004 European Soccer Cup, took place in Portugal at the same time, this improved the chances of having the event covered by the media.

RoboCup2004 was locally organized by a Portuguese committee composed of 15 researchers and university professors from several universities, therefore underlining the national nature of the event organization. This committee worked closely with the international organizing and technical committees to set up an event with the record number of 1627 participants from 37 countries, and an estimated number of over 700 robots, divided among 346 teams.

Figure 1 shows the evolution of RoboCup in terms of the number of participating teams (total and per league). Noticeable is the significant increase of the number of junior teams in RoboCup2004 (163 teams). The number of senior teams has reduced when compared with last year's RoboCup, as the number of teams allowed to participate in RoboCup2004 was restricted for the first time. However, the number of teams that submitted qualification material was significantly larger than the number of participating teams (a total of 392 senior teams submitted qualification material and a total of 162 senior teams participated in RoboCup2004).

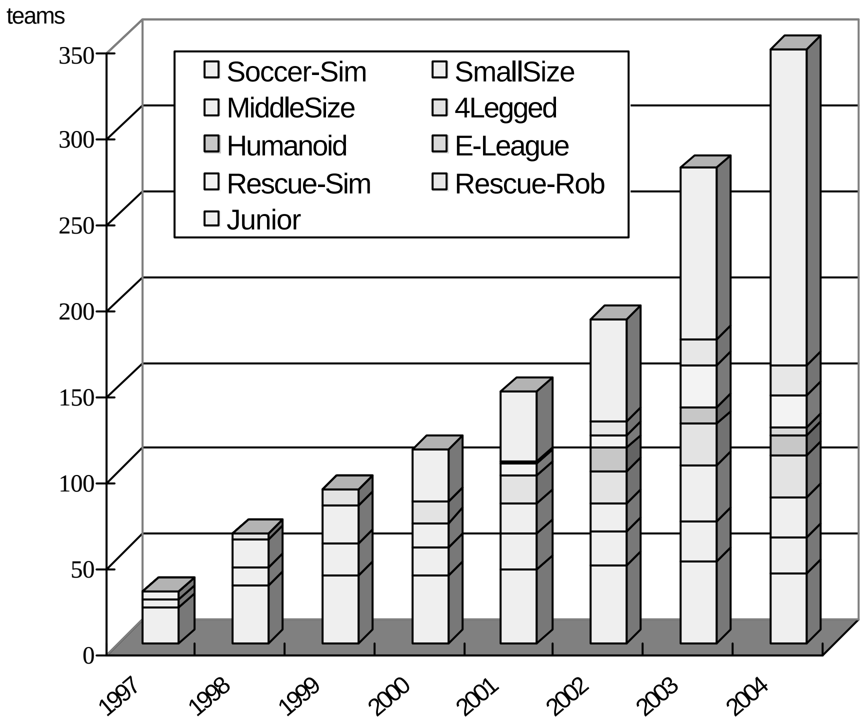

Figure 1: The evolution of RoboCup in terms of the number of teams.

Twenty technicians from FIL were involved in the preparation of the competition site, and 40 student volunteers supported the event realization. The event was hosted by the Institute for Systems and Robotics (ISR), a research institute located on the campus of IST.

The main changes in the RoboCup2004 competitions were:

- **Illumination –** common to most real robot leagues (except the 4-legged league), the illumination was no longer based on light spot projectors assembled on trusses around the fields, but simply on the actual artificial light of the competition site.
- **Larger fields** – most real robot leagues have larger fields, with the goal of reducing robot density on the field, so as to improve game quality and foster strategies based on cooperation.
- **E-League** – originally demonstrated at RoboCup 2003 as the "U-League", the E-League took its place as the newest RoboCup league in RoboCup2004. By focusing on high level issues, it provides an entry-point for new teams that do not have the experience or resources to participate at the level of the senior leagues.

In the following sections we will briefly overview the main research progress this year, the technical challenges and the competition results by league. More details on competitions, photos, short video clips and other related information can be found on the official web page of the event at www.robocup2004.pt.

2. RoboCup2004 Symposium

The 8th RoboCup International Symposium was held immediately after the RoboCup2004 Competitions as the core meeting for the presentation of scientific contributions in areas of relevance to RoboCup. Its scope encompassed the fields of Artificial Intelligence, Robotics, and Education.

The IFAC/EURON 5th Symposium on Intelligent Autonomous Vehicles (IAV04) took also place at the Instituto Superior Técnico, Lisbon from 5 to 7 July 2004. IAV2004 brought together researchers and practitioners from the fields of land, air and marine robotics to discuss common theoretical and practical problems, describe scientific and commercial applications and discuss avenues for future research.

On July 5, the IAV04 Symposium ran in parallel with the RoboCup Symposium and both events shared two plenary sessions: one by James Albus, from NIST, USA, describing the well-known and widely applied NIST Real-time Control System (RCS) cognitive architecture and its applications to multiagent systems, the other by Shigeo Hirose, from the Tokyo Institute of Technology (TIT), Japan, on the development of rescue robots at TIT, with some impressive video demonstrations of real robots.

The other two plenary sessions specific to the RoboCup2004 Symposium were presented by Hugh Durrant-Whyte, from U. of Sydney, Australia, on autonomous navigation in unstructured environments, with applications to field robotics, and Luigia Carlucci Aiello, from Universitá di Roma “La Sapienza”, Italy, who summarized the challenges overcome in the past seven years of RoboCup, as well as the new challenges for the years to come.

In the last day of the symposium, a panel discussion was held on “Applications of RoboCup Research”, moderated by Hans-Dieter Burkhard, and with the presence of Hiroaki Kitano (ERATO Kitano Symbiotic Systems Project, JST, Japan), RoboCup Founding President, Christian Philippe (ESTEC/ESA), and M. Isabel Ribeiro (ISR/IST), IAV04 General Chair. Applications to biology, aerospace robotics and land robotics were covered by the panelists.

118 papers were submitted to the RoboCup2004 Symposium. Among those, 30 were accepted as regular papers and 38 as poster papers. Both will be published in the RoboCup subseries of the Springer LNAI book series.

This year, the awarded papers were:
Scientific Challenge Award: “Map-based Multi Model Tracking of a Moving Object”, Cody Kwok and Dieter Fox, introducing an approach for tracking a moving target using particle filters, and
Engineering Challenge Award: ”UCHILSIM: A Dynamically and Visually Realistic Simulator for the RoboCup Four Legged League”, Juan Cristóbal Zagal Montealegre and Javier Ruiz-del-Solar, describing a robotic simulator specially developed for the RoboCup four-legged league.

Figure 2: View of some of the participants at the entrance of the venue.

Figure 3: Overall view of RoboCup2004 site.

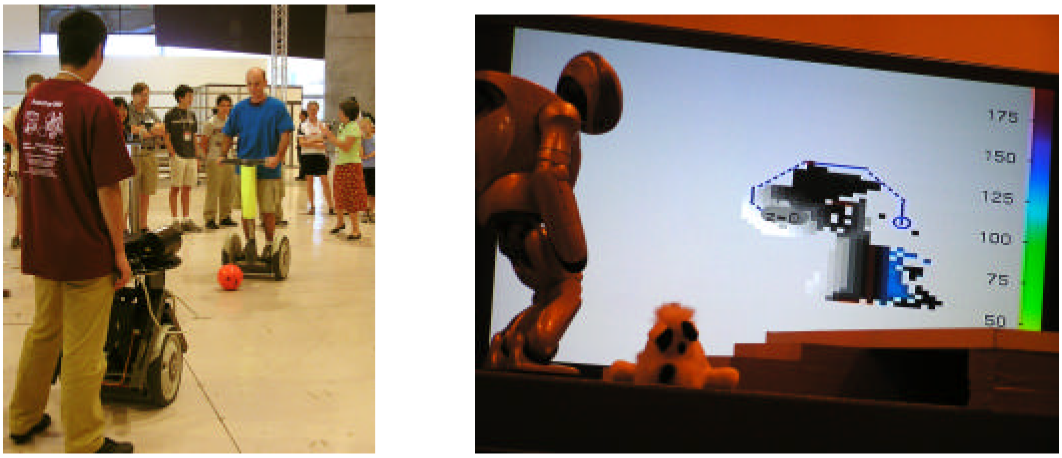

Figure 4: Demonstrations: on the left, SegWay Soccer; on the right, QRIO mapping its environment.

