RoboCup Soccer Leagues

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RoboCup was created in 1996 by a group of Japanese, American, and European Artificial Intelligence and Robotics researchers with a formidable, visionary long-term challenge: "By 2050 a team of robot soccer players will beat the human World Cup champion team." At that time, in the mid 90s, when there were very few effective mobile robots and the Honda P2 humanoid robot was presented to a stunning public for the first time also in 1996, the RoboCup challenge, set as an adversarial game between teams of autonomous robots, was fascinating and exciting. RoboCup enthusiastically and concretely introduced three robot soccer leagues, namely "Simulation," "Small-Size," and "Middle-Size," as we explain below, and organized its first competitions at IJCAI'97 in Nagoya with a surprising number of 100 participants [RC97]. It was the beginning of what became a continously growing research community. RoboCup established itself as a structured organization, the RoboCup Federation www.RoboCup.org, fostering annual competition events, where the scientific challenges faced by the researchers are addressed in a setting that is attractive also to the general public. The RoboCup events have become the most popular and attended in the research fields of AI and robotics, including also a technical symposium with contributions relevant to the RoboCup competitions and beyond to the general AI and robotics.

In addition to robot soccer, RoboCup has reached out to addressing societal challenges with further dedicated robot competitions. Since 1999, RoboCup Rescue [RR12], motivated by the difficulties faced after the Kobe earthquake in 1997, is addressing the development of robots to support search and rescue operations. Since 2006, RoboCup@Home [H09] focuses on human-robot interaction and develops useful robotic applications that can assist humans in everyday life. Recently, RoboCup addresses industrial domains: the competition RoboCup@Work is at a preliminary stage. And a new sponsored league by Festo, the Logistics League, was introduced in 2012 to address abstract factory logistics. Finally, since 2000, RoboCup Junior is an educational initiative for students up to the age of 19, providing a new and exciting way to understand science and technology.

RoboCup organizes a single yearly international event (RoboCup 2014 will be in Joao Pessoa, Brazil, July 21-25) that attracts more than 1500 participants and nearly 200 teams for the major leagues and about 1500 participants for the junior. RoboCup has a broad international participation, with teams joining from about more than forty countries worldwide. As the number of RoboCup researchers significantly increased over the time, RoboCup had to limit the participation at the yearly international event to a fixed number of competiting teams per event. Consequently, researchers also organize regional communities and regional events, several of which are as large as the main event.

In this article, we focus on RoboCup robot soccer, and present its five current leagues, which address complementary scientific challenges through different robot and physical setups. Full details on the status of the RoboCup soccer leagues, including league history and past results, upcoming competitions, and detailed rules and specifications are available from the league homepages and wikis (wiki.robocup.org). The initial description of the Simulation, Small size and Mid size leagues can be found in [RC97]; moreover, several annual reports have been subsequently published in different venues, including the AI Magazine. The proceedings of the annual RoboCup Symposium [RC1998-2013] provide a large collection of research achievements in all the RoboCup leagues. Finally, collections of papers from the Humanoid League appear as special issues [IJHR 2008, RAS 2009].

Simulation League

The simulation league is a competition of virtual soccer agents (robots). The physical level simulation as soccer-playing robots is simplified and abstracted, so that researchers can focus on developing strategic-level intelligent agents to realize cooperative behaviors. Currently, this league consists of two sub-league, 2D (two-dimensions) and 3D (three-dimensions), according to the abstraction level of the physical simulation.

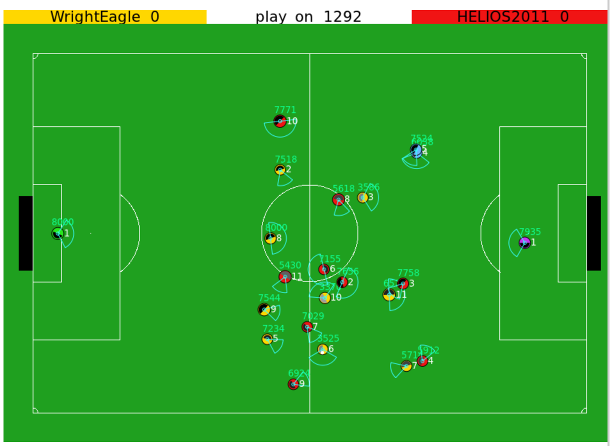
The 2D sub-league is a game of two teams of 11 players using a FIFA's full-size 2D soccer field. A player is modeled as a circle with two facing directions (body and head), and can do "turn", "dash", "kick" and "turn-head" as basic actions. So, the agent program needs to dynamically generate suitable sequences of these actions according to each situation.

