The RoboCupRescue Robot League: Guiding Robots Towards Fieldable Capabilities

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***Abstract*—The RoboCupRescue Robot League is an international competition where teams from all over the world compete against an arena that allows them to demonstrate their advanced robotic capabilities for emergency response applications. The league is also a community that works together to advance the state-of-the-art towards improving performance and the standards that help quantify this performance. In this paper, we present the current state of the competition, its links to the wider standardization process and how it is guiding robots towards fieldable capabilities.**

I. Introduction

The International RoboCup Competition is perhaps best known for its soccer playing robots, which aim to beat the winners of the human World Cup by 2050. Since its earliest years, RoboCup has also been the venue for a somewhat different competition, the RoboCupRescue Robot League (RoboCup RRL), which focuses on robots that can save lives [1]. The latest competition, held in Istanbul, Turkey, brought together 16 teams from 11 countries.

The RoboCup RRL focuses on the development of advanced robotic capabilities for emergency response applications. Teams from all over the world bring robots that demonstrate these capabilities. They compete in an arena, shown in Figure 1, based on standard test methods, developed with the active collaboration of first responders, industry and researchers. The competition aims to increase the awareness of the challenges posed by USAR applications, objectively evaluate robotic implementations in representative environments, promote collaboration between researchers and educate emergency responders about emerging robotic technologies and capabilities. In this paper, we report on the current state of the competition and the relationship between the competition, test methods and recent world events that have refocused attention on the increasing applicability of such robots.

The competition draws teams from academic institutions all around the world who focus on different robotic technologies and approach the competition from differing perspectives. The wide variety of configurations, compared to typical commercial implementations, provides the opportunity to refine test apparatuses, procedures and metrics. This ensures that they provide appropriate benchmark performance evaluations to address and challenge evolving robot designs. In addition to the competition itself, the RoboCup RRL is a community that aims to foster collaboration and improvement towards the task of developing technologies for emergency response applications. Teams that demonstrate innovation and best-in-class robot capabilities are encouraged to disseminate those solutions at annual camps to enable researchers and their technologies to move forward faster towards eventual deployment. The aim is for teams to share their innovations and developments and to compete together, against the application.

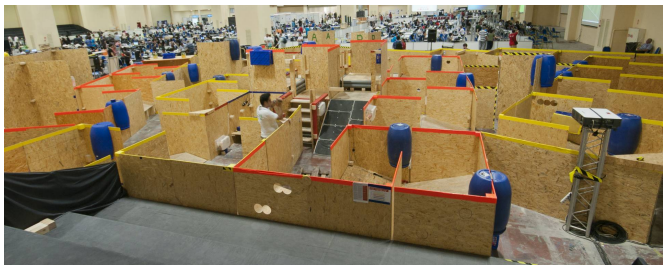

Fig. 1. The 2011 RoboCupRescue Robot League arena in Istanbul, Turkey.

II. The Competition

The RoboCup RRL is first and foremost a competition that puts teams up against an application, represented by the arena. Teleoperated and autonomous robots must complete missions within the arena where they traverse terrain of varying difficulty to find simulated victims, determine their vital signs, deliver aid to them and build a map that would allow rescuers to safely locate and rescue them.

The RoboCup RRL champion is the team that demonstrates consistent excellent performance throughout all areas of the competition. This year's Champion team, along with second and third place, are shown in Figure 2. The championship is determined based on points that are awarded for the number of victims found, the quality of the information returned in their

