The AAAI-2002 Robot Rescue

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■ The purpose of the AAAI-2002 Robot Rescue event is to challenge researchers to design useful robotic systems for urban search and rescue (USAR). The competition rules are written to simulate a real rescue response in a simulated disaster environment developed by the National Institute of Standards and Technology. This article provides an overview of the current state of the art for USAR robotics, an overview of the AAAI-2002 Robot Rescue event, and a discussion of the future of the Robot Rescue event.

This year marked the third annual Robot Rescue event at the Eighteenth National Conference on Artificial Intelligence (AAAI-2002) in Edmonton, Alberta, Canada. The event comprises a competition and an exhibition. The competition is a low-fidelity simulation meant to encourage participants to contribute to the field of urban search and rescue (USAR) robotics and make them aware of the AI and engineering research challenges encountered when working within the USAR field (Casper et al. 2001). Competitors are challenged to quickly locate as many victims as possible within constraints, which provide the competitor with a sense of what a real USAR situation involves. Nine teams were involved in the AAAI-2002 Robot Rescue Competition, more than doubling the number of teams from the previous year.

For the first time, the rescue community was involved in developing the rules for and running the Robot Rescue event. Hillsborough County Fire Rescue Special Operations Chief Ronald Rogers joined the rules committee after the 2001 Robot Rescue event. He also served as a judge for the competition. The feedback Chief Rogers provided was valuable for the competition organizers and the individual competitors.

This article provides an overview of the current state of the art for USAR robotics and an overview of the AAAI-2002 Robot Rescue event by describing the arena, rules, and participating robotic systems. A discussion of the lessons learned and challenges present what the future changes and challenges for Robot Rescue events hold.

Robot Rescue Competition 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, Messina, and Evans 2001a, 2001b; Murphy, Blitch, and Casper 2002; Murphy et al. 2000). The arena consists of three sections that vary in difficulty: (1) yellow, (2) orange, and (3) red. The yellow section, the easiest region, is similar to an office environment containing light debris. The orange section is more difficult to traverse because of the variable floorings, second story accessible 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.

Victim goals are placed within the arena according to Federal Emergency Management Agency (FEMA) statistics on victim location (National Fire Academy 1993). The four main cues to detect victims are (1) sound, (2) heat, (3) color, and (4) movement. A victim goal can be detected by one or more of the cues.

Robot Rescue Competition Rules

The Robot Rescue competition rules keep the USAR task of quickly recovering live victims in focus by addressing several issues that arise in real USAR responses. It is at this time that you transport and set up the robot, decide the number of personnel required to run the robot, and emphasize accurate victim location.

The teams competed in three rounds in the NIST arena. Scores were calculated for every round based on the performance equation (Casper and Yanco 2002).[1] The final score, used to determine the quantitative place awards, was the best score from the three rounds. To contend for one of the three quantitative place awards for the competition, the final score had to be above the minimum score. This score was equivalent to one operator running one robot in the easiest arena section, finding one victim, and providing an arena layout with hand-marked victim location information. Qualitative awards were awarded based on the systems presenting innovative AI applied to the USAR field.

Robot Rescue Competitors and Exhibitors

Ten teams participated in the AAAI-2002 Robot Rescue Competition and Exhibition: (1) Idaho National Engineering and Environmental Laboratory (INEEL), (2) Georgia Institute of Technology, (3) Swarthmore College, (4) Young Scholars Club, (5) University of Rochester, (6) Carnegie Mellon University's (CMU) Robotics Club, (7) University of Manitoba, (8) Utah State University, (9) the MITRE Corporation, and (10) New Roads High School. This is more than double the number of teams that participated in the AAAI/RoboCup-2001 Robot Rescue Competition and Exhibition (Casper and Yanco 2002). The 10 teams varied widely in capabilities and approaches taken.