The 3D sub-league uses a more realistic model of robots based on Aldebaran's Nao, which can act in a 3D space. Players' actions are motor commands to each joint of the body. Hence, controlling the motion of the robot becomes more challenging than in the 2D sub-league.

In recent years, the simulation league, especially the 2D sub-league, is becoming a game of strategies rather than of individual skills or team tactics. In the early stage of the simulation league, the participants focussed on the development of skills to control each player for better ball-handling and motion planning, as in other physical robot leagues. After this stage, there was a shift of attention towards the team tactics, like formation (positioning of players), pass planning, and role assignments. Participants thus addressed team tactics and adaptation/learning methods to adjust pass plans among multiple players. While this capability still brings several open issues, several teams started working on the strategic game plan level, in which they change their play styles and formations according to the opponent performance during a game. Therefore, dynamic opponent modeling is required in order to build winning teams. In the near future, deep planning/learning methods to model opponents and to fake the opponent analysis are expected to emerge.

Separation among levels of strategy, tactics, and skills is not trivial, and the architecture still raises interesting open issues. However, in order to encourage researches on more strategic planning/learning, the simulation league adopts a "coach agent" system. A coach agent can observe all movements in the field and can communicate with player agents in restricted timings, for example during out-of-play. Therefore, the coach agent can make a team-strategic decision and control team tactics according to the game situation. This means that participants need to think how to divide the control of the game between coach and players.

The simulation league has been used as a testbed to measure performance of learning and representation of teamworks (collaborative behaviors of multiagent). For example, the ability to transfer learned behavior from simple tasks to complex ones in multiagents was shown by using the framework of simulation league. Because soccer as a multiagent game is a complex problem, the design of teamwork in simulation league is an outstanding research challenge, that can be addressed by applying incremental and iterative methods like machine learning.



(a) screen shot of 2D simulation

(b) screen shot of 3D simulation

Small-Size Robot League

The RoboCup Small-Size Robot League consists of a specific setup in which two teams of small robots compete against each other under three core assumptions: (i) robots can be built by researchers, only under a size restriction, i.e., there are no constraints on any other aspects of the robot hardware, e.g., weight, cost, materials, capabilities, e.g., kicking devices; (ii) a central vision system is allowed to be used to perceive the complete playing field, and (iii) robots can receive motion commands remotely from an external computational, non human, source.

The RoboCup Small-Size League was one of the first three leagues of RoboCup, and like all the other leagues, has interestingly evolved every year to increase the technical challenges faced by the participants. The size of the field started as the size of a ping-pong table and for the coming 2014, the playing field will be twice as large of last year’s, and of size 12 x 8 meter with corresponding line markings and goal sizes. The playing ball is an orange golf ball. The number of robots per team has increased from 3 up to 6 now. For about the last ten years, each robot must fit within a 180mm diameter circle and be no higher than 15cm. All the teams converged to choosing to use the allowed centralized perception and computation, and the league evolved to a common robot marking system, now processed by a common vision system, SSL-Vision, whose output is then shared to all the individual team computing The SSL-Vision is open source, created and maintained by the league’s community, and can be configured to be used beyond the specific small-size league setup.

A common computer is used to communicate referee commands and position information to the team computers. After initial manual robot setting at game stoppage events, the robots completely autonomously process all referee and game calls by positioning themselves; typically, most, sometimes all, of the processing required for coordination and control of the robots is performed on external computers.

Robot hardware design is still a challenge, because of the size restrictions and of the new sensing capabilities that become possible on-board the robots. Nonetheless, perception is essentially solved by the external vision system, thus the scientific focus of the Small Size League is on robot control: the speed of the robots as well as of the ball is very fast; moreover, the capabilities of the players in terms of dribbling, interception and shooting are remarkable, and typically achieved through machine learning approaches. However, the teams compete mostly at the strategic level, about positioning, passing and high-level decision making. Sequences of multiple passes and complex plays have become commonplace. Machine learning is applied also in many high level tasks: a unique example of learning the opponents' behaviors and strategies in real robot systems has been shown in this league.

