RoboCup 2003: New Scientific and Technical Advancements

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Abstract

This paper reports on the RoboCup-2003 event. RoboCup is no longer just the Soccer World Cup for autonomous robots, but has evolved to become a coordinated initiative encompassing four different robotics events: Soccer, Rescue, Junior (focused on education) and a Scientific Symposium. RoboCup-2003 took place from the 2nd to the 11th of July 2003 in Padua (Italy), and it was co-located with other scientific events in the field of AI and Robotics. In this paper, in addition to reporting on the results of the games, we highlight the Robotics and AI technologies exploited by the teams in the different leagues and describe the most meaningful scientific contributions.

I. Introduction

RoboCup is an international scientific initiative that at the moment of writing involves more than 300 research groups active all around the world. As the charter of the International RoboCup Federation states: *"RoboCup is an international research and education initiative. It is an attempt to foster AI and intelligent robotics research by providing a standard problem where wide range of technologies can be integrated and examined [...]"*.

In the early years of RoboCup, this *"standard problem"* was the soccer game. Soccer was chosen because of the many challenging issues a robot must face in order to play the game effectively. For example, it has to react in real time to a highly dynamic environment, to cooperate with teammates, to be able to distinguish between teammates and opponents, and so on. The ultimate goal of RoboCup was formulated as *"building by the year 2050, a team of fully autonomous humanoid robots that shall win a soccer match against the human World Champion under the official regulations of FIFA"* [Kitano 99]. We do not promise that this goal will be reached by 2050, but the RoboCup initiative has already produced the result of creating interest and disseminating knowledge about Artificial Intelligence and Robotics, growing from a small meeting for few interested scientists to the biggest robotics event in the world. In fact, today, RoboCup has evolved and the soccer games are just one part of RoboCup activities, which now consist of:

- RoboCup International Competitions and Conferences;
- Technical Conferences (usually co-located with the RoboCup Event);
- RoboCup Challenge Programs (in which challenges are designed to foster the RoboCup Community to be active in different research issues)
- Education Programs for primary, secondary and undergraduate students;
- Infrastructure Development (for example, every year, the training arena built by the Rescue League is kept in the country hosting the RoboCup Event as an open facility for research groups active in rescue robotics).

In the rather short history of RoboCup, the number of participating teams has increased so quickly, Fig. 1 that the organizers now have to put a limit on the number of participating teams in each League. In fact, in recent years, some leagues have introduced a qualification. Nevertheless, the number of teams registered in the competitions has steadily increased year after year. In RoboCup-2003, we reached the limit beyond which the organization of the event and the space requirements became unmanageable: we had a total of 1244 registered participants and 243 teams coming from about 30 countries from four of the five Continents.

Every year during the competition and the Symposium, new technologies emerge in one or more leagues. In the ensuing years, these new technologies are consolidated and diffuse also to other leagues and become more and more important in the larger robotic community, outside of RoboCup. An example of the scientific and technical advancements achieved by the RoboCup researchers, "RoboCuppers" as they call themselves, is the fact that some of the fundamental problems addressed by Asada et al. [Asada et al. 1999] in the very early years of the RoboCup competitions are now solved by most of the teams (e.g. real-time perception, reliable hardware platforms, centralized control of a robot team, basic cooperative behavior) and the current team research is focusing on more advanced issues.

One example from past years is omnidirectional vi-

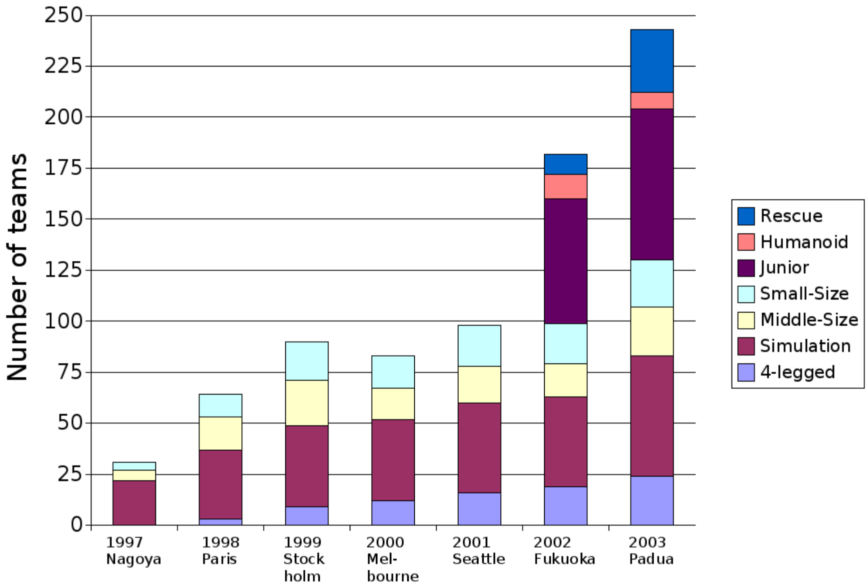

Fig. 1. The number of team participating in the RoboCup Competitions from 1997 to 2003.

Country	Teams	Country	Teams
Japan	42	Taiwan	3
Iran	37	Austria	2
Germany	35	Turkey	2
U.S.A.	18	Chile	1
Australia	15	Finland	1
China	14	Latvia	1
Italy	14	Malaysia	1
Canada	9	Mexico	1
Portugal	9	New Zealand	1
Singapore	9	Norway	1
Netherlands	5	Poland	1
Sweden	5	Romania	1
U.K.	5	Spain	1
Russia	4	Thailand	1
Slovakia	4	**Total**	**243**

TABLE I

The participating teams divided by country of origin

sion that proved to be effective in highly dynamic environments like RoboCup [Suzuki et al. 1998] [Bonarini 2000][Marchese and Sorrenti 2001][Menegatti et al. 2002][Marques and Lima 2000]. This year the promising technologies awarded by the Symposium are:

- recognition and prediction of situations [Miene et al. 2003];
- automatic color camera calibration [Cameron and Barnes 2003];
- information processing that overcomes physical sensor limitations [Quinlan et al. 2003].

Other important scientific contributions that go beyond the individual leagues and have a far-reaching effect in the robotics community outside of RoboCup are described in the Journal Special Issues explicitly on RoboCup [RAS 2001] [AI 1998] or the special issue on general research on Multi-robot Systems that has seen significant contributions from the RoboCup community [IEEE-TRA 2002]. One example is the work reported in [Weigel et al. 2002]. The paper focuses on multi-agent coordination for both action and perception, based on a robust probabilistic tracking technique using laser-range finders and a global perception integration module running in a off-field computer.

A complete overview of the seven-year-long history of RoboCup can be obtained from the collection of Springer books on RoboCup [Kitano 1998][Asada and Kitano 1999][Veloso et al. 2000][Stone et. al 2001] [Birk et al. 2002][Kaminka et al. 2003], and from the annual reviews of the RoboCup Event in this Magazine [Noda et al. 1998][Asada et al. 2000][Coradeschi et al. 2000][Stone et al. 2001][Veloso et al. 2002].

Currently, the competitions of the RoboCup World Cup are divided into three major branches: RoboCup Soccer, RoboCup Rescue and RoboCup Junior. In *RoboCup Soccer*, the research of the teams is focused on the final goal of building robotic soccer players; in *RoboCup Rescue*, the teams apply their research to robotics-assisted urban search and rescue operations; and in *RoboCup Junior*, robotics is seen as an educational vehicle to interest students in computer science and engineering fields at the same time fostering personal growth in areas such as teamwork and

Fig. 2. A view of the RoboCup-2003 fields.

communication skills. In every branch, there are several *"Leagues"* differing in the size and characteristics of the robots used. This paper follows this organization, and each section reports on the status and advancement of the different leagues that participated in 2003 in Padua. RoboCup-2003 was organized by the RoboCup Federation and by PadovaFiere S.p.A. (the Fair of Padua).

