AI Magazine Volume 25 Number 2 (2004) (© AAAI)

2003 AAAI Robot Competition and Exhibition

Bruce A. Maxwell, William Smart, Adam Jacoff, Jennifer Casper, Brian Weiss, Jean Scholtz, Holly Yanco, Mark Micire, Ashley Stroupe, Dan Stormont, and Tom Lauwers

■ The Twelfth Annual American Association for Artificial Intelligence (AAAI) Robot Competition and Exhibition was held in Acapulco, Mexico, in conjunction with the Eighteenth International Joint Conference on Artificial Intelligence. The events included the Robot Host and Urban Search and Rescue competitions, the AAAI Robot Challenge, and the Robot Exhibition. In the Robot Host event, the robots had to act as mobile information servers and guides to the exhibit area of the conference. In the Urban Search and Rescue competition, teams attempted to find victims in a simulated disaster area using teleoperated, semiautonomous, and autonomous robots. The AAAI Robot Challenge is a noncompetitive event where the robots attempt to attend the conference by locating the registration booth, registering for the conference, and then giving a talk to an audience. Finally, the Robot Exhibition is an opportunity for robotics researchers to demonstrate their robots' capabilities to conference attendees. The three days of events were capped by the two Robot Challenge participants giving talks and answering questions from the audience.

The robot events were a major attraction at the Eighteenth International Joint Conference on Artificial Intelligence (IJCAI-03), with many local visitors taking advantage of the opportunity to see robots in action. Participation in the robot events was strong; despite high travel and robot shipping costs, nine teams participated in the competition, with three teams also participating in the exhibition.

The purpose of the Robot Competition and Exhibition is to bring together teams from colleges, universities, and research laboratories to share experiences, compete, and demonstrate state-of-the-art robot capabilities. Of interest this year was that some of the prizes for the competition events were iRobot ROOMBA robot vacuum cleaners. Six years ago, at the Sixth American Association for Artificial Intelligence (AAAI) Robot Competition, one of the events challenged teams to develop a vacuum cleaning robot (Arkin 1998). This year, that event came back full circle, with people now buying robot vacuum cleaners for their homes at a price similar to that of a nonrobotic vacuum. Thus, progress continues, and the highlights of this year's competition could be a window into consumer and commercial robots of the next decade.

The major issue in developing robot systems for demonstration and competition continues to be system integration, and this year saw a new level of system design and integration in several of the robot entries. As always, current results in AI, sensing, and robotics research continue to find their way into the robot systems, particularly in the areas of navigation, map building, and vision.

Robot Host

This year the two competition events—Robot Host and Urban Search and Rescue (USAR)—focused on helping people, albeit in very different situations.

For the Robot Host event, the teams had two tasks: (1) mobile information server and (2) ro-

Figure 1. Robots Participating at the Conference.

A. University of Rochester robot, MABEL, interacting with conference attendees. B. University of New York at Stony Brook robot, BUTLERBOT, serving information about the conference.

bot guide. The primary task was to interact with people and provide information to them about the conference—talks and exhibit locations, for example. The secondary task was to act as a guide for conference attendees, guiding them either to specific talk rooms or exhibition booths. Other than outlining the mission and requiring a safety qualifying round, the task contained no specific restrictions or constraints on the environment or the robots. The robots performed their duties in the middle of the main lobby of the conference center, navigating around people and natural obstacles. Judging for this event was informal, with judges providing feedback to the teams and overall relative scores for the different parts of the event.

This year two teams participated: (1) the University of Rochester and (2) State University of New York (SUNY) at Stony Brook (figure 1). Both teams incorporated speech recognition, a visual interface, vision capability, and synthetic speech on a mobile platform. This suite of capabilities has been standard for this task since RUSTY the robot, developed for the 1998 Hors D'oeuvres, Anyone? event by the University of North Dakota (Maxwell et. al. 1999). The Hors D'oeuvres, Anyone? event involved serving snacks to conference participants and evolved into the Robot Host event in 2002. The visual interfaces, navigation capabilities, and speech and vision processing have improved significantly since 1998, and the user interfaces for the two robots this year were the most advanced and complete human-robot interfaces seen in this competition event.

The advances this event has encouraged have been largely in the area of sensing in a natural environment. A reactive approach to navigation in this task is generally sufficient, but the robots cannot behave appropriately without knowledge of their surroundings. In particular, they need to know where people are in the environment and identify characteristics of people to hold intelligent conversations. Visual sensing has been the primary mode of obtaining information, with additional information coming from speech recognition.

This year, both teams' strength lay in their information-serving programs and natural language interpretation. MABEL, the University of Rochester's robot, was able to hold limited conversations with a human being using speech recognition and natural language interpretation. MABEL could also read name tags and use that information to address people by name. Unfortunately, this feature was not fully implemented during the competition, emphasizing the importance of systems integration. BUTLERBOT, from SUNY Stony Brook, could respond to queries typed into its keyboard and could even tell jokes. Both teams had large crowds form around their robots during demonstration times, and both robots performed robustly for extended periods.

The guide portion of the competition—where the robots were supposed to be able to lead people to requested locations—was less successful. Both teams, despite attempting to do so, were unable to navigate the environment or lead people around the exhibition area. The University of Rochester planned to do navigation and localization with the sonar sensors on its robot but were unable to integrate the code with information serving in time. SUNY Stony Brook planned to use visual landmarks, but a last minute problem with its motor drivers immobilized its robot for most of the competition.

Since RUSTY in 1998, every winning entry in this event has combined computer vision, speech recognition, speech synthesis, and navigation into a working system.

Both teams' strength lay in their high-level programming revolving around speech recognition, vision, and natural language interpretation. Their weakness lay in their hardware and low-level systems. Overall, integration of the systems was the greatest challenge to the teams, as it has been since the inception of this event.

First place this year went to the University of Rochester, and second place went to SUNY Stony Brook. Both the first- and second-place teams won an iRobot ROOMBA and a $1000 certificate toward the purchase of an ActivMedia robot.

