AI Magazine Volume 23 Number 1 (2002) (© AAAI)

AAAI/RoboCup-2001 Robot Rescue

Jennifer L. Casper and Holly A. Yanco

■ The AAAI/RoboCup Robot Rescue event is designed to push researchers to design robotic systems for urban search and rescue. The rules were written to approximate a real rescue situation in a simulated environment constructed by the National Institute of Standards and Technology. This article discusses the arena, the rules for the 2001 event, the research approaches of the participants, and future challenges.

This year's Robot Rescue event was held in conjunction with the American Association for Artificial Intelligence (AAAI) and RoboCup at the colocated RoboCup and International Joint Conference on Artificial Intelligence. The year 2001 was the first year that the rescue event was part of RoboCup, and the second year that the event was held as part of the AAAI Robot Competition. The joint rules committee from RoboCup and AAAI brought two communities together to develop the rules and scoring method. There were four registered teams in the competition: (1) Sharif University, (2) Swarthmore College, (3) Utah State University, and (4) the University of Edinburgh. Additionally, several teams exhibited their robots in the rescue arena, including the University of South Florida and the University of Minnesota. This article discusses the 2001 Robot Rescue event: the course, the rules, the research approaches of the participants, and the final scores.

Robot Rescue League Arena

The robots competed and exhibited in the Reference Test Arena for Autonomous Mobile Robots developed by the National Institute of Standards and Technology (NIST) (Jacoff et al. 2001, 2000). The arena consists of three sections that vary in difficulty: The yellow section, the easiest region, is similar to an office environment containing light debris (fallen blinds, overturned table and chairs). The orange section is more difficult to traverse because of the variable floorings, second-story access by stairs or ramp, and negative obstacles. The red section, the most difficult section, is an unstructured environment containing a simulated pancake building collapse, piles of debris, unstable platforms to simulate a secondary collapse, and other random materials. Figure 1 shows the NIST arena floor plan.

Robot Rescue League Rules

Urban search and rescue (USAR) is defined as search and rescue efforts involving structural collapse and other urban environments (Fire 1993). The main task of USAR is to recover live victims. Robots involved with USAR must identify victims and send back the locations to trained medical rescue personnel for removal of the victims from the collapsed area. The Robot Rescue League rules, designed by the rules committee, keep the USAR task in focus by addressing several issues that arise in real USAR situations, such as the time to transport and set up the robot; the number of personnel required to run the robot; and, most importantly, accurate victim location.

The quantitative scoring equation includes the number of people required to operate the robots (fewer rescue personnel needed to control robots), the percentage of victims found, the number of robots that find unique victims (leading to quicker search times), and the accuracy of victim reporting (best to be as localized

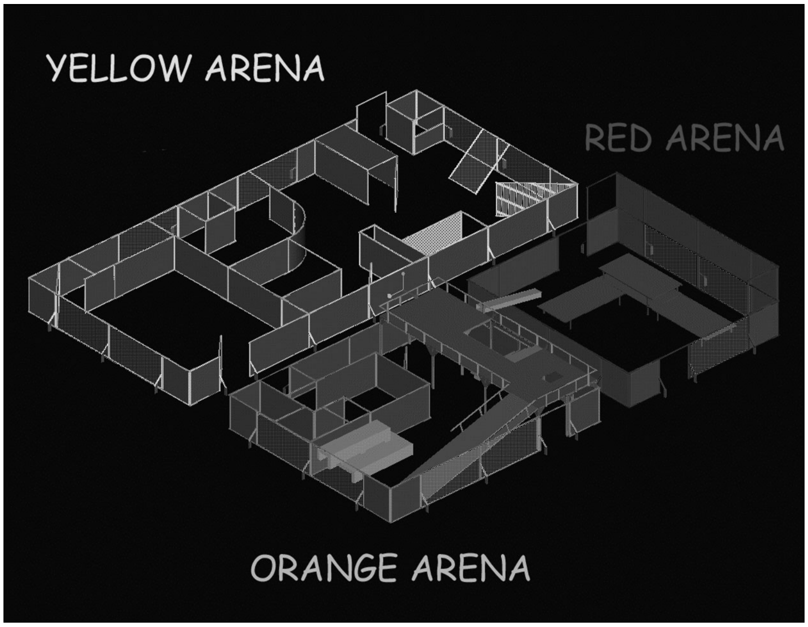


Figure 1. Diagram of the Reference Test Arena for Autonomous Mobile Robots Used for the AAAI/RoboCup 2001 Robot Rescue League (diagram courtesy of NIST).