II. Symposium

Every year the RoboCup competitions are held together with the International RoboCup Symposium. This year the Symposium was held the 10th and 11th July, directly after the competitions

The Symposium attracted 150 to 200 researchers per day. More than 60 researchers not affiliated with teams in the competitions registered specifically to attend the Symposium. The number of submissions to the RoboCup Symposium is increasing year after year. The RoboCup-2003 Symposium received 125 submissions, an increase of 64% over RoboCup-2002. A total of 31% of the submitted papers were accepted for oral presentations.

For the first time, the RoboCup-2003 Symposium was held in parallel sessions due to the large number of participants and oral presentations. The presentations were grouped into four sections: Artificial Intelligence, Artificial Vision, Humanoid and Legged Robotics, Miscellaneous Robotics. From the titles of the sections, it is easy to understand that the scope of the presented papers stretched beyond the RoboCup competitions to cover general research topics. The RoboCup Symposium is the place where the scientific achievements of the teams are discussed and formalized and where the achievements in the RoboCup games are diffused to the scientific community.

The RoboCup-2003 Symposium was opened by Manuela Veloso and Masahiro Fujita in the beautiful ancient Main Hall of the University of Padua, see Fig.3. This was the hall where Galileo Galilei taught, where are preserved the original *"cathedra"* of Galileo and the family crests of ancient students of the University of Padua. Veloso spoke on the achievements and the progress of RoboCup in its seven year history and Fujita gave a demonstration of the impressive capabilities of the new humanoid companion robot developed by Sony.

The other invited talks were given by Ulrich Nehmzow, on the use of dynamical systems methods and chaos theory in the study of robotic-environment interaction, and by Paolo Dario, a President of the Robotics and Automation Society of IEEE, on the use of robotics in medicine and other fields. We had also a video contribution from Maja Mataric, that was not able to attend the Symposium, on multi-robot cooperation.

The RoboCup Symposium Committee every year awards two prizes: the RoboCup Scientific Chal-

Fig. 3. The opening invited talk held in the ancient Main Hall of the University of Padua.

lenge Award and the RoboCup Engineering Challenge Award (see the special inserts in the next pages). The Scientific Challenge Award was won by Andrea Miene et al., for a method to recognize and predict game situations. The Engineering Challenge Award was given ex-aequo to Daniel Cameron et al., for an autonomous mechanism for color calibration, and to Michael J. Quinlan et al., for an example of how the limitation of a physical sensor can be overcome by appropriate information processing.

The RoboCup 2003 Symposium was rounded-off by the beginning of the RoboCup Roadmap discussion. The RoboCup Roadmap is aimed at identifying the intermediate milestones to be reached in order to achieve the ultimate goal of 2050. The discussion takes into account the milestones to be reached in the different leagues and also the synergies, the interactions, and possibly the merging of the different leagues.

III. Scientific Collateral Events

RoboCup-2003 was co-located with several scientific events. We had a one-day *Workshop on Synthetic Simulation and Robotics to Mitigate Earthquake Disaster* chaired by Daniele Nardi, a one-day Conference on *Multi-robot systems: trends and industrial applications* organized by SIRI (the Italian Association for Robotics and Automation) and chaired by Giuseppina Gini and Rezia Molfino and the three-day Japan-Italy bilateral seminar of JSPS (Japanese Society for the Promotion of Science) and CNR (National Research Council of Italy) chaired by Minoru Asada and Enrico Pagello. The JSPS-CNR Bilateral Seminar was an exciting event highlighting the scientific cooperation between Italy and Japan, and it involved a tight schedule with many talks and panel discussions. In the end, the technical discussion between scientists of the two countries concluded with the agreement to commence work on cooperative projects in two areas that have been identified as some of the most important application areas for AI and Robotics technologies, namely Rescue Robotics and Simulation Environments for Mobile Robots.

IV. RoboCup Soccer

RoboCup Soccer is the oldest branch of RoboCup activities, and the one directly involved in the achievement of the ultimate goal. It is divided into five leagues, each one dealing with a different set of research issues. In the *Soccer Simulation League*, researchers work on multi-agent coordination and high-level strategies without having to bother with hardware limitations. In the *Small-Size League*, the research is focused on the centralized control of many small robots. In the *Four-Legged League*, the focus is on the development of software for autonomous robots able to process local sensory information and to cooperate with other robots, without the troubles of customized hardware because a stable, reliable and standardized platform is used (Sony AIBO robot). In the *Middle-Size League*, the researchers have to build, maintain and program a team of fully autonomous wheeled robots. In this league, the robot has to move at high speed (often more than 2 m/s) on a large field (10 meters by 7 meters) carrying its own sensors and its own power-supply. It must be able to cooperate with its teammates and to sense the environment effectively (recognizing the objects in the field of play and discarding objects outside of the field, such as the audience or human team members). Finally, in 2002 the Humanoid league was introduced. Here, humanoid robots, while not yet performing full soccer matches, demonstrate different abilities through a series of technical challenges.

Beginning a couple of years ago, the different leagues have introduced challenge competitions in addition to full soccer games. This serves the purpose of pushing the teams to improve their abilities for future competitions and to advance the technology, e.g., to be less dependent on color information, to have more reliable sensing, to develop cooperative behaviors and so on.

A. Simulation League

In contrast to the real robot leagues, many of the challenging features of the Simulation League are hidden to the casual observer. Nevertheless, the league has made big progress in the last several years in both game quality (it looks similar to real soccer games) and the scientific methods behind the teams.

The purpose of the simulation league is to provide a testbed for the development of advanced control architectures and algorithms. Therefore, soccer simulation has to provide a reasonably abstract view relative to a concrete hardware robot (since real platforms change from year to year). However, simulation has to be realistic enough to allow the transfer of developments to the real robots league as a crucial requirement for the final goal in 2050. The Simulation League has many features meeting the above specification: 11 independent autonomous software agents per team, selectable trade-offs between accuracy of sensor information and timing, restricted communication abilities, noise in action and sensing, and heterogeneous players. A successful team in the simulation league has to address all of the following issues:

- decentralized control of 11 independent and autonomous software agents;
- acting under limited sensor information;
- coordination with limited communication bandwidth;
- resource management of limited power;
- dealing with different player capabilities;

The big advantages of the simulation league are that only limited hardware resources are required (2-3 PCs are usually enough to reasonably play a game); the robots are unbreakable; and each game can be exactly logged and replayed with all state information available. This makes algorithm development quite effective, and enables the teams to concentrate on sophisticated abilities in both individual robot capabilities and team coordination issues.

Therefore, the Simulation League is the most advanced with respect to team coordination. In the Simulation League, the ability to play reasonable passes is a crucial requirement to be competitive. Also, the restricted energy resources ('stamina') require a careful distribution of tasks in both defense and attack.

This year's tournament again showed a big advance in the performance of the teams. For the first time, all games were started automatically, which resulted in a very smooth time schedule and forces the developers to provide more autonomy to their teams (e.g., by effectively using the 'coach'). From 56 teams that were qualified, 46 teams participated in the tournament. In the first round, all participating teams showed a good level of individual skills. The teams that advanced to the second round additionally showed a good level on team play abilities. The 12 finalist teams that entered the third round all showed high level of team play and on basic capabilities, including very precise knowledge of own and other player's positions and intentions. Exciting games happened among these teams. Unlike in previous years, games often were not decided until the end, with both teams scoring goals.