In 2004, the Robot Host tasks will be folded into the Robot Challenge, a noncompetitive event where the task is to attend the conference, including taking on volunteer responsibilities such as information serving and acting as a guide.

As we say "adios" to the Robot Host event, it is worth noting the achievements that this event has encouraged since its inception in 1997. In contrast to recent entries, the winning team in 1997 had their robots driving single file in a circle, with each robot randomly lowering a cup filled with treats.

This contrast demonstrates the primary advance encouraged by this event: the integration of numerous complex AI systems on a single mobile platform. Since RUSTY in 1998, every winning entry in this event has combined computer vision, speech recognition, speech synthesis, and navigation into a working system. The first two Ben Wegbreit Awards for Integration of AI Technologies, for example, went to two robots in this event: ALFRED in 1999 (figure 2) and MARIO & CO. in 2000, both from Swarthmore College (Maxwell et. al. 2001, 2000). A second advance encouraged by this event was the removal of artificial situations and the effective navigation of a robot in typical human situations. In 2000, in particular, the serving area was extremely crowded with people, tables, and other obstacles. MARIO, a small RWI Magellan robot with a plate of cookies on top, succeeded in covering most of the area with a speed and agility not seen before in the Hors D'oeuvres, Anyone? event.

In retrospect, one can argue that there are now known solutions for most of the major problems associated with the task of building an information or snack-serving robot: navigation in a dynamic environment, detection of people, simple speech recognition, and speech synthesis. Although some subtasks, such as determining whether a person already has his/her hands full, are still in the realm of active research, much of the problem now demands a team of engineers to undertake integration and make the system robust. However, it is important to note that this integration task might require more than simply engineering. There is still no consensus method for designing a robot software architecture that is easy to program and robust in a dynamic environment. Competitions such as the one at AAAI encourage the development of such structures and tools and create a bridge between research robots and practical systems. Hopefully, we can look for ALFRED's descendent helping to cater an event a decade from now.

Urban Search and Rescue

The USAR competition entered its fourth year at IJCAI-2003. The competition requires robots to search a simulated disaster area for victims. The rules permit teleoperation or direct supervision of the robots during the search but encourage autonomous or semiautonomous systems if it makes the robots faster in their search capability.

The goal of the Rescue Robot Competition is to increase awareness of the issues involved in search and rescue applications, provide objective evaluation of robotic implementations in representative environments, and promote collaboration between researchers. The primary challenges of this event include mobility, sensory perception, planning, mapping, and the design of practical operator interfaces for systems that use teleoperation or supervision.

Figure 2. ALFRED *Preparing to Serve Hors D'Oeuvres at a Reception in Philadelphia.*

Mapping and navigation, in particular, have presented the greatest difficulty to participants because of the complexity and clutter of the simulated disaster site.

The competition encourages participants to contribute to the field of USAR robotics and provides the competitors with a sense of what a real USAR situation involves. Six teams competed in the 2003 AAAI Rescue Robot Competition: (1) Idaho National Engineering and Environmental Laboratory (INEEL), (2) Swarthmore College, (3) University of Manitoba (Canada), (4) University of New Orleans, (5) University of Rochester, and (6) Utah State University.

Competition Arena

The National Institute of Standards and Technology's Reference Test Arenas for Urban Search and Rescue Robots provided the venue for the Rescue Robot Competition. Three arenas—(1) yellow, (2) orange, and (3) red—denoting increasing levels of difficulty, form a continuum of challenges for the robots (figure 3). A maze of walls, doors, and elevated floors provides a variety of trials for robot navigation and mapping capabilities. Variable flooring, overturned furniture, and problematic rubble provide obvious physical obstacles. Sensory obstacles, intended to confuse specific sensors and perception algorithms, provide additional challenges. For example, corner reflectors or absorbent materials can reduce the accuracy of sonars, glass or mirrored walls can affect laser range finders, and loose paper on the floor can have an adverse effect on wheel encoders. Other obstacles, such as stairs, ramps, holes,

Figure 3. The Urban Search and Rescue Arena: Yellow Zone (left), Orange Zone (middle), and Red Zone (right).

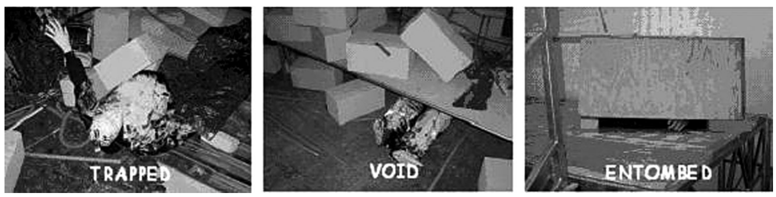


Figure 4. Examples of How Simulated Victims Might Be Situated.

and unstable flooring, clearly challenge both sensing and mobility. All these features combined encourage development of better sensors and robust sensor fusion algorithms to reliably and quickly negotiate the arenas and locate victims.

The objective for each robot in the competition, and the incentive to traverse every corner of the arenas, is to find simulated victims. Each simulated victim is a dressed mannequin emitting body heat and other signs of life, including motion (shifting or waving), sound (moaning, yelling, or tapping), and carbon dioxide to simulate breathing. Particular combinations of these sensor signatures imply the victim's state: unconscious, semiconscious, or aware. Each victim is placed in a particular rescue situation: surface, trapped, void, or entombed (figure 4). These terms have specific definitions within the USAR community, and the definitions are given to the teams prior to the competition.

The victims are distributed throughout the environment in roughly the same situational percentages found in actual earthquake statistics (NFA 1993). Each victim also displays an identification tag that is usually placed in hard-to-reach places around the victim, requiring advanced robot mobility to see. Once a victim is found, the robot(s) must determine the victim's location, situation, state, and tag and then report their findings on a victim data sheet and a human-readable map to the incident commander (or judge).

