RoboCup Rescue Robot and Simulation Leagues

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Abstract

The RoboCup Rescue Robot and Simulation competitions have been held since 2000. The experience gained during these competitions has increased the maturity level of the field, which allowed deploying robots after real disasters (e.g. Fukushima Daiichi nuclear disaster). This article provides an overview of these competitions and highlights the state of the art and the lessons learned.

Introduction

After the Great Hanshin Earthquake of 1995 in Kobe, the Japanese government decided to promote research related to the problems encountered during large-scale urban disasters. A major outcome of this initiative was the RoboCup Rescue competitions. In this article, we introduce the RoboCup Rescue leagues, namely the Rescue Robot League (RRL) and the Rescue Simulation League (RSL) (Tadokoro et al. 2000; Kitano and Tadokoro 2001).

Disaster mitigation is an important social issue involving large numbers of heterogeneous agents acting in hostile environments. The associated Urban Search and Rescue (USAR) scenarios have great potential for inspiring and driving research in multi-agent and multi-robot systems. Since the circumstances during real USAR missions are extraordinarily challenging (Murphy et al. 2008), benchmarks based on them, such as the RoboCup Rescue competitions, are ideal for assessing the capabilities of intelligent robots. Robots that can navigate through affected areas after a disaster, most likely will also be capable of negotiating the very same environment under normal circumstances. If robots are able to recognize humans entombed under piles of rubble of collapsed buildings, they will also be able to recognize them within their natural environment.

The goal of the RoboCup Rescue competitions is to compare the performance of different algorithms for coordinating and controlling teams of either robots or agents performing disaster mitigation in a simulated yet realistic environment. By their nature, the USAR scenarios demand solutions for the coordination of large and distributed teams of heterogeneous robots.

The competitions are held annually as a part of the RoboCup World Championships. In addition, regional competitions are held in RoboCup Opens such as the ones in US, Germany, The Netherlands, Japan, Iran, Thailand and China. The RoboCup Opens are organized by the national committees, whereas the international competitions are organized by league organization committees. The competition rules are determined by the technical committees whose members are elected annually.

Due to the complexity of the problems addressed in the competitions, the barrier for the entry of new teams is high. For this reason, the leagues have recently introduced several measures for facilitating software reuse among the teams.

In the following sections we describe the competitions in RRL and RSL.

Rescue Robot League

The Rescue Robot competitions started in 2000 as a part of the AAAI Mobile Robot Competition and Exhibition, and was later integrated into RoboCup in 2001. In 2012, approximately 100 teams competed in the regional opens; 11 teams from seven nations qualified for the world championship in RoboCup 2012 held in Mexico City.

The objective of this league is to promote the development of intelligent, highly mobile, dexterous robots that can improve the safety and effectiveness of emergency responders performing hazardous tasks. Annual competitions and subsequent field exercises with emergency responders are used to:

- Increase awareness about the challenges involved in deploying robots for emergency response applications.

- Provide objective performance evaluations based on DHS-NIST-ASTM International Standard Test Methods for Response Robots.

- Introduce Best-In-Class implementations to emergency responders within their own training facilities.

- Support ASTM International Standards Committee on Homeland Security Applications (E54.08.01).

The main task of the competition is to find simulated victims emitting several signs of life in a maze with different levels of harsh terrain, and to indicate the location of the victims and of automatically detected landmarks on a map

generated by the robot online. The signs of life can be the visual appearance and movements of the victims, simulated body heat, CO_2 levels, and audio signals. The harsh terrain is built of different ramps, stairs, and so called "step fields", which is a normed pattern of wooden blocks resembling the structure of a rubble pile (see Figure 1).

Figure 1: Rescue robot of team Stablize from Thailand inspects a simulated victim near a step field at the RoboCup 2012.

Both remote controlled and autonomous robots are allowed in the competitions to foster the improvement of the mobility of the robots, human-robot interaction, and the development of autonomous agents that are capable of handling such unstructured environments. To highlight the achievements in these categories special awards are given for *Best-in-Class Autonomy*, *Best-in-Class Mobility*, and *Best-in-Class Manipulation*.