$$\text{Score} = N^* \frac{N_r}{\left(1+N_o\right)^3} * \overline{A}$$

Figure 2. Quantitative Scoring Equation for the AAAI/RoboCup Robot Rescue Physical Agent League.

as possible). A team's score was computed using the equation in figure 2. Each team's final score was the best score from four 25-minute rounds. The variables used are as follows: *N*, a weighed sum of the victims found in each region divided by the number of actual victims in each region; *Ci*, a weighting factor to account for the difficulty level of each section of the arena ($C_{yellow} = .5$, $C_{orange} = .75$, $C_{red} = 1$); *Nr*, the number of robots that find unique victims; *No,* the number of operators; *F,* a binary value representing whether an indicated victim is actually present; *V*, the volume in which the reported victim is located, given by the operator in the warm zone to the judge; and, *A*, the mean accuracy measure determined by *F*/*V* averaged over all identified victims.

Robot Rescue League Competitors and Exhibitioners

Sharif University was the only competitor that was able to travel in the orange and red arenas (figure 3). The current version of Sharif University's rescue robot, EMDAD1, is teleoperated; an operator remotely controls the robot using a laptop connected to the robot through a TCP/IP WLAN and receives images and sounds from the scene the robot is moving through. EMDAD1's mechanical structure is composed of a tracked mechanism and a two–degree-of-freedom (2-DOF) pneumatic manipulator. This structure was designed and fabricated for moving over a 45-degree slope and passing over obstacles with a maximum height of 10 centimeters. The robot uses two acid 12-volt batteries permitting an operating autonomy of approximately four hours. The manipulator carries the cameras, the microphone, and the direct-current (DC) stepper motor for moving the mentioned sensors. A 1.5-liter polymer reservoir is used for reserving the pressured air.

The software developed for this robot consists of a user-friendly interface, control programs, simple versions of path drawing and planning, and stereo vision image-processing programs. In the next robot version, additional software will be implemented to provide more autonomy for victim detection, collision avoidance, and decision making.

Swarthmore College's MARIO & CO. entry consisted of two MAGELLAN PRO robots (figure 4). The robots have two modes of execution: (1) autonomous or (2) semiautonomous. A human operator is needed to observe or manipulate the robot's activity and to switch the robot between autonomous and semiautonomous modes. In the autonomous mode, the robot makes an extensive search of an unknown area by finding frontiers of unknown space and pursuing those that are the most promising. In the semiautonomous mode, the robot is able to execute low-level commands (such as move forward, turn, show sensor readings) or higher-level commands (such as going to a point while avoiding obstacles). This mode allows the human to make more strategic decisions and let the robot take care of the immediate environment.

Each robot also has two visual capabilities: (1) the ability to detect skin color in an image and provide an estimated location for the sighting based on a ground-plane assumption and (2) the ability to build a red-blue anaglyph image of the environment from left and right panoramic images (figure 5). The skin-detection module is quickly trainable in real time,

