RoboCup@Sapienza

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1 RoboCup

RoboCup was started in 1997 by a group of Artificial Intelligence and Robotics researchers with the following grand challenge, to be achieved by 2050 [9]: "*to build a team of robot soccer players, which can beat a human World Cup champion team.*"

Since then, RoboCup Federation[1] established itself as a structured organization and as one of the major events in the research field of Artificial Intelligence and Robotics. A quote from the website of the RoboCup Federation, best describes its objective.

> *It is our intention to use RoboCup as a vehicle to promote robotics and AI research, by offering a publicly appealing, but formidable challenge. One of the effective ways to promote engineering research, apart from specific application developments, is to set a significant long term goal. When the accomplishment of such a goal has significant social impact, it is called grand challenge project. Building a robot that plays soccer by itself does not generate significant social and economic impact, but the accomplishment will certainly be considered as a major achievement of the field. We call this kind of project as a landmark project. RoboCup is a landmark project as well as a standard problem.*

Currently, the major scientific international events include a section dedicated to Robotic Soccer aiming at the grand challenge. A number of regional events have also been established as well, some reaching a size almost comparable to the main event. RoboCup has a broad international participation, with teams from more than forty countries worldwide.

The competitions inspired to soccer have different formats and address different research challenges. 2D and 3D soccer simulation leagues are performed in a simulated environment, where each simulated robot has limited and noisy perception of the environment; participant teams are required to develop software for each single robotic agent and for their coordination. The research focus in these simulation leagues is on multi-agent systems, coordination, learning, and game strategy. The small size-league is characterized by small wheeled robots (18 cm in diameter), playing in two teams of up to 6 robots in a field of 6 m x 4 m, using an orange golf ball. In this league, an external vision system allows for accurate perception and the main challenges are fast motion, planning complex actions and learning opponent behaviors. In the mid-size league, robot size is about 50 cm x 50 cm and two teams of 5 robots each play on

[1] www.robocup.org

a 18 m x 12 m field using a standard yellow or orange size 5 soccer ball. Here local perception requires sensor fusion as well as distributed approaches to robot coordination. Standard platform league is currently played with the Aldebaran NAO humanoid robots (formerly with the Sony Aibo), with two teams of 5 robots playing in a 9 m x 6 m field using an orange street hockey ball. In this league, in addition to the issues of the mid-size league to be addressed on a more challenging platform, the interaction between perception and action plays a critical role. Finally, the humanoid robot leagues (kid, teen and adult sizes), playing in a field similar to the one used in the Standard platform league, encompass all of the above mentioned issues, on top of a dedicated hardware development.

The second main section of RoboCup competitions targets systems with a more direct impact on our society. RoboCup Rescue is focussed on robots supporting human rescuers in the aftermath of disasters (e.g. Fukushima nuclear accidents or L'Aquila earthquake). This section includes both 2D and 3D simulated leagues as well as a main robot league, where robots perform several rescue tasks in arenas defined by the National Institute of Standards and Technology (NIST). RoboCup@Home addresses the development of robots that interact with humans helping them in home environments. The competition is performed in an arena reproducing an apartment with typical layouts and furniture, that is not known before-hand by the participating teams. Moreover, some test are executed in the public space of the main venues hosting the event, as well as in real restaurants, shopping malls nearby. Finally, more recently, RoboCup@Work has been set up as a league aiming at a new generation of industrial robots. In this league mobile manipulators are used for executing tasks related to manufacturing, automation, and general logistics.

The third section of RoboCup is dedicated to competitions among juniors. 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 through hands-on experiences with electronics, hardware and software.

In this paper, we overview the achievements of the group at Sapienza first in terms of participation and results in the competitions and then in terms of research contributions. We conclude by discussing the impact of RoboCup@Sapienza and by providing a retrospective analysis.

2 Participation and results

The Italian community joined RoboCup since its first edition, and our research group at Sapienza University of Rome, in 1998. Since then, we participated in RoboCup competitions, first within the ART national Italian team[2] and from 2001 as the SPQR team[3]. Figure 1 shows the evolution over the years of the robotic platforms used for the soccer competitions, moving from wheeled robots, to four-legged and finally to small humanoid robots; while Figure 2 shows rescue and @Home robots.

Moreover, Daniele Nardi is currently President of the RoboCup Federation (since 2011), and he has been Vice-President (2008-2011), and Trustee (since 2003). Luca Ioc-

[2] www.dis.uniroma1.it/ART
[3] spqr.dis.uniroma1.it

chi is Trustee (since 2013), formerly Executive for the RoboCup@Home league. They also contributed in the organization of scientific events, (e.g., co-chairs of RoboCup Symposia, workshops in international conferences, special issues in AI and robotics journals), as well as in the organization of regional competitions (such as Mediterranean Open 2010 and 2011, RomeCup, etc.).