Due to the use of standardized test elements, the progress of the league over the years can readily be seen. When the random step fields were introduced in 2005, none of the robots were able to cross them in a reliable manner. Today, driving through the step fields is the state-of-the-art for the remote controlled robots. During the same time, fully autonomous robots had to learn handling uneven terrains since their section of the arena was no longer flat, but increasingly filled with continuous or crossed ramps. Such a challenging environment increases the complexity of path planning and requires an active sensing approach with stabilized distance and victim sensors. Nevertheless, the quality of the generated maps have increased over the years, and all of the competing teams can now map the whole arena. An example of a very precise map is given in Fig. 2. This map shows both the obstacles in the arena, and also the victim locations and other landmarks found autonomously by the on-board vision system. These maps are scored based on the completeness of the exploration and accuracy.
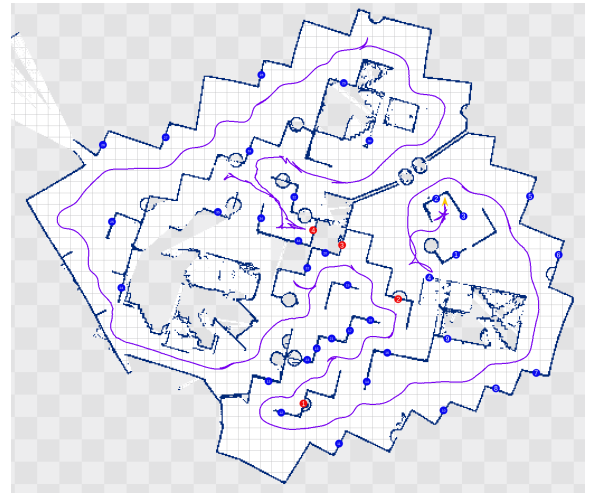

Figure 2: Map generated by an autonomous robot of team Hector from TU Darmstadt (RoboCup RRL Final 2012).

The scientific output of the league over the years include online SLAM solutions (Kohlbrecher et al. 2011; Pellenz and Paulus 2009; Kleiner and Dornhege 2009) and solutions for efficient exploration strategies (Wirth and Pellenz 2007). The performance of these approaches were demonstrated and tested in practice during several RoboCup competitions. The mapping system introduced by Kleiner *et al.* has also been integrated into a commercial robot platform for bomb disposal by the German company *telerob GmbH* and has also been nominated for the EU technology transfer award for 2011. The robot *Quince* developed by Japanese universities and evaluated in the RRL in various iterations, was finally deployed at the Fukushima Daiichi nuclear power plant in the aftermath of the massive earthquake and tsunami that hit eastern Japan in 2011. It was used for inspection missions in highly contaminated areas (Nagatani et al. 2011).

The league has recently established an open source standard software solution based on ROS which makes the best algorithms broadly reusable thus enabling the new teams to reach quickly to the world class performance level.[1]

Rescue Simulation League

This league aims to develop realistic simulation environments for benchmarking intelligent software agents and robots which are expected to make rational decisions autonomously in a disaster response scenario. RSL has two major competitions, namely the *Agent* and the *Virtual Robot* competitions. There are described in the subsequent sections.

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[1] The current status of the common software framework for RoboCup Rescue initiative is documented in the ROS wiki at http://www.ros.org/wiki/robocup_rescue.

Agent Competition

The rescue agent competition aims to simulate large scale disasters such as earthquakes and explore new ways of autonomous coordination of heterogeneous rescue teams under adverse conditions (Kitano et al. 1999; Tadokoro et al. 2000). This competition was first demonstrated during RoboCup 2000 and was later launched as an official competition in 2001.

About 25 university teams participate in the agent competition annually. These teams have their background mainly from AI and robotics, and come from different countries such as USA, Japan, Germany, England, Portugal, Turkey, Iran, China. Table 1 summarizes the number of teams that participated during the last years.

Table 1: The numbers of teams that participated in the Agent competition during the last years.

2001	2002	2003	2004	2005	2006
7	8	30	34	40	42
2007	**2008**	**2009**	**2010**	**2011**	**2012**
31	35	22	33	21	22[a]

[a]Includes six teams of the "RMasBench" challenge.