3. Soccer Middle-Size League

The middle-size league (MSL) this year had 34 pre-registered teams, 24 among which were qualified for the official competition. The pre-registered teams were asked to submit a team description paper, a video, and a list of publications. The league technical committee evaluated each of the pre-registered teams based on the submitted data, and teams were ranked. The top 24 teams were qualified.

3.1. Competition

The 24 teams were divided into 4 groups, each of which consisted of 6 teams, for the first round robin stage. Then, the top 4 teams from each group passed to the second round robin. There, 16 teams were divided into 4 groups again, and the top 2 teams from each group passed to the final tournament. WinKIT (Kanazawa Institute of Technology, Japan), Persia (Isfahan University of Technology, Iran), MINHO (University of MINHO, Portugal), FU-Fighters (Freie Universität Berlin, Germany), CoPS-Stuttgart (University of Stuttgart, Germany), Trackies2004 (Osaka University, Japan), EIGEN (Keio University, Japan), and Brainstormers-Tribots (University Osnabrueck/Dortmund, Germany) got through the preliminary round robins. Table 1 shows the result of the competition. Not only omni-vision systems but also omni-directional vehicles using omni-wheels became popular. Furthermore, the vehicles speed is increasing, so the games seem more speedy and vigorous.

Table 1: Results of the MSL Soccer Competition

Rank	***Team (Affiliation)***
1st	EIGEN (Keio University, Japan)
2nd	WinKIT (Kanazawa Institute of Technology, Japan)
3rd	CoPS Stuttgard (University of Stuttgart, Germany)

3.2. Technical Challenges

In order to promote the scientific goals of RoboCup, the technical committee holds a technical challenge competition to show specific scientific and engineering achievements. The middle size league this year had two main technical challenges:

- Ball control and planning and
- Scientific or engineering achievements.

In the ball control and planning challenge, six to eight black obstacles are put at arbitrary positions on the field. The ball is put on the middle of the penalty area line, and a robot inside the same goal. The robot should dribble the ball into the opposite goal within 90seconds, while avoiding all obstacles. The trial is repeated three times with various setups. Team *Persia*, from Isfahan University of Technology, Iran, was the winner this year.

In the scientific or engineering achievements challenge, teams are free to show one significant achievement each, and all the other team leaders together with the TC members judge them. The team *Persia* also won this challenge.

The Clockwork Orange and AllemaniACs (Gönner *et al*, 2005) teams developed real-time color calibration method without human intervention and showed also good performance.

A "cooperative mixed-team play" challenge took also place. In this event, teams demonstrate cooperative mixed-team play between at least two robots from different teams. This year one team consisted of robots almost only from German teams and the other of robots from non-German teams. The match was very enjoyable and the robots showed good collaborative play during the game. Still, it would be interesting to see cooperation among international teams to emerge from this challenge, e.g., by creating standards for communication protocols.

3.3. Research Advances

This year, a considerable number of changes in rules and regulations of the MSL took place. First, the field size was enlarged to 8m x 12m. Flexibility in number of players was added by introducing the area occupied by the whole team as the main criterion for the maximum number of allowed players per team. If the team builds smaller robots, it can have a larger number of robots on the field during a game. The MSL technical committee expects that this rule change will encourage teams to show more cooperative behaviors (e.g., passing a ball to a teammate, coordinated defense, positioning for receiving a pass) of their robots, since the chances that those behaviors are advantageous increase under the situation of a larger number of robots in a non-crowded field. Actually, some robots tried to pass a ball and receive it and unfortunately sometimes failed because of the lack of precise ball handling.

Also, to track a ball on a large field is becoming a hard problem for vision systems, since the ball in the image of omni-vision systems is very small if the ball is far from the robots. In some situations, robots were not able to detect a ball located far from them, resulting in the game becoming stuck. We expect more efficient vision and cooperative distributed perception systems to solve this problem in the near future.

A referee box system was introduced for conveying referee decisions to robot players without intervention of operators from the teams. In the small size and 4-legged leagues, this technology has been introduced already, and it successfully enhances the autonomy of the game. Unfortunately, the development of the referee box for the middle size league was delayed; so only start/stop commands were implemented in the 2004 referee box, not yet suitable to be used for throw-in/goal-kick procedures, whose introduction is postponed to next year. Figure 5 shows a snapshot of a MSL game.

Figure 5: A Middle Size League match.

4. Soccer 4-Legged League

The Soccer Four-Legged Robot League (4-LL) is the only RoboCup league in which a standardized robot platform is used, namely the *Sony specially-programmed AIBO*, a four-legged robot with 20 degrees of freedom and a color camera as its main sensor. Therefore, teams in this league concentrate on developing control software while completely ignoring questions of robot construction. However, using a common platform, they gain the ability to exchange code between the different teams, to run the code of other teams on their own robots in practice matches at home, and to use one of the most powerful mobile robotic systems available today that is — being a mass product — relatively cheap. In addition, a standardized platform lets the teams focus on the development of efficient algorithms rather than on tricky mechanical constructions as in other leagues. For instance, teams are forced to solve the problem of selective directed vision, because the AIBO has a single camera in the front of its head that can be moved in three degrees of freedom. This poses many interesting research questions, namely how to decide where to look at (active vision), how to self-localize, how to model the objects in the world that are currently not visible, and how to sense and model the world using multiple communicating robots.

4.1. Competition

In 2004, three of the 23 teams that participated in the competition were national teams, i.e., they consisted of members from more than a single city, which is, although not impossible, hard to realize in leagues with self-built robots. In addition, the two new teams in the competition, the *Hamburg DogBots* and the *Dutch Aibo Team*, based their software on the previous year's code of another team, the *GermanTeam*, which gave them a good start (the *Hamburg DogBots* reached the quarter final). However, 2004 also was the competition with the largest diversity in robot platforms, because Sony released a new AIBO in summer 2003, the ERS-7, which is significantly stronger than its predecessor, the ERS-210. In fact, only a single team using the old model reached the quarterfinal.

The eight best teams reached the quarter final with impressive goal differences, the average of which was 31:4. However, even under these strong teams, the two finalists *UTS Unleashed!* (University of Technology, Sydney, Australia) and the *GermanTeam* (Humboldt Universität Berlin, Universität Bremen, Technische Universität Darmstadt, Universität Dortmund, Germany) won their quarter and semi finals with rather high scores (*UTS Unleashed!* 9:1, 5:1, *GermanTeam* 9:0, 9:2). In a close match, the *GermanTeam* won the final against *UTS Unleashed!* 5:3. The abilities of the robots of these two teams were quite different. While *UTS Unleashed!* had stronger single players that won many duels, the *GermanTeam* had better positioning of the robots and a very strong goalkeeper. The three first places of the 4LL Soccer Competition are shown in Table 2.