Fig. 1. Soccer robots used in RoboCup: a) ART - Middle-Size (1998-2000), b) SPQR - Sony AIBO ERS-210 (2001-2003) c) SPQR - Sony AIBO ERS-7 (2004-2007), d) SPQR - NAO Humanoid (since 2008).

RoboCup was brought to the attention of the Italian Artificial Intelligence community by Luigia Carlucci Aiello and by Enrico Pagello, who organized a well attended workshop in the Fall 1997. After that a joint project ART (Azzurra Robot Team) (Figure 1 a)) [11, 12] was sponsored by Consorzio Padova Ricerche and supported by the Italian National Research Council. Daniele Nardi was the CT (Technical Coordinator) of the project. The first kicks to the ball by ART robots started in the Spring 1998, and the first participation in RoboCup was in 1998, Paris. In 1999, at JCAI Stockholm, ART obtained the second place in the mid-size league. The project ended in 2000 after winning a European championship in the Netherlands, and participating in RoboCup 2000 in Melbourne.

In 2000, the first SPQR (Soccer Players Quadruped Robots) team from Sapienza, entered the Sony Aibo league (Figure 1 b)), obtaining the fourth place. Since then, SPQR participated in the league till 2007, with different generations of AIBO robots (Figure 1 c)), reaching the quarter finals and developing several technical contributions, including the pass that won the "Best Demo" Award at AAMAS 2008 [13].

Fig. 2. Robots used in RoboCup Rescue and @Home: a) SPQR - Rescue robot (2003-2004), b) RoboCare - @Home robot (2006).

In RoboCup 2003, Padova, SPQR joined the new RoboCup Rescue Competition. SPQR then participated both in the Real Robot Rescue League (Figure 2 a)) and in the Virtual Robot Simulation League, building on the results achieved through a collaboration with the Italian Firemen Dept. In the Virtual Robot Simulation League SPQR team obtained the 3rd place in 2007 and won the Technical Challenge for the Human Robot Interface in 2009. Moreover, during RoboCup 2009, members of the SPQR team made the first demonstration in RoboCup Rescue with quadrotors.

In RoboCup 2006, Bremen, we obtained the third place in the RoboCup@Home league, based on the platform developed within RoboCare[4] (Figure 2 b)), the first Italian Project addressing the use of robots in a home environment to help the elderly people.

Since Robocup 2008, Suzhou, China, SPQR participated in the NAO humanoid league (Figure 1 d)), also teaming up with Univ. Santiago, Chile (2010). Worth mentioning is the first goal ever scored in the humanoid competitions with a back-kick. This year, SPQR won the Iranian Open, and obtained the third place in the German Open. In the last RoboCup in Eindhoven, SPQR was eliminated at the end of the second phase, because of the goal difference, after winning four games in a raw and loosing only the last one!

3 Research

Our participation in RoboCup has been motivated in the first place by the research challenges put forward by the competitions. Our experience in mid-size league focussed on two topics: localization and cooperation. Initially, we looked at specialized methods

[4] robocare.itsc.cnr.it

for localization that are applicable in RoboCup by looking at the lines of the soccer field [7]. After this initial work, localization and SLAM (Simoultaneous Localization And Mapping) have become one of the key research lines in our group. Cooperation among robots is needed in robot soccer and achieving it in a national team poses outstanding technical and scientific challenges. ART has been the first example of national team, and the key feature for success was the ability of the robots to cooperate through a simple, but effective approach, based on dynamic task assignment [4, 8], that afterwards has been a minimal prerequisite for all robot soccer teams. Cooperation and coordination became another research line in our group. We have then developed multi-robot systems for a variety of applications, including exploration and surveillance.

One of the most important abilities for soccer robots is understanding the situation through on-board sensors, in particular vision. An important challenge is thus real-time image processing and understanding with limited computational power. In this context, we developed an efficient method for color segmentation [6], that provides increased robustness to variable illumination conditions. Moreover, analysis of RGB-D data of cameras looking at the soccer field has been used to estimate the ground truth pose of the robots and the ball, useful for many evaluation tasks [14].

The results and competences acquired through the mid-size robots, have been exploited in two directions. First of all, the approach to teamwork for robot soccer has been the basis for our subsequent participation in the standard platform league. The design of an autonomous mobile robot has also been transferred into the realization of autonomous rescue robots, capable of exploring indoor environments, dangerous to enter for humans, searching for victims. Further developments on the wheeled rescue robots led to new strategies for navigation and exploration [3] as well as to novel approaches to the design of the interface for the remote operator controlling multiple robots [15].

