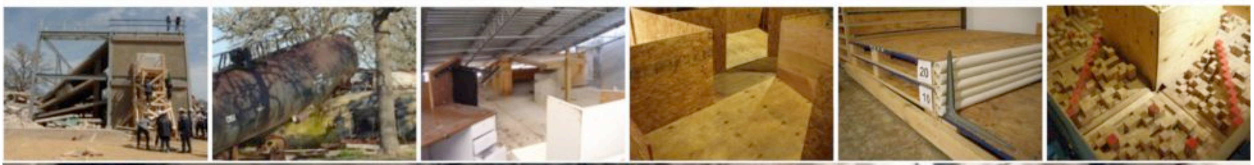
Homeland Security

NIST

Response Robot Evaluation Exercise

TX-TF1 Training Facility - Disaster City
College Station, TX
June 18-22, 2007
(with a standards meeting June 22, 2007)

www.isd.mel.nist.gov/us&r_robot_standards usar.robots@nist.gov



Executive Summary

The Department of Homeland Security, through the Science and Technology Directorate Standards Program, is developing performance standards for robots applied to urban search and rescue (US&R). The National Institute of Standards and Technology (NIST) is leading this effort with collaboration from subject matter experts within the Federal Emergency Management Agency (FEMA) US&R Task Forces and other response organizations, along with robot manufacturers and robot researchers intent on this application domain. The resulting standard test methods are being developed within the Homeland Security Applications Committee E54 of ASTM International.

Due to the breadth and complexity of urban search and rescue missions, and the diverse and evolving technologies present within robotic systems, the definition of performance requirements and associated test methods is an ambitious undertaking. The robot providers and eventual end-users need to reach common understandings of the envisioned deployment scenarios, environmental conditions, and specific operational capabilities that are both desirable and possible for robots applied to US&R missions. Toward that end, NIST organizes events that bring emergency responders together with a broad variety of robots and the engineers that developed them to work within actual responder training facilities. These informal response robot evaluation exercises provide collaborative opportunities to experiment and practice, while refining stated requirements and performance objectives for robots intended for search and rescue tasks. The most recent event was held June 18-22, 2007 at Disaster City in College Station,, which is the FEMA Texas Task Force 1 Training Facility.

Responders from the FEMA Task Forces were able to experiment with a wide range of robotic platforms: 16 models of ground vehicles, 1 wall climber, and 1 aerial vehicle. Nine different deployment scenarios were used around Disaster City. In each of these scenarios, responders used the robots to search areas of interest for simulated victims and other embedded tests. Eleven draft test methods and their associated test artifacts were evaluated and were also available to support robot/operator practice and training. These reproducible test methods, which are intended to help guide developers toward effective solutions while providing responders with known practice, training, and evaluation methods, were refined based on the experiences and feedback from this event. Some of the resulting test methods, which are dubbed "Wave 1," have already begun to be submitted to ASTM International for balloting in the coming months. Robot developers arrived two days before the responders, to allow them focused time for running their robots through the test methods. This made the robots generally more available for responders to practice operations and use them in scenarios.

Some additional complementary activities were offered at this exercise. A compressed and tailored version of a rescue robotics awareness class, which has been developed by the Center for Robot Assisted Search and Rescue at the University of South Florida was made available to responders (and developers). Relevant technology initiatives were also shown to responders to make them aware of promising upcoming developments that may prove useful to the search and rescue community and have them provide their feedback to the developers.

A draft version of what will eventually be a robot compendium was produced for this exercise. A listing of all the expected robots, including pictures and manufacturer's specifications were organized by robot category and size. The draft test methods were defined, and there was a section allocated to each robot, in which the test results will eventually be filled in. Small, portable, "pocket guide" versions were distributed to all participants as a reference guide. Responders could use this to jot down notes or as a reference to find out more information about a robot.

An informal meeting of the ASTM E54.08.01 Task Group was held on the final day. The test methods were reviewed and discussed to reach agreement on their final forms.

Extensive data was collected throughout the event. Responders, manufacturers, and researchers were asked to provide feedback on the scenarios, test methods, and robots. Videos and images were captured of all robots in action. Measurements per the draft test methods were captured for practically all the robots (on test methods that were applicable to their particular category). In the data collection, priority given to capturing performance when the robots were operated by "experts."

