# RoboCupRescue Robot League

Index International Exposition Center
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***League Chairs:***
*Adam Jacoff, National Institute of Standards and Technology (NIST), USA*
*Tetsuya Kimura, Nagaoka University of Technology, Japan*
*Satoshi Tadokoro, International Rescue System Institute (IRS), Japan*
*Andreas Birk, International University Bremen, Germany*

The RoboCupRescue Robot League made several important strides this year toward fielding advanced robotic technologies to support emergency responders performing urban search and rescue missions. Many of the twenty-six teams hosted in Osaka demonstrated capabilities built upon specific successes of previous year's implementations, and continued to push the state-of-the-art of small robots operating within unstructured environments (see Figure 1). Improvements in robot perception, navigation, mapping, and remotely teleoperative interfaces were demonstrated in updated arenas designed to challenge emerging capabilities and encourage innovative and practical solutions. The overall strength of this year's teams inspired growing confidence that robots can and will play a critical role in disaster response within the next few years.

***Figure 1. An overview of the RoboCupRescue Robot League arenas, teams, and robots.***

### Updated Arenas

The arenas used to host the competition were replicas of the *NIST Reference Test Arenas for Urban Search and Rescue Robots*, which were fabricated on-site by Japan's International Rescue System Institute. This year's arenas featured new *random step fields*, which were developed to help assess advanced robot mobility in complex, rubble-like terrains and confined spaces (see Figure 2 and 3). They use readily available components assembled into easily describable configurations to provide scalable mobility tests for large-size, mid-size (shown), and small-size robots. Variants of these random step fields will likely be proposed as standard test methods for advanced robot mobility in urban search and rescue applications, and this RoboCupRescue event provided an important opportunity to gain insight into their effectiveness as test artifacts and to refine their design. A wide variety of different robotic implementations attempted to negotiate these obstacles in practice sessions and during missions with varying degrees of success. Although the teams generally found them quite challenging for both locomotion and remote perception, robot performance clearly improved with each successive mission. After the competition, all the arena elements, including the random step fields, were divided among three Japanese robotics laboratories in Sendai, Yokohama, and Kawasaki. Since then, at least a few other teams have also built random step fields in their laboratories to facilitate development of advanced robot mobility and intelligent behaviors. In this way, the RoboCupRescue Robot League has played a key role in proliferating well-defined test methods that are essential to compare performance, and highlight successful approaches, for robotic implementations across countries and across continents.

***Figure 2: The RoboCupRescue Robot League arenas in Osaka, Japan. After the competition, elements of these arenas were distributed among robotics laboratories in Sendai, Yokohama, and Kawasaki, Japan.***

***Figure 3: Recently developed random step fields were used within the arenas to provide well-defined mobility challenges. And as always, simulated victims emitting various signs of life (human form, heat, sound, motion, and/or $CO_2$) provided the incentive for robots to search the arenas in their entirety.***

**Changes to the Rules**

Significant changes to the competition rules were implemented this year to lead the league ever faster toward developing innovative, practical, capable robots:

1. "Best-In-Class" missions were instantiated to separately evaluate two different capabilities: fully autonomous behaviors and advanced mobility platforms. The intent was to highlight effective sub-systems that could contribute to overall team implementations in the main competition. The scoring was abstracted for these missions so that simply attaining close proximity to the simulated victims accumulated points. Incapacitated robots could be "reset" to the start point to try again, but would loose all accumulated points and elapsed time in the mission. The "Best-In-Class" missions were conducted as follows:
    a. The fully autonomous robots operated within the complex hallways and rooms that formed the Yellow arena with generally limited flooring issues except for miscellaneous paper to disrupt wheel encoders. Autonomous behaviors such as wall following and centering between obstacles generally proved effective at negotiating this arena. 2-D and 3-D mapping of the environment was stressed. The Japanese Society of Instrument and Control Engineers (SICE) provided a "Best-In-Class: Autonomy" award for the winner.
    b. The advanced mobility robots negotiated the random step fields of the Red Arena as their minimum capability, but also operated on the stairs and ramps of the Orange arena. The

Japan Chapter of the IEEE Robotics and Automation Society (RAS) provided a "Best-In-Class: Advanced Mobility" award for the winner.

2. The main competition combined elements of the Yellow, Orange, and Red arenas into one continuous arena, which encouraged greater emphasis on mixed initiative solutions with remote teleoperation and bounded autonomous capabilities. The goal was to encourage improvements in robot performance (e.g. assistive capabilities for navigation or victim identification), development of effective operator interfaces to manage multiple robot teams to collaboratively search the arenas, and emphasize robot survivability (e.g. navigation behaviors to avoid hazards or recover from radio drop-out). For teams to find every victim in the arenas, they needed to traverse random step fields (Red arena elements), ascend/descend stairs (Orange arena elements), and autonomously navigate complex hallways (Yellow arena elements), all within the same mission. A few teams successfully demonstrated all three capabilities, while many more reliably demonstrated two of the three capabilities and noted that next year they would solve the third – or collaborate with other teams to do so.