Idaho National Engineering and Environmental Laboratory

The goal of the INEEL entry was to interleave multiple levels of human intervention into the functioning of a robotic system for synergistic interaction between robots and humans that will, in turn, allow the robotic system to learn to adapt its own level of initiative. The research was motivated by operational experience at the INEEL in conducting remote characterization of hazardous environment using robotic platforms (Bruemmer, Marble, and Dudenhoeffer 2002; Bruemmer et al. 2002). The experience indicated that both teleoperated and fully autonomous approaches failed to build on the strengths of the robot and the human working as a cohesive unit. The approach used involved creating a dynamic autonomy control architecture, allowing the user to move between these two poles, which supported altering communication, cognitive, perceptual, and action capabilities of the user and robot.

The INEEL team demonstrated how the robot could adjust its level of autonomy on the fly, leveraging its own, intrinsic intelligence to exhibit levels of control from teleoperation to full autonomy. The robot had the ability to actively protect itself and the environment as it navigated. In addition, the robot continuously assessed and adapted to changes in its own perceptual capabilities. The robot interface supported mixed-initiative interaction between the operator and the human. The interface displayed an abstracted representation of the robot's experience and sensor suites as well as results from fusion algorithms for sensing and interpreting environmental features. See figure 1 for image of the interface.

An iROBOT ATRV JR. was the chosen robot platform of this one robot team. The sensor suite consisted of a Sony CCD camera with pan, tilt, and zoom capability; infrared proximity sensors; a forward-looking infrared (FLIR) camera; inertial sensors; tilt sensors indicating pitch and roll; laser range finder; front and rear bump strips; and 17 ultrasonic sensors located around the midsection of the robot. Figure 2 shows the INEEL robot operating in the arena.

Georgia Institute of Technology

The Georgia Tech Robot Rescue team consisted of five teleoperated, nonhomogeneous robots: one iROBOT ATRV JR. robot and four Sony robot dogs (figure 3). The ATRV JR., equipped with cameras and a laser, was a wheeled vehicle capable of traveling higher speeds than the robot dogs. The ATRV JR. had the ability to carry four robot dogs. The ATRV JR. was used to quickly traverse the arena. The robot dogs were deployed once the ATRV JR. could not go any further. The unique aspect of this team was its ability to produce accurate two-dimensional (2-D) maps of the explored environment based on laser information.

Swarthmore College

For the past two years, Swarthmore College's Robot Rescue entries have combined autonomy with teleoperation to generate semiautonomous systems. The goal was to use the best features of both forms of control. The robot possesses quicker reactions and a better sense of its immediate environment, but the