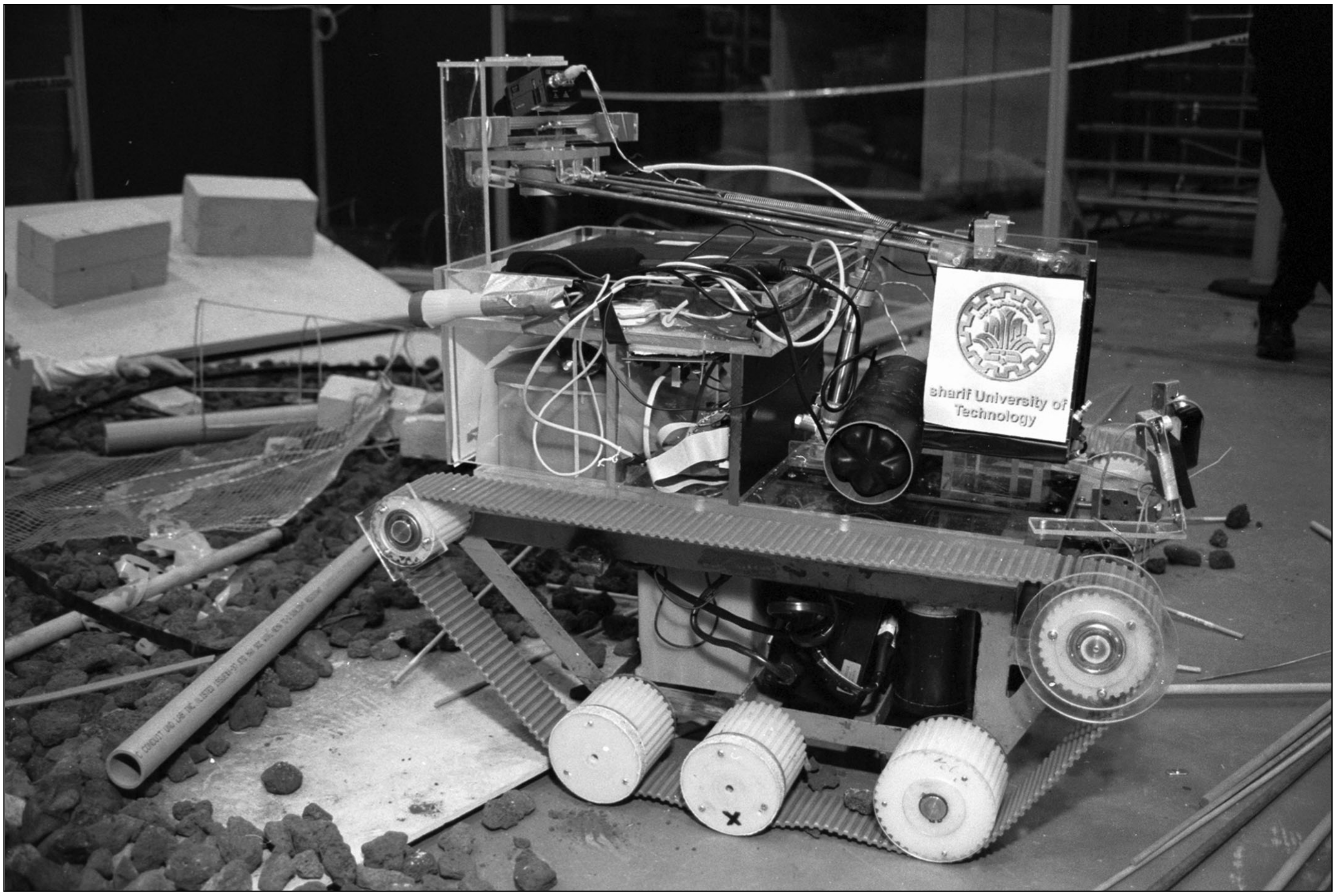


Figure 3. Sharif University's EMDAD1 Robot Searching the Red Section.

making it adaptable to its environment. The anaglyph image provides more information of the robot's environment to its operator. The robots build maps using evidence grids. During map construction, markers representing known locations are placed on the map. Once a victim is located, the robot generates a path from the entrance to the victim by connecting the markers without obstacles between them.

The Utah State University entry was meant to explore the viability of swarms of inexpensive, simple robots. The robots, which made up the BLUE SWARM 2 (BLUE SWARM 1 was an earlier experiment using analog controls), are modified toy cars using a very simple microcontroller (a BASIC STAMP 2E) running a simple set of rules for interacting with the environment. The sensors are limited to bump and infrared sensors, and communication between the robots does not exist. The desired outcome was sufficient coverage of the competition area without the need for detailed rules or interrobot coordination. They achieved this outcome but were not scored because they were unable to communicate the location of victims (figure 6). Future plans include a more reliable platform and a method for returning the locations of victims to a rescuer.

The University of Edinburgh Robo-Rescue Team robots were developed as a collaborative M.Sc. project that aimed to do research on different aspects of AI related to multiagent systems, behavior-based robotics, and search strategies for rescue scenarios (figure 7). The two robots have three-wheeled aluminum chassis with two DC motors for traction and one DC modeling servomotor for heat scanning. There are three incremental encoders for dead reckoning and rotation measurement (each one fixed to each wheel), four SRF04 Ultrasonic Ranger (two at the front and one on each side) and two front bumpers (left and right) for obstacle avoidance, one magnetic compass with digital output for positioning, one passive infrared (PIR) sensor for heat detection, and one radio packet controller at 418 megahertz for communication between robots and the base station. Both robots use HANDY BOARDS as the main controller.