Picture by Bart van Overbeeke

Middle-size Robot League

In the RoboCup Middle Size League two teams of 5 robots play on a green 18 x 12m indoor carpet field, with white lines (similar to a real football field) and 2 x 1m net goals. The maximum dimensions for each robot are 80cm height, 50cm diameter and 40kg weight. The robots are equipped with a computer to process the data acquired and use several sensors all of them on the robot itself (no external sensors are allowed). These robots play football autonomously, using wireless network to communicate among them. They also communicate with an external computer, which receives the instructions from the referee, through a so called referee-box, but all sensing and computation is done onboard.

No external intervention by humans is allowed in the game, except to remove robots from the field, should they break down. So the robots are totally distributed and autonomous. Robots recognize objects and localize themselves using sensor information, they decide which action to take, and control the motors and actuators autonomously accordingly. Matches are divided in two 15-minute halves.

This league has archieved major developments in the last few years. MSL teams have developed software which allows amazing forms of cooperation between robots. The passes are very accurate and some beautiful goals are scored after passing the ball, rather than just dribbling an opponent and playing individually.

Mid Size League removed long time ago the coloured goals, the coloured corner posts, the large fences around the field, as well as the special lighting. The ball can also be of any colour, having the teams just a couple of minutes to show the robots the ball to be used. The speed of the robots, while controlling the ball is impressive. Velocities of up to 3 to 4 meters per second are easily achieved, thus requiring suitable control techniques. The robots also use dribblers, which are devices able to minimaly control the ball without dragging it on the floor, since the rules state clearly that the ball must roll free. The ball does not always move on the floor, since most teams developed kicking mechanisms, which allow ball kicking upwards, thus making the game more similar to the humans one. Although the kicks are so strong that the ball can be thrown from one goal to the other, the rules forbid such plays and try to enforce the development of cooperative behaviours to score goals. With robots from this league, it was possible to play games with humans since 2007; this game is now happening every year to test the progress achieved by the robots.

Several challenges related to motion an perception have been solved in MSL along the years, leading to very effective omnidirectional mobile platforms and vision systems. The current capabilities of the robots allow teams to focus on cooperation and strategy, but a new set up with artificial grass is being addressed, which might require substantial innovation in the overall design.

Standard Platform League

Of the three original leagues introduced in 1997, two of them required designing and building one's own robots (the small-size and middle-size leagues), and one abstracted away some real-world complexities (the simulation league). The Standard Platform League (SPL) was introduced in order to provide an avenue for participants to work with real robots, but without the need to design and build their own.