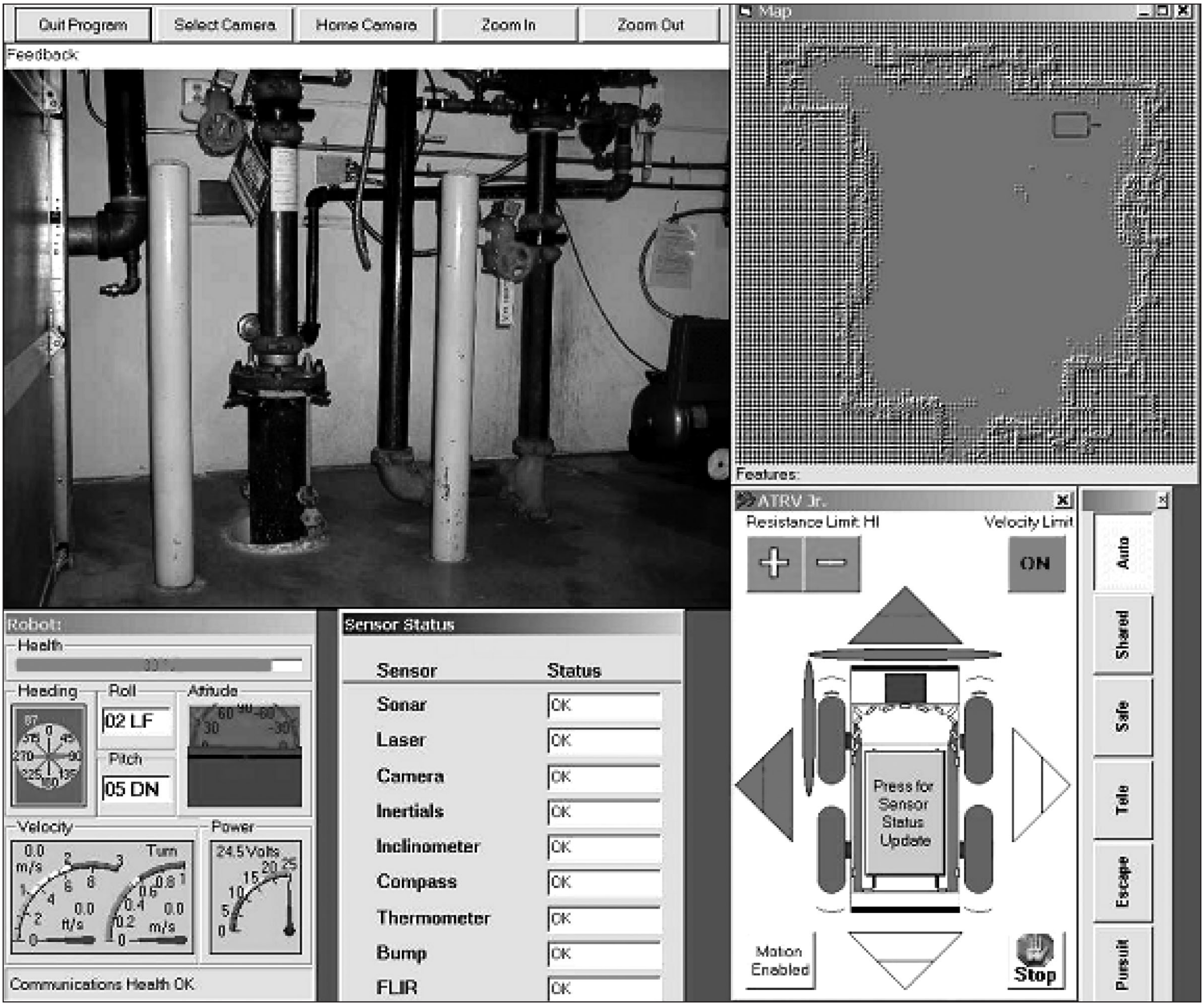

Figure 1. INEEL Robot Interface.

human operator has a better sense of where to go, what to look at, and how to interpret images from a camera. The system gave the operator the ability to specify relative goal points, stop or orient the robot, and control a pan-tilt-zoom camera. The robot autonomously managed navigation to the goal point using a reactive obstacle-avoidance system. Giving the robot reactive control turned out to be extremely important because the robot was able to sense things in the environment that were not perceptible to the operator, such as transparent surfaces.

As in 2001, Swarthmore used two similarly equipped ActivMedia PIONEER robots (figure 4), primarily using one robot to watch the other as they traversed the course. This approach turned out to be helpful in overcoming obstacles that were not readily apparent from the point of view of the lead robot. A secondary purpose of using two robots was to have a spare in case of equipment failure, which turned out to be critical in the final run because the lead robot's camera control cable failed. The trailing robot continued on and proceeded to find three more victims. Such a scenario is not unreasonable to expect in a true rescue situation.

The focus this year for Swarthmore was on having a control system that permitted quick reaction times for both the operator and the two robots. Using the IPC communication protocol, developed at Carnegie Mellon University, lag time was reduced, and the frame rate of images coming from the robots' cameras across the wireless network was increased compared to the *X*-forwarding system used the previous year.

Figure 2. Idaho National Engineering and Environmental Laboratory Robot Entry Operating in the Orange Section of the National Institute of Standards and Technology Arena.

Young Scholars Club

The Young Scholars Club robot team was the only team that ventured into the red arena. The two-robot entry was unique in its robot platforms (figure 5). The two platforms used were custom-built vehicles and teleoperated during the three competition rounds. The sensor suite on each robot consisted of a camera to provide the user with the robot eye view. The operator control unit consisted of a laptop and a minitelevision for display.