The two robots used obstacle-avoidance and

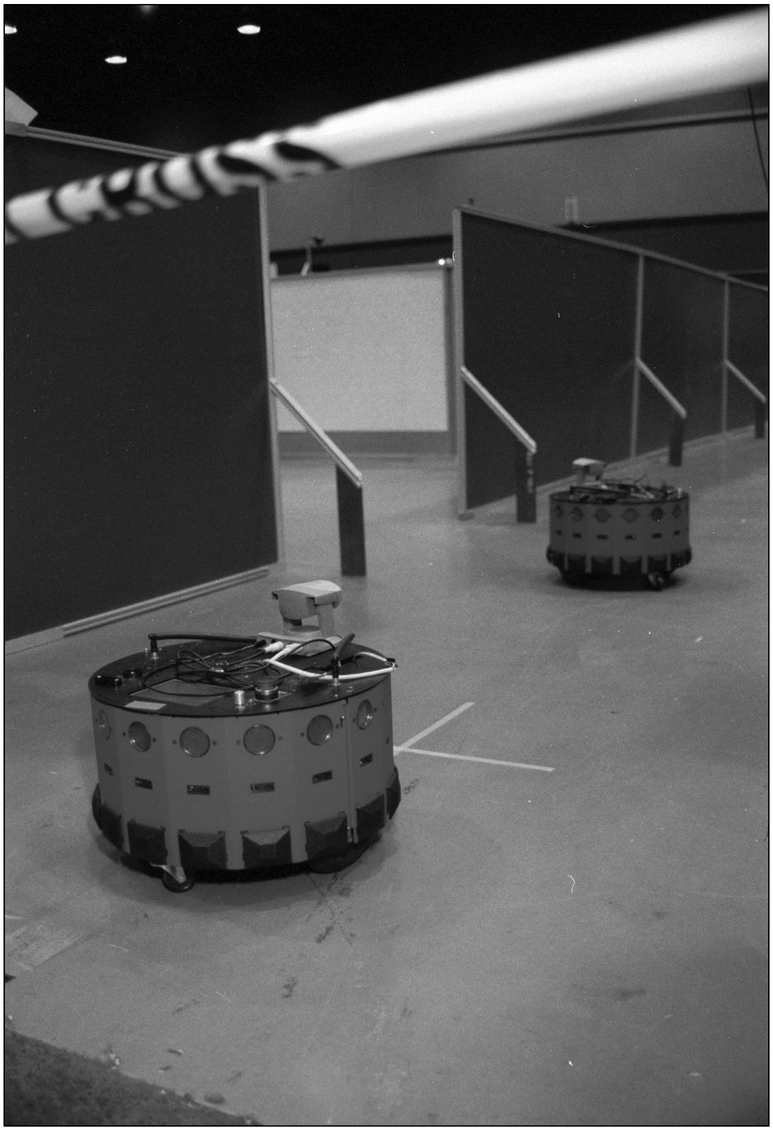


Figure 4. Swarthmore's MARIO & CO. Robot Team in the Yellow Section.

heat-detection behaviors to guide their way through the yellow section of the NIST arena. Ultrasonic range sensors provide the range information for obstacles in the environment. The PIR sensor continually searches for heat as it navigates and provides a desired direction for the robots to travel in. The location of the robots and victims are determined by dead reckoning and the positioning system of the robot relays on the magnetic compass. Because of technical difficulties with the robots, this team demonstrated in the course during their competition rounds.

The University of South Florida's (USF) Robot Rescue Team consists of three IROBOT URBANS, a controlling network, and necessary operators (Casper and Murphy 2000). The IROBOT URBANS have a footprint of 62 centimeters by 50 centimeters and are polymorphic or shape shifting through use of their flippers. The flippers enable the robots to climb stairs or rubble as well (figure 8). Each URBAN has a color CCD camera located on its front side, 13 sonar sensors, a magnetic compass, and an accelerometer. An Indigo ALPHA miniature FLIR Systems camera was attached to one of the three URBANS as an additional sensor. Futaba radiofrequency model airplane controllers were used to control the URBANS. The controlling network was composed of four laptop computers connected on a 10/100-megabyte switchable ethernet hub, one supervisory laptop for the incident commander, and three operator control units (OCUs) for the three URBANS. A Breezecom wireless ethernet hub provided communication to the URBANS.