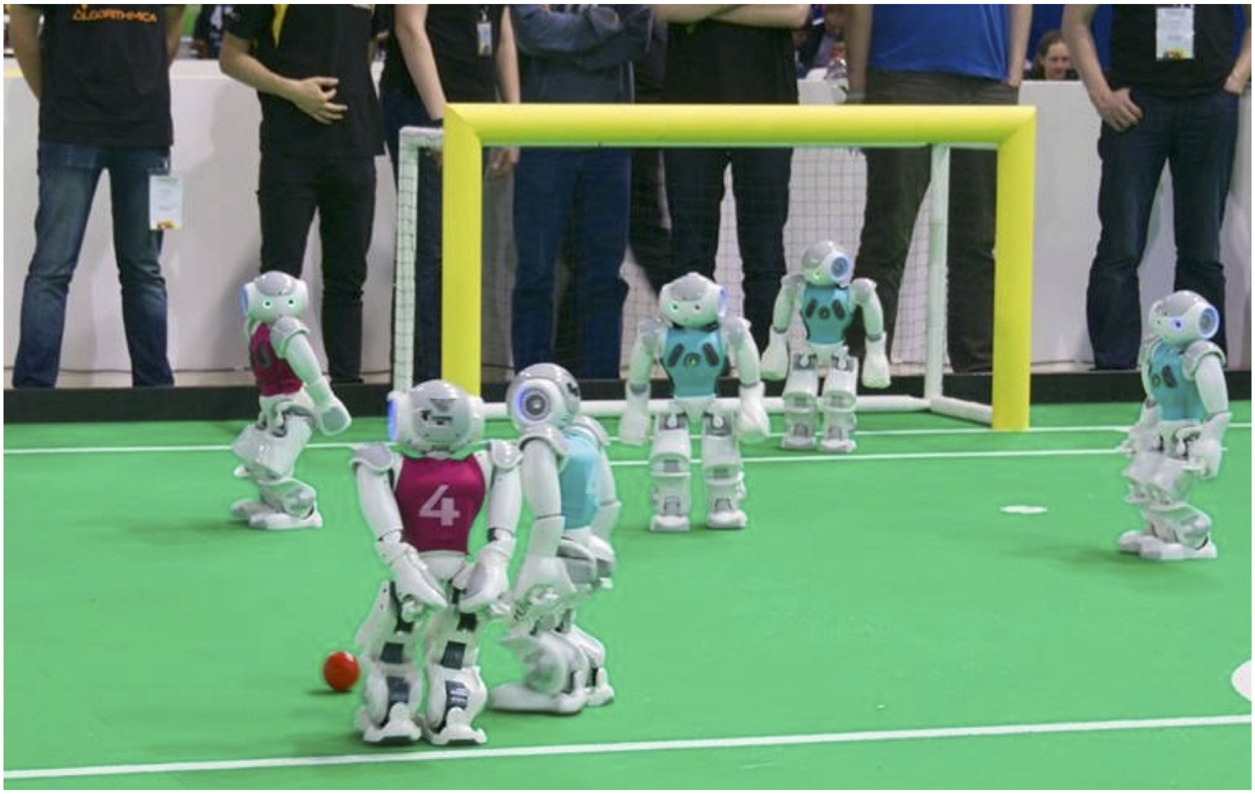
Originally called the 4-legged league due to its use of the Sony Aibo robot, this addition to the RoboCup portfolio also added a new dimension of challenge over the existing robot leagues, namely legged locomotion (the previous robots all moved on wheels). There was a 3-team demonstration in 1998 followed by the first full-fledged league in 1999. The league continued to use the Aibo as the standard platform, until the robot was discountinued in 2007. In that year, an open competition to provide the next standard platform led to a transition to the 2-legged (humanoid) Aldebaran Nao robot, beginning in 2008 and continuing to the present day. Games are currently played among teams of five robots each on a 6x9m.

Throughout the league's history, all sensing and computation has been required to be performed onboard the robot. Inter-robot communication is allowed either through sound or through a wireless access point (with limited bandwidth). The main sensors are cameras located in the robot's head, with limited fields of view. Thus perenial technical challenges have included real-time processing of high-resolution color-based images, and active reasoning about where on the field the robot should focus its attention. For example, constantly focussing on the ball's location may be at odds with looking around to notice where other robots are located or to self-localize.

The self-localization challenge in this league has gradually evolved from originally being based on different-colored goals and six uniquely-patterned beacons placed at known locations around the field, to the current status which includes two goals of the same color and no other field markings other than the white lines. Thus robots are now faced with the challenge of determining which direction on the field they are facing on a fully symmetric field. They can do so at first by tracking their movement over time from a known starting position (e.g. using a kalman filter or particle filter). However, especially when they fall over near midfield, there is significant risk of becoming disoriented when they stand back up. One solution to this problem is communication of the ball's location among the teammates as a way of breaking the field's symmetry.

Speed and robustness of robot locomotion and speed and power of kicking have been important differentiators in this league, with teams with fast-moving robots having a large advantage. However, strategy and teamwork, including both where to kick the ball, and where robots without the ball should position themselves, have also played important roles.

The most recent addition to the SPL has been a new "drop-in player" challenge that requires tests robots' abilities to cooperate with previously unknown teammates in an ad hoc teamwork setting.



Humanoid Robot League

At the beginning of the Humanoid League in 2002, participating humanoid robots were quite diverse with sizes from only 10 up to 220 cm. The early competitions focused on basic abilities like walking, standing on one leg and on penalty kicks. Performance factors were applied to account for the diversity between robots. Today robots compete in three different, well established size classes. In KidSize (40-90cm height) teams compete with four players per team and in TeenSize (80-140cm) with two. In Adult Size (130-180cm) one striker robot plays against a goal keeper robot first and then the same robots play with exchanged roles against each other. In parallel to the soccer games, the technical challenges are run as another competition which addresses specific individual robot (like throw-in, dribbling around obstacles) and team skills (e.g. multiple double passes) required to advance research and development of humanoid soccer robots.