Table 2: Top three teams in the 4LL Soccer Competition

Rank	***Team (Affiliation)***
1st	GermanTeam (HU Berlin, U Bremen, TU Darmstadt, U Dortmund, Germany)
2nd	UTS Unleashed! (University of Technology, Sydney, Australia)
3rd	NUBots (University of Newcastle, Australia)

4.2. Technical Challenges

Traditionally, there are three technical challenges in the Four-Legged League. For the first time in 2004, one of them was an *Open Challenge*, in which teams were encouraged to demonstrate parts of their research, and the demonstrations were assessed by the other teams. The demonstrations included robot collaboration, ball handling, object recognition, and tracking by vision or sound, etc. The *Open Challenge* was won by the *GermanTeam*, demonstrating four robots moving a large wagon. The four robots were controlled by the fifth robot on top of the wagon to score a goal with a *Mid-Size-League* ball (cf. Figure 6). The second challenge was the *Almost SLAM Challenge*, in which a robot had to learn some unknown colored landmarks in the surroundings to later on perform metric self-localization using them. It was won by *rUNSWift* (University of New South Wales, Australia), who reached four of five possible positions within a range of less than 50 cm. The third challenge was the *Variable Lighting Challenge*, in which a robot had to score as many goals as possible within three minutes while the lighting conditions are changing. This seemed to be too tough, because even the winner *ASURA* (Kyushu Institute of Technology, Japan) only scored two goals. The overall winner of the technical challenges was *UTS Unleashed!*.

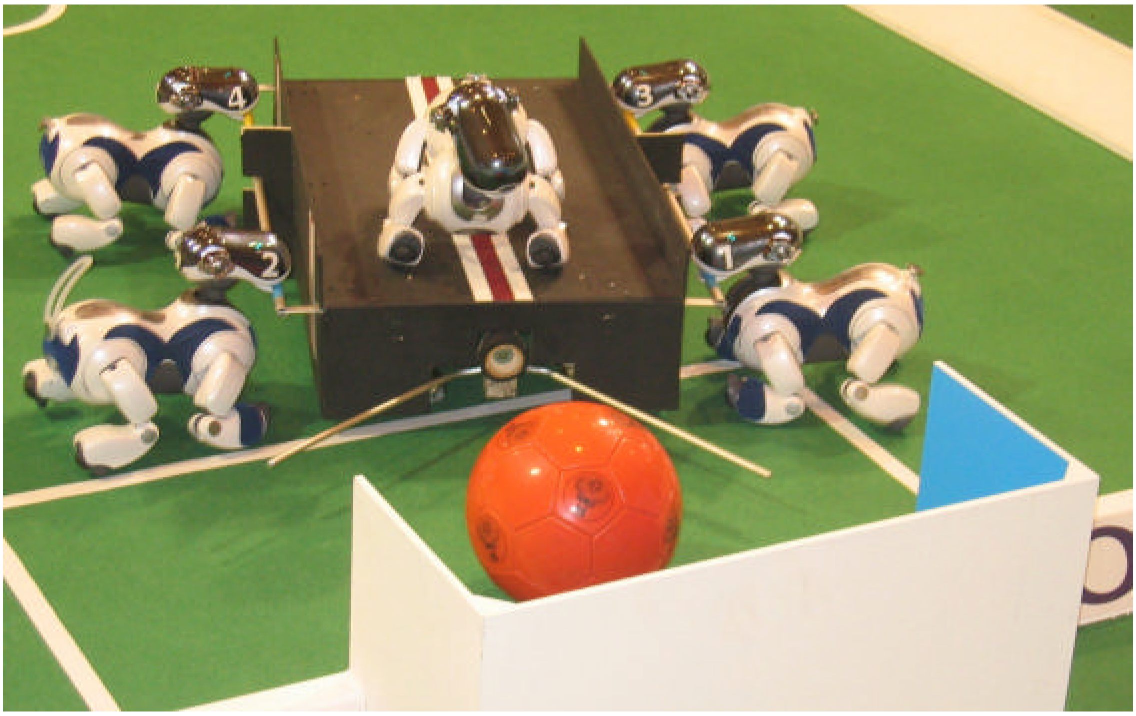

Figure 6: 4-LL Open Challenge: four robots controlled by a fifth one score a goal

4.3. Research Advances

As every year, some of the rules were modified to increase the challenges for the teams. The major change was the replacement of the *Obstruction* rule by the *Field Player Pushing* rule, i.e., instead of removing passive robots that block the way to the ball for others without going for the ball, this time robots that pushed against other robots were penalized if they were not the closest robot to the ball of their team. This rule change forced the implementation of obstacle avoidance, and it was the consequence of the *Obstacle Avoidance Challenge* that was performed in 2003, working quite well (Hoffmann *et al.* 2005). This improved the games a lot, because there was significantly less crowding of robots around the ball. For instance, it was not necessary to call *Field Player Pushing* in the final. Another rule change was the removal of the two center beacons, which made self-localization more difficult, especially for the goalie. The idea behind this change was to force teams to work on self-localization using the field lines (Seysener *et al.* 2005), which had already been demonstrated by the GermanTeam at RoboCup 2003 (Röfer and Jüngel 2004). This team significantly benefited from their ability at RoboCup 2004, because their goalie was localized very well and the field players were only rarely called for entering their own penalty area (which is not allowed). For instance, in the final, the robots of *UTS Unleashed!* were penalized nine times for being an *Illegal Defender*, while the robots of the *GermanTeam* never committed this infraction. Another rule change that required self-localization was *full autonomy*, i.e. the robots should walk to their kickoff positions on their own. This ability was still not implemented by all teams because the penalty for ignoring it was rather low.

Besides improving self-localization, there was quite a rush on doing research on gait optimization in this league (Kim and Uther 2003, Quinland et al. 2003, Kohl and Stone 2004, Röfer 2005). As a result, the games were significantly faster. For instance in RoboCup 2003 the fastest gait was 27 cm/s, in 2004 it was 41 cm/s, using the new robots. Another observation was that now many teams were able to estimate the speed of the ball to perform blocking moves, either using extended Kalman filters or Rao-Blackwellised particle filters (Kwok and Fox 2005). In addition, 3-D simulations are becoming a common tool in this league, even physical ones (Montealegre and Ruiz-del-Solar 2005).

5. Soccer Small-Size League

In the Small Size League (SSL), teams of five robots each play against each other on a green carpet field. The robots are restricted to a height of 15cm and a diameter of 18cm. Color cameras mounted over the field allow external host computer to see the whole playing field and decide the action of each player robot. Commands are relayed to the robots via radio-frequency means. Color markers on top of the robots are used to identify individual robots. The official ball is an orange golf ball.

5.1. Competition

A total of 21 teams from 11 countries competed in the RoboCup2004 SSL competition. Two of the teams are joint teams comprising members from different countries. In the preliminary round, teams in 4 groups played in a round robin fashion. The top 2 teams from each group proceeded to the playoff stage. The winners of the competitions are listed in Table 3.

Table 3: Top three teams in the SSL Soccer Competition

Rank	*Team (Affiliation)*
1st	FU Fighters Freie (Universität Berlin, Germany)
2nd	Roboroos (University of Queensland, Australia)
3rd	LuckyStar (Ngee Ann Polytechnic, Singapore)

5.2. Research

There were three major changes to the SSL this year:

1) No special lighting was provided for the playing field. Teams had to cope with the dim and uneven lighting at the RoboCup venue. Many teams had a hard time calibrating their global vision system for the bad lighting condition. Many were surprised by the dark shadow cast by the camera mounting structure and were not prepared for it (cf. Figure 7). In the end, all teams were able to play, but vision related problems were noticeable during many of the matches. Due to the excellent lighting condition of past years, many teams were able to make do with simple vision algorithms and vision research was generally neglected in SSL. We will probably see more teams working on improving their vision system so that performance is on par with having uniform lighting.
2) The new playing field of 4x5.5m was slightly more than twice the area of the previous field. The intention was to open up the space so as to encourage more passing during the game. There was also a new rule restriction on dribbling, so as to

discourage individualistic style of play. Some of the teams were observed to make a few purposeful passes during matches. And some of these passes did result in a big advantage for the team. Hopefully, next year, more passes and more sophisticated passes will happen.