The top teams all showed mature capabilities in team play, stamina management, active vision, the use of heterogeneous players, and communication. The main reason for the success of the winning teams is a highly elaborated software design that considers all of the above issues. Different techniques are used for different aspects of the overall problem. Methods are taken from mathematical optimization theory, machine learning, evolutionary algorithms, and also classical AI techniques, such as heuristic search. However, there is no single technique that can be judged to be the 'most successful'; it rather is a carefully balanced application of useful approaches of various fields. For example, the winning team UVA Trilearn (Netherlands) uses coordination graphs in order to specify multi-agent decision making [Menegatti 2004]. They applied coordination graphs to the continuous domain by assigning roles to the agents and then coordinating the different roles. Furthermore, they used a method to predict the optimal action of the other agents, making communication unnecessary. The second placed team, Tsinghuaelous (China) use reinforcement learning and A^* for a kicking procedure [Menegatti 2004],

Fig. 4. The LCD and projector displays on which the games of the Simulation league are displayed.

gradient-based POMDP learning for ball handling, a coordination scheme for defense based on a global plan and methods for adaptive communication. The third placed team, Brainstormers (Germany) worked for several years on machine learning methods for the soccer domain and have realized a growing part of basic skills (kicking, positioning, intercepting) and tactical multi-agent coordination issues (attack play) by neural network based Reinforcement Learning methods [Menegatti 2004], partially combined with constraint-based search methods.

The coach competition aims at measuring the usefulness of an additional observing and advice-giving agent, the 'coach'. By sending messages to a team, the coach can influence strategic behavior like being more defensive, or going via the wings. The winner of the coach competition was UT Austin Villa (USA), with a coach that learned from analyzing previous games, followed by FC Portugal (Portugal) and the team Iranians (Iran).

In the visualization competition, teams compete for the best visualization or game analysis system. This year, many interesting contributions have been presented (3D monitors, graphical game analysis tools), most of which are freely available. The competition was decided by voting. This year, the competition was won by the Caspian team (Iran), followed by the Iranians (Iran), and team Avan (Iran).

Currently, a new simulator is developed. Its main features are a 3D world representation and the ability to simulate a broad range of robotic actuators and sensors. Its first release is scheduled to January 2004 and the first competitions will take part during RoboCup2004 in Portugal. It will be another major step towards bridging the gap between simulation and reality.

Logfiles of the games and further information can be found at the simulation league website at

http://www.uni-koblenz.de/ fruit/orga/rc03

B. *Small-Size League*

The Small Size League competition hosted 20 teams from all over the world. Each team demonstrated 5 robots on a field that was 2.8 meters by 2.3 meters in size. The official ball was an orange golf ball. Teams were allowed to use one or more global cameras, so the vision problem was easier to solve, allowing most teams to focus their research on team dynamics and coordination. All teams used one or two cameras placed 3 meters above the field to extract the position of the ball and robots. Both the image processing and the high level decisions were typically performed on an external computer and the low-level commands were sent to each robot over a radio link. Team performance was very dependent on the quality of that radio link. Fortunately, due to the experience of most teams and a carefully chosen schedule, there were very few problems.

The major advance this year was the implementation of full team autonomy from human commands. That was possible due to the introduction of the referee box. All the in-game commands, sent from the

Fig. 5. A phase of the game in the Small-Size League.

referee to the teams, were sent directly to the software that controls each team. This resulted in no human intervention during the games, which greatly improved the flow. This year there was a certain convergence on the robot design as most teams adopted an optimized solution. Almost all teams used three or four omni-directional wheels per robot. The additional maneuverability of these robots made the two-wheel configuration almost obsolete on this league. Most top teams focused on having an efficient dribbler and kicker. The dribbler devices were typically a set of rotating rubber cylinders that transmit a backspin to the ball keeping it almost glued to the robot even when traveling on the field. It was a general concern that this feature was overused and some kind of limitation should be imposed for next year's competitions.

The three top teams: BigRed'03 from Cornell University U.S.A., RoboRoos from The University of Queensland, Australia and FU Fighters Freie Universitaet Berlin, Germany, placed 1st, 2nd and 3rd respectively. These teams were very evenly matched and all the games between them were decided by only one goal. The champions, the BigRed'03 team, showed excellent robot and ball control which allowed them to score the decisive goals. The RoboRoos team had the best overall ball control and their dribbler was able to rob the ball from almost any opponent. The FU Fighters robots showed their famous speed and teamwork, which allowed them to score more goals than any other team in the competition. In general, both the team members and the public found this year's games to be fast, exciting, competitive and much more fun to watch than previous years.

For more information on the Small-Size League please visit the web site:
http://www-2.cs.cmu.edu/ brettb/robocup/

C. Four-Legged League

The distinguishing feature of the four-legged league has been that all teams use a common hardware platform, the Sony AIBO robot. Since the platform is fixed, the teams are freed from hardware design concerns and are able to concentrate on software development. The common platform also means that teams are easily able to share programs. These features have allowed the league to progress rapidly since new teams can quickly become competent by using previous code as examples for their own development and experienced teams are able to understand, in detail, how other competitors have solved similar problems.

Games in this league are played by two teams of four robots each, on a field almost 3 meters by 5 meters in

Fig. 6. A phase of a game in the Four-Legged League.

size surrounded by a white edge, colored goals, and six color-coded landmarks. All sensing and processing must be done on-board the robots. Radio communication between robots is allowed, but bandwidth is limited to 2Mbps. Radio communication is also used by the referee to send the robots start, stop and penalty signals from a referee box.

In RoboCup-2003, 24 teams from 15 countries participated in this four-legged robot league. The rUNSWift team, from Australia, earned the first place award in the 2003 tournament. This team was previously champion in 2000 and 2001, and placed 2nd in 2002. UPennalizers (USA) placed second, and NUbots (Australia) placed third. In the four-legged league, two different philosophies of robot programming are measuring themselves, i.e. hand-coded robot programs vs. learned behaviors and controls. The winning team, rUNSWift, used machine-learning techniques to optimize the speed of the walking gait (particularly useful when playing on different fields with different carpet and foam backing) and reinforcement learning for path planning and obstacle avoidance. While the NUbots team obtained a winning strategy by carefully hand-coding elementary behaviors and locomotion. One of the strong points of UPennalisers was the implementation of an efficient Rao-Blackwellised particle filter for robot localization.

The quality of the games has grown very rapidly during the short lifetime of this league. In the first years, most of the research effort was focused toward achieving reliable low level functionalities: locomotion, ball control, perception, and self-localization. Typically, a team with better locomotion and simple strategy would outperform a team with sophisticated strategy, but slow or imprecise motion. Today, most teams feature fast and stable walking, accurate ball control, reliable ball perception, and good self-localization. A major factor in this progress is the code sharing policy adopted within the league. A drawback of this policy is a potential reduction in diversity, since many teams prefer to improve on existing successful techniques rather than try to invent radically new ones.

The league is experiencing a shift in the research focus from lower-level functionalities to higher level skills like planning, coordination, and adaptation. Most teams in 2003 used some form of multi-robot cooperation, including dynamic role assignment and information sharing. Much more development in this respect is expected in the next years. For instance, still very little passing occurs between players, and learning has only been used to improve perception and motion abilities.