Once we started working with legged robots, we had to deal with locomotion. While this is not a major research direction in our group, we were able to establish fruitful collaborations [19, 16], to apply learning techniques [5] and to develop new features in a 3D realistic simulator [17] (Best Paper Award at RoboCup Symp. 2006).

Given our background in knowledge representation and reasoning, our long term goal is to use symbolic representations and, specifically, devise plans for robot actions. After few years focussed on the development of basic skills, we were able to support the development of our systems with an explicit representation of actions and plans. To this end we developed a formalism, called PNP (Petri Net Plans) [18], that allows for several advanced features, such as sensing actions, parallel execution, interrupts and communication among agents. Using this formalism, we provided an explicit model of the pass [13], and showed how plans can be refined through learning [10].

Last, years of experience in the design of software for robotic systems led us to deliver our development environment OpenRDK [2], based on a blackboard architecture that supports data exchange among the modules as well as the ability to inspect data and processes and thus to build tools that suitably support debugging.

4 Impact

The presence and impact of RoboCup at Sapienza was far beyond our initial expectations: more than 200 students contributed over the years, with several master theses, projects and course work. At least half of them had the chance to participate in an International event. Our activity in RoboCup substantially contributed to the creation in 2009 of the Master Course (Laurea Magistrale) in Artificial Intelligence and Robotics, which is still one of the few curricula in Italy with a significant AI component.

We started RoboCup Camps, to share within the community the result of winning teams, thus fostering progress in the field. We organized RoboCup Camps, for mid-size (Padova 2000), for four legged robots (Paris 2001), and for Rescue Robots (Rome 2004-2007). The success of this kind of hands-on schools extended outside RoboCup.

Robot competitions are sometimes viewed as pure educational activities of limited interest for research. However, the European Community has recently recognized the role of competitions by integrating its research programs on robotics with specific initiatives, supporting the benchmarking of robotic systems through competitions. Our research group is a member of the RoCKIn[5] Coordination Action, started January 2013.

While RoboCup aims at a grand challenge with no direct application to real life problems, several offsprings of RoboCup have become success stories, such as Kiva Systems, Aldebaran Robotics and the Quince Robot in Fukushima. Our best success story at Sapienza is the ARGOS system [1], currently deployed in the Grand Canal in Venice to track boats, that was built on the expertise acquired in tracking robot soccer players and the ball on a green carpet.

Finally, our RoboCup activity has attracted the interest of the media and of several initiatives aiming at promoting science and technology. We have been invited in several television programs in the main national Italian channels. Moreover, we have been organizing demonstrations at museums, exhibits and social spaces bringing the research in Artificial Intelligence to the attention of the general public. In particular, we have contributed in the organization of RomeCup (since 2009), mostly focused on RoboCup Junior and of Mediterranean Open (2010-2011), with international competitions of humanoid soccer robots.

5 Retrospective

In conclusion, we certainly did not expect all the above when we started more than fifteen years ago: RoboCup has become a well-recognized and well-established approach to research and education in Artificial Intelligence and Robotics and it has been a very successful driver for the research and academic development of our group.

Obviously, nothing comes without problems, and for those readers that might now be considering undertaking a similar project, here are potential difficulties they may have to face.

The first issue is financing: it is not easy to acquire the money needed to support the project. In fact, funding agencies (with few exceptions among which the grant we

[5] http://rockinrobotchallenge.eu/

obtained by Italian National Research Council), do not provide schemes to support projects that directly target competitions, unless they are sponsoring the competitions themselves (as in the case of the ongoing DARPA Challenge, or, more recently, the European Community). Consequently, we had to collect the budget to buy the robots from our university and from sponsorships, as detailed in the acknowledgements. However, any residual money from other projects has been absorbed by our RoboCup activities.

A second key issue is the cost in terms of human resources: besides hunting for funding, managing teams of students, driving them towards successful implementations, while keeping a focus on research goals are time consuming tasks. In particular, teamwork has been a real challenge and sometimes a source of difficult relationship among the team mates; the motivations that lead to enter a competition are often strong, and can give rise to stressful situations.

Another challenge is the maintenance of both hardware and software. While this is a well-known issue for projects that target robotic prototypes, robots that play soccer break more often than ordinary robots. Moreover, the software running on the platforms is difficult to maintain, not only because of the frequent releases of components that are needed for the competition, but also because the software is developed by students that leave after a big final rush of implementation, that is usually not released in a form that supports re-use by others.

It is sometimes argued that it is difficult to keep the right balance between engineering and research, when designing and implementing systems for a competition. This is the subject of an ongoing debate in the research community: our contribution to it can be easily inferred from the results presented in this paper. Finding the right balance is a challenge, but there is a significant pay-off both in terms of research achievements and in terms of the contribution to the student's skills and capabilities. Consequently, we keep going on.

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