3) The field boundary walls were removed so as to move towards a more human football like environment. Effective match time was reduced to less than 40% for most matches as the ball left the field too readily. One of the major challenges for teams in the league will be to play a more controlled game so as to keep the ball in play more often. This will require better ball control, more precise shooting and passing and more intelligent form of play.

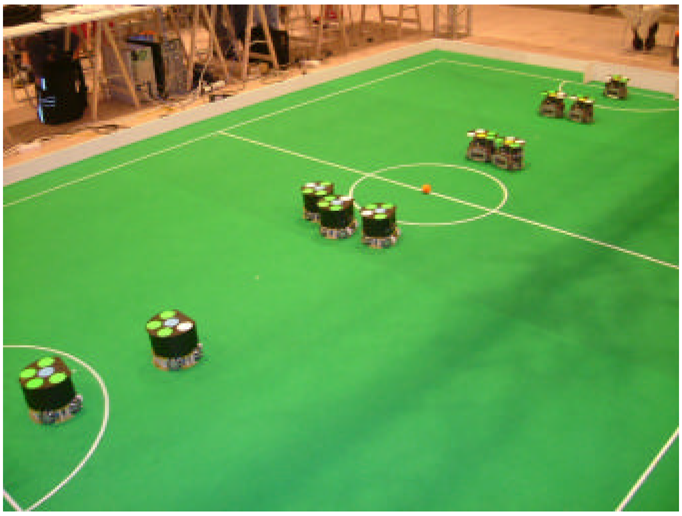

Figure 7: Kick-off during a SSL match. Note the dark shadow cast by the camera mounting structure on the right side of field, which posed a big problem to many teams' vision system

Most teams had similar mobile base, which is basically a four-wheel drive omni-direction system introduced by Cornell in 2002. The four-wheel design affords good traction capability and many team robots were able to move at speed above 1.5 m/s with high acceleration and deceleration. A few teams introduced a "chip kick" mechanism, which allows a robot to kick the ball over the opponent robots. Currently, the "chip kicks" lack accuracy in distance and direction control, which resulted in the ball going out of field most of the time. Most notably, the FU Fighters robot is able to do both chip kick and normal straight kick powerfully. This is achieved by having two different kicking mechanisms, squeezed ingeniously into the tight body space of the robot. Coupled with their high speed and precise robot control, they won all their matches.

Despite the major rule changes introduced this year, teams were able to cope with the rules and compete well. Most teams were not able to take advantage of the increased field size as they were tied up with adapting to the new rules. With the rules expected to undergo only minor revision next year, teams will have more time to work on new team strategies that take advantage of the bigger field space.

6. Soccer Humanoid League

The Humanoid League (HL) made its debut at RoboCup 2002 and has been one of the most interesting highlights of the RoboCup since then. The challenges in this league are different from other leagues. Unlike others, the main challenge in the HL is that of maintaining the dynamic stability of robots while the robots are walking, running, kicking and performing other tasks. Furthermore, the perception and biped locomotion of humanoid soccer robots have to be coordinated and be robust enough to deal with challenges from other players. The HL is expected to be the main thrust for RoboCuppers to fulfill their dream of developing a team of fully autonomous humanoid robots that can win against the human world soccer champion team by the year 2050 (Kitano *et al*, 1997).

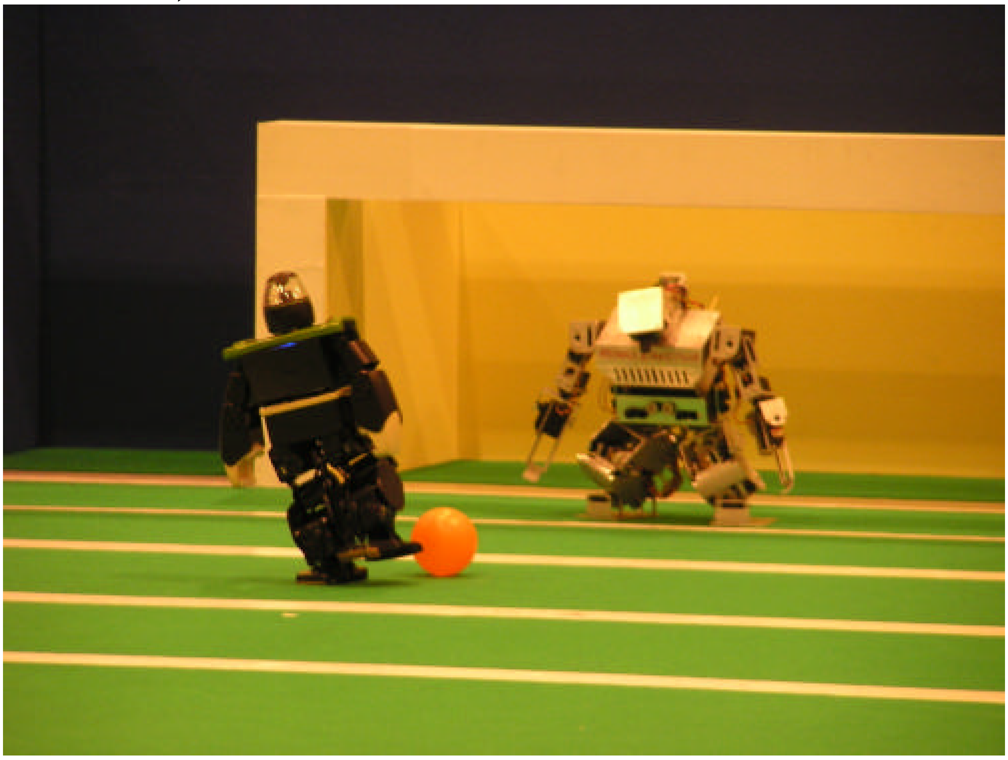

Figure 8: Penalty kick by Team Osaka's ViSion robot.

The participation in the HL at RoboCup 2004 was encouraging. A significant increase in the number of countries and number of teams had indicated their interest to take part in the competition. For the first time, a qualifying selection had to be made. In the end, a total of 16 teams from 6 countries were selected to take part in the HL of RoboCup 2004. This year, for the first time, there were participating teams from Iran and Germany.

6.1. Competition

The competition consisted of three non-game disciplines (Zhou, 2004), namely humanoid walk, penalty kick and free style. In additional to the above traditional competitions, technical challenges, including obstacle walk, balancing-on-a-slope walk and ball passing, were conducted for the first time at RoboCup 2004.

A number of excellent robots were presented in the competition. After some good and tightly competed matches, Team Osaka engaged as the overall winner (cf. Figure 8), and received the Best Humanoid Award in addition to the Technical Challenge Award. In the different categories, the winners were:

- **Humanoid Walk**: Team Osaka (Systec Akazawa Co., Japan)
- **Humanoid Free Style**: Team Osaka (Systec Akazawa Co., Japan)
- **Humanoid Penalty Kick H80**: Senchans (Osaka University, Japan)
- **Humanoid Penalty Kick H40**: Team Osaka (Systec Akazawa Co., Japan)

6.2. Research Advances

2004 is the third year the HL competition is running. Tremendous improvements were witnessed in numerous aspects of the participating humanoid robots. In the following, we look at some of the features of humanoid soccer robots from different fields of technology.