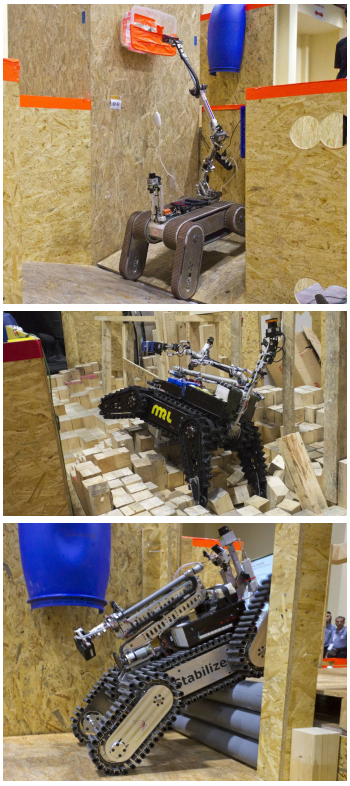

Fig. 2. The Champion team, iRAP Judy from Thailand, shown reaching for a victim in the Orange crossing ramps (top), Second Place team, MRL from Iran, shown in the Stepfields (center) and Third Place team, Stabilize, shown on the Pipe Step (bottom).

Fig. 3. The Best-in-Class Mobility winner, iRAP Judy from Thailand, shown in the Stepfields (top). The Best-in-Class Manipulation winner, YRA from Iran, shown placing a water bottle into a head-height victim box (center). The Best-in-Class Autonomy and Mapping winner, Team CASualty from Australia, shown in the Random Maze (bottom left) and with its generated map (bottom right, courtesy of The University of New South Wales).

maps and vital signs and the ability to bring objects, representing aid, to the victims. The victims are spread throughout the arena, requiring the negotiation of varying terrains. Some victims may only be found by autonomous robots, simulating situations in the real world where surroundings restrict radio contact between a robot and its operator. Thus in order to score well a team must bring a wide variety of capabilities in reliable, well engineered implementations.

However, the RoboCup RRL also seeks to encourage specific innovation in a very diverse range of capabilities applicable to this task, innovation that requires considerable expertise and specialization. To this end, many teams that come to the competition don't aim to win the championship. These teams come from research groups that are small or specialized and thus find it difficult to field the breadth of capabilities that make a championship team. Instead, these teams aim to demonstrate best-in-class capabilities in specific and valuable aspects of the Response Robotics problem including Mobility, Autonomy and Mapping, Manipulation and User Interfaces.

The League encourages the entry of teams with specializations in these specific fields by supplementing the championship awards with Best-in-Class Awards for teams that demonstrate reliable, best-in-class performance in these areas. The best performing robots in this year's Best-in-Class Competition rounds are shown in Figure 3.

Best-in-Class Awards are determined in two parts. Teams are awarded points for demonstrations of specific capabilities within missions in the main competition. Each victim that a team finds in difficult terrain will give them one point towards the Best-in-Class Mobility award while each victim found by an autonomous robot scores a point towards Best-in-Class Autonomy and Mapping and each object delivered to a victim scores a point towards Best-in-Class Manipulation.

This score is combined with a score determined in a dedicated Best-in-Class Competition round. The arena is reconstructed to isolate these capabilities and allow teams to demonstrate them in dedicated test method apparatuses. Teams must demonstrate best-in-class mobility by driving 10 laps through a difficult terrain course. The Best-in-Class Autonomy and Mapping round is held in a large maze with non-flat flooring that robots must autonomously explore and map. The Best-in-Class Manipulation round requires robots to demonstrate the ability to grasp objects and move them to specific locations with speed, reliability and precision.

Teams with demonstrated best-in-class capabilities are encouraged to share their innovations with the rest of the RoboCup RRL community to facilitate the general improvement in the capabilities of all teams. As an example of this success, in the space of only a few years, the ability to

automatically generate 2D maps has spread from only a very small number of teams to the majority of teams in the league. 3D mapping and fully autonomous exploration of 3D terrain is also spreading through the RoboCup RRL community. This is assisted by camps and workshops, held around the world, where teams that demonstrate best-in-class performance have taught the rest of the community how to replicate their capabilities. The RoboCup RRL has also branched out internationally, with annual regional open competitions held in Germany, Iran, Japan and Thailand. These competitions provide a forum for an even wider variety of domestic teams.

The RoboCup RRL competition and community are continuously evolving, guided by the close relationship between the teams, first responders and the standards process. To this end, the rules that govern the competition change from year to year, guided by and disseminated through the camps and workshops held throughout the year. The rules also evolve during the competition, in daily meetings held with all team leaders, in order to adjust to the wide and varying capabilities brought to the competition. This process of continuous refinement helps to ensure that the rules remain fair, that realism is balanced with practicality and that exceptional performances in the demonstration of valued capabilities are properly rewarded.