Rules

The competition rules focus on the basic USAR task of identifying live victims.[1] The rules also promote competitors to address related USAR tasks, such as determining victim condition and providing accurate victim location in addition to live victim recovery.

In the 2003 competition, the teams competed in missions lasting 20 minutes each, earning a score for each mission based on the performance metric, shown in figure 5. The first round consisted of three missions, with each team's score being the best two out of three scores. The final round consisted of two missions, and the winner of the competition had the best cumulative score after five missions.

The performance metric used for the competition has evolved over the years. It encourages teams to generate easily understandable and accurate maps of the environment and identify detailed victim information through multiple sensors. It also encourages the teams to minimize the number of operators to run the robot. There is no penalty for direct teleoperation of a robot, but semiautonomous or fully autonomous robots have the potential to make a single operator faster and more efficient, resulting in more victims found and a higher overall score. The performance metric also discourages uncontrolled bumping behaviors that might cause secondary collapses or further injure victims. Finally, an arena multiplier accounts for the difference in difficulty negotiating each arena: the more difficult the arena, the higher the arena multiplier for finding each victim.

The 2003 rules, and the performance metric, changed significantly from 2002 (see Casper and Micire [2003] for 2002 competition details), primarily to encourage the teams to focus on the primary issues of the USAR competition: navigation, mobility, mapping, operator interfaces, and sensor fusion. Because of the strict scoring, the performance metric and rules largely determine the focus of the participants' efforts, and small changes in the robot systems can effect significant scoring improvements (figure 5). Most of the changes this year were intended to make the scoring more robust and less susceptible to gaming so that teams with the best core abilities would score well.

Competitors

The six competing teams—(1) INEEL, (2) Swarthmore College, (3) University of New Orleans, (4) University of Rochester, (5) University of Manitoba, and (6) Utah State University—developed unique systems with diverse characteristics (figure 6). The INEEL team developed a custom interface for an iRobot ATRV-

$$\text{ARENA WEIGHING}\left(\frac{\text{MAP QUALITY} + \text{VICTIM LOCATION} + \text{VICTIM TAG} + \text{VICTIM SITUATION} + \text{VICTIM STATE} - \text{ARENA BUMPING} - \text{VICTIM BUMPING}}{\left[1 + \text{NUMBER OF OPERATORS}\right]^2} \right)$$

Figure 5. Formula for Determining the Score of a Robot in the Urban Search and Rescue Competition.

JR. equipped with vision, sonar, infrared, and laser sensors. The semiautonomous system provided the operator with multiple modes for robot control, such as autonomous, teleoperation with intelligent assistance, and pure teleoperation. The system interface displayed information useful to the operator: sensor readings, robot view, robot status, and environment maps.

The Swarthmore University team competed with a system demonstrating a human-robot interface for sliding autonomy on an iRobot MAGELLAN robot. One operator was needed to manage as many as two robots during the competition missions. The system provided the operator with the ability to adjust the autonomy during operation. Its unique mapping implementation allowed the operator to tag interesting points in the environment and adjust the map accuracy based on those points.

The University of New Orleans team consisted of a heterogeneous group of Sony AIBO robots and a blimp. A varying number of operators were needed to teleoperate the robots and manage the mapping system. Virtual Synergy, a three-dimensional (3D) virtual world, was used in the mapping system and provided an interactive interface for robot control and map management.

The University of Rochester team competed with an ActivMedia PIONEER robot requiring an operator for control. The operator teleoperated the robot through the environment and searched for victims using the robot's camera. The tether attached to the robot, as seen in figure 6, provided a communication line between the robot and the control unit.

The University of Manitoba and Utah State University teams developed fully autonomous, custom robot platforms for competition. The platforms were designed to be inexpensive and expendable to provide swarms or teams of robots that could quickly search an area.

Awards and Performance

Two place awards and a technical award were presented at this year's competition. The place awards are based solely on the teams' performances during the competition missions. The technical award is given to the team exhibiting novel AI applications and technical innovations. Interface designs for the top three teams is shown in figure 7.

INEEL won the first-place award, and Swarthmore University won the second-place award. These two teams had the highest cumulative scores from four (of five total) missions. Both teams performed well, but INEEL was able to find victims in both the yellow arena and the orange arena, even negotiating the ramp at one point to find a number of victims on an elevated floor. They also showed 100-percent reliability by scoring points in every mission, with the highest single-mission score of 27.6 and an average score of 9.2. Swarthmore attempted the more advanced arenas but was not able to find victims to score points, which hurt its overall reliability (60 percent). Because Swarthmore mainly stayed in the yellow arena with its reduced arena weighting, avoiding costly penalties, its high score was 12.5, and its average score was 6.1.

The University of New Orleans earned a technical award for its innovative attempt at collaborative mapping. However, its reliance on multiple operators to control several ro-