In addition to the games, the four-legged league organizes a few "technical challenges" every year. These are meant as test-beds for major planned changes, in order to push the teams to prepare for these changes and to verify if the league is ready for them. In 2003, the three challenges were: (1) to use a black and white soccer ball instead of the current orange one; (2) to self-localize without the help of artificial beacons; and (3) to perform reliable collision avoidance. The top teams in the combined ranking were: German Team (Germany, 1st place), rUNSWift (Australia, 2nd place) and ARAIBO (Japan, 3rd place).

The last challenge showed that most teams are able to perform vision-based collision avoidance, even if reliability is limited by the lack of proximity sensors around the body of the AIBO. The first and second challenge, however, indicated that the league is not yet ready to eliminate the colored landmarks that simplify the perception problem. Going toward less artificial environments and more natural lighting conditions is one of the next steps in the evolution of our league.

More information on the Four-Legged League can be found at the URL: http://www.openr.org/robocup/index.html

D. Middle-Size League

The RoboCup-2003 Middle-Size League attracted 24 teams from 11 countries to participate in the robot soccer tournament.

In this league the field of play is moving very fast toward a real soccer field. In 2002, the walls surrounding the field were removed and substituted with a fence of poles half a meter tall. In 2003, the poles were removed, keeping only a security bar around the field to prevent robots from leaving the field. The field was also enlarged to 10 meters by 7 meters. The tournament was played concurrently on four such fields.

Nearly all the participating teams accommodated this change in field set-up without problems, demonstrating the robustness of their robot vision systems which were able to distinguish between objects on the field of play and objects outside the field of play.

The development of the robots shows a clear trend toward omni-directional drives, omni-directional vision systems and increased speed of the robots. Particularly new teams like Brainstormers Tribots (Germany), Mostly Harmless (Austria) and Persia (Iran) came up with new platforms using this kind of drive and sensor concept.

This year's winner of the Middle-Size League tournament was the Fusion team from Japan which played an exciting final match against WinKIT, also from Japan. As in the previous year, two Japanese teams reached the final. This year's third place team was Persia (Iran), who beat last year's champion EIGEN (Japan) in their final match. The winning Fusion (Japan) team showed a remarkable ability to control the motion of the robot especially when dribbling the ball. A key point for this skill was definitely good integration and fine-tuning of motion control with the physical ball control device. The robots were able to drive curves without losing the ball and so they were able to effectively dribble around opponents.

The challenge competition consisted of two events. In the first challenge, the robot had to demonstrate ball dribbling through randomly positioned, static obstacles and to score once passed mid-field. The second challenge was a free challenge. Every team had up to five minutes of oral presentation and a short demonstration of innovative capabilities. Some teams demonstrated co-operative behaviors or the ability to play with a standard FIFA ball. Other teams gave insights into their ongoing research, including for example studies on new ball stopping mechanisms, continuous passing or other soccer playing behaviors that had been evolved in a physical robot simulator. The challenge winner was the team Attempto! Tübingen from Germany.

Vision is a major research topic of all Middle-Size teams. Teams rely on foreign libraries only if they use dedicated hardware for vision processing. All teams use color information, but only half the teams use shape detection and even less use edge detection. Only very few teams use existing software libraries like CMVision, OpenCV or commercial products. Only four teams performed research on auto color calibration, which will become particularly important when lightning conditions are relaxed in the future.

The teams' solution to the self-localization problem was mainly based on visual landmarks. Most teams only used the bigger landmarks such as the goals and the corner posts. But half of the teams also detected the lines on the field. Meanwhile, only half of the teams used statistical approaches for self localization, i.e. Monte-Carlo, particle filters or comparable methods.

One half of the teams used reactive control architectures as adapted from books on behavior-based robotics, i.e. subsumption architecture or motor schema. One third of the teams used their own architectures like Dual Dynamics, inference machines, hybrid control system, 2-level FSMs or Fuzzy approaches. One third of the teams developed robot skills using learning approaches. Less than one half of the teams extended reactive motion control methods with path planners, which in the majority of cases were based on potential field methods.

In next year's competition, the Middle-Size fields will be even bigger, increasing to 12 meters by 8 meters. This will allow teams to have more than four robots playing in the field. And the lighting conditions will be less standardized with the teams playing in indoor ambient light. These changes to the league are meant to foster team play and incrementally migrate to more natural lighting conditions. Probably by 2004, a referee box will be available, allowing the robots to react to referee decisions like fouls, throw-ins and corner kicks. This will reduce manual interactions and game interruptions, moving one incremental step toward the vision of playing successfully against humans by the year 2050.

For additional information on the Middle-Size League please, visit the web site:
http://www.ais.fraunhofer.de/robocup/msl2003/

E. Humanoid League

The Humanoid League (HL) has different challenges than other leagues. The main difference is that the dynamic stability of robots needs to be well maintained while the robots are walking, running, kicking and performing other tasks. Furthermore, the humanoid soccer robot has to coordinate perceptions and biped locomotion, and be robust enough to deal with challenges

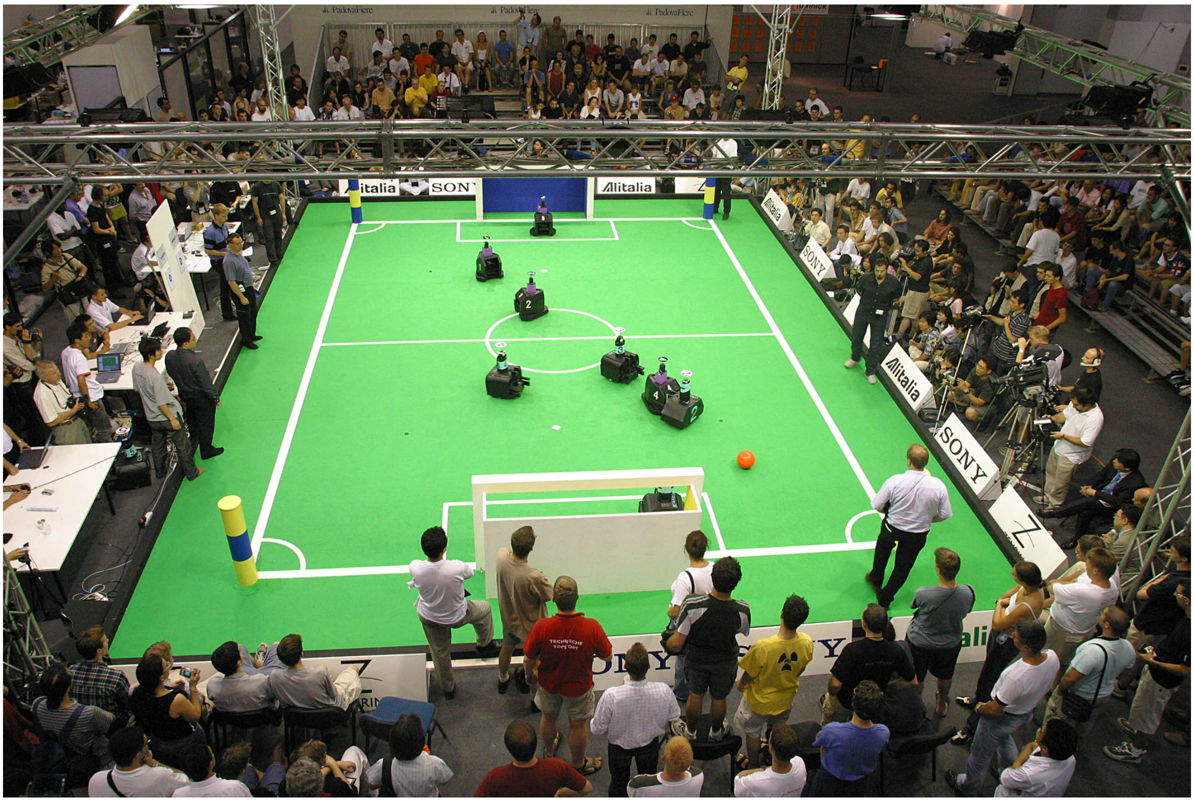

Fig. 7. The final game of the Middle-Size League. The WinKit team is defending the blue goal, the Fusion team is defending the yellow goal.

from other players.