University of Rochester

The University of Rochester robot rescue team entry, an ActivMedia PIONEER DX2 named MABEL, competed in both the Robot Rescue competition and the Robot Host competition. MABEL's sensor suite consisted of sonars and a Sony camera with pan, tilt, and zoom capability. It had three core software components: (1) a navigation and control component, (2) a dynamically generated graphic user interface (GUI), and (3) a person-finding vision component.

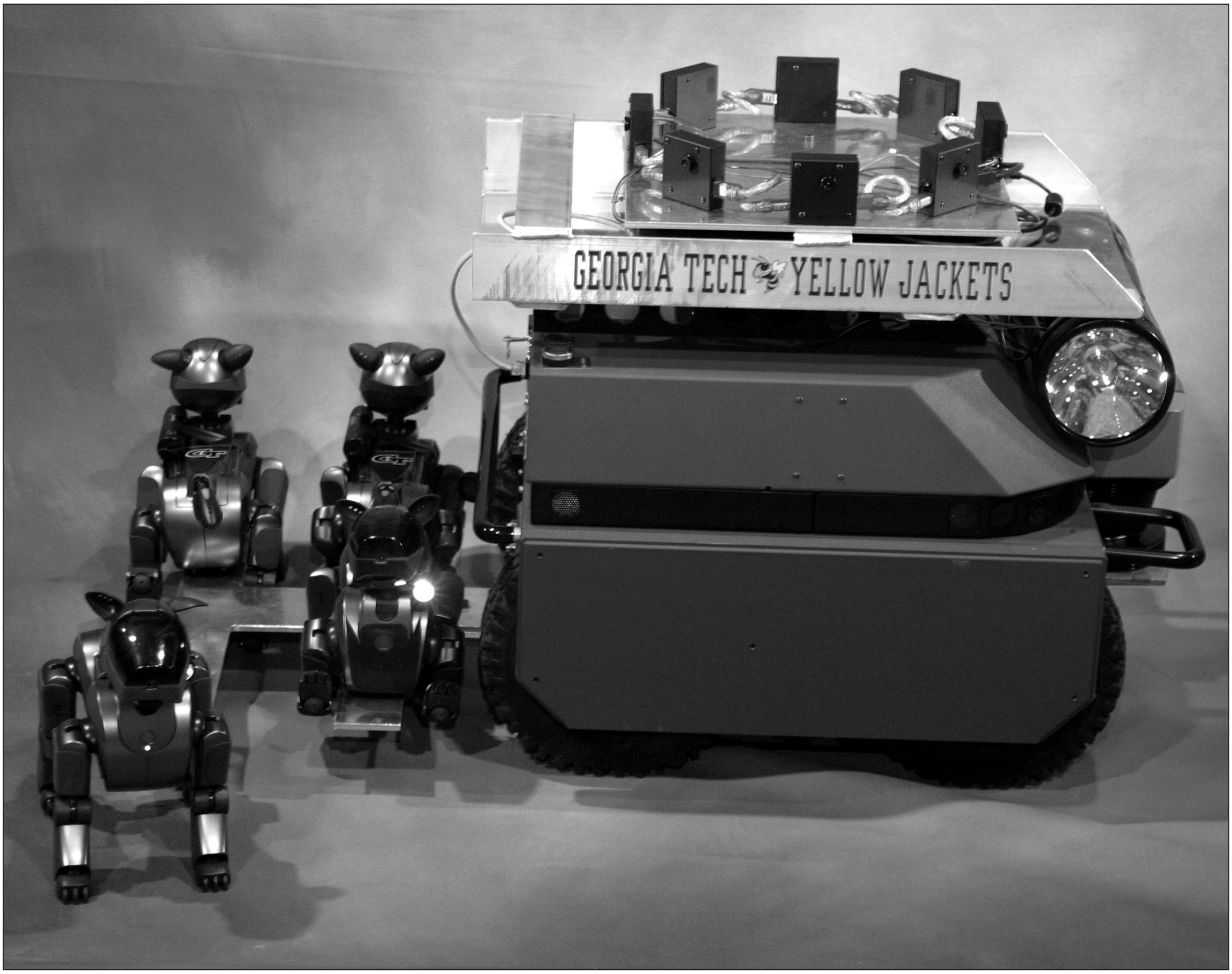

Figure 3. Georgia Institute of Technology Robot Entry.