This report provides a summary of all the activities and results from this event. Highlight images and video of the robots can be downloaded from the NIST project home page:
http://www.isd.mel.nist.gov/US&R_Robot_Standards.

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1. Introduction and Background

The event held at Disaster City, which is a training facility for the Texas FEMA Task Force 1 operated by the Texas A&M University's Texas Engineering Extension Service, is part of an ongoing program funded by the Department of Homeland Security and conducted by the National Institute of Standards and Technology to develop performance standards for robots applied to urban search and rescue. During the initial phase of the program, FEMA Task Force members participated in a series of workshops in which the performance requirements for US&R robots were defined. During these workshops, potential robot deployment categories and employment roles were also enumerated. Roughly one hundred requirements were defined and organized into a systematic structure, along with thirteen robot deployment categories.[1] The output of the program is to be a set of standard test methods complemented by usage guides to help responder entities decide which robot categories are best suited to which response scenarios. The performance test methods will provide a common language, reproducible test artifacts, and performance objectives defined by the responders to help robot developers refine their system designs and objectively measure performance. The usage guides will provide recommended performance ranges for different deployment scenarios. ASTM International is the host organization for the resulting standards, under the Operational Equipment subcommittee within the Homeland Security Applications Committee (E54.08)[2].

Due to the multi-disciplinary nature of robotics and the complexity of the urban search and rescue application, the derivation of performance test methods from the initial requirements is a multi-stage, iterative process. An initial attempt at prioritization of requirements was performed based on the responders' input regarding which requirements applied to the greatest number of robot deployment categories; in other words, the requirements deemed most essential to any robot deployment, were selected. This initial list of requirements comprise the candidate set of "Wave 1" requirements for which performance test methods are being developed and standardized in 2006-2007. Subsequent standardization waves will occur periodically as the technologies and robots mature enough to address the additional performance requirements.

Response robot evaluation exercises, such as the one held at Disaster City, introduce emerging robotic capabilities to emergency responders while educating robot developers regarding the performance requirements necessary to be effective, along with the environmental conditions and operational constraints necessary to be useful. They also provide an opportunity to refine draft or emerging test methods and associated test artifacts being developed to measure robot performance in ways that are relevant to emergency responders. Conducting these events in actual US&R training scenarios helps correlate the proposed standard test methods with envisioned deployment tasks and lays the foundation for the usage guides which will identify which robot categories appear best suited for particular response tasks. Furthermore, exercises allow responders as well as robot developers to gauge progress in the maturity of the various component technologies as well as the integrated robotic systems.

Three other response robot evaluation exercises were held prior to the most recent one in Texas. The first one was held in August, 2005 at the Nevada FEMA Task Force 1 Training Facility. In April 2006, an exercise was held at this same site, Disaster City®. In August 2006, Maryland Task Force 1 hosted an exercise at the Montgomery County Fire Rescue Training Academy. Reports from these first three events can be found at http://www.isd.mel.nist.gov/US&R_Robot_Standards/events.

[1] http://www.isd.mel.nist.gov/US&R_Robot_Standards/Requirements%20Report%20(prelim).pdf

[2] http://www.astm.org/

2. Participants

NIST's team of test engineers and support personnel worked with the TX-TF1 personnel on the planning and execution of this event, which accommodated roughly sixty people and more than twenty robots across 8 different scenario props at Disaster City.

The primary participants from the emergency responder community were representatives from FEMA US&R Task Forces, as has been the case throughout the DHS/NIST performance standards program for US&R robots (see Fig. 1). One FEMA canine team participated throughout the event.

Figure 1: Responders Operating Robots and Exploring US&R Training Props

As for robot participation, there were 16 different models of ground vehicles, 1 wall climber, and 1 aerial vehicle. The robots represented 7 of the 13 envisioned US&R deployment categories identified in earlier workshops.[3] Table 1 lists each model of robot available on site for the responders to use. There were multiple instances of some of the more mature models available. Representatives from the robot developers/manufacturers typically deployed their own robots, but some were deployed by the Southwest Research Institute[4], the Center for Robot Assisted Search and Rescue (CRASAR)[5] and by the Alliance for Robotic Assisted Crisis Assessment & Response (ARACAR)[6].