- **Mechanical structure and materials**: The mechanical structure of the robots comes with better design, lighter body (used innovative material like carbon alloy) and supports a more ergonomic look.
- **Walk**: Ability to walk on uneven terrain was observed in the balancing walk on a slope - a technical challenge conducted for the first time this year. Tremendous improvement in the walking speed of the humanoid robots was also observed. The humanoids should start from one end of the field, walk to the other end, turn round at the marker placed in the middle of the area, and return to the initial position. The distance between the initial position and the marker was 5 times the height of the humanoid. The humanoid walk competition recorded the best time of 50 seconds this year, a far cry from the best time of 3 minutes 29 seconds two years ago.
- **Kick**: Striker capability in detecting the ball and changing the direction of kicking in response to the goalkeeper's position were noted in the penalty kick competition this year. Diving capability of the goalkeeper to save the goal, both in the ability to change the diving direction in response to the kicking direction of the striker and the ability to stand up again after diving were observed for the first time this year in the penalty kick competition.
- **Passing**: Ball passing capability was observed in the ball passing technical challenge and the demonstration of ball passing between two robots by the team from Osaka University was particularly impressive.
- **Manipulation**: Whole body coordination was demonstrated by many robots in their ability to stand up from a lying down position and various dancing and upper body movement demonstrations.
- **Power**: Most the robots this year come equipped with internal power supply.
- **Communication**: Several robots this year come with wireless communication capability, either in the form of Bluetooth or wireless LAN. Multimedia integration was also noticed in some robots.
- **Perception**: The introduction of omni-vision systems in a humanoid robot was made by Team Osaka's ViSion robot. It remains disputable whether this vision technology should be introduced to humanoid robotics. Coordination of perception and locomotion was demonstrated this year through the capability of some robots to perform various actions in response to the environment, either in the humanoid walk, penalty kick and technical challenge competitions.

For the next some years dynamic walking is surely the most interesting particular challenge in the humanoid league. The best humanoid robot is still significantly slower than an average human.

Looking back at the HL in 2004, it can be seen that there are some areas in the humanoid robots where improvements are still lacking:

1. Battery technology is still short of expectations. Most robots have to change its internal battery after a brief period of activity.

2. There is still room for improvement in on-board computing.
3. Locomotion of humanoid robot is still way far from perfect. The best humanoid robot is still significantly slower than an average human.
4. Improvements are still needed for versatility in movements, increase in speed of locomotion, implementation of jumping, running movements, etc.
5. Vision and recognition also need to be improved.

Beginning next year, in the penalty kick competition, the ball will no longer be put at a fixed position but rather it will be put in a range of possible locations. This calls for higher perception capability. Of course, most of the robots are still a far cry from being robust. Many of them will still hang and malfunction at times. Safety also remains a problem for most of the robots.

Overall, essential soccer skills were demonstrated in the HL competition this year. Looking to the future, one-against-one and two-against-two soccer games that require humanoid collaboration will be initiated soon.

7. Soccer Simulation League

In the RoboCup Soccer Simulation League, two teams play against each other over a local network. Each participant connects 11 player agents and possibly a coach agent to the server, which simulates the soccer field and distributes the sensorial information to the agents. Most important news in Soccer Simulation League was the introduction of a new simulator, where players are spheres in a three-dimensional environment with a full physical model. A prototype of this new simulator was introduced to the community on the RoboCup 2003 Symposium (Kögler and Obst 2004) and further developed throughout the year between the competitions (cf. Figure 9). The time from the first release of a usable version in January until the qualification deadline in March was enough for already 15 teams to qualify and participate. In addition to the new three-dimensional competition, the “traditional” two-dimensional competition was kept, and 32 teams participated here. For the 2D competition, it was the first time that qualification for participation was held in the so-called Internet League, where participants upload their teams to a server. In Internet League, matches against other teams are scheduled and started automatically. A third competition in Soccer Simulation League was the coach competition with 7 teams. Here, participants have to provide a coach agent that can direct players from its team using a standard coach language. Coaches are evaluated by playing matches with a coachable team against a fixed opponent. Countries with most participants in Soccer Simulation League are Iran, Japan, and Germany.

7.1. Competition

Especially the participants in 3D simulation eagerly expected the first match. It was exciting to see how the teams used the basic agent capabilities of the new simulator for navigating on the field and moving the ball. Agents in the 3D simulation can move in any direction, but because of inertia and delayed effects of the motor commands, methods to approach a moving ball are not straightforward and were handled differently. Despite the short development time, some of the participants managed to not only implement low level skills like intercepting the ball and dribbling, but also team level behavior like passing and cooperative handling of special situations. It seems that experiences made in 2D were transferred to the 3D league, so that some of the matches looked already very advanced.

The team with the best gameplay was “UTUtd 2004” from Iran (Mahmoudian et al. 2004), which ended up being 3rd, after losing unluckily to AT Humboldt from Germany in the semifinal by golden goal (the first team scoring a goal wins). Developers of AT Humboldt (Berger et al. 2004) built their 3D team using the same flexible architecture they already have been using for their 2D teams, so that it was possible for them to improve their performance between the first day and the finals.

Table 4: Top three teams in Soccer Simulation League competitions.

	3D Simulation	***2D Simulation***	***Coach Competition***
1.	Aria (Iran), Amirkabir University of Technology	STEP (Russia), ElectroPult Plant Company	MRL (Iran), Azad University of Qazvin
2.	AT-Humboldt (Germany), Humboldt University Berlin	Brainstormers (Germany), University of Osnabrueck	FC Portugal (Portugal), Universities of Porto and Aveiro
3.	UTUtd 2004 (Iran), University of Tehran	Mersad (Iran), Allameh Helli High School	Caspian (Iran), Iran University of Science and Technology

7.2. Research Advances

In the 2D competition, the approaches for the teams vary a lot, and it seems that there is generally no unique best method to implement a successful team. As all top teams in this competition are all long time participants of RoboCup Soccer Simulation League, the level of play seems so much advanced that it is generally difficult for new teams to catch up.

The overall level of play increased impressively from RoboCup 2003 to RoboCup 2004, even though probably none of the participants thought that this was possible to that degree. From ranking 8th in 2003, the team “STEP” from Russia became winner of this years' competition. Their approach to improve the coordination between single agents is a kind of playbook, which describes scenarios and conditions in a rule-based language (Stankevich et al. 2004). For the fifth time since 2000, the team “Brainstormers” from Germany managed to get among the top three teams of the competition. This team is known for using reinforcement learning for different behaviors (Riedmiller et al. 2004). The number of behaviors has been extended each year, so that now their players are using learned behavior whenever they move in the opponent half. “Brainstormers” success with reinforcement learning over the years has inspired a number of teams to also use it for single skills of players in combination with other techniques.

Besides reinforcement learning, behaviors are often hand-coded in various teams. In this case, there are different approaches for selecting the appropriate behavior: the spectrum ranges from evolutionary methods (Nakashima et al., 2004) to rule-based systems. An interesting area of research that is tackled by some of the participants is to create architectures for agents in a team, and there is also research in methods to aid the construction of cooperative agents. As the data the agents in the 2D competition get are noisy and incomplete, methods to maintain a correct and complete world model are also interesting. For example, a couple of participants are using particle filters (Fox et al., 2001) to improve the self-localization of their players.

Figure 9: RoboCup Soccer Simulation League: 3D simulator (Picture by Achim Rettinger).

The long discussed step into Simulation League 3D has been taken. Some aspects of the 2D simulator are still missing in the new 3D simulator, for instance there is no possibility for agents to communicate with each other. Once the 3D simulator supports this, there are not many reasons for the community to keep the 2D simulation league as a competition. However, with the existing code bases for teams and the tools created over the years, the 2D simulator will stay an excellent testbed for multi-agent research for quite a while. A long term challenge for the 3D simulator will be to keep the balance between providing an abstraction of the hardware leagues and being an useful tool for the creation of software smart enough to face the challenge of successfully controlling humanoid robots in a soccer team. A challenge for the community will be to keep the format of the competition so that the results are meaningful and new participants can build upon the research from previous years.