The purpose of the navigation and control component was to allow a single user to control the robot and camera through two behaviors. The user could switch between teleoperation and autonomous navigation through the *wander behavior*. The *go home* behavior caused the robot to return to the point of origin. This feature was designed to be a fail safe in the likely event that the operator loses contact with the robot.

The GUI component provided the user with a visual model of the robot state, including the location and angle of the robot relative to its initial state and data received from the sonar array. The GUI component was used to construct a map of the space the robot explored based on sonar readings and display victim locations. The visualization also allowed the user to change the level of data and the scale of the area displayed.

The final component of the robot rescue system was the vision and person-finding component. If a person was located as indicated by the person-finding component, the navigation component calculated a vector along which the victim can be located based on camera, sonar, and robot-position information.

Carnegie Mellon Robotics Club

The Carnegie Mellon Robotics Club entry, named the TARTAN SWARM, was a low-cost multirobot approach to human detection. Each robot was based on a simple modular differential drive platform, mounted with a heterogeneous array of sensors. Sensor types included both vision and pyroelectric sensing. Human detection was communicated through two channels: (1) a low-bandwidth channel between neighboring robots and (2) a coded radio broadcast indicating success.

Figure 4. Swarthmore College Robot Entry.

University of Manitoba

The University of Manitoba KEYSTONE FIRE BRIGADE robot designs were based on a small-size RoboCup team from the University of Auckland. They were designed to be robust, versatile, and autonomous. The KEYSTONE FIRE BRIGADE used a small CMOS camera and Thomas Braunl's EYEBOT controller. The EYEBOT controller consisted of a 35-megahertz 68332 processor with 2 megabytes of static random-access memory. The design had the advantages of being inexpensive; providing the ability to directly connect a CMOS camera to the processor; and providing the necessary interface to connect motors, servos, gyroscopes, and many other sensors directly to the controller.

Utah State University

The Utah State University entry, the BLUE SWARM SENTINEL, was based on a radio-controlled *Sentinel* tank sold by Radio Shack. The *Sentinel* chassis was modified by replacing the radio-controlled electronics with a network of three Parallax, Inc., BASIC STAMP 2E microcontrollers. One microcontroller was responsible for controlling the tank's motors, and the second was responsible for two-way communication to a PC-based GUI using radio frequency transmitter-receiver pairs. The third microcontroller was responsible for sensing the outside world through a combination of infrared transmitters and detectors, a 3-bit compass module, and a thermopile temperature sensor. In addition, an X10 wireless camera was installed on the tank's turret to provide a real-time view of the area being searched by the robot. The *Sentinel* was also intended to coordinate the efforts of the BLUE SWARM 2 robots that Utah State entered in the 2001 USAR competition (Casper and Yanco 2002).