Started in the previous year, the Humanoid League is still rapidly developing. Test-games could be performed. However, the competition consisted of four non-game tasks including standing on one leg, walking, penalty kicking and free style.

A number of excellent robots were presented in the competition. After a good competition with tight results, Honda International Technical School's HITS-Dream received the Best Humanoid Award. Second place was awarded to the Senchans team from Osaka University.

Humanoid soccer robots are complex machines, which should have advanced abilities from very different fields of technology. In this article, we look at seven levels: materials, locomotion, manipulation, power, communication, perception and intelligence. The task of Humanoid Robot soccer is rather hard [?]. However, advances in each field are emerging quickly. Thus, it seems feasible to achieve the following developments by 2010:

- Materials: artificial muscle, softer surfaces for robots
- Walk: dynamic walk, jump and run
- Kick: kick moving ball, passing
- Manipulation: human-like gripping
- Power: 6-hour rechargeable batteries
- Communication: body and natural language processing
- Perception: navigation in human environments
- Intelligence: task understanding

For the next years, dynamic walking is surely the most interesting challenge in the humanoid league (cf. Table II). The best industrial robot is still significantly slower than an average human.

In addition, it is noted that integration is one of the biggest challenges in the field of humanoid robotics. Whilst it is not that difficult to build a vision system or to control mobility, it is hard to do all these things at the same time, on the same robot, with both high reliability and secure recovery procedures in the case of a subsystem failure.

A road map for the next a few years could be the following:

- 2004: more challenges in the Free Style competition, e.g., balancing, passing and obstacle walk.
- 2005: one versus one game, fully autonomous robots.
- 2006: two versus two game, challenges on multiple object tracking and collision avoidance.

Next year's rules are still being discussed. Please see the homepage of the Humanoid league (URL:

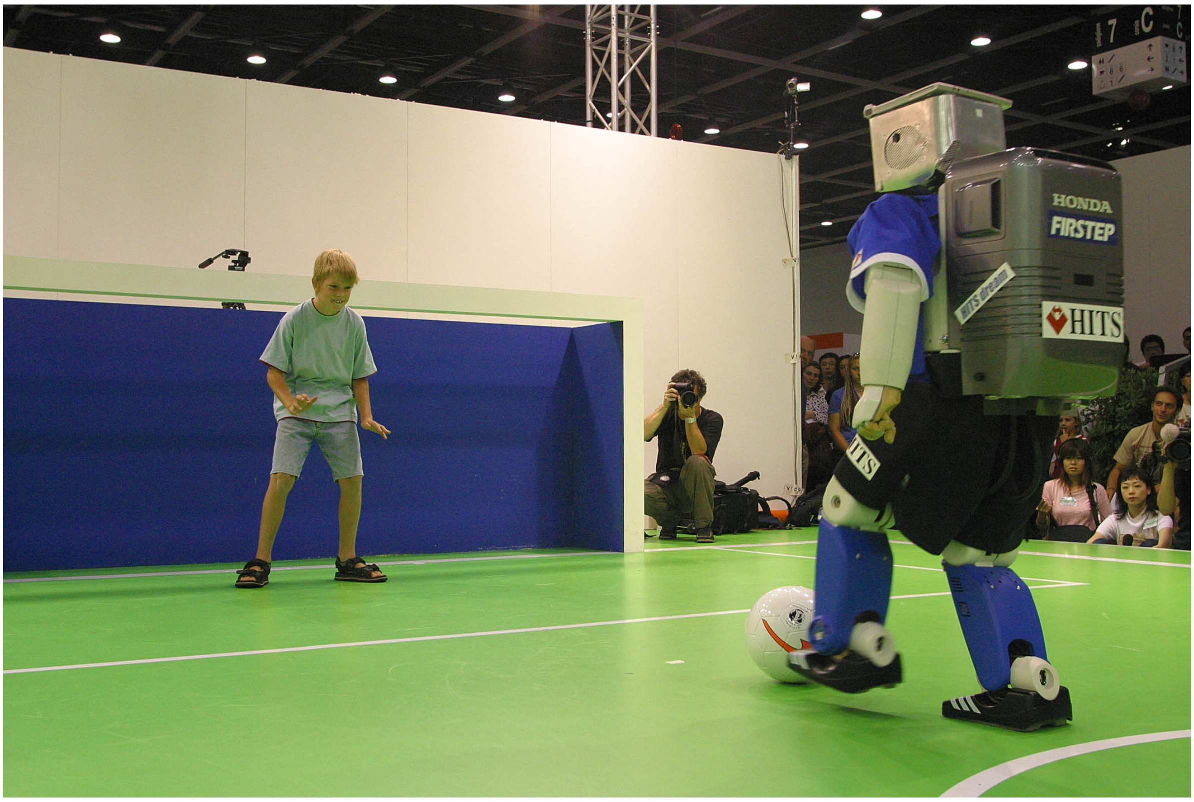

Fig. 8. The most exciting moment in RoboCup-2003: the Honda humanoid FirstStep is kicking a penalty against a human goalkeeper.

Team	Time
HITS-Dream	40 s
Senchans	256 s
Foot-Prints	268 s
Robo Erectus	346 s
(Real Human	< 15 s)

TABLE II

Results from the walking competition: The task was to go to a pole, go around it and return to the starting position. The distance between the starting position and the pole was 5 times of the height of the robot.

http://www.ais.fraunhofer.de/robocup/HL2004) and the mailing list for upcoming changes and developments.

V. RoboCup Rescue

Robotic-based Urban Search and Rescue was chosen as an important domain for RoboCup because it is socially relevant while also sharing several key technical challenges with soccer. For example, some of these commonalities include: "*long-term strategy planning, logistics, interaction with human agents* [...]". RoboCup Rescue brings these issues into focus by trying "*to investigate the essence of autonomous multi-agent systems through the use of an additional domain similar to soccer*" [Asada et al. 1999]. When these words where written, RoboCupRescue was an infant project. After three years of development and competitions, we can say that many technologies have been applied from RoboCupSoccer to RoboCupRescue, e.g., this year a fully autonomous robot almost directly from the Middle-Size League competed in the Rescue Robot League and behavior prediction techniques used in Soccer Simulation League were used also to predict changes in the disaster environment of the Rescue Simulation League games.

A. Simulation League

The RoboCup-2003 Rescue Simulation League tournament hosted 17 teams, many competing for the first time. After RoboCup-2002, useful tools like Java-based agent developing kits, JGISEdit, and a Multi-platform map editor with a map of the city of Foligno, Italy helped new teams to join the RoboCup Rescue community.

In rescue simulation games, a team has specific resources available: a certain number of fire fighters, police, and ambulances. These agents are inserted into a virtual city in which a simulated disaster happens, namely an earthquake, which causes fire ignition, collapsed buildings and injured people. The goal of the team is to coordinate and exploit their resources in order to minimize human casualties and damage to the buildings. The team performance is scored based on the number of victims saved and the time it takes to successfully complete the rescue operations.