The competition is based on a complex simulation platform representing a city after an earthquake (Figure 3). Due to the variations among potential disaster scenarios, typically rather than a single agent type, strongly diverse teams of agents are required. In the competitions, teams of fire brigade, police and ambulance team agents try to extinguish fires and rescue victims in the collapsed buildings. The scoring is based on the number of victims saved on time and the number of remaining buildings with various levels of fire damage. The urban areas considered in the competitions typically contain up to 5000 buildings and the each of the fire brigade, police and ambulance teams may consist of at most 30 agents. There may be up to 200 civilians that need to be rescued.
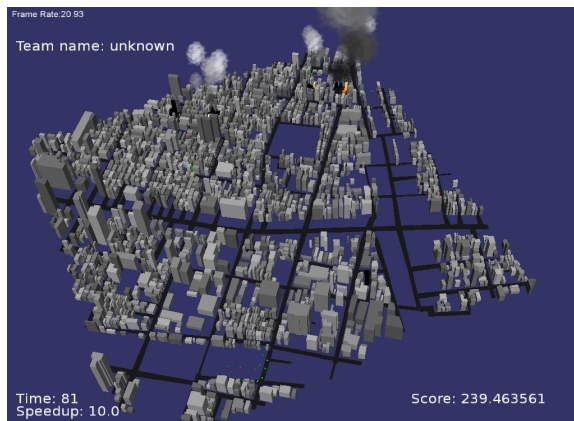

Figure 3: A typical scenario involving the simulation of fires and building collapse on a model of the city of Kobe in Japan.

The overall goal of developing robust software systems that are capable of efficiently coordinating large agent teams for USAR raises several research challenges such as the *exploration* of large scale environments in order to search for survivors, the *scheduling and planning* of time-critical rescue missions, *coalition formation* among agents, and the *assignment* of agents and coalitions to dynamically changing tasks. In the target domain, these issue are even more challenging due to the restricted communication bandwidth. Moreover, the simulated environment is highly dynamic and only partially observable by the agents. Under these circumstances, the agents have to plan and decide their actions asynchronously in real-time while taking into account the long-term effects of their actions.

Over the years the winning entries in the competition showed a strong focus on highly optimized computations for multi-agent planning and model-based prediction of the outcome of the ongoing incidents. Several techniques for multi-agent strategy planning and team coordination in dynamic domains have also been developed based on the rescue simulator. Task allocation problems inherently found in this domain were first described in (Nair et al. 2002). The solutions developed for the distributed constraint optimization problems (DCOPs) encountered during the simulations were evaluated in (Ferreira et al. 2010). The coalition formation with spatial and temporal constraints (CFST) model and the state-of-the-art DCOP algorithms used for solving CFSTs were given in (Ramchurn et al. 2010). The problem of scheduling rescue missions were identified and described together with a real-time executable solution based on genetic algorithms in (Kleiner et al. 2005).

Furthermore, there has been substantial work on building information infrastructure and decision support systems for enabling incident commanders to efficiently coordinate rescue teams in the field. For example, Schurr *et al.* introduced a system based on software developed in the rescue competitions for the training and support of incident commanders in Los Angeles (Schurr and Tambe 2008).

RSL aims to ease the entry for newcomer teams. However, the rich set of problems that need to be addressed by the agent teams competing in the competition and the degree of sophistication of current successful solutions makes this a non-trivial task. *RMasBench* (Kleiner, Dornhege, and Hertle 2011) is a challenge recently introduced for this purpose. Certain aspects such as task allocation, team formation, and route planning are extracted from the entire problem addressed by the agents and are presented as subproblems in stand-alone scenarios with an abstract interface. Consequently, the participating teams are able to focus more on the topics relevant to their own research rather than dealing with all of the low-level issues. Currently, *RMasBench* has a generic API for DCOP algorithms together with reference implementations of state-of-the-art solvers, such as *DSA* (Fitzpatrick and Meetrens 2003) and *MaxSum* (Farinelli et al. 2008).

In order to facilitate code sharing among the participating teams, a novel protocol for inter-agent communication is currently being developed in RSL to be integrated with the official release next year. This new addition will increase

the modularity of agent solutions and will also allow combination of different agent solutions within a single team.

Virtual Robot Competition

RoboCup Virtual Robot competitions are being held since 2006. The competition attracts mainly academic teams from universities often with experience in the RoboCup Rescue Robot League. The number of participating teams is typically eight (Table 2), but this is partly due to the strict qualification rules of this competition.

Table 2: The numbers of teams that participated in the Virtual Robot competition.