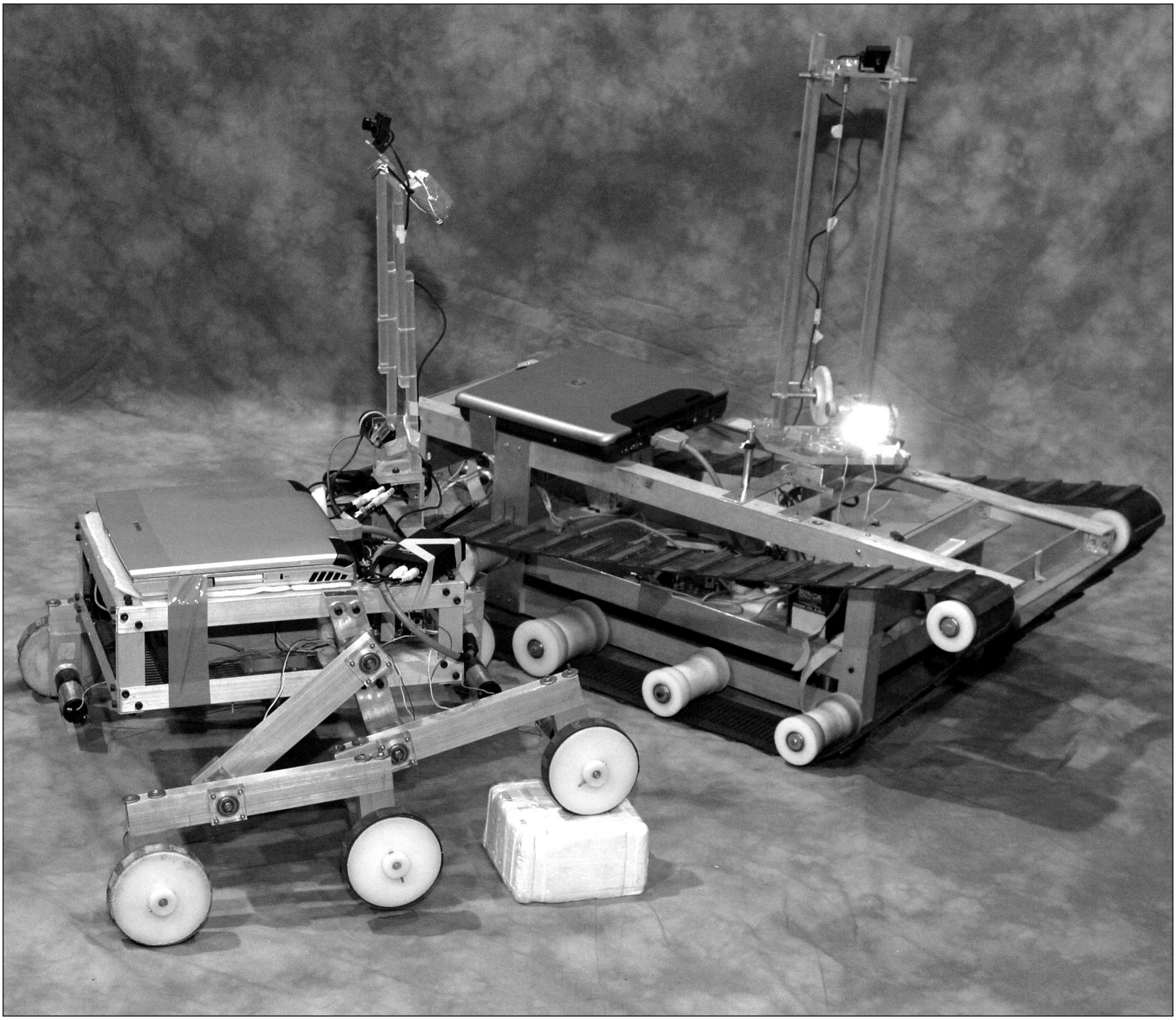

Figure 5. Young Scholars Club Robot Team Entry.

The MITRE Corporation

The MITRE Corporation entry intended to develop an approach to coordinated search using a team of robots controlled by a single human. The semiautonomous robots would be able to share information directly with one another and with a human using a commander console program. The three ActivMedia PIONEER 2-AT robots were each equipped with sonar and a single-color camera. Future goals include integrating other platforms (for example, IROBOT PACKBOT) and sensors (for example, laser range finder, pyrosensors, and microphones). Because of experienced hardware trouble, full-sensor integration and software development were in an early stage of development causing the team to withdraw as competitors, but they still exhibited.

New Roads High School

The goals of the SCARABS team entry from New Roads High School were to build viable robots at minimal cost; learn about math, computer science, electronic engineering, physics, AI, system integration, character development, and teamwork. RINGO, the 2002 Robot Rescue entry, was an updated version of the prototype run in previous competitions. The camera in the omnidirectional vision system was replaced with the Axis 2120 network camera. The 2120's ethernet connection and built-in

Linux web server allows a single ethernet cable for video and robot control and the future possibility of running CMU's CMVISION color-tracking software inside the camera. A laptop computer provided the operator interface.