[3] Statement of Requirements for Urban Search and Rescue Robot Performance Standards (Preliminary Version), May 2005. http://www.isd.mel.nist.gov/US&R_Robot_Standards/Requirements Report (prelim).pdf

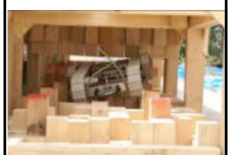
[4] http://www.swri.org

[5] http://crasar.csee.usf.edu/

[6] http://www.aracar.org/

Table 1: Participating Robots

IMAGE (Roughly by size)	NAME	DEVELOPER (Brought by)	DEPLOYMENT CATEGORY
Wall Climbers			
	VRAM Mobile Robot Platform (VMRP) (suction)	Vortex HC, LLC (SwRI)	4. Ground: Wall Climber
Ground			
	ToughBot	OmniTech Robotics, LLC	1. Ground: Peek Robot
	ActiveScope (Camera)	Tohoku University, Tadokoro Laboratory	1. Ground Peek Robot
	Eye Ball	Remington Technologies	1. Ground: Peek Robot
	Dragon Runner	Foster-Miller/Automatika	3. Ground: Non Collapsed/Wide Area Survey
	Bombot	West Virginia High Tech Foundation	3. Ground: Non Collapsed/Wide Area Survey

	Negotiator Tactical Surveillance Robot	Robotic FX, Inc.	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 6. Ground: Confined Space Shape Shifters
	Hazardous Envi-ronment Robotic Observer (HERO)	First Response Robotics, LLC	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 6. Ground: Confined Space Shape Shifter
	PackBot Explorer	iRobot Corp. (CRASAR)	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 6. Ground: Confined Space Shape Shifters
	PackBot EOD (w/ manipulator)	iRobot Corp. (ARACAR)	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 7. Ground: Retrieval Robot
	Matilda	Mesa Robotics, Inc.	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey
	Matilda (w/ manipulator)	Mesa Robotics, Inc.	2. Ground: Collapsed Structure/Stair Climber 3. Ground: Non Collapsed/Wide Area Survey 7. Ground: Retrieval Robot
	Modular Logistics Platform	Segway, Inc.	3. Ground: Non Collapsed/Wide Area Survey

	Talon (w/ manipulator)	Foster-Miller, Inc. (NIST)	3. Ground: Non Collapsed/Wide Area Survey 7. Ground: Retrieval Robot
	Talon HAZMAT (w/manipulator)	Foster-Miller, Inc.	3. Ground: Non Collapsed/Wide Area Survey 7. Ground: Retrieval Robot
	Robotic Mobility Platform (RMP 200/ INL)	Segway, Inc.	3. Ground: Non Collapsed/Wide Area Survey 7. Ground: Retrieval Robot
	Robotic Mobility Platform (RMP 400/ INL)	Segway, Inc.	3. Ground: Non Collapsed/Wide Area Survey 7. Ground: Retrieval Robot
Aerial			
	AirRobot	AirRobot GmbH	8. Aerial: High Altitude Loiter

3. Scenarios

This section briefly describes the training scenarios, or props, that were used during this exercise. Responders rotated through the scenarios described below as well as the technology initiatives station (see Section 6) and test methods. Each scenario is followed by a list of test methods that could be considered abstractions of certain aspects of the scenario.

Government/Municipal Building Collapse (#133)



This is the newest and most realistic building collapse prop in Disaster City. It was designed by rescuers to incorporate the challenges from the world's largest disasters. It has a hanging slab like the Oklahoma City disaster which is 30 square meters (100 square feet) and weighs 5500 kilograms (12,000 pounds). Responders are to deploy robots to search for trapped victims within the prop's confined spaces and severely sloped floors. Robots can also be deployed to support techniques to render the structure safe. There is no other place in the United States where rescuers can practice this.

Test Methods Evoked

- Visual Acuity (Dark)
- Inclined Plane
- Confine Space Cubes

Passenger Train Wreck (#126 and #127)



Passenger rail cars were hit by industrial hazmat tanker cars of unknown substance and both trains partially derailed. Ground robots should circumnavigate the train wreck, over tracks, various debris, and rubble. The robots should 3-D map the perimeter along with the location and positions of each car, including under elevated car (used in advanced shoring class). Robots should search the Sleeper Car ramping up from the ground, search each curtained alcove on both sides looking for simulated victims. For the Crew Car on its side, robots should be inserted to explore the interior to locate any simulated victims or read the placards on hazardous canisters which may be in the mail room. Access to the mailroom is too small for a responder in Level A suit.