The software implemented on the controlling network contained several pieces of individual code. The supervisory laptop was used as an output device to display the robot positions and orientations through the Science Applications International Corporation (SAIC) ONESAF software. ONESAF is a strategic military command simulator developed by SAIC that is capable of representing all varieties of military entities, terrains, and buildings; it makes artificially intelligent decisions depending on the units' goals and present state. ONESAF was interfaced to the URBANS through SAIC's DIS code. The supervisory laptop also displayed the current camera views and pose of any one of the active robots at a time through the USF GRABIMAGE program. The three URBAN OPERATOR CONTROL UNITS (OCUS) ran a modified version of RWI's OCU software used to provide the operator with information and limited control (robot camera view, sonar readings, flipper orientation, velocity, battery power, and activation of headlights). The OCUS also ran USF's joystick server software that was required for Futaba controller capabilities.

Figure 5. Right 360-Degree Panoramic Image Produced by the MARIO & CO. Robot Team (Photo Courtesy Swarthmore College).

The SCOUT Robot Project is headed by the University of Minnesota Computer Science Department as part of the Distributed Robotics Program at the Defense Advanced Research Projects Agency (DARPA). SCOUTs are small (11 centimeters long by 4 centimeters in diameter), portable robots designed for surveillance and search applications (Rybski et al. 2001). They carry an on-board camera for sensing their environment and can transmit video and digital data over a radio-frequency link. SCOUTs locomote by using their wheels to roll and their leaf-spring "tails" to jump over small obstacles. They are designed to collect information in areas and situations that can be dangerous to humans. Because of their low ground clearance, a variant on the basic SCOUT design has been developed that can change the diameter of its wheels, allowing the robot to increase its ground clearance and climb over larger obstacles.

The small size of the SCOUTs restricts the on-board computational power, so control is facilitated by an off-board proxy-processing scheme through a radio-frequency link. The communications link is limited because of the space and power limitations of the SCOUTs. A distributed process management-scheduling system has been developed to allow multiple workstations to simultaneously control a team of SCOUT robots by assigning resources to each robot in an attempt to maximize system performance. This process-management system also allows SCOUT control with varying degrees of autonomy. For example, a human operator can remotely control the robot by viewing the data returned from its camera, or a team of SCOUT robots can autonomously disperse into an area and report back when they have reached a goal point or found something interesting. The user interfaces allow human operators to interrupt autonomous behavior, take control, and release when desired.

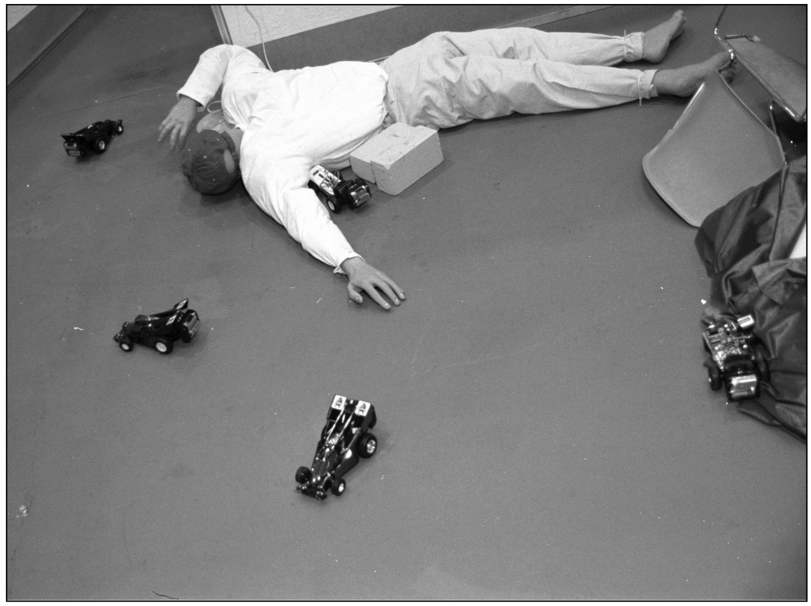


Figure 6. Utah State's BLUE SWARM 2 in the Yellow Section.