Because of hardware problems, RINGO was unable to compete. However, future endeavors involve custom software to make it possible for the robot to be operated and mapped by a single person. The software will consist of three parts: (1) robot control, (2) mapping, and (3) printing. Victim status and obstacle information can also be recorded.

Competition Results

Overall team performance improved this year over that of the 2001 Robot Rescue competition. Three qualitative awards were given to teams displaying novel AI applications and technical innovations. Multiple teams also surpassed the minimum score required to acquire the quantitative place awards, unlike the previous year (Casper and Yanco 2002).

The three qualitative awards were distributed to teams deserving the honor. The Georgia Tech team incorporated an accurate real-time mapping algorithm useful in reporting the location of victims found. INEEL developed a unique and useful user interface for communicating information between the robot and the operator. The Young Scholars Club constructed a custom, rugged, outdoor platform capable of traversing rough terrain. Three teams were awarded first, second, and third place quantitative awards: The Young Scholars Club gained first place, Swarthmore College placed second, and Georgia Tech placed third.

Competition Lessons

This year's competition was unique in having feedback from a fire professional. Special Operations Chief Ron Rogers served as a judge for the competition and provided feedback on the competition and course. The following two paragraphs outline the mains lessons learned based on the feedback from Chief Rogers and competition officials.

Two main lessons were learned during the competition that affected the rules. First, a penalty is needed for wandering outside the designated hot and warm zones (competition arena and the area surrounding the hot zone). Second, wireless communication is a problem even in ideal environments. On a few occasions, competitors drove their robots outside the hot and warm zones, the competition arena. Penalties should be given to discourage this behavior. If this were a real scenario, and the hot zone happened to involve a hazardous material, driving outside the boundaries of the hot and warm zones would risk contaminating unprotected areas and further disaster. Wireless interference was an issue during the competition. Wireless dropouts are a common problem that roboticists will encounter in the field. A USAR response is often flooded with teams working on concrete and steel structures where radios for communication commonly drop out.

Three main lessons were learned during the competition that affect the course: (1) decrease light quality to improve course realism, (2) reconfigure the course to better reflect a disaster site, and (3) add Styrofoam sheets to simulate sheets of concrete. Lighting is never ideal in a disaster site. To better simulate realistic lighting, the arena should be draped in a see-through shade cloth, and emergency lighting should be added throughout the course, allowing the audience to view the course during competition and competitors to get a better feel for the odd lighting encountered during a disaster. Rescue teams most often enter the hot zone of a disaster site from the easiest and safest point of entry. The environment gets progressively more difficult as the team progresses through it. The competition arena should also reflect this realism by uniting the three course sections into one and have the entry point stationed at the easiest area. Sheets of concrete are commonly found in a disaster site. Sheets of painted Styrofoam can be used to simulate concrete sheets to add a sense of realism of the course.

Future Challenges

This year's competition challenged competitors to utilize the AI aspects of their robot systems to quickly locate victims within the NIST arena and accurately report the victim locations on a map. Competitors rose to the challenge and succeeded in some cases.

Future competitions will continue to challenge competing robotic systems by increasing the realism of the competition and arena. Real USAR environments pose many challenges in terms of navigation, communication, and other hardware issues (Micire 2002). Additionally, many software issues must be addressed (Casper 2002; Micire 2002). Human-robot interaction is an issue for USAR robot systems where a human is involved and needs to retrieve information from the robot system. Victim detection is another difficult task; color cues are not the only means of detection and might not always be available as the victim might be covered in dust. Obtaining an accurate location of a victim is difficult but needed because a robot is useless if it can detect a victim without providing even a relative location of where the victim is. As robot systems improve, the competition arena and rules will need to adjust to provide a more realistic scenario for guiding the ongoing development of USAR robot systems.

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The following people contributed descriptions of their robot entries: Bruce Maxwell from Swarthmore College, Dan Stormont from Utah State University, David Bruemmer from INEEL, Eric Meisner from the University of Rochester, and Mike Randall from New Roads High School.

Notes

1. For scoring details, see www.csee.usf.edu/-robotics/USAR/RobotRescue2002/).

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