Even though the overall disaster situation is unknown to the rescue teams (the locations of agents, fire ignitions, and the magnitudes of earthquakes), the GIS map data and the disaster simulator programs are provided in advance. Apparently, this simplifies the Rescue Simulation task as compared to the Soccer Simulation League. In fact, the factors that change the city-wide disaster environment are easier to predict than the behavior of an opponent team in soccer games. For example, a Rescue Simulation team with an understanding of particular features across a simulated city and how they may become overloaded with traffic during a disaster has a notable advantage in planning and executing operations. On the other hand, dealing efficiently with a myriad of possible reactions to events is very important in real disasters and is one of the important applications of AI and Computer Science.

This year the map of Foligno, Italy was adopted as an official map for the competition. Simulating a disaster in this city illustrated the importance of RoboCup Rescue to the audience in general, but particularly to the Italian audience at this event. An earthquake seriously damaged the city of Foligno just a few years ago. The Foligno map was twice the size of the two previously used maps, Kobe, Japan and the so-called Virtual City, and provided ample challenges for the teams competing in RoboCup-2003. In the preliminary games, all teams performed rescue operations at two disaster situations in the three different maps.

As compared to the games played in RoboCup-2002, the teams showed increased abilities both in the single autonomous agents (fire fighter, police, and ambulance) and in the cooperative abilities among the agents. In order to improve the capability of their agents, the teams used on-line learning methods for rescue formations, clustering methods or agent group formation mechanisms.

The winning team this year was Arian. One of the key feature of their software agents was the capability to predict the future state of the disaster map. So the actions of Arian agents, at one simulation step, were decided not only from past and present states but also from future disaster state. Very impressive were also the performances of the second team, Yowai (Japan) and of the third S.O.S (Iran).

For next year's competition, new challenges may be introduced: (1) on-line learning competition: given unfamiliar maps, teams do some operations and compete according to their improvement over multiple games. (2) given all teams a fixed set of rescue agents, the teams build a set of *"Head Office Agents"* competing in their ability to control the rescue agents. (3) interaction with real rescue robots for decision support and application of intelligent controls.

Also, new map generation and automatic simulation tools will enable opportunities to promote both Rescue Simulation research and application objectives in the future.

Interested readers can find more information on the Rescue Simulation League at the URL:
http://robomec.cs.kobe-u.ac.jp/robocup-rescue/

B. Robot League

RoboCup2003 hosted the third annual Rescue Robot League competition, which included 12 teams from 8 countries. The goal of this competition, which is exactly similar to the annual American Association for Artificial Intelligence (AAAI) competition is to increase international 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. Both competitions require robots to demonstrate capabilities in mobility, sensory perception, planning, mapping, and practical operator interfaces, while searching for simulated victims in unstructured environments. The rescue 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).

The objective for each robot in the competition is to find simulated victims at unknown positions in the arenas. Each simulated victim is a clothed mannequin emitting body heat and possibly other signs of life including motion (shifting or waving), sound (moaning, yelling, or tapping), and carbon dioxide to simulate breathing. The victims are distributed throughout the environment in roughly the same situational percentages found in actual earthquake statistics.

The competition score metric focus on the tasks of identifying live victims, determining victim condition, providing accurate victim location, and enabling victim recovery, all without damaging the environment. Also, false victim identifications were discouraged for the first time, so teams that mistakenly identified sensor signatures as signs of life suffered point reductions. The twelve competing teams developed unique systems with very diverse characteristics.

This year's competition hosted twelve teams that

Fig. 9. A phase of the games of the Simulated rescue League. The LCD displays are showing the disaster map in the city of Foligno (Italy).

Fig. 10. A robot found a victim in the Rescue Robot League and the two referees are updating the score.

demonstrated robotic systems with very diverse characteristics. The first place award winner was the RO-BRNO team from Brno University of Technology in the Czech Republic. They developed a very capable custom robot and integrated several components to form an extremely effective operator interface. Their robustly fabricated four-wheel, skid-steered robot was equipped with vision, infrared, and audio sensors for victim identification. The operator interface used a joystick to control robot motion along with heads-up display goggles that tracked the orientation of the operator's head to automatically point the robot's cameras. This allowed superior remote situational awareness and enabled the operator to intuitively and dexterously negotiate narrow arena passages, causing very few penalties. The second place award winner was the CEDRA team from Sharif University of Technology in Iran. They developed a wheeled mobility platform with an articulated body design similar to planetary explorers. They also employed a joystick interface with the operator looking at two flat panel video displays. The third place award winner was the MICROROBOT team from the Isfahan University of Technology in Iran. They used two robots equipped differently and used cooperatively. One robot was small and fast with only a camera for initial victim identification and operator generated mapping. Once a victim was potentially located, the second, slower robot was dispatched to the location with more specific victim identification sensors. The technical award winner was the team from the International University - Bremen (IUB) in Germany. They also deployed two robots but were recognized for their arena mapping implementation, which used a proximity range finder to automatically generate obstacle maps of the environment. This was the only autonomous mapping demonstrated during the competition, which is highly encouraged in the performance metric, but did not contribute quite enough points to earn a place award. Other interesting approaches included fully autonomous robots, a robot almost directly from the mid-size soccer league, and even a blimp. The two fully autonomous teams demonstrated robots capable of navigating parts of the yellow arena but didn't produce maps showing victim identifications, another key performance criteria, so did not score well. Minor rules modifications proposed for next year may artificially limit the use of radio communications during missions to simulate radio signal dropout and interference that occurs at actual disaster sites. The intent is to encourage more development of autonomous behaviors and/or active tether management systems that are practical for eventual deployment.

For the second year, human-factors researchers used the competition event to study human-robot interaction during missions. The operators, the interfaces to their robots, and the robots themselves were video taped during missions. These video streams along with objective monitoring of operator actions and interviews conducted immediately after each mission captured the workload required to perform each task and provided the basis for study of effectiveness and ease-of-use issues. A formal analysis of this data is underway with the goal of identifying effective interface components and methods so that other teams, and other applications, may benefit.

More information can be found at:
http://www.isd.mel.nist.gov/RoboCup2003/

VI. RoboCup Junior

RoboCupJunior celebrated its fourth year of international competitions with a continued increase in levels of interest and participation, involving 74 teams (258 participants) from 16 countries world-wide.

The idea of RoboCup Junior was first introduced in 1998 as a version of robot soccer that uses an infrared emitting ball to simplify vision and a pitch with a greyscale floor in order to simplify localization [Lund and Pagliarini 1998]. In 2000, RoboCup Junior (RCJ) held its first international competition in Melbourne, Australia. A strong team of in-practice teachers, led by Brian Thomas, organized RCJ-2000 and developed three challenges, each geared towards students with different interests and abilities: *Soccer*, a two-on-two game based on the setup of Lund and Pagliarini (which was a one-on-one game) and adapting the rules of the RoboCup Small-Size League; *Sumo*, a line-following challenge for intermediate-level students; and *Dance*, a creative challenge designed for primary-age students. The initiative has grown in popularity, with events co-located at every international RoboCup since Melbourne.

The first research into the effectiveness of RCJ as a hands-on learning environment was conducted in Melbourne. This research has continued since 2000, including a paper that won the Scientific Challenge Award at the 2002 RoboCup Symposium [Sklar et al. 2002]. This research has shown that that many of the skills universally affected in a positive way as a result of RoboCup Junior preparation and participation fall within the realm of social and personal development, such as teamwork and self-confidence. Further study was conducted in 2003, and the results are forthcoming.