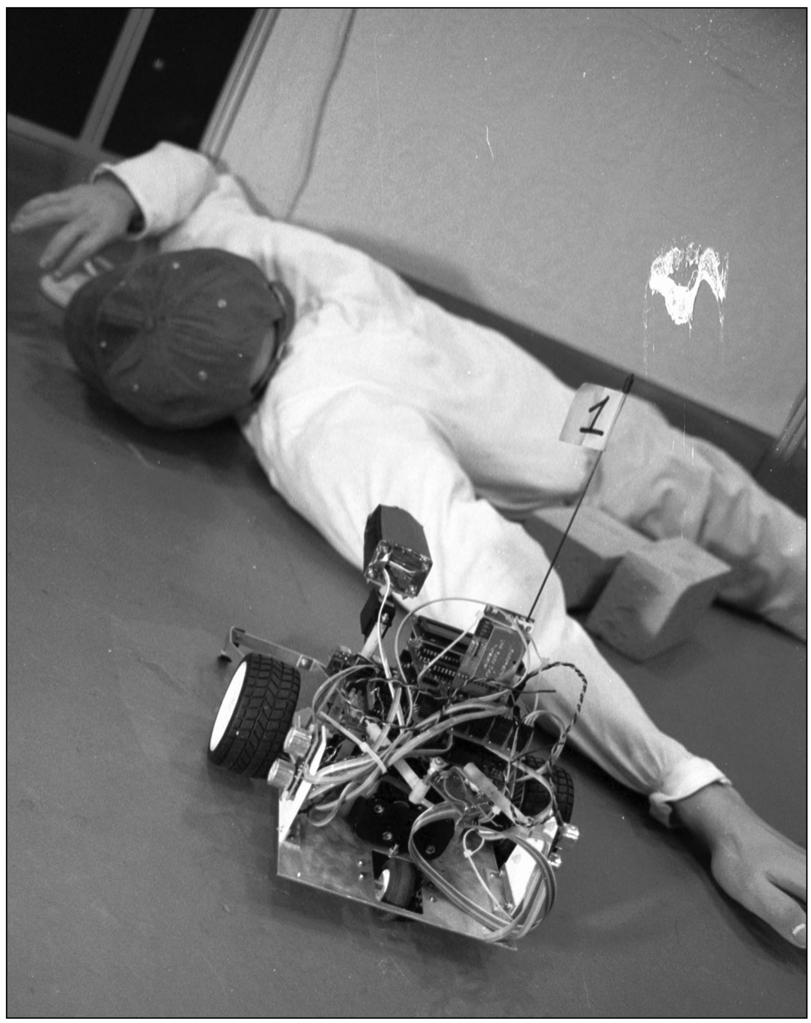


Figure 7. One of University of Edinburgh's Robots Approaching a Victim in the Yellow Section.

Awards and Final Scores

No team scored enough points this year to receive a place ranking. A team was required to surpass the set minimum score to compete for a ranking. However, two technical awards were presented. Sharif University received a Technical Award for Advanced Mobility for Rescue, and Swarthmore University received a Technical Award for Artificial Intelligence for Rescue. Each technical award included one robot: an ActivMedia AMIGOBOT and an iRobot/RWI MAGELLAN PRO.

We expect that teams in 2002 will improve and hopefully exceed the minimum score nec-

Figure 8. University of South Florida's URBAN *Traversing Rubble in the Red Section.*

essary for ranking because both Swarthmore and Sharif were close to meeting the minimum standards in 2001. Swarthmore succeeded in finding three victims in the yellow section during its final round and one during the semifinal round. Sharif also succeeded in locating victims in two rounds: two victims in the red section during the semifinal and one victim in the orange section and two in the red section during the final.

Future Challenges

The 2001 competition challenged the competitors to produce systems capable of handling a simulated USAR environment. The rules were built on real USAR scenario issues that include time to transport and set up the robot equipment and the number of personnel required to run the robot equipment, with an emphasis on accurate victim location. The NIST arena used in 2001 allowed for a wide range of robots to compete (from lab-grade robots to rugged tracked vehicles). The rules also permitted the use of robots with different levels of autonomy.