III. The Arena

The competition always sees improvements in robot capabilities from one year to the next. As a result, the competition arenas become more challenging each year so that the top teams are effectively separated. Of equal importance is the need to provide teams that have specific, innovative approaches to specific challenges with a platform in which they may demonstrate their capabilities to encourage their use by other teams in future competitions.

The competition arena is based on draft ASTM International Standard Test Methods for Emergency Response Robots [2], developed by the US National Institute of Standards and Technology and sponsored by the Department of Homeland Security, Science and Technology Directorate. These are consensus standard test methods, developed with the active involvement of robotics researchers, commercial robot developers and test administrators and based on robot requirements provided by emergency responders. They provide researchers with specific performance goals in easy to replicate test apparatuses.

The test method apparatuses are incorporated into the arena as specific, standard obstacles that the robots must pass in the course of navigating the arena. For example, a *Mobility: Obstacles: Pipe Step*, shown at the right of Figure 2, consists of a variable height step with pipes that are free to rotate so that robots cannot rely on traction at the edge of the step. It is incorporated into the arena by placing it between the lower level of the arena and an upper level, where a victim may be found by the robot. In total, 12 draft test method apparatuses appeared in this year's arena. These test methods are in various stages of the standardization process.

Several of these apparatuses and associated standards were first developed or saw early refinement in RoboCupRescue arenas over several years, before being more widely disseminated through the standardization process. For example, the *Mobility: Terrains: Stepfields*, shown at the left of Figure 2 and the top of Figure 3, were introduced into RoboCupRescue in 2005 where their specifications were tuned in the presence of the wide variety of robots with varying approaches to mobility. They were first tested in their final form in the 2008 competition and have subsequently become an ASTM International Standard Test Method apparatus [3].

Likewise, the *Mobility: Terrains: Crossing Pitch/Roll Ramps* were first developed and evaluated during the 2008 competition where they were used to provide an additional challenge to robots that were able to handle terrain that was more difficult than continuous flooring, such as drops and small steps, but were unable to traverse the more difficult stepfields. These too have been promoted, largely unchanged, to ASTM International Standard Test Method apparatus status.

Teams in the RoboCup RRL bring capabilities from the lab that are yet to become available in the field. The close integration between the competition and the standards development process accelerates the development of new performance metrics for robot capabilities that may currently only exist in the research lab. For example, performance metrics for autonomous mapping and navigation in 2D and 3D environments, developed during NIST Response Robot exercises [4], have been refined in the RoboCupRescue competition. This refinement, in the presence of the wide variety of sensors and algorithm implementations presented by the many RoboCupRescue Robot League teams, and in collaboration with researchers, helps to improve the sensitivity, relevance and applicability of the metrics once such capabilities become available in fieldable robots.

IV. Application Outside the Arena

The RoboCup RRL has always been grounded in the reality of the application that inspires it. The relatively clean, safe environment of the arena may seem far removed from the chaotic, dirty, wet and hazardous environments that real response situations often entail. However, the specific challenges in the arena closely reflect those that exist in the real world, albeit presented in a way that balances realism against accessibility by researchers. After all, the RoboCup RRL seeks to encourage new and early innovations, which will in the future develop into field hardened implementations. Yet world events have seen members of the RoboCup RRL community participate in real environments, demonstrating the close linkage between the competition and the application.

Several teams in the competition have also sent robots, sensors or other capabilities to robot testing events hosted around the world at Urban Search and Rescue facilities in Australia, Germany, Japan, the US and beyond. These collaborations with the first responder community help to validate both the approaches that the teams have taken, as well as the overall direction of the RoboCup RRL.