3. All preliminary and semi-final missions were conducted concurrently in two similar arenas and operator stations. This allowed 50% more teams to participate while maintaining an emphasis on system reliability by having the teams attempt up to seven missions in different arrangements of the arenas over the course of the event. The mission start times in the concurrent arenas were staggered to provide continuous entertainment for the audience. In the final round of competition, the two arenas were combined into one large arena and mission durations were doubled.

**Robot Teams**

During this year's qualification process for the Osaka event, teams submitted team description papers and competed in regional open RoboCupRescue competitions in the USA and Germany. The league's technical committee selected 26 teams from 11 countries (Australia, Canada, France, Germany, Iran, Italy, Japan, Korea, Sweden, Thailand, and USA). They demonstrated a notable variety of robotic technologies for searching complex environments, finding simulated victims, and localizing and mapping their locations. This year's teams clearly improved upon last year's successes. Some of the awardee teams demonstrated break-through performances which are documented in their team description papers available on the competition website (*http://www.isd.mel.nist.gov/projects/USAR/competitions.htm*). For the first time a few teams used versions of the same basic robot, which is now purchasable although somewhat expensive. This similarity in mobility allowed direct comparison of higher-level approaches to sensors, algorithms, and operator interfaces. This trend should continue as lower cost mobility platforms demonstrate effective mobility and get adopted by various teams.

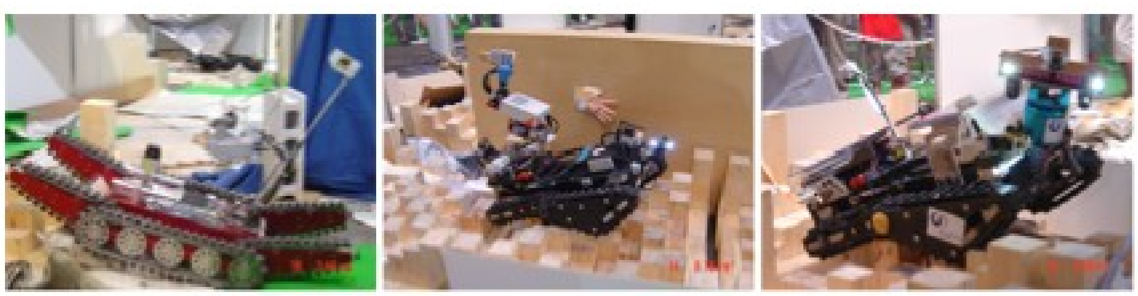

***Figure 4: The top three Place Awards went to capable mobility platforms deploying state-of-the-art sensors for mapping along with effective operator interfaces.***

*1st Place:* The Toin Pelicans team (see Figure 4a) from Toin University of Yokahama, Japan, repeated as winners this year. They were mainly recognized for their very capable, double tracked mobility platform with independent front and rear flippers. Their camera position, which was shown to be very effective last year (downward looking from above and behind the robot so as to contain the entire robot and surrounding area within the field of view), provided excellent remote situational awareness for the operator while allowing configuration management of the robot's flippers to facilitate mobility over large obstacles and within confined spaces. This year they added a small line scan laser range sensor to produce practical maps of the environment as well, making their overall implementation very effective.

*2nd Place:* The Roscue team (see Figure 4b) from the Korean Institute of Science and Technology, Korea, competed with a now commercialized robot of their own design. They demonstrated the general reliability of their robot, which was probably the most hardened system in the competition having already been fielded with military units. The overall effectiveness of their approach to quickly find and clearly map many simulated victims was evident mission after mission.

*3rd Place:* The Casualty team (see Figure 4c) from the University of Technology and the University of New South Wales, Australia, used a similar mobility platform as the 2nd Place team, but added a state-of-the-art ranging camera which captured range data of the scene at video frame rates to enhance their remote situational awareness of the environment and generated 3-D maps as well.

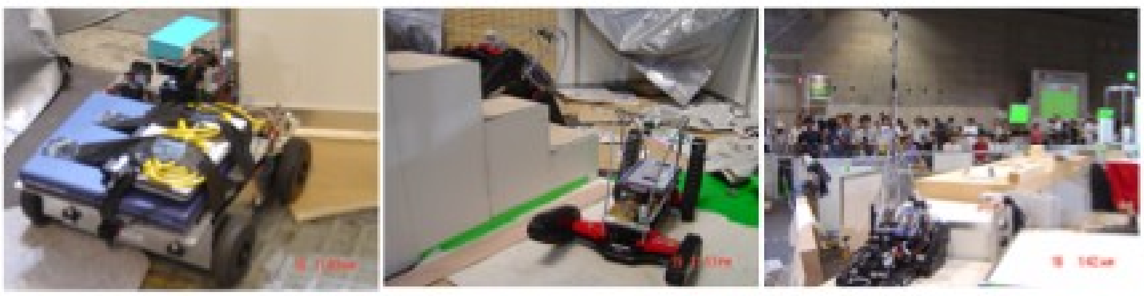

***Figure 5: The Best-In-Class Award winners***

*Best-In-Class Autonomy:* The Rescue Robots Freiburg team (see Figure 5a and 5b) from the University of Freiburg, Germany, demonstrated a mixed initiative approach with multiple robots: one fully autonomous robot and three remotely teleoperated tracked vehicle toys which they "robotized" for the competition. The fully autonomous robot competed alone in the "Best-In-Class Autonomy" competition (see Figure 5a), and although it had limited mobility it found the most victims in the Yellow arena. Their robotized tracked vehicle toys, however, showed great promise to support future development because they have independently controlled front and rear flippers and are capable of very agile mobility (see Figure 5b). Robotized toys such as this may provide very low cost, yet highly mobile platforms for teams interested in developing advanced mobility behaviors.