Future competitions will continue to challenge both the hardware and software aspects of systems competing. Real USAR environments pose many challenges in terms of navigation, communication, and other hardware issues. Additionally, many software issues must be addressed. Victim detection is a difficult task; color cues might not always be available because the victim might be covered in dust. Obtaining a three-dimensional location of a victim is also difficult, but it is pointless to detect a victim without being able to provide even a relative location of where the victim is.

It is crucial in a USAR scenario to distribute appropriate information to the appropriate individuals. For example, the robot must at least provide the robot operator with a robot's eye view and, if possible, vital robot statistics when necessary (such as notifying the operator if it is low on power). Victim location information is crucial to give to the rescue team leader who determines the focus of the search. The team leader would then be able to quickly change the focus of the search. As robot systems improve, the competition arena and rules will need to compensate to provide a more realistic scenario for the ongoing challenge of developing USAR robot systems.

Acknowledgments

The AAAI/RoboCup Robot Rescue Competition would not have been possible without support from the Defense Advanced Research Projects Agency, the Naval Research Laboratory, and the American Association for Artificial Intelligence. The Robot Rescue arena was developed and constructed by the National Institute of Standards and Technology (NIST); thank you to Elena Messina, Adam Jacoff, and the rest of the NIST crew. Also thanks to ActivMedia and iRobot for their contributions.

Thank you to Robin Murphy for her help in running the competition and committee. The steering committee members were Jacky Baltes, John Blitch, Silvia Coradeschi, Adam Jacoff, Hiroaki Kitano, Pedro Lima, Alan Schultz,