Test Methods Evoked

- Visual Acuity (Ambient Light and Dark)
- Random Step Fields

Industrial Cargo Trains with hazardous materials (#116 and #117)

Some of the hazardous tanker cars are also derailed, and apparently leaking fluids in places. Simulated surface victims appear incapacitated in/around the cars. Aerial and ground robots should negotiate circumnavigate the area, over tracks and various rubble and debris to search the perimeter, map the location of all cars, simulated victims, and the source and extent of all leaks. They should also read the hazardous materials placards and possibly return with samples for testing.

Test Methods Evoked

- Visual Acuity (Ambient Light)
- Random Step Fields
- Manipulator Dexterity

House of Pancakes (#130)

The House of Pancakes is a partially collapsed building of unknown use with roof almost in contact with the ground on the only accessible side. Enter through confined access under the metal roof or through breach, explore overall maze of obstacles and debris) to look for simulated victims and hazards. Robots are to be used to read hazardous materials placards or identify cracks in walls when found. If possible, they are to provide shoring to access area or lift other obstructions (large blocks are inside). Shoring is a lower priority at this stage of the project.

Test Methods Evoked

- Visual Acuity (Ambient Light)
- Mobility: Random Step Fields
- Confined Space Cubes

Single Family Dwelling (#129)



Partially collapsed dwelling due to earthquake. Main entrances are compromised, so the exterior wall has been breached with a 0.6 m (24") triangle. Enter the maze of rooms either through the door under a leaning collapse or through the breach to perform a pattern search of the entire dwelling for simulated victims and hazardous materials stored inside. Negotiate various rubble and debris, perform a thorough search for simulated victims, move through and interact with the environment where necessary, and map the rooms to provide responders with all necessary information pertaining to victims, hazards, entrances/exits. There is also a basement accessible from the outside down steep stairs.

Test Methods Evoked

- Visual Acuity (Dark and Ambient Light)
- Confined Space Cubes
- Mobility: Random Step Fields
- Stairs
- Directed Perception
- Manipulator Dexterity
- Door Opening (Future Test Method)

Additional scenarios were available for practice and experimentation, but were not extensively utilized, so they are not described in this report.   The other available scenarios were the Strip Mall, Concrete Rubble Pile #2, and Wood Rubble Pile #3. These are described in the report from the 2006 Disaster City Exercise.

4. Draft Test Methods

A set of test methods designed to address specific responder-defined robot requirements were set up throughout the site and embedded into some scenarios. This provided an opportunity to refine these test methods based on feedback from responders and developers as they used them for practice and operator training. The initial test methods and artifacts are described briefly below. Based on feedback from the participants, the resulting test methods will be introduced into the standardization process through the ASTM International E54.08.01 task group.

In this exercise, high priority was placed on ensuring that there was as close to 100% coverage by all robots of all relevant test methods. This was managed by a central dispatching station in which the Dispatch Leader (a NIST team member) had a matrix with all the robot names as columns and all the test methods as rows. Since not all test methods applied to all robots, the required tests were marked on the matrix for each robot. Robot teams were required to check in with the dispatcher, providing their robot specification sheet if they had not done so in advance. They reviewed the information that NIST had pertaining to their robot for the "pocket guide" (see below) and made any necessary corrections. They then were assigned to a test method that was available. Figure 2 shows the central dispatching board.

Given the large number of robots that had to be run through the test methods, a time limit was placed on each test for this exercise. However, this is not the intended design for the test methods. The actual test measurement methodology includes capture of the total duration of time it takes for a robot to complete a particular test's task(s). This measurement was captured for those that took less than 20 minutes.