8. Rescue Real Robot League

The goal of the RoboCupRescue Robot League competition is to increase awareness of the challenges involved in urban search and rescue (USAR) applications, provide objective evaluation of robotic implementations in representative environments, and promote collaboration between researchers. The competition requires robots to demonstrate capabilities in mobility, sensory perception, planning, mapping, and practical operator interfaces, while searching for simulated victims in unstructured environments. The arenas constructed to host the competitions are based on the *Reference Test Arenas for Urban Search and Rescue Robots* developed by the U.S. National Institute of Standards and Technology (NIST) (Jacoff et. al. 2003). They form a continuum of challenges for the robots including physical obstacles (variable flooring, overturned furniture, and problematic rubble) to disrupt mobility, sensory obstacles to confuse robot sensors and perception algorithms, and a maze of walls, doors, and elevated floors to challenge robot navigation and mapping capabilities (cf. Figure 10). All combined, these elements encourage development of innovative platforms, robust sensory fusion algorithms, and intuitive operator interfaces to reliably negotiate the arenas and locate victims.

Figure 10: RoboCupRescue 2004 Robot League Arenas

The objective for each robot in the competition is to find simulated victims in unknown locations within the arenas. Each simulated victim is a clothed mannequin emitting body heat and other signs of life including motion (shifting or waving), sound (moaning, yelling, or tapping), and carbon dioxide to simulate breathing. They are placed in specific rescue situations (surface, lightly trapped, void, or entombed) and distributed throughout the arenas in roughly the same percentages found in actual earthquake statistics.

The competition rules and scoring metric focus on the basic USAR tasks of identifying live victims, assessing their condition based on perceived signs of life, determining accurate victim locations, and producing human readable maps to enable victim extraction by rescue workers – all without damaging the environment or making false positive identifications.

This year's team qualification process included over forty team description papers and regional open competitions in both the USA and Japan. The league chairs and technical committee selected twenty teams from eight countries to compete, almost doubling last year's participation. Overall, the league demonstrated a notable variety of robotic technologies for searching complex environments, finding simulated victims, and localizing and mapping their locations. The overall quality of the implementations was clearly improved from last year's teams. Particularly innovative approaches, documented in team description papers (which can be downloaded from http://robotarenas.nist.gov/competitions.htm), provided break-through improvements in several key elements and will clearly be emulated in the future.

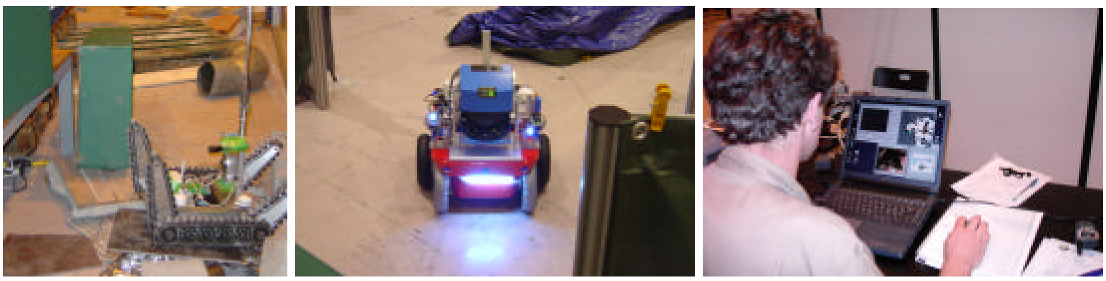

Figure 11: RoboCupRescue Robot League awardees in action. From left to right: Toin Pelicans; Kurt 3D; ALCOR.

After several rounds of competitive missions, the scoring metric produced three awardees that demonstrated best-in-class approaches in each of three critical capabilities (cf. Figure 11):
1st Place: The Toin Pelicans team, from the University of Toin, Japan, were mainly recognized for their very capable, multi-tracked mobility platform with independent front and rear flippers. Their innovative camera perspective mounted above and behind the robot – so as to contain the entire robot and surrounding area within the field of view – provided superior remote situational awareness for the operator, and allowed precise configuration management of the robot's tracks to facilitate mobility over large obstacles and within confined spaces. Other teams used similar overview cameras, some on flexible rods, also to good effect.

2nd Place: The Kurt3D team, from the Fraunhofer Institute for Artificial Intelligence Systems, Germany, were mainly recognized for their application of state-of-the-art 3D mapping techniques using a tilting line scan ladar within the complex environment of the arenas.

3rd Place: The ALCOR team, from the University of Rome "La Sapienza," Italy, was mainly recognized for their intelligent perception algorithms for victim identification and mapping.

The league's goal was clearly achieved this year by evaluating state-of-the-art technologies, methods, and algorithms applied to search and rescue robots through objective testing in relevant environments, statistically significant repetitions, and comprehensive data collection. Although several teams demonstrated clear advances in certain key capabilities, more collaboration between teams (and between countries) is needed to produce ultimately effective systems for deployment. When viewed as a stepping-stone between the laboratory and the real world, this competition provided an important opportunity to foster such collaborative efforts and further raised expectations for next year's implementations. It also enticed many new researchers into the USAR domain.

This year's competition also featured a focused workshop on Simulation and Robotics to Mitigate Earthquake Disaster, which took place on the team set-up day prior to the start of competition and then re-convened after the final awards ceremony. It assembled 15 papers and over 50 people from the existing RoboCupRescue leagues – the simulation league and the real robot league – and others from the autonomous soccer leagues interested in getting involved in this new domain. Two new league initiatives were introduced:

1. a high fidelity arena/robot simulation environment to provide a development tool for robot programming in realistic rescue situations, and
2. a common robot platform for teams to use if they choose based on a standard kit of components, modular control architecture, and support for the simulation mentioned above.

Both of these initiatives received encouraging support and will become integrated into the league during the first RoboCupRescue "camp" hosted this fall at a fire-rescue training facility in Rome, Italy, which houses last year's RoboCupRescue arenas. This five day event will provide an educational opportunity for researchers to learn about the state-of-the-art for search robots and a chance to develop modular solutions for five distinct elements: a) mobility behaviors, b) perception for victim identification, c) localization and mapping in complex environments, d) operator interfaces, and e) simulation tools. The results of this event be available to all teams interested in this domain and will be demonstrated during the 2005 competition in Osaka, Japan.

9. Rescue Simulation League

In the RoboCup2004 Rescue Simulation League there were two competitions. In addition to the usual agent competition, the infrastructure competition was established this year to promote research. The competition results are given in Table 5. A brief description of the competitions is given below.

Table 5. Rescue Simulation League Competition Results

Agent Competition	1. ResQ Freiburg, University of Freiburg, Germany 2. DAMAS-Rescue, Laval University, Canada 3. Caspian, Iran University of Science and Technology, Iran
Infrastructure Competition	ResQ Freiburg, University of Freiburg, Germany
SICE Technical Award	S.O.S., Amirkabir University of Technology, Iran

9.1. Agent Competition

In the agent competition, a team has a certain number of fire fighters, police, and ambulances with centers that coordinate each kind of agent. The bounds on these are determined by the competition rules whereas the actual numbers are determined by the Technical Committee (TC) and announced just before each run. The agents are assumed to be situated in a city in which a simulated earthquake has just happened, as a result of which some buildings have collapsed, some roads have been blocked, some fires have started and some people have been trapped and/or injured under the collapsed buildings. Multiple simulators are used to represent the development of the events and the results of the actions of the agents. The goal of each team is to coordinate and use its agents to minimize human casualties and the damage to the buildings. The rescue domain represents a real multi-agent scenario since most of the encountered problems cannot be solved by a single agent. For example, fire brigades depend on police forces to clear blocked roads in order to reach their target. Similarly, if the fire spreads out in many directions then they can be extinguished more efficiently by using more than one agent. Moreover, the task is challenging due to the limited communication bandwidth, the agents' limited perception and the difficulty of predicting how disasters evolve over time. In the competition, even though the overall disaster situation (the locations of agents, fire ignitions, and the magnitudes of earthquakes) for each run is unknown to the teams, the disaster simulator programs and the global information systems (GIS) map data, except the random maps, are provided in advance. The team performance score is calculated using a formula that is based on the number of victims saved and the area of houses that are not burnt within the allocated time.