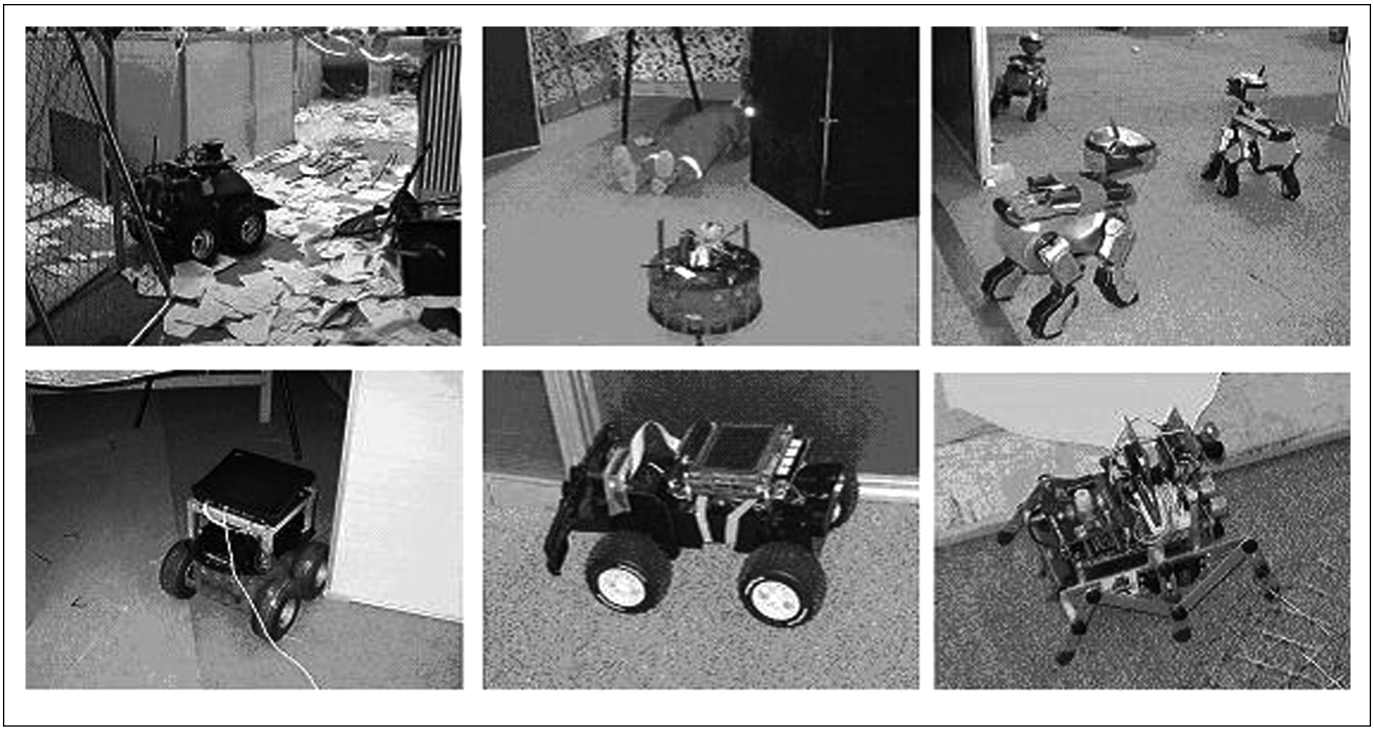


Figure 6. The Six Competing Robots in the 2004 Urban Search and Rescue Competition: INEEL (top left), Swarthmore College (top middle), University of New Orleans (top right), University of Rochester (bottom left), University of Manitoba (bottom middle), and Utah State University (bottom right).

bots generally lowered its overall scores. The University of Rochester also performed well during particular missions. Meanwhile, the University of Manitoba and Utah State University demonstrated fully autonomous custom-made robots with varying degrees of success in negotiating the simplest arena but didn't attempt to produce maps of the arenas with the victims identified—a key element in scoring.

Human-Robot–Interaction Assessment

For the second year, Jean Scholtz and Holly Yanco conducted a study of human-robot interaction during the USAR competition. (For results of the study of the Rescue Competition at AAAI-2002, see Yanco, Drury, and Scholtz [2004].) Teams participating in the competition were asked if they would allow video capture of the robots moving in the arena and the operator interactions with the robots. A video capture box designed and built at NIST was used to capture the graphic user interfaces and any separate monitors showing the video being sent back from the robot. The robots were videotaped navigating the arena to observe the problems that the robots had. Although the formal analysis of these data is not yet completed, the following list summarizes some of the general impressions formed during the competition.

First, although mobility is not typically a user interface issue, the awareness of mobility difficulties is critical. Operators had difficulty determining and overcoming problems with obstacles during navigation and, hence, stayed mostly in the yellow and orange areas.

Second, operators were largely unaware of robots causing damage to the arena. Although the operators seemed to generally know where the robots were in the arena, they did not have good indicators of the relationship to nearby victims and obstacles. (See Drury, Scholtz, and Yanco [2003] for a discussion of human-robot–interaction awareness.)

Third, some robots automatically generated maps, but operators were not able to effectively use this information during navigation.

Fourth, when autonomy was used, it seemed to result in fewer collisions with obstacles, but the initiative to use various levels of autonomy had to be taken by the operators.

Fifth, operators relied primarily on vision for victim identification. Other sensors (for example, thermal or audio) were only used after the initial identification, which places a constant demand on the operators to watch the video for indications of victims.

Sixth, tethers caused problems in the cluttered arenas. Teams did not have sophisticated tether management or an operator devoted to this task, which placed an additional burden on the operator.

Seventh, in general, user interfaces were designed for experienced users. Many contained nonobvious keystroke shortcuts.

Eighth, operators used video as the primary sensor for navigation, which resulted in stressful conditions for the operators when video was of poor quality.

Although the competition provides an excellent test bed for USAR robots, the short period of time allocated for each run doesn't adequately stress the work load for the operator. Operators are under stress because of the short period of time they have to locate victims, but having to run the robot in an actual USAR environment is much different than 20-minute competition missions. The short competition runs also allow the operator to mentally keep a map of the robot's path.

The competition currently supports only operators and robots. In actual USAR, the operator would also be responsible for communicating information back to the team. Additionally, the team might request that the operator search particular areas. Future competitions might include longer periods of time in the arenas, forced communication dropouts, and more interaction with judges posing as USAR team members to adequately assess the usability and utility of the human-robot interactions.

Search and Rescue Field Challenges

The USAR field is a challenging environment for robots. This field demands that rescue robots be highly mobile, robust, adaptable, intelligent, and easy to use (Casper 2002; Casper and Murphy 2003; Micire 2002). This year's competing systems were diverse in terms of characteristics and capabilities.