*Best-In-Class Advanced Mobility:* The Intelligent Robot Laboratory team (see Figure 5c) from the University of Tsukuba, Japan, used a very tall, vertically extending arm with a downward looking camera to provide exceptional remote situational awareness for their robot, which was otherwise very similar to the two Place Award winners. Their overhead perspective allowed them to control the robot's position somewhat more deftly than the others and their ability to stow it away to lower their overall center of gravity allowed them to cover more of the arena, including the random step fields, the stairs, and the ramps.

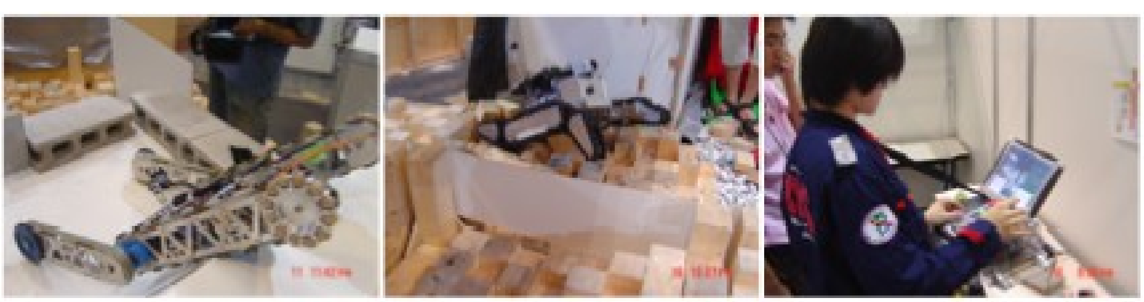

***Figure 6: The Innovation Award winners***

*Innovation Award:* The Shinobi team (see Figure 6a) from the University of Electro-Communications, Japan, was recognized for their lightweight robot – only 9 kg -- that demonstrated excellent maneuverability over the random step fields, the stairs, and the ramps. Their tracked front flipper design could also configure itself to ride on drive wheels in the tips of the flippers along with omni directional wheels in back to facilitate steering. This robot could go everywhere in the arenas it wanted due to it's lightweight yet functional design, and could get there fast! Only two unlucky interactions with a hanging fabric caught in the tracks prevented this robot from winning the Best-In-Class Advanced Mobility award. Its lightweight design made it an especially practical platform.

*Innovation Award:* The Resquake team (shown in Figure 6b), from the Toosi University of Technology, Iran, was recognized for their independently suspended, double tracked vehicle design which allowed each track to maintain contact with the ground while traversing the complex rubble in the random step fields. Most double tracked vehicles suffered from intermittent high-centering over such obstacles, but this design allowed its tracks to maintain enough contact to pull itself through such situations. The tracks could also vary their geometry in the front and rear to provide more mobility options when controlled properly.

*Innovation Award:* The Nutech-R team (shown in Figure 6c), from Nagaoka University of Technology, Japan, was recognized for their human wearable operator interface. The effectiveness of this lightweight approach will hopefully encourage teams toward smaller, more mobile operator interfaces that could allow operation in and around a rubble pile, on ladders, or anywhere else responders must go.

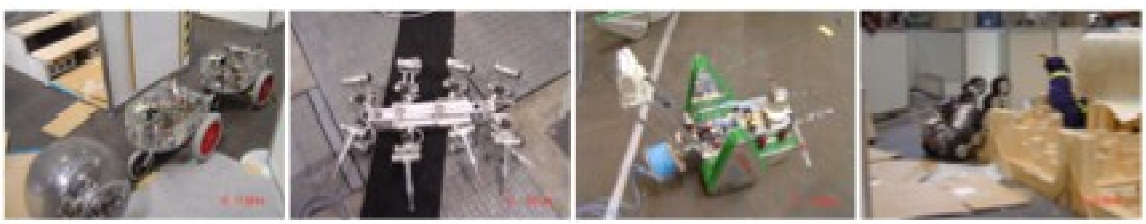

***Figure 7: Other interesting robots showed the variety of approaches being considered for urban search and rescue application.***

Many teams demonstrated successful elements of an eventual solution, but didn't happen to score well for one reason or another (see Figure 7 for a few examples). In general though, these teams expressed a clear desire to refine their systems based on the lessons learned in their mock deployment, and to come back next year with new and improved robots. The clear benefit of these gatherings is in the lessons learned by all teams as they watched their robots perform side by side with other robots. Such experiences will surely inspire new ideas which will move this league several steps closer to developing practical robots for emergency response that can help save lives.