For the 2004 agent competition, there were 34 teams who submitted qualification materials. Among these, 20 teams were selected by the TC. Of the 20 qualified teams only 17 teams competed. In addition to the three maps used in previous competitions, namely, Kobe, VC and Foligno, random maps were also used for the first time. The random maps were generated using the *Rescuecore* tool developed by The Black Sheep team. This year, instead of using configuration files prepared by the teams, as was the previous practice, files prepared by TC were used. These were prepared so that as the competition progressed to the later stages the difficulties of the situations were increased appropriately. The preliminaries consisted of two stages. In the first stage, which can be called the traditional competition, the teams competed on six maps with different configurations. The first six teams went to the semifinal. The remaining 11 teams competed in the second stage, which was designed to test the robustness of the teams under varying perception conditions. Here the teams were expected to show only slight changes in performance as the conditions deteriorated. The top two teams that had the best scores went to the semifinals. Thus eight teams competed in the semifinals where four maps were used. In the final, top four teams of the semifinals competed.

The winning team this year was ResQ Freiburg. Their platoon agents have reactive and cooperative behaviors, which can be overridden by deliberative high-level decisions of the center agents. Specially developed prediction modules calculate the instantaneous and long-term effects of the actions for evaluation purposes. For the planning of complex sequences of group actions a new multi-agent planning method for abstract search spaces that are generated by agent-specific clustering methods is used. The agents of DAMAS-Rescue, which was the second team by a small margin, have been developed with a special agent programming language. Their Fire Brigade agents choose the best fire to extinguish based on the knowledge they have learned with a selective perception learning method. The performance of Caspian the third team was also very good.

One of the major problems encountered by the teams was the loss of messages between agents and the simulation system. For the competition of 2005 changes to the simulation environment to solve this problem are being planned.

9.2. Infrastructure Competition

The environment rescue agents act in a large-scale simulation, which is both highly dynamic and only partially observable by a single agent. Real disaster situations can rarely be predicted and, are often not adequately dealt with when they actually occur. Therefore, it is one of the main goals of the RoboCup Rescue Simulation League to develop realistic disaster simulators that allow agents to develop realistic mission plans. Infrastructure competition tests the performance of the simulator components developed by the teams. The awarded team is requested to provide the component for the next year's competition. For this reason teams are expected to accept the open source policy before entering the competition. Teams present their tools in front of all teams during Robocup and ranking is decided with votes from TC members and teams in both agent and infrastructure competitions.

This year only two teams have qualified and only ResQ Freiburg team competed. They presented a 3Dviewer and a Fire Simulator. Both components were voted to be used in 2005 if they are ready on time. The 3D viewer is capable of visualizing the rescue system both online and offline. The fire simulator is based on a realistic physical model of heat development and heat transport in urban fires. Three different ways of heat transport (radiation, convection, direct transport) and the influence of wind can be simulated. The protective effects of spraying water on buildings without fire are also simulated (Nuessle *et. al.*, 2004).

10. RoboCup Junior

RoboCup is an extraordinarily long-term research initiative and its 2050 goal is far beyond the end of the professional careers of its initiators and most currently active researchers. Interesting young students for RoboCup is therefore a very important activity and the task of the educational division of RoboCup - RoboCupJunior.

Figure 12: View of the RoboCupJunior area.

The idea of RoboCupJunior was pioneered by Lund and Pagliarini (Lund and Pagliarini 1999). They developed a version of robot soccer which uses an infrared-emitting ball and a field covered with a grayscale floor. This setup simplified the tasks of detecting the ball and localizing on the field such that robots built from widely available robot construction kits could successfully play the soccer game. In 2000 and 2001, respectively, two additional challenges were introduced, where kids build and program robots performing on a stage or executing search and rescue tasks.

The use of robotics and robotic technologies in an educational setting has proven to be a very effective way of raising interest in science and technology among students. As research on the learning effects of preparing and participating in RoboCupJunior has shown (Sklar, Eguchi and Johnson 2003), students especially improve their individual and social skills (building self-confidence, developing a goal-oriented, systematic work style, improving their presentation and communication abilities, exercising teamwork, resolving conflicts among team members). RoboCupJunior has spread in more than 20 countries around the world. We estimate that this year more than 2000 teams world-wide adopted the RoboCupJunior challenges and prepared for participation in RoboCup in local, regional, or national competitions. The largest RoboCupJunior communities are China (~1000 teams), Australia (~500 teams), Germany, Japan, and Portugal (over 100 teams each).

In 2004, RoboCupJunior organized its fifth international championships (cf. **Figure 12**). Because of the large number of potential participants, teams in many countries had to qualify for the international championships in national team selection events, in order to

bring down the number of participants to some manageable number. Nevertheless, with 163 highly competitive teams from 17 countries, 677 participants, and about 300 robots, RoboCupJunior enjoyed a 120% increase in the number of teams and 162% increase in the number of participants and celebrated its highest level of participation ever.
The Lisbon RoboCupJunior event featured competitions in eight leagues, covering four different challenges - RoboDance, RoboRescue, RoboSoccer 1-on-1, and RoboSoccer 2-on-2 - and in each challenge two age groups - Primary for students aged under 15, and Secondary for students 15 and elder. Due to the limited space available for the RoboCupJunior team area, a different and longer overall schedule was adopted this year. The event duration was five days. The first day was reserved for team registration and a series of meetings, where we instructed referees, coaches, and participants about the latest version of the rules to ensure consistent refereeing and a smooth tournament. Three days were reserved for preliminary rounds. Scheduling ensured that each team had all its games on a single day. In all leagues, teams had to have their robots checked for compatibility with the rules prior to participating in any game or event. Furthermore, at least the teams qualifying for the playoffs were interviewed in order to scrutinize their ability to explain their robot designs and programs. On the other two days, teams were encouraged to watch and learn more about the senior RoboCup leagues, and to visit a few of the many Lisbon sights to learn about Portuguese culture. The event culminated on its last day, where we had all playoff games, finals, the RoboCupJunior Award Ceremony, and a marvelous and remarkable Junior Party at the Lisbon Oceanarium.

Table 6 summarizes a few statistics on the 2004 RoboCupJunior event. With over 400 dances, runs, or soccer games overall and about 100 every day, the event had a dense schedule and plenty of activity to watch for spectators. Remarkable is the almost five-fold increase in participation of female students, which was up to 22% of overall participants (last year 15%).

Table 6: RoboCup Junior Statistics on Participation and Events

RoboDance	**#teams**	**#stud**	**#fem**	**% fem**	**#dances**
Primary	20	96	49	51	29
Secondary	22	98	30	31	29
RoboRescue	**#teams**	**#stud**	**#fem**	**% fem**	**#runs**
Primary	20	74	16	22	58
Secondary	18	58	11	19	54
RoboSoccer	**#teams**	**#stud**	**#fem**	**% fem**	**#matches**
1-on-1 Primary	18	73	10	14	53
1-on-1 Secondary	16	55	5	9	43
2-on-2 Primary	19	83	13	15	59
2-on-2 Secondary	30	140	12	9	76
Total	**163**	**677**	**146**	**22**	**401**

10.1. RoboCupJunior Rescue

The RoboRescue challenge was designed to be an entry-level challenge students can manage even after a few weeks of work with robots. The challenge is performed in an environment mimicking an urban search and rescue site. Robots have to follow a curved path, marked by a black line, through several rooms with obstacles and varying lighting conditions in it. On their path, they must avoid falling off while mastering a steep slope to the final room. The task is to find two kinds of victims on the path, marked by green and silver icons. Points are awarded for successful navigation of rooms and for detecting and signaling victims, and the time for executing the task is recorded when it is completed. This year, RoboRescue saw a tremendously increased interest with 20 and 18 teams in Primary and Secondary, respectively. With around 20%, female participation is almost at the overall average. On each day, about one third of the teams competed and had to perform two runs through the environment. The best three teams advanced to the finals, where 9 teams competed in each age group. Somewhat to our surprise, the vast majority of teams demonstrated perfect runs and quickly navigated through the environment while finding and signaling all victims, so that the timing was the decisive factor for making it to the finals and winning.