Although fully autonomous systems would be useful in aiding robot operation, adjustable autonomy (also referred to as mixed initiative or dynamic autonomy) and intelligent teleoperation methods can serve as intermediate solutions. Adjustable autonomy, for example, decreases the operator's task load by flexibly sharing the load between the system and the operator. Examples of this feature were seen in two of the competing systems—that by INEEL and that by Swarthmore. A more flexible and self-adapting teleoperated system could provide automatic bandwidth management and failure recovery. For example, image compres-

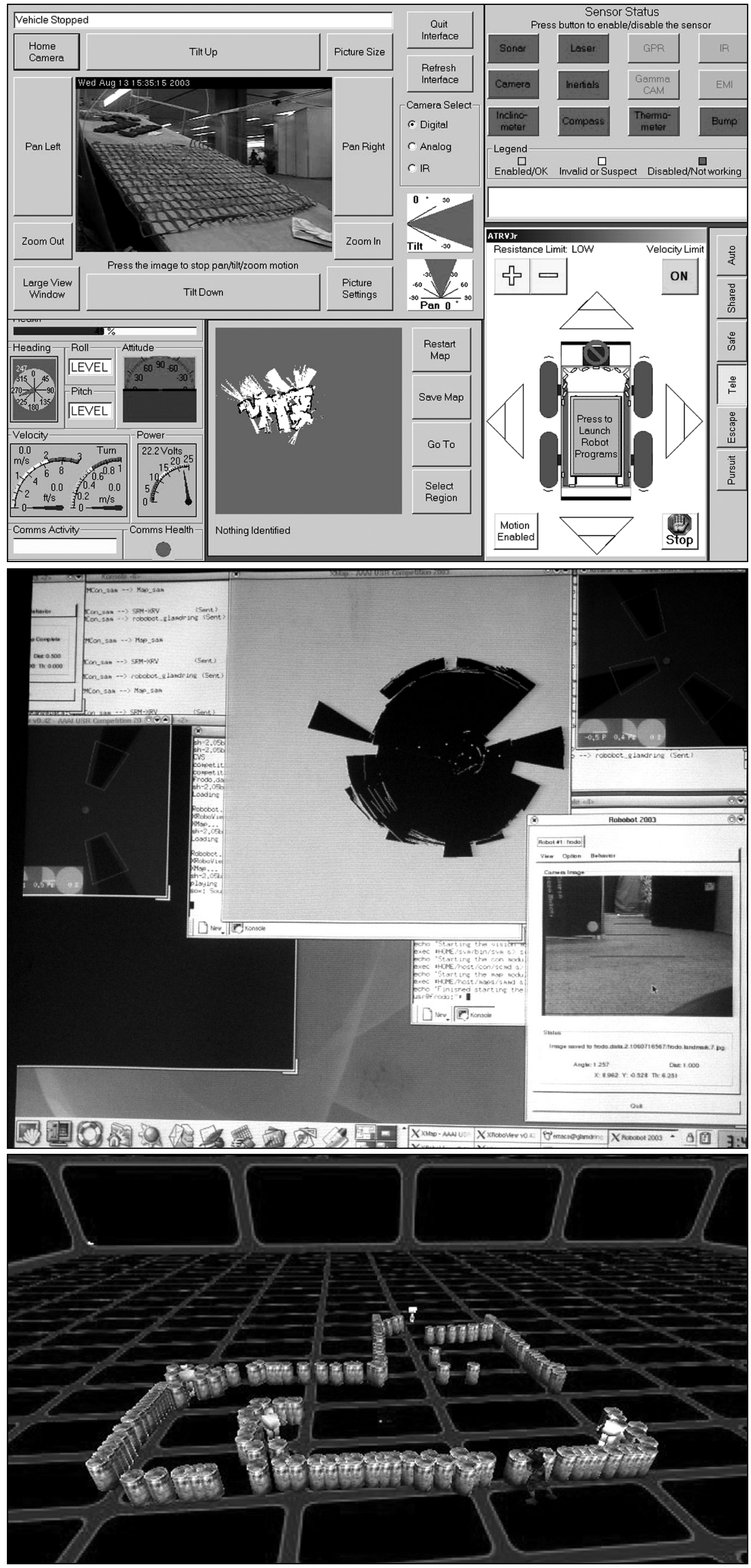


Figure 7. Interface Designs for the Top Three Teams.

Top: INEEL. *Middle:* Swarthmore College. *Bottom:* University of New Orleans.

sion could be increased as the signal level decreases, and in the event of communication failure, the robot could return to the last signal location, which is an area where more research is needed.

To communicate what areas the robot has searched and where potential victims are, mapping is a crucial aspect of search and rescue. Raw sensor data are difficult for people to understand and are not sufficient when communicating map information to nonoperators. A major challenge is to develop algorithms to filter and interpret raw sensor data to increase map quality and readability. Additionally, relying solely on encoders for position information is unreliable because the potential for wheel slippage on debris is high (Thrun et. al. 2003). Therefore, research and integration of other methods of localization and motion detection—such as visual or range sensor landmarks—is necessary.

Victim detection and assessment is one of the primary tasks in search and rescue. This task might be better executed through the use of image-processing and -filtering techniques to bring out victim features. Motion detection and skin color are commonly used, but other characteristics can be detected. For example, victim temperature is detectable through infrared sensors, and sound localization is possible using an array of microphones. Estimating airway, breathing, and circulation is fundamental for victim assessment, so future advancements in these areas would improve the operator's ability to evaluate the victim. Adding such capabilities, however, stresses the need for more research on sensor fusion and system integration.

Finally, mobility is a significant challenge in search and rescue. Most current research robots are incapable of navigating the orange and red sections of the NIST test bed, which are more representative of actual search and rescue environments. Previous competitions have shown that tracked vehicles provide more robust mobility. Although tracked mobility is certainly not the only answer to this problem, advancements in robust mobility are greatly needed to compete at realistic operation levels. However, advances in localization and mapping without wheel encoders or global positioning system–type absolute location sensors is necessary before a tracked vehicle can realistically compete given the premium put on accurate maps and victim location.