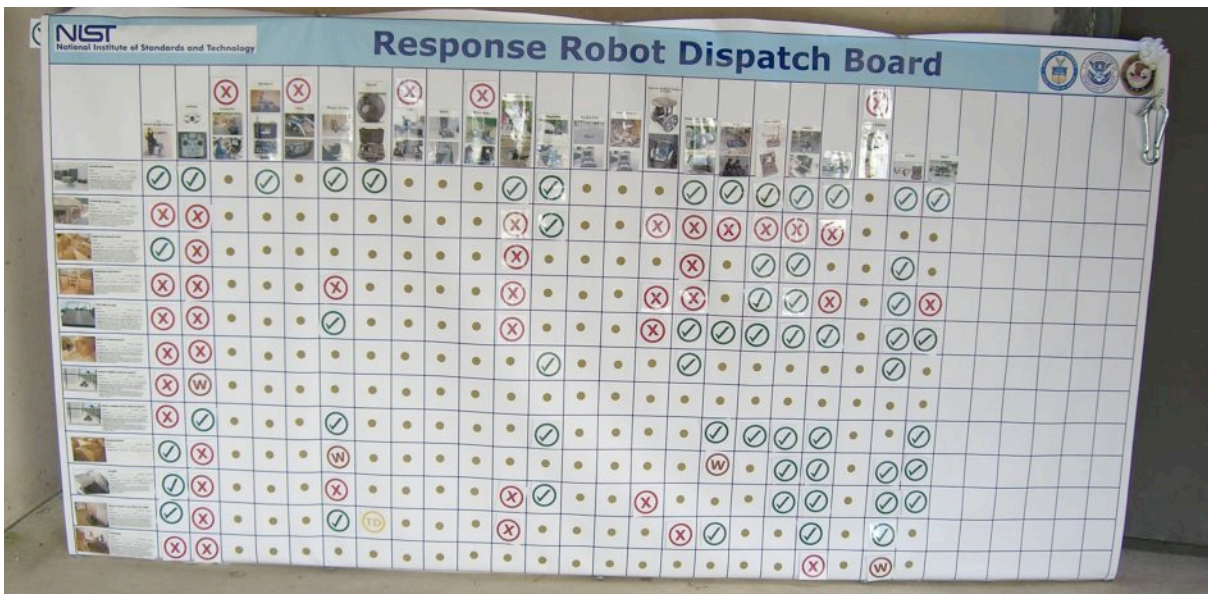


Figure 2: The central dispatch board. The participating robots are listed in the columns and the rows represent the test methods that they are to run. Cells marked with a red X mean that a particular test method did not apply to that robot. A green check mark indicated that the test had been completed. A "W" meant that the robot was "working" in a test method.

A test method data capture sheet was designed for each test method to guide the process. The sheets for all the tests as deployed in this exercise are included below. Some modifications are being made as a result of the feedback from the participants as well as test administrators. The data capture sheets contain the generic design of the test apparatus setup. At time of performing the test, the administrator is to capture the actual configuration of the apparatus by making the appropriate marks on the forms (e.g., for a ramp test, they are to select what the angle of the ramp is). The various quantities that are to be measured in the course of the test are clearly indicated on the form. The self-declared training level for the robot operator is captured (less than 24 hours, between 24 and 100 hours, and over 100 hours of training). This is useful for benchmarking performance and for generating statistical data by experience category.

Each test method had at least one administrator. They were responsible for capturing the ground truth (i.e., particular configuration for the test setup in this particular instance). They explained the test to the robot operators and kept track of time. The operators were encouraged to capture some of the data themselves on the test method sheets (see below). The administrators helped them with this procedure. Every attempt was made to ensure safety to humans as well as to robots throughout. If a robot seemed to be in a precarious position or situation, the administrators alerted the operators. The reverse side of the form was used in this exercise to capture comments by the test administrator and by the responders and the robot team members. In particular, responders and robot team members were asked whether the test was realistic enough (i.e., whether it captured representative elements of tasks that would be performed in the field during search and rescue) and whether the test was fair.

General comments about the test methods are included in the individual descriptions below. Specific information about the implementation of test methods is also included.