Teams from Japan have long been involved in the domestic Japanese search-and-rescue community. This close collabo-

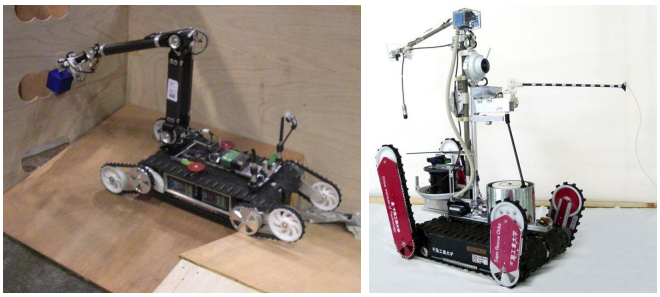

Fig. 4. The Quince robot, during the 2010 RoboCupRescue Robot League competition in Singapore (left) and equipped for inspection and monitoring within the Fukushima Daiichi Nuclear Power Station (right, courtesy of CIT, Tohoku University, IRS and NEDO).

ration is demonstrated in their domestic competition, which contains unique elements specific to Japanese buildings [5], and their robots which bear the hallmarks of development in collaboration with first responders with unique capabilities in manipulation and mobility, and unusual and specialised mechanisms such as snake-like robots. More recently, the 2011 competition saw the sudden withdrawal of several teams from Japan, when their robots and expertise were required in the aftermath of the 2011 East Japan Earthquake. For example, the Quince robot, the result of collaboration between the Chiba Institute of Technology (CIT), Tohoku University, International Rescue System Institute (IRS), and New Energy and Industry Technology Development Organization (NEDO) and shown in Figure 4, appeared in the 2010 RoboCup RRL competition as part of team Pelican United. They achieved considerable success, winning the Best-in-Class Manipulation award. After the earthquake, it was used first for collapsed building inspection in Sendai and later at the Fukushima Daiichi Nuclear Power Station Reactor Building of Unit 3 where it was used for visual inspection and to measure water and radiation levels [6].

Thailand also has a vibrant RoboCup RRL community with significant levels of support from both industry and government. The Thai domestic competition encompasses over 100 teams, only three of which are chosen to compete at the international competition. As a result of this highly competitive selection process, Thai teams perform exceptionally well.

In Germany, the RoboCup RRL community is also involved in wider development efforts for safety, security and rescue robotics (SSRR). For example, teams that participate in the RoboCup RRL also participate in events such as the European Land Robot Trials [7] which see teams of robots tested in military and civilian SSRR applications.

Iran also saw many teams that were inspired by the 2003 earthquake in Bam. Since 2004 they have also had a vibrant domestic RoboCupRescue Robot League competition and have been well represented at the international level with success both in the Championship as well as best-in-class performances.

V. Future Directions

The RoboCup RRL has seen considerable improvements in capabilities such as mobility and sensing. Going forward, the RoboCup RRL hopes to encourage development in autonomy, mapping, manipulation and user interfaces by adapting the rules to increase their importance. Autonomy in particular has been the subject of focus for several years and the league has progressed from only one or two viable autonomous robots to an active, competitive field with most teams having this capability. Reliable, capable autonomous operation is valuable in reducing the cognitive load on the operator, especially in tasks that precede the robot's actual work, such as navigating downrange or climbing stairs. Current best-in-class implementations are limited to continuous flooring. The League is encouraging teams to extend these capabilities to implementations that are able to autonomously overcome 3D terrain such as stairs and stepfields. 3D perception and mapping, likely to be a prerequisite for such capabilities, is also being encouraged. The ability to manipulate objects and bring them to victims in the arena is also encouraged, with the introduction of the Best-in-Class Manipulation award in 2009. As the league progresses, it is anticipated that more teams will use points gained in manipulation to augment their scores, just as mapping capabilities spread in past years.

The RoboCup RRL also aims to expand its community activities with more events held around the world where researchers may collaborate and exchange ideas. The annual workshops, started in 2004, have spawned several teams that have performed well and are now being augmented by workshops that focus specifically on software development in support of these robots. By bringing together a community of researchers, working together and in friendly competition, the RoboCup RRL hopes to guide new, emerging robotic technologies towards becoming fieldable capabilities.

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