As robot teams begin demonstrating repeated successes against the obstacles posed in the arenas, the level of difficulty will be increased accordingly so that the arenas provide a stepping stone from the laboratory to the real world. Meanwhile, the yearly competitions provide a direct comparison of different approaches, objective performance evaluation, and a public proving ground for field-able robotic systems that might ultimately be used to save lives.

The Robot Challenge

The Robot Challenge, first dreamed up at the 1998 AAAI Robot Competition, entered its fifth year in 2003. The challenge is for a robot to successfully attend the national conference, which includes finding the registration desk, registering for the conference, navigating to a talk venue, giving a talk, and answering questions. Other possible tasks include acting as a conference volunteer and talking with conference attendees during coffee breaks.

This year, for the first time, robots from two teams—Carnegie Mellon University (CMU), the Naval Research Laboratory, Metrica Labs, Northwestern University, and Swarthmore College working together and Washington University at St. Louis—autonomously completed the main challenge tasks. Both teams were successful at getting their robots to a fake registration booth, registering, going to the talk venue, and giving a talk. Neither of the robots could attempt the trek to the real registration booth because it was on the second floor, and more importantly, the convention center had no elevators. The combined team actually brought two robots, GRACE and GEORGE, both of which independently undertook the challenge, demonstrating slightly different capabilities.

The first stage of the challenge is navigation within an unknown environment to find the registration desk. Using different approaches to the task, both teams were able to make significant progress without intervention. However, in both cases, sensing seemed to be the limiting factor. Washington University at St. Louis used specialized signs to simplify the sensing process rather than rely on the conference signs or interact with people. Variations in lighting gave the robot LEWIS difficulty sensing some of the signs and caused it to make some errors in detecting the correct direction of arrows on the signs. Despite these difficulties, LEWIS successfully located the fake registration booth on its own.

For both GRACE and GEORGE, (figure 8), the primary sensing modality and source of direction information while they interacted with people was speech recognition. GEORGE also attempted gesture recognition in combination with speech. The robots' ability to understand and correctly follow utterances such as "go

Figure 8. The Combined Team of GRACE and GEORGE Performing Their Tasks.

A. GRACE locating the proper line and moving toward the registration desk during its challenge run. B. GEORGE (left) and GRACE (right) giving a talk about their performance.

down the hallway" was impressive, but a high failure rate of the speech-recognition system meant that they had some difficulties reaching the registration booth. Once near the booth, GEORGE continued on to the talk area, bypassing the registration booth interaction. GRACE, however, quickly and successfully moved toward the proper line in front of the registration booth by identifying and reading the text on two specially colored signs, one reading *humans,* the other reading *large robots*.

At the registration booth, GRACE demonstrated natural conversation within a specified range of topics. Conversation followed the natural course of registration, although GRACE occasionally reiterated requests because sensing could not identify that the requests had been met. LEWIS, (figure 9), although limited to input through a graphic interface, was considered by the judges to be easy to interact with.

Navigating to the talk area and giving a talk is the final stage of the challenge. Both robots were able to navigate to the proper location and give the talk. It is worth noting that both teams used a CARMEN-based navigation method, which indicated some convergence onto a set of standard tools for certain robot tasks.

As with humans, the two presenters took different presentation styles. GRACE used an impressive language-understanding software package to extemporaneously talk about each slide, and LEWIS spoke from a script. Although LEWIS answered questions by repeating a humorous stock response, GRACE was able to interpret and respond to questions with the same language-processing system used to give the talk.

Washington University received the title of Challenge Champion for 2003, and an iRobot Roomba, and the GRACE team received the Grace under Fire Award for success in spite of tremendous challenges and hardware difficulties. The GRACE team also received a technical award for integration.

In 2003, the Ben Wegbreit Award for Integration of AI Technologies, which includes a $1000 prize, went to Washington University for LEWIS's smooth run in the Challenge Event.

Clearly, the major challenge of the Robot Challenge has been integration. The task requires a large number of advanced AI methods to work together, combined with a large number of sensors and sensing modalities. GRACE, for example, had four computers, two camera systems, a laser range finder, sonars, and an LCD video screen on a pan-tilt mount. It was running software that was capable of speech recognition, natural language processing, stereo vision, color vision processing, facial an-

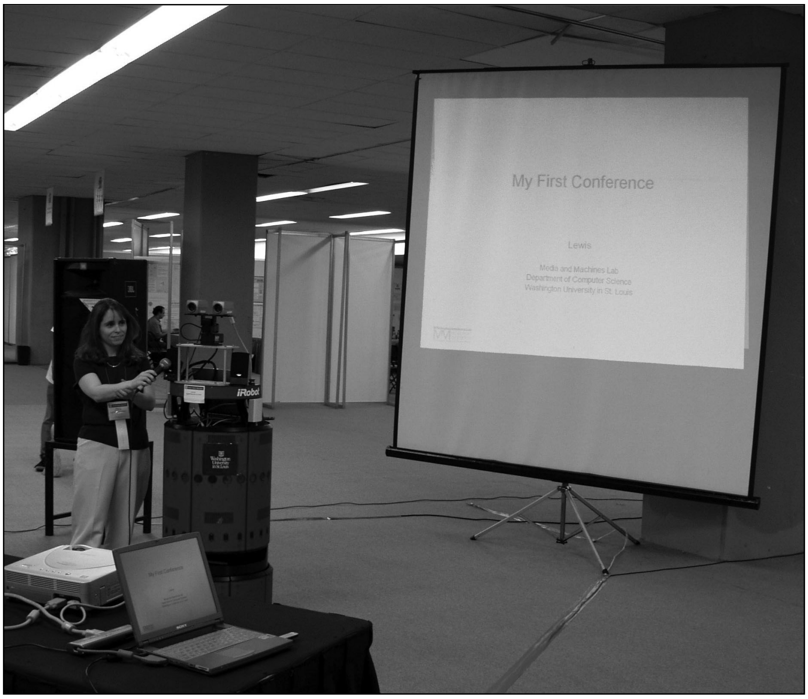


Figure 9. LEWIS, from Washington University at St. Louis Giving a Talk about Its Performance during the Challenge.

imation, navigation, localization, and overall task management. The GRACE team had to develop new software just to manage the various software packages and permit debugging in the complex environment.