A supporting component of the overall standards development program is the compendium of robots. This will be a comprehensive listing of all robots that have run through the tests methods (once they've been approved by the consensus standards process). The results of the test methods will be listed for each robot (where applicable) alongside images of the robot and manufacturer-provided specifications. To provide a flavor for this eventual deliverable and to help the responders capture their own observations and impressions of the different robots, a preliminary version of the compendium was available for this exercise. In the form of a booklet that could be easily carried around, the "pocket guide" had manufacturer's specifications for each robot, as well as a page to hold the test method results. The results were not filled-in, but were meant to give the participants a feel for what will eventually be captured in the robot performance tests. Robots were grouped by Ground, Aerial, Aquatic, and Wall Climbers, and were listed within each group by increasing size. Additional sections included a site overview map, program and event introductions, information about sensors that were paired with robots, safety guidelines, and a description of each test method. Several users of the guides found the photographs useful in recognizing robots as they traversed the various test methods and scenarios. Figure 3 shows the cover of the pocket guide and a sample of the pages for a ground robot.

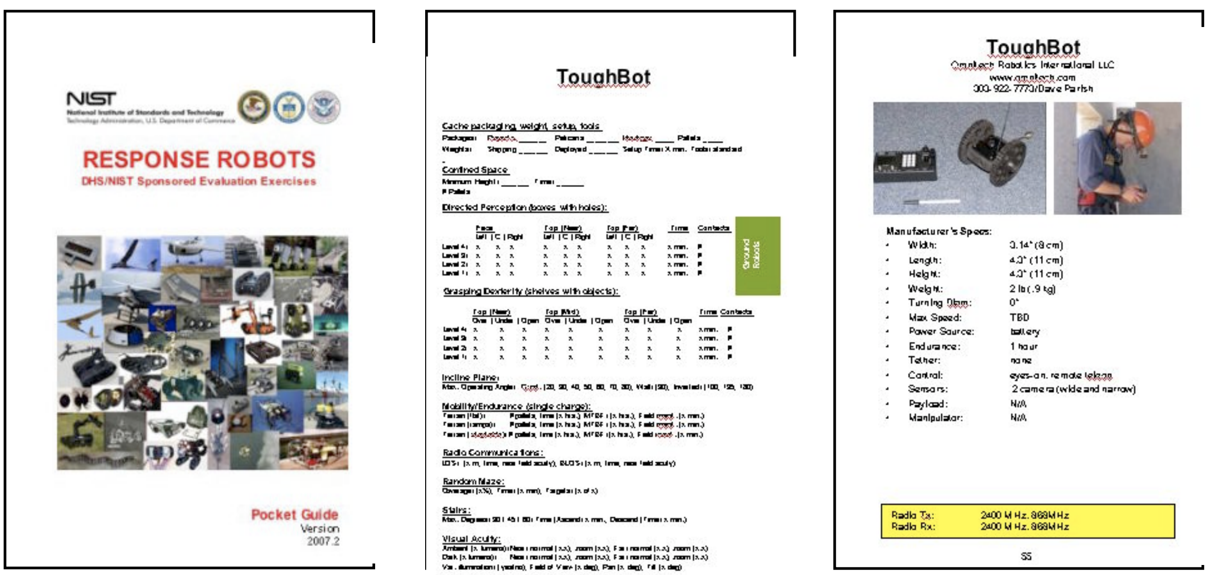


Figure 3: Pocket Guide

4.1 Logistics

Initial, high priority, and easily measured aspects of how robots would impact the logistics within a response organization are being included in the first wave of standards. Figure 5 shows the form that captures all the measurements within the Logistics area. The different types of requirements that drove the practice[7] are listed below.

Logistics – Cache Packaging – Volume

This simple practice addresses the requirement that the robot and all associated components (such as the operator control unit and spare parts) must be compatible with the responders' cache packaging and transportation system. Based on responders' definitions of the metric, three standard packing cases were available for the manufacturers to determine which ones were required to contain the entire robotic system. Figure 4 shows examples of typical cases used by FEMA responders.

Logistics – Cache Packaging – Weight

This simple practice addresses the requirement on the part of the responders that they be able to move and store all equipment using existing methods and tools. A scale was available for robot manufacturers to weigh their robotic system.

Logistics – Setup Time

In this test method, the robot manufacturer or developer has to indicate the amount of time it takes (on average) for the robot to be set up at a deployment site. This covers the entire process from unpacking to the time when the robot is ready to be used in a mission.

Logistics – Tools Required

This test method addresses the requirement on the part of responders to know what types of tools are required for servicing a robot in the field.

Logistics – Downrange weight

This captures the weight of the robot and of the operator control unit when the robot is deployed. This measure informs responders about what weight they can anticipate having to carry into downrange from the base of operations.