Table 7: The list of RoboCupJunior award winners by category

RoboDance Primary		
1	Coronation Quebec 1	Canada
2	The Rock	Germany
3	Peace of the World	Japan
RoboDance Secondary		
1	Kao Yip Dancing Team	China
2	Mokas Team	Portugal
3	Gipsies	Israel
RoboRescue Primary		
1	Chongqing Nanan Shanh	China
2	Dragon Rescue 100%	Japan
3	Chongqing Nanan Yifen	China
RoboRescue Secondary		
1	Dunks Team Revolution	Portugal
2	Ren Min	China
3	Across	USA
RoboSoccer 1-on-1 Primary		
1	Shanghai Road of Tianjin	China
2	Shenzhen Haitao	China
3	Wuhan Yucai	China
RoboSoccer 1-on-1 Secondary		
1	Liuzhou Kejiguang	China
2	I Vendicatori	Italy
3	TianJin Xin Hua	China
RoboSoccer 2-on-2 Primary		
1	NYPSTC1	Singapore
2	Ultimate	Japan
3	Red and Blue	South Korea
RoboSoccer 2-on-2 Secondary		
1	Kao Yip 1	China
2	Espandana Juniors	Iran
3	Kitakyushu A.I.	Japan

10.2. RoboCupJunior Soccer

The RoboSoccer leagues play soccer on a table that is covered by a large grayscale floor and surrounded by a black wall. The only difference is that the 1-on-1 field is smaller. Goals can be detected by their walls colored gray, and the well-known infrared-emitting ball is used for play. With 83 teams, more than half of all teams, and more than the total of last year, participated in RoboSoccer. For the first time, we had two teams competing in Secondary 2-on-2 where teams were based on international cooperation between schools in Germany, Portugal, and the U.K. Participation of female students is below average in this challenge, particularly in the Secondary leagues. Although a detailled statistical analysis is not available, registration records indicate that this is probably related to the different levels of acceptance of soccer as a "girl's sport" in various countries. (Well accepted in Americas and Asia, less common in Europe.) The distribution of teams across leagues was more even this year, which is most likely due to moving the age limit for Primary leagues from 12 to 14. On four days of tough competition, participants, coaches, and referees went through 231 games which produced an average of 15 goals per match and 3497 goals overall. Match results like 23:22 and 36:19 meant plenty of cheers, as teams celebrated every single goal, and made the RoboCupJunior area a beehive of activity. Even seasoned RoboCupJunior organizers were stunned by sophisticated robots and the spectacular level of play the teams demonstrated across all of the four Junior soccer leagues.

10.3. RoboCupJunior Dance

The RoboDance challenge asks students to create some kind of stage performance, which involves robots. Students may engage themselves as part of the performance, or give a narrative to the audience while the robots perform on stage. There is a two-minute time limit for the performance, and international judge committees assess the performance in seven categories and give points on scale from 0 to 10. RoboDance is without doubt the RoboCupJunior activity allowing most flexibility in the design and programming of the robots, and challenges students' inspiration and creativity. Every year one is again surprised and delighted by the creative designs and the audience loves to watch the carefully choreographed performances. This year, we had 42 teams with 194 participants. Female participation in this league is well above average, and has reached 51% and 31% of participants in Primary and Secondary respectively. In both RoboDance leagues, teams were assigned to one of three groups. All teams of the same group performed on stage on one of the three days of preliminaries, and the best three teams advanced to finals of that league. The two rounds of dance performances on finals day showed really spectacular performances, giving the judges a very hard time to select the best teams, and drew a large audience.

The award winners of this year's competition are listed by league in Table 7. Detailed results of the RoboDance, RoboRescue, and RoboSoccer competitions can be found online at http://www.robocup2004.pt/scoresAndStandings/results-RCJ/.

10.4. RoboCupJunior Future Challenges

Although the event was significantly larger and longer this year, it ran quite smoothly thanks to the help of many committed teachers, team coaches, parents, and local volunteers, who refereed all events and contributed wherever and whenever help was needed. However, the still increasing interest in RoboCupJunior raises issues about how it should evolve in the future. These issues were discussed in meetings with the national representatives of RoboCupJunior and the technical committees for the leagues. In RoboSoccer, getting rid of the grayscale floor, which has been difficult to produce at reasonable prices in satisfying quality such that sensors of all robot kits used can get good readings, would significantly ease work in schools as well as organization of tournaments. It seems that a majority of teams is not using the grayscale any more and relies on magnetic orientation sensors available for most kits. Organizationally, we would like to stimulate exchange and cooperation between teams from different countries. A different tournament format has been suggested and will most likely be applied in the future. In RoboDance, some teams used a very large stage area or expected a particular kind of floor. Rule changes imposing some reasonable limit on available stage area and providing specifications of floor properties are most likely. In order to stimulate cooperation between teams, we may encourage teams to build ad hoc cooperations and demonstrate their joint team performances to the audience on the last day. In RoboRescue, we want to carefully increase the complexity and difficulty of the rescue arena with the help of experts from the senior rescue leagues.

11. Wireless communications

One major drawback is the strong problems still experienced across all the real robot leagues with wireless communications. A study made during the event showed that most of the trouble comes from two main factors:

? The 3-channel separation used for the IEEE 802.11b/g standards is not enough in practice. In fact, the probes installed in several hall sites detected a signal-to-noise ratio always lower than 40% in all 14 channels, resulting in large number of *frame losses* and *frame retries*.

? The whole wireless channel spectrum was saturated, most probably by other participants who did not even know their laptops had wireless communications active, but also by the public, media devices, mobile phones, etc. The number of violation events (e.g., one team attempting to use the access point of another field or league) per hour was extremely high, especially in the first days and during the event hours.

The wireless communications problem resembles the initial belief of most RoboCup participants and promoters that using colors to distinguish objects would help overcoming perception problems and dive in quickly into other topics of research concerning cooperation and coordination among robots. Reality has shown that color segmentation in real situations is not a solved problem. Similarly, wireless communications are used by most teams in real robot leagues to “simplify” cooperation and coordination through the usage of explicit communications. However, the actual experience forced teams again to face the hard troubles posed by reality: one must reduce (or even avoid) explicit communications, and be robust to their failures. This opens new research avenues, e.g., on implicit communication, robust communication protocols for robots acting in dynamic adversarial environments.

12. Conclusions

Overall, RoboCup2004 was a successful event from a scientific standpoint. The main technical challenge of holding the competitions under a reduced artificial light of the exhibition hall, instead of having special illumination per field as in the past, was overcome by most teams without significant problems, thus showing the evolution on perception robustness within the RoboCup community. Another noticeable improvement is the increase in teamwork across most real robot soccer leagues, from passes to dynamic behavior switching, including formation control and cooperative localization. Even in the humanoid league a pass between biped robots was demonstrated by one of the teams.

On the educational side, RoboCup Junior was a tremendous success, despite the increased organizational difficulties brought by the fact that the number of participants almost doubled that of 2003. The number of juniors involved tends to keep increasing, and so the hopes that RoboCup is seriously contributing to grow a new large generation of youngsters eager to learn science and technology.

The next RoboCup will take place in Osaka, Japan, in July 2005.

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