In Padua, teams could enter four different challenges: one-on-one soccer, two-on-two soccer, dance and rescue. Three different age groups were represented: primary (up to age 12), secondary (age 12-18, or end of high school) and undergraduates. The biggest changes in the event from 2002 were the introduction of a newly designed rescue challenge and the development of a new entry-level soccer league for undergraduates, called the *ULeague* (see figure 14). Note that some teams entered more than one challenge within their age group.

At RoboCupJunior-2003, soccer remained the most popular challenge, engaging 67% of teams overall. Some of the secondary students took advantage of state-of-the-art technological improvements and used, for example, magnetic sensors for direction and ultrasonics for collision avoidance. LEGO Mindstorms continues to be the most popular medium for robot construction but many teams, particularly in Asia, use the Elekit SoccerRobo. More advanced teams, most notably from Australia and Germany, even constructed their hardware completely from scratch.

Robot dance continues to be very popular with students of all ages. As in the previous year, the standard was very high, demonstrating that dance has all the technical challenges of other Junior events, combined with great opportunities for artistic creativity in music, choreography and costume. This year, many participants chose to perform with their robots, including one team who sang and played music on guitar. Altogether, dance has grown to become one of the most popular spectator events at RoboCup.

The newly redesigned event of RoboCupJunior Rescue attracted participants across both primary and secondary teams. It is easy to get started with this event, but the challenge becomes more demanding as students raise their aspirations. We expect it to become much more popular in future years due to the progressive and personal nature of the challenge. The task for the robot is to follow a black line through a

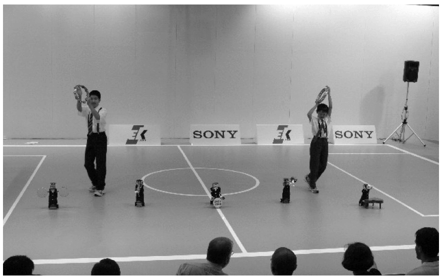

Fig. 11. (a) Dance

Fig. 12. (b) Rescue

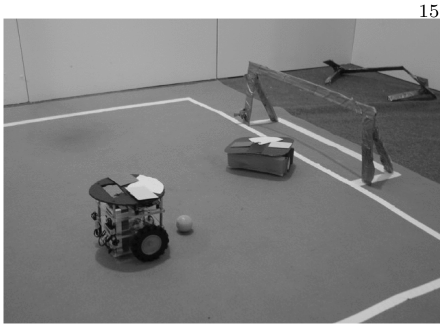

Fig. 13. (c) ULeague Soccer

Fig. 14. RoboCupJunior 2003 challenges.

"building" (essentially a dollhouse) looking for "victims" – bodies cut out of silver foil and green tape – which are laid across the black line. A number of rooms are connected by corridors and ramps across multiple stories, and robots have to deal with differing light levels in upper and lower levels. Points are awarded for the number of bodies detected as well as the fastest time to complete the course.

In the new ULeague challenge, teams from USA, Canada, Australia and Germany participated. The purpose of the ULeague is to provide an opportunity within RoboCup for students to bridge the gap between RoboCupJunior and the senior leagues, such as the Small-size league. In the ULeague setup, a common solution is provided for global vision and team communication, and the burden is on teams to devise coordinated behaviors for their robots and/or hardware platforms.

RoboCupJunior has seen strong growth in the number of female participants, particularly in the dance challenge, which provides a unique outlet for creativity. While RCJ attracts in total an average of 15% female students overall (increased from 10% in 2000), the dance challenge at RCJ-2003 had 31% female participation. This trend has been duplicated in all of the national open events held thus far, most notably in Australia where over half the RCJ dance participants were female. This is impressive, as the scale of the Australian RoboCupJunior effort is such that each state has its own regional championship and five hundred students participate in the country's national RoboCupJunior event each year.

One of the most encouraging observations from this year's event was the level of cooperation between teams, especially between secondary and primary students. The students' preparation area was a hive of activity and intense pressure, but many of the older students took the time to help younger students with technical or programming problems. Many RCJ events will be occurring world-wide in 2004, including Open events in Australia, Germany, Japan, Canada and the USA – in addition to the annual international event at RoboCup-2004 in Lisbon. For further information about events and rules for each challenge, refer to our web site: `http://www.robocupjunior.org`

VII. Conclusions

In this paper we have brought to attention some of the important research achievements obtained at last RoboCup 2003, held in Padua (Italy). If we compare both the performance of the Teams from various Leagues in the Games and Challenges, and the scientific results illustrated at the Symposium, with the fundamentals problems introduced in some of the early seminal papers appeared in the literature from 1997 to 1999, we may certify that remarkable advancements have been already achieved in the area of Artificial Intelligence and Autonomous Robots. RoboCup Community is now an important reference point for a larger scientific environment than those simply interested to Soccer Robotics technology. New leagues, like Rescue Robotics and Humanoids, are quickly evolving, and have already proved to be an excellent experimental test-bed. The record peak of 1244 registered participants, and 243 teams competing, has definitively made the Annual RoboCup International Competitions and Conferences one of the most important meeting in the world, like IJCAI in the field of Artificial Intelligence, and ICRA and IROS in field of Robotics.

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IX. References

[Kitano 1999] Kitano H., Preface, Special Issue: RoboCup the First Step (Kitano ed.) Artificial Intelligence vol 110, N 2, p. 189-191, Elsevier June 1999

[Asada et al. 1999] Asada, M.; Kitano, H.; Noda, I.; and Veloso, M. 1999. RoboCup: Today and Tomorrow–What We Have Learned. Artificial Intelligence 110(2): 193-214.

[Suzuki et al. 98] S. Suzuki and M. Asada. An application of vision-based learning in RoboCup for a real robot with an omnidirectional vision system and the team description of Osaka University "Trackies". In M. Asada and H. Kitano, editors, RoboCup98: Robot Soccer World Cup II, volume 1604 pp. 316-325 of LNCS. Springer, 1999.

[Bonarini 2000] Bonarini, A. The body, the mind or the eye, First? In M. Veloso, E. Pagello, and H. Kitano, editors, RoboCup99: Robot Soccer World Cup III, volume 1856 pp. 210-221 of LNCS. Springer, 2000.

[Marques and Lima 2000] Marques C. and Lima P. A localization method for a soccer robot using a vision-based omni-directional sensor. In P. Stone, T. Balch, and G. Kraetzschmar, editors, RoboCup-2000: Robot Soccer World Cup IV pp. 96-107, LNCS. Springer, 2001.

[Marchese and Sorrenti 2001] Marchese F., Sorrenti D. G., Omni-directional vision with a multi-part mirror. In P. Stone, T. Balch, and G. Kraetzschmar, editors, RoboCup-2000: Robot Soccer World Cup IV pp. 179-188 LNCS. Springer, 2001.

[Menegatti et al. 2002] Menegatti E., Nori F., Pagello E., Pellizzari C., and Spagnoli D. Designing an omnidirectional vision system for a goalkeeper robot. In A. Birk, S. Coradeschi, and S. Tadokoro, editors, RoboCup-2001: Robot Soccer World Cup V., pages pp. 7887. Springer, 2002.