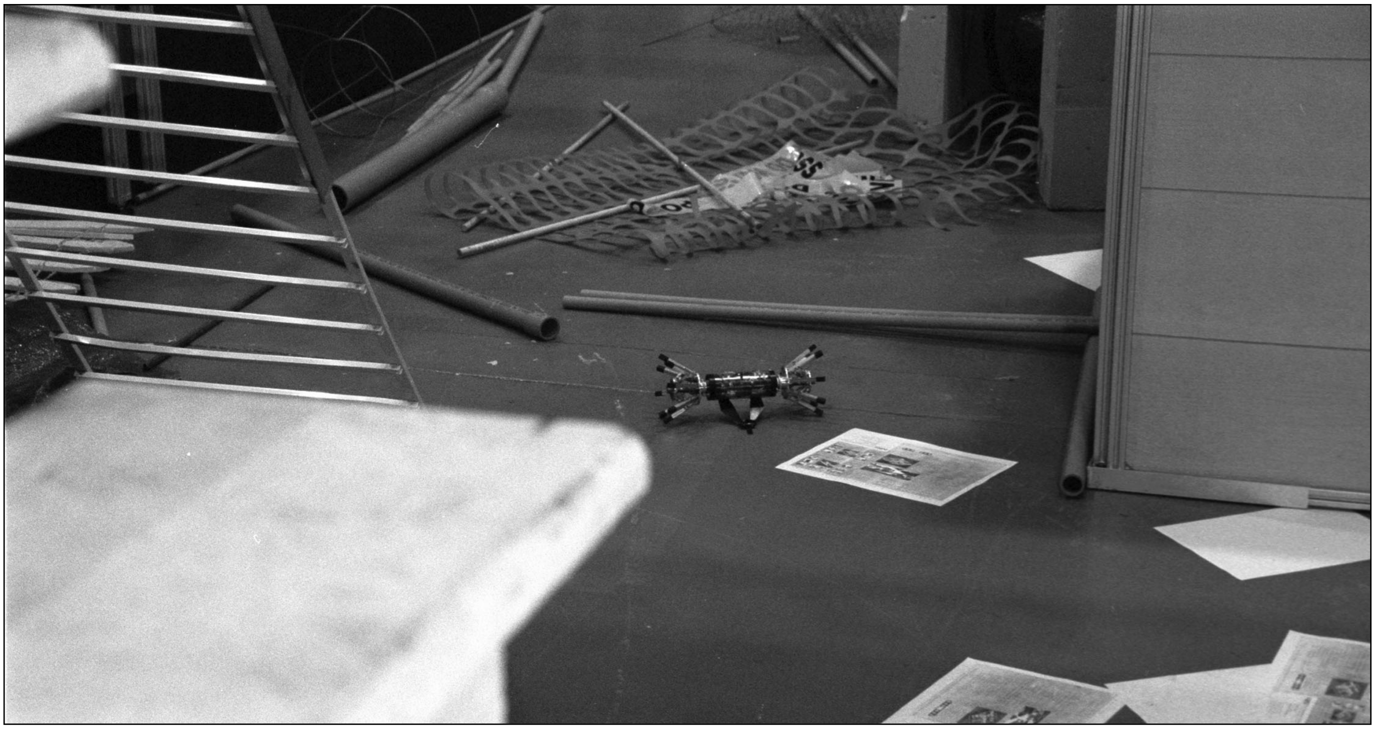


Figure 9. University of Minnesota's SCOUT *in the Orange Section.*

Satoshi Tadokoro, and Milind Tambe. Also thank you to John Blitch, Jean Scholtz, Alan Schultz, and Jacky Baltes for judging the competition.

The following people contributed descriptions of their robot entries: Amir Hossein Jahangir (EMDAD1, Sharif University); Bruce Maxwell and Edward G. Jones (MARIO & CO., Swarthmore College); Dan Stormont (BLUE SWARM 2, Utah State University); Jesus Juarez-Guerrero, Ioannis Pissokas, and Daniel Farinha (Robo-Rescue Team, University of Edinburgh); Todd Wasson (Rescue Robot Team, University of South Florida); and Paul Rybski (SCOUT, University of Minnesota).

References

Casper, J., and Murphy, R. 2000. Issues in Intelligent Robots for Search and Rescue. Paper presented at the SPIE Ground Vehicle Technology II, 24–28 April, Orlando, Florida.

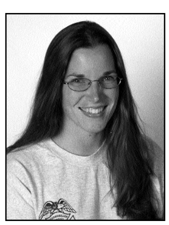
Jacoff, A.; Messina, E.; and Evans, J. 2001. A Reference Test Course for Autonomous Mobile Robots. Paper presented at the SPIE-AeroSense Conference, 16–20 April, Orlando, Florida.

Jacoff, A.; Messina, E.; and Evans, J. 2000. A Standard Test Course for Urban Search and Rescue Robots. Paper presented at the Performance Metrics for Intelligent Systems Workshop, 14–16 August, Gaithersburg, Maryland.

National Fire Academy, United States Fire Administration, and Federal Emergency Management Agency. 1993. Rescue Systems I, USFA/NFA-RSI-SM, United States Fire Administration, Emmitsburg, Maryland.

Rybski, P.; Burt, I.; Dahlin, T.; Gini, M.; Hougen, D.; Krantz, D.; Nageotte, F.; Papanikolopoulos, N.; and Stoeter, S. 2001. System Architecture for Versatile Autonomous and Teleoperated Control of Multiple Miniature Robots. Paper presented at the 2001 IEEE International Conference on Robotics and Automation, 21–26 May, Seoul, Korea.

Schultz, A. 2001. The 2000 AAAI Mobile Robot Competition and Exhibition. *AI Magazine* 22(1): 66–72.



Jennifer Casper received her B.S. in computer science and art from the University of Wisconsin at La Crosse in 1998 and is currently working to complete an M.S. in computer science from the University of South Florida (USF) at Tampa, where she is a Ph.D. candidate. She is also a research assistant with the Perceptual Robotics Laboratory at USF. Her specific research interests are in the human-robot interfaces for urban search and rescue (USAR) robots and the development of USAR robots. Her e-mail address is jcasper@csee.usf.edu.

Holly A. Yanco is an assistant professor in the Computer Science Department at the University of Massachusetts at Lowell. She earned her M.S. and Ph.D. from the Massachusetts Institute of Technology in 1994 and 2000, respectively. She has taught at Wellesley College, Boston College, and ArsDigita University. Her research interests include adjustable autonomy, assistive technology, multiple robot teams, and human-robot interaction. She is a coeditor of the book *Lecture Notes in Artificial Intelligence: Assistive Technology and Artificial Intelligence.* Yanco exhibited her communicating robots, BERT and ERNIE, at the first AAAI Mobile Robot Competition and Exhibition in 1992 and exhibited her research in several of the following years. She organized the robot exhibition in 1997, chaired the robot rescue event in 2001, and cochaired the overall event in 2001. In 2002, she will cochair the AAAI Mobile Robot Competition and Exhibition again. Her e-mail address is holly@ss.uml.edu.