With its focus on autonomous robots with human-like body plan and senses, the league has a unique profile in humanoid robotics. Perception and world modeling have to cope with human-like external sensing, i.e., vision with human-like limited field of view and hearing. It is not allowed to simplify these by using nowadays popular, non-human like active range sensors. A significant aspect of human-like embodiment is the strong restriction of the foot size with respect to the height of the center of mass requiring to deal with dynamics and stability of walking. To cope with the high uncertainty in perceiving the state of the world, a humanoid robot must strongly coordinate visual perception with body motions to search for and track objects of interest properly while planning and performing versatile bipedal locomotion minimizing the likelihood of falls.

Back in 2002 almost all robots struggled with basic locomotion capabilities like standing on one leg, walking and kicking. Nowadays and despite the strong requirement for a human-like body plan and senses, teams of autonomous humanoid robots in Kid and Teen Size perform fast and exciting soccer games with many goals. Some of the best autonomous humanoid robots in the world with most versatile and robust motion abilities regularly compete in the Humanoid League.

Since the beginning of the Humanoid League, every year the Louis Vuitton Humanoid Cup, a crystal globe crafted by Baccarat, is awarded to the overall best humanoid robot. The award winning team is entitled to hold the Cup for a year until the next RoboCup World Championship event.

Since 2006 every year a workshop dedicated on the scientific challenges and progress in humanoid soccer robots is being held at the annual IEEE-RAS International Conferences on Humanoid Robots.

[Picture of Humanoid TeenSize: http://wiki.robocup.org/wiki/File:HI-teen.jpg ((C) D. Kriesel)]

Conclusion

RoboCup is nowadays one the main international events in Artificial Intelligence and Robotics. The impact of RoboCup spans over science, education, and society. The RoboCup Symposium is the scientific venue, where the RoboCup researchers present their technical solutions to the scientific community. The proceedings of the RoboCup Symposium are yearly published, since the first edition in 1997; furthermore, contributions arising from RoboCup research and practice consistently appear in a variety of forms, including master and PhD theses, and the multiple publication venues in Artificial Intelligence and Robotics. RoboCup also offers significant soft skill training effects for young researchers working together in a team for a common goal in a limited timeline. Despite the competition framework, all participants enjoy a very open, cooperative, and enthusiastic atmosphere and unique experience.

The robot Quince from RoboCup Rescue was deployed during the rescue operations in the Fukushima-Daiichi Nuclear Power Plant. Kiva Systems, of whose one of the technical founders was a very successful RoboCup researcher, revolutionized automation by using hundreds of mobile robots for storing, moving and sorting inventory. Aldebaran Robotics' NAO robots are recognized worldwide by research labs in robotics and have quickly become a commercial success, also after it was introduced and seleted at RoboCup 2007 for a standard robot soccer platform.

The success and achievements of RoboCup have been supported by its dynamic organization that is continuously considering new challenges and yearly revising the rules and conditions of each of its leagues in response to the technical and scientific accomplishments and interests of the research community, while keeping always on its roadmap towards its ultimate multiple goals.

References

[IJHR 2008] Special issue on humanoid soccer robots, International Journal of Humanoid Robotics: Volume 5, Number 3, September 2008.

[RAS 2009] Special issue on humanoid soccer robots, Robotics and Autonomous Systems, Volume 57, Number 8, July 2009.

[RC1997] H. Kitano (Ed.), RoboCup 1997: Robot Soccer World Cup I, Springer Verlag, 1998.

[RC1998-2013] Robot Soccer World Cup II-XVIII, Springer Verlag, 1999--2014.

[RR12] R. Sheh, A. Jacoff, A.-M. Virts, T. Kimura, J. Pellenz, S. Schwertfeger, and J. Suthakorn, “Advancing the State of Urban Search and Rescue Robotics through the RoboCupRescue Robot League Competition,” in *Proceedings of the 8th International Conference on Field and Service Robotics (FSR2012)*, 2012.

[H09] T. Wisspeintner, T. van der Zant, L. Iocchi, S. Schiffer, "RoboCup@Home: Scientific Competition and Benchmarking for Domestic Service Robots", *In Interaction Studies*, vol. 10, no. 3, pp. 392-426, 2009.