2006	2007	2008	2009	2010	2011	2012
8	8	10	11	5	6	4

The important research issues related to the competition are:

- *Utility-based mapping* - autonomous generation of maps from the fused data of multiple vehicles to be used by both robots and humans for exploration and marking victims.
- *Victim detection* - automatic detection of victims from fused sensor data (image processing, acoustics, etc.).
- *Advanced mobility* - robust control algorithms capable of autonomous navigation in small spaces on non-flat flooring.
- *Multi-robot control* the ability to control multiple platforms with a single operator in realistic environments means that the robots have to be semi-autonomous.

Originally a single scoring formula was used to evaluate the solutions associated with these issues. Simplified challenges were later introduced in 2009 to create more objective measures of performance. Each challenge was about a particular sub-problem with only one measure of performance and a corresponding automatic scoring tool. These challenges, namely mapping, navigation and coordination over a mesh network, were used for qualification for the semifinals. Since 2011 the challenges have been combined again into a single mission. The goal is now defined in terms of an entirely automated scoring procedure. The scoring program is expected to allow for head-to-head competition between two competing teams. This also allows permanent installations of servers, each with its own world, which can be used for testing in preparation of the RoboCup. In this way, the teams can test their approach prior to the competition hence providing a lower barrier of entry for new teams. Furthermore, the scoring procedure takes into account the individual sub-problems solved in the comprehensive challenge so that the teams can assess their performance in all of the domains independently.

The main challenge for the teams is the control of a large team of robots (typically eight) by a single operator. This is state-of-the art; the only real comparison is the champion of the Magic competition (Olson and others 2012), where 14 robots were controlled by two operators. The single operator has to use high level commands (such as the areas to be searched, routes to be followed, etc.) but is also needed to verify observations whether or not one of the robots has detected a victim (based on color and/or shape). Due to poor lighting and the number of occlusions, the conditions are generally not favorable for automatic victim detection, and manual conformation is always needed. The approach to a victim is quite critical (the robot should come within the communication range ($< 1m$), but is not allowed to touch the body or any of the limbs). This means that the workload for the operator is quite high, providing an advantage for the teams which are able to automate the decision making within the robot team as far as possible, and only involve the operator when needed.

The shared map generated during the competition has a central role in the coordination of such large robot teams. This is where the sensor information selected to be broadcasted via often unreliable communication links is collected and registered. The registration process is asynchronous; some information may arrive at the base-station even minutes after the actual observation. There is no guarantee that the operator has time to look at this information directly, which implies that the map within the user interface has to be interactive and should allow the operator to call back observations that were made at any point of interest (independent of when the observation was made and by which robot). At the same time the registration process should keep the map clean (no false positives or wrong associations), because it is the area where the coordination of the team behaviors is done.

Figure 4: Outdoor scenario for the Virtual Robot competition in the Dutch Open Final 2012.

In the final of the RoboCup 2012 competition the teams were able to find 12 of the 13 victims. The champion did this in 33 minutes (40 minutes were allowed). The competence level of the finalists is so high that next year the competition maps will have to be scaled up (both in size and difficulty). A possible way of increasing the difficulty of the competition is to include outdoor scenarios, as already demonstrated during the Dutch Open (see Fig. 4).

There are many publications related to this competition[2]. The approach of the winning team in RoboCup 2012 will be published in the Lecture Notes on Artificial Intelligence series (Amigoni, Visser, and Tsushima 2013).

Outlook

The next competition will be in June 2013 in The Netherlands, followed in 2014 by a competition in Brazil. Co-locating this competition with a demonstration of the progress of the teams participating in the DARPA Robotics Challenge is also intended. Information on the competition is available on several websites, software repositories and fora. A good introduction to both leagues can be found on the wiki of the RoboCup organization [3].

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[2]http://www.robocuprescue.org/wiki/index.php?title= Publications_on_Virtual_Robots_and_USARSim

[3]http://wiki.robocup.org/wiki/Main_Page#RoboCup_Rescue

algorithms for teamwork and contributions for real world by disaster simulations.

Adam Jacoff is a robotics research engineer in the Intelligent Systems Division of the National Institute of Standards and Technology (NIST). His current efforts are focused toward developing standard test methods for emergency response robots to objectively evaluate robot performance and support development of advanced mobile robot capabilities. He is a trustee of the RoboCup Federation.

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