Clearly, there is also more work to be done in specific areas of robotics and human-robot interaction, particularly in the area of sensing and extracting knowledge from sensor data. Speech recognition and visual sensing, in particular, are still brittle in the real-world conference environment. Advanced AI reasoning and task management and control are difficult to use in the absence of reliable information about the world. The Robot Challenge, with its real-world problems and absence of engineered cues, makes clear the need for more robust, real-time algorithms for identifying features in the world.

Robot Exhibition

The purpose of the Mobile Robot Exhibition is to provide a forum for roboticists to demonstrate research that does not fit within the scope of the Mobile Robot Competition or to focus on an aspect of a competition entry that might not be apparent just by observation. This year, no robots were entered only in the exhibition; however, three of the competition teams chose to demonstrate interesting elements of their competition entries. The three schools who participated in the exhibition were (1) University of New York (SUNY) at Stony Brook, (2) the University of New Orleans, and (3) the University of Rochester.

SUNY Stony Brook exhibited its entry in the Robot Host competition—BUTLERBOT. It had a poster that described the three areas it focused on for the competition: (1) navigation, (2) computer vision, and (3) human-robot interaction. In addition to the poster, it had the robot on display, and the team was available to answer questions. It was able to describe how BUTLERBOT used multiple sensors, including infrared, to avoid obstacles and used the vision system to determine where to find the greatest number of people nearby to assist. Interaction with human participants was supplemented with data from a MySQL database that contained information relevant to the conference. A human could choose to interact with the robot by browsing a list of frequently asked questions or searching the database by entering a query. BUTLERBOT also had an ELIZA-type voice system tied into a Microsoft agent AVATAR to allow the robot to converse with a participant in a more natural way.

The University of New Orleans invited guests at the exhibition to participate in a race and scavenger hunt through the USAR yellow arena using its Sony AIBO robot dogs. Participants, most of whom had never teleoperated a robot before, were able to see for themselves the challenges of navigating the AIBO robots used for the race through the cluttered USAR arena using the robot vision system. They were also asked to identify Mardi Gras beads that were distributed throughout the arena. In addition to the teleoperation challenges, the University of New Orleans team demonstrated its UNREAL TOURNAMENT–based mapping software that allowed the operators to build a map by placing tokens representing obstacles in the 3D representation of the USAR arena.

The University of Rochester demonstrated MABEL, its entry in the Robot Host competition. The research focus for MABEL was on the integration of voice, vision, and control systems; face and name tag recognition; and navigation in the conference center. For the exhibition, the team demonstrated its face and name tag–recognition capabilities as well as had team members team available to explain what MABEL was doing and their role in its development.

Summary

The Twelfth AAAI Robot Competition and Exhibition continued the tradition of demonstrating state-of-the-art research in robotics.

Many of the improvements this year were largely invisible to those watching the robots, but improvements in integrating systems and vision capabilities will eventually make the robots more robust, more adaptable, and better able to succeed in their challenging tasks. Without progress in these invisible areas, progress in the more visible robot capabilities will be slow.

The challenge of making robots that can navigate and successfully complete tasks in the real world was the focus of all the events in 2003, which is a great advance over the events of a decade ago that required special arenas and brightly colored objects. Where are we going next?

In 2004, it will be the AAAI National Conference in San Jose, California. Bill Smart (Washington University at St. Louis) and Shiela Tejada (University of New Orleans) will be cochairing the event. We invite everyone in robotics to participate and demonstrate their current research.[2]

Acknowledgments

The AAAI Robot Competition and Exhibition would not have been possible without the generous support of the Defense Advanced Research Projects Agency, AAAI, and the Naval Research Laboratory. The USAR event would not have been possible without the arena, which was provided by the National Institute of Standards and Technology. We would also like to express our appreciation to Ben Wegbreit, ActivMedia, and iRobot for their continued support of this event.

The event chairs were Ashley Stroupe for the Robot Challenge; Tom Lauwers for the Robot Host event; Jennifer Casper, Adam Jacoff, and Brian Weiss for USAR; Dan Stormont for the exhibition; and Magda Bugaska for the Robot Workshop. We also want to thank Holly Yanco for her advice as a former robot competition cochair. For assistance with the USAR arena and the taping of the robots for a human-robot–interface study, we want to thank Elena Messina, Ann Virts, Michael Baker, Robert Casey, Brenden Keyes, Jean Scholtz, Philip Thoren, and Jeff Young. Finally, we want to thank all the people who helped as judges or provided feedback on the events.

Most importantly, we want to thank the teams for their participation and hard work. In spite of a lack of air conditioning at night, mosquitoes in the convention center, and other issues during the conference, all the teams put in extra effort and provided an excellent demonstration of the state of the art in robotics. The crowds of local visitors watching the robots at their various tasks were a testament to the importance of the AAAI Robot Competition and Exhibition in educating the broader world about current research in robotics and AI.

Notes

1. See www.rescue-robotics.com/RescueRules/Robot-Rescue2003/ for details.

2. For more information about the events and competitions, see palantir.swarthmore.edu/aaai04.

References

Arkin, R. 1998. The 1997 AAAI Mobile Robot Competition and Exhibition. *AI Magazine* 19(3): 13–17.

Casper, J. 2002. Human-Robot Interactions during the Robot-Assisted Urban Search and Rescue Response at the World Trade Center. Master's thesis, Computer Science and Engineering, University of South Florida.

Casper, J., and Murphy, R. 2003. Human-Robot Interactions during the Robot-Assisted Urban Search and Rescue Response at the World Trade Center. *IEEE Transactions on Systems, Man, and Cybernetics* 33(3): 367–385.