[Miene et al. 2003] Miene A., Visser U., Herzog O., Recognition and prediction of motion situations based on a qualitative motion description. In Polani D., Browing B., Bonarini A., Yoshida editors, RoboCup-2003: Robot Soccer World Cup VII, LNCS. Springer,(to appear)

[Cameron and Barnes 2003] Cameron D. and Barnes N., "Knowledge-Based" Autonomous Dynamic Color Calibration. In Polani D., Browing B., Bonarini A., Yoshida editors, RoboCup-2003: Robot Soccer World Cup VII, LNCS. Springer,(to appear)

[Quinlan et al. 2003] Quinlan M.J., Murch C.L., Middleton R. H., and Chalup S. K., Traction Monitoring for Collision Detection with Legged Robots. In Polani D., Browing B., Bonarini A., Yoshida editors, RoboCup-2003: Robot Soccer World Cup VII, LNCS. Springer,(to appear)

[Kitano 1999] Special Issue on RoboCup: the First Step (Kitano ed.) Artificial Intelligence vol 110, N 2, p. 189-191, Elsevier June 1999

[IEEE-TRA 2002] Arai, T.; Pagello E.; Parker L (2002). Guest Editorial. Advances in Multi-robot Systems IEEE TRANSACTIONS ON ROBOTICS AND AUTOMATION. (vol. 18 pp. 655-661)

[RAS 2001] Special issue on the EuroRoboCup of the Journal of Robotics and Autonomous Systems, Elsevier, Amsterdam, Vol 36, no 2, August 31, 2001

[AI 1998] Special Issue: RoboCup, Guest Editor: Hiroaki Kitano Applied Artificial Intelligence, Volume 12, Number 2-3, 1998

[Kitano 1998] Kitano, H., ed. 1998. RoboCup-97: Robot Soccer World Cup I. Lecture Notes in Artificial Intelligence, Volume 1395. New York: Springer.

[Asada and Kitano 1999] Asada, M., and Kitano, H., eds. 1999. RoboCup-98: Robot Soccer World Cup II. Lecture Notes in Artificial Intelligence, Volume 1604. New York: Springer.

[Veloso et al. 2000] Veloso, M.; Pagello, E.; and Kitano, H., eds. 2000. RoboCup-99: Robot Soccer World Cup III. Lecture Notes in Artificial Intelligence, Volume 1856. New York: Springer.

[Stone et. al 2001] Stone, P.; Balch, T.; and Kraetzschmar, G., eds. 2001. RoboCup-2000: Robot Soccer World Cup IV. Lecture Notes in Artificial Intelligence, Volume 2019. New York: Springer.

[Birk et al. 2002] Birk, A.; Coradeschi, S.; and Tadokoro, S., eds. 2002. RoboCup 2001: Robot Soccer World Cup V. Lecture Notes in Artificial Intelligence, Volume 2377. New York: Springer.

[Kaminka et al. 2003] Kaminka, G.; Lima, P. U.; and Rojas, R., eds. 2003. RoboCup 2002: Robot Soccer World Cup VI. Lecture Notes in Artificial Intelligence. New York: Springer. Forthcoming.

[Noda et al. 1998] Noda, I.; Suzuki, S.; Matsubara, H.; Asada, M.; and Kitano, H. 1998. RoboCup-97, The First Robot World Cup Soccer Games and Conferences. AI Magazine 19(3): 49-59.

[Asada et al. 2000] Asada, M.; Veloso, M.; Tambe, M.; Noda, I.; Kitano, H.; and Kraetzschmar, G. K. 2000. Overview of RoboCup-98. AI Magazine 21(1): 9-19.

[Coradeschi et al. 2000] Coradeschi, S.; Karlsson, L.; Stone, P.; Balch, T.; Kraetzschmar, G.; and Asada, M. 2000. Overview of Robocup-99. AI Magazine 21(3): 11-18.

[Stone et al. 2001] Stone, P.; Asada, M.; Balch, T.; D'Andrea, R.; Fujita, M.; Hengst, B.; Kraetzschmar, G.; Lima, P.; Lau, N.; Lund, H.; Polani, D.; Scerri, P.; Tadokoro, S.; Weigel, T.; and Wyeth, G. 2001.

RoboCup-2000: The Fourth Robotic Soccer World Championships. AI Magazine 22(1): 11-38.

[Veloso et al. 2002] Veloso, M.; Balch, T.; Stone, P.; Kitano, H.; Yamasaki, F.; Endo, K.; Asada, M;. Jamzad, M.; Sadjad, B. S.; Mirrokni, V. S.; Kazemi, M.; Chitsaz, H.; Heydarnoori, A.; Hajiaghai, M. T.; and Chiniforooshan, E. 2002. RoboCup-2001: The Fifth Robotic Soccer World Championships. AI Magazine 23(1): 55-68.

[Asada et al. 2003] Asada, M.; Obst, O; Polani, D.; Browing, B.; Bonarini, A; Fujita, M.; Christaller, T.; Takahashi, T.; Tadokoro, S.; Sklar E.; Kaminka G.A.; An Overview of RoboCup-2002 Fukuoka/Busan. AI Magazine XXX : 21-40.

[Lund and Pagliarini 1998] Lund, H.H. and Pagliarini, L., Robot Soccer with LEGO Mindstorms. In RoboCup-98: Robot Soccer World Cup II, Lecture Notes in Artificial Intelligence (LNAI) vol. 1604, Springer Verlag, 1998.

[Sklar et al. 2002] Sklar, E. and Eguchi, A. and Johnson, J. RoboCupJunior: learning with educational robotics. In Proceedings of RoboCup-2002: Robot Soccer World Cup VI.

[Weigel et al 2002] CS Freiburg: Coordinating Robots for Successful Soccer Playing Authors: Thilo Weigel, Jens-Steffen Gutmann, Markus Dietl, Alexander Kleiner, and Bernhard Nebel in IEEE Trans on Robotics and Automation, Special Issue on Multi-robot Systems, T. Arai, E. Pagello, L. Parker (Eds.), Vol 18, No. 5, October 2002 pp. 685-700

Soccer competitions		
Simulation league		
1st	UVA TRILEARN	University of Amsterdam, HOLLAND
2nd	TSINGHUAELOUS	Tsinghua University, CHINA
3rd	BRAINSTORMERS	University of Dortmund, GERMANY
Small size robot league		
1st	BIG RED	Cornell University, USA
2nd	ROBOROOS	The University of Queensland, AUSTRALIA
3rd	FU FIGHTERS	Freie Universitaet Berlin, GERMANY
Middle size robot league		
1st	FUSION	Kyushu Univ. and Fukuoka Univ., JAPAN
2nd	WINKIT	Kanazawa Institute of Technology, APAN
3rd	PERSIA	Isfahan University of Technology, IRAN
4 legged robot league		
1st	RUNSWIFT	University of New South Wales, AUSTRALIA
2nd	UPENNALIZERS	University of Pennsylvania, USA
3rd	NUBOTS	The University of Newcastle, AUSTRALIA
Humanoid league - Luois Vuitton Cup		
	HITS DREAM	Honda Int. Technical School, JAPAN
Humanoid league - Walk		
1st	HITS DREAM	Honda Int. Technical School, JAPAN
2nd	SENCHANS	Osaka University HANDAI FRC, JAPAN
3rd	FOOT-PRINTS	private, JAPAN
RoboCup Rescue		
Rescue Simulation		
1st	ARIAN	Sharif University of Technology, IRAN
2nd	YOWAI	The Univ. of ElectroCommunications, JAPAN
3rd	S.O.S.	Amir Kabir University of Technology, IRAN
Rescue Robot		
1st	ROBRNO	Brno Univ. of Technology, CZECH REPUBLIC
2nd	CEDRA	Sharif University of Technology, IRAN
3rd	IUT MICROBOT	Isfahan University of Technology, IRAN

TABLE III

The winning teams in the different leagues