Casper, J., and Micire, M. J. 2003. The AAAI-2002 Robot Rescue. *AI Magazine* 24(1): 51–60.

Drury, J. L.; Scholtz, J.; and Yanco, H. A. 2003. Awareness in Human-Robot Interactions. In Proceedings of the IEEE Conference on Systems, Man, and Cybernetics, 912–918. Washington, D.C.: IEEE Press.

Maxwell, B. A.; Anderson, S.; Gomez-Ibanez, D.; Gordon, E.; Reese, B.; Lafary, M.; Thompson, T.; Trosen, M.; and Tomson, A. 1999. Using Vision to Guide an Hors D'oeuvres Serving Robot. Paper presented at the Second Workshop on Perception for Mobile Agents, 26 June, Fort Collins, Colorado.

Maxwell, B. A.; Meeden, L. A.; Addo, N.; Brown, L.; Dickson, P.; Ng, J.; Olshfski, S.; Silk, E.; and Wales, J. 2000. ALFRED: The Robot Waiter Who Remembers You. In Eighth AAAI Mobile Robot Competition: Papers from the AAAI Workshop, 1–12. Technical Report WS-99-15. Menlo Park, Calif.: AAAI Press.

Maxwell, B. A.; Meeden, L. A.; Addo, N. S.; Dickson, P.; Fairfield, N.; Johnson, N.; Jones, E. G.; Kim, S.; Malla, P.; Murphy, M.; Rutter, B.; and Silk, E. 2001. REAPER: A Reflexive Architecture for Perceptive Agents. *AI Magazine* 22(1): 53–66.

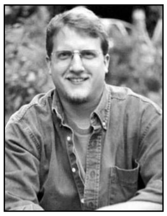
Micire, M. 2002. Analysis of the Robotic-Assisted Search and Rescue Response to the World Trade Center Disaster. Master's thesis, Computer Science and Engineering, University of South Florida.

NFA. 1993. Rescue Systems I. USFA/NFA-RSI-SM. Washington, D.C.: National Fire Academy.

Thrun, S.; Haehnel, D.; Ferguson, D.; Montemerlo, M.; Triebel, R.; Burgard, W.; Baker, C.; Omohundro, Z.; Thayer, S.; and Whittaker, W. 2003. A System for Volumetric Robotic Mapping of Abandoned Mines. In Proceedings of the IEEE International Conference on Robotics and Automation, 4270–4275. Washington, D.C.: IEEE Computer Society.

Yanco, H. A.; Drury, J. L.; and Scholtz, J. 2004. Beyond Usability Evaluation: Analysis of Human-Robot

Interaction at a Major Robotics Competition. *Human-Computer Interaction* 19:117–149.



Bruce A. Maxwell (maxwell@ swarthmore.edu) is an assistant professor of engineering at Swarthmore College. His main research interests are computer vision, mobile robotics, and computer graphics. He was general cochair of the 2003 Mobile Robot Competition and Exhibition.

William Smart is an assistant professor of computer science and engineering at Washington University at St. Louis. His main research interests are in the areas of mobile robotics, machine learning, and reliable software architectures. He is the general cochair of the 2004 Mobile Robot Competition and Exhibition. His e-mail address is wds@cse.wustl.edu.

Adam Jacoff is an engineer in the Intelligent Systems Division at the National Institute of Standards and Technology. He is one of the developers of the standard urban search and rescue (USAR) course for evaluating robotic search and rescue technologies and was a cochair for the 2003 AAAI USAR event. His e-mail address is adam.jacoff@nist.gov.

Jennifer Casper is the marketing and sales manager and research director for American Standard Robotics, Inc. Casper is a nationally registered emergency medicine technician, serves as a special operations volunteer for Hillsborough County Fire Rescue, is a technical search specialist for Florida Task Force 3, and serves on committees for the Florida Fire Chief's Association. Her research is focused on human-robot interactions in urban search and rescue environments. Her e-mail address is jcasper@asrobotics.com.

Brian Weiss is an engineer in the Intelligent Systems Division at the National Institute of Standards and Technology in Boulder, Colorado. He helped design the urban search and rescue (USAR) course and was a cochair of the AAAI's USAR event in 2002 (AAAI–02) and 2003 (IJCAI–03).

Jean Scholtz is a researcher at the National Institute of Standards and Technology. Her research focus is the evaluation of interactive systems. She is interested in human-robot interaction and has been doing evaluation research in human-robot interaction in the domains of search and rescue, off-road driving, and on-road driving.

Holly Yanco (holly@cs.uml.edu) is an assistant professor in the Computer Science Department at the University of Massachusetts at Lowell. Her research interests include adjustable autonomy, assistive technology, multiple robot teams, and human-robot interaction. Yanco is the AAAI Symposium Committee chair and served as the cochair of the AAAI Robot Competition and Exhibition in 2001 and 2002.

Mark Micire is the chief executive officer and president of American Standard Robotics, Inc. Micire serves as a special operations volunteer for Hillsborough County Fire Rescue and a technical search specialist for Florida Task Force 3. His research is focused on robotic platforms for urban search and rescue. His e-mail address is mmicire@asrobotics.com.

Ashley Stroupe is a staff engineer at the Jet Propulsion Laboratory in the Planetary Robotics Lab. Her research interests include autonomous robots and multirobot systems in complex environments. Current applications include multirobot exploration and manipulation. Her e-mail address is ashley.w.stroupe@ jpl.nasa.gov.

Daniel P. Stormont is currently a Ph.D. candidate at Utah State University at Logan, following a 22-year career in the U.S. Air Force. His research interests are in AI, swarm intelligence, and autonomous mobile robots. His e-mail address is stormont@cc.usu.edu.

Tom Lauwers is a Ph.D. student at the Carnegie Mellon Robotics Institute and was chair of the Robot Host event at the 2003 AAAI Robot Competition and Exhibition.