Test Practice Comments

All robots manufacturers were exposed to this practice as part of their initial check-in procedures. There were no comments about this practice. This is being interpreted as being acceptable to those who became familiar with it.

Figure 4: Logistics Test Practice. Left shows Vendor Tents and Robot Check-In/Dispatch (blue tent). The Logistics Methods were included in the check-in procedure. Right shows Cache Packaging.

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[7] The nature of the Logistics data capture is such that it has been deemed a "practice" by ASTM, rather than a test method. A practice is defined by ASTM as "a definitive set of instructions for performing one or more specific operations that does not produce a test result."

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National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Developing

Standard Practice For Response Robots

Logistics - Cache Packaging

ROBOT: ________________ ☐ TETHER ☐ RF

OPERATOR: ________________ ORG: _________________

SKILL LEVEL: ☐ 0-24 HRS ☐ 24-100 HRS ☐ > 100 HRS

INSTRUCTIONS: 1) Note the number and weight of each packaging container necessary for robot to deploy for 10 days, without re-supply for the first 96 hours. 2) Time the setup process until ready to go downrange. 3) Weigh the deployable robot and operator control unit. 4) Note the tools needed to perform setup and repair.

Planning for a 10 day deployment, without resupply for the first 72 hours

Number of packages plus total weight for each type of package

_____ Pelicans _______ kg or ______ lb

_____ Hardiggs _______ kg or ______ lb

_____ Ropacks _______ kg or ______ lb

_____ Pallets _______ kg or ______ lb

Pallet dimension: ______ x ______ mm (______ x ______ in)

Total Weight: _______ kg or ______ lb

NOTE: Brand name packaging is listed on this form. See text of standard practice for equivalent dimensions if another brand can be used.

Measure the length of time to unpackage the robot system and fully prepare it for deployment.

Setup Time:

Start Time: ____________

End Time: ____________

Elapsed: ____________ minutes

Down-Range Weight:

Robot: __________ kg Operator Control Unit: __________ kg Total: __________ kg

Robot: __________ lbs Operator Control Unit: __________ lbs Total: __________ lbs

---

Setup and Repairs can be performed at the base of operation

Tools Needed:

☐ None

☐ Typical Toolbox: Metric or English (circle one)

☐ Any Specialized Tools: Describe: ________________________

Describe: ____

Describe: ____

TEST LEADER DATE NOTES ☐

Figure 5: Logistics Practice Data Capture Form

4.2 Sensing - Vision System

Sensing – Vision System – Acuity (Near Field)

This test method captures the responders' expectation to use video for key tasks such as maneuvering (hence the real-time emphasis), object identification (hence the color emphasis), and detailed inspection (hence the emphasis on short-range system acuity). The responders noted the need to consider the entire system, including possible communications signal degradation and display quality, when testing this capability. They also noted that this requirement is closely tied to the need for adjustable illumination to avoid washing out the image of close objects. The responders made no distinction regarding tethered or wireless implementations to address this requirement. The near and far field tests are implemented together below. An example set up (from Disaster City) is shown in Figure 7. The data capture sheet is shown in Fig. 8.

Sensing – Vision System – Acuity (Far Field)

This test method captures the responders' expectation to use video for key tasks such as maneuvering (hence the real-time emphasis), object identification (hence the color emphasis), and path planning (hence the emphasis on long-range system acuity). The responders noted the need to consider the entire system, including possible communications signal degradation and display quality, when testing this capability. They also noted that the limiting case for long-range system acuity is probably assessment of structural integrity of buildings. This requires identifying and measuring cracks in walls, inspecting the tops/bottoms of load bearing columns, and generally assessing the squareness of walls, ceilings, and floors. The responders made no distinction regarding tethered or wireless implementations to address this requirement. The associated reference test artifacts are shown below.

The visual acuity test method used both near and far field charts and hazard labels in view from a single viewing location for the robot (Fig. 6). The robots were placed at the appropriate locations. The operator was to correctly read the smallest line possible, which corresponds to certain lines on the real-life hazard and shipping labels.

Figure 6: Example of correlation between eye charts and domain-relevant label sizes

Sensing – Vision System – Acuity (Aerial)

This test method addresses the responder requirement to visually identify features of interest, in this case from aerial robots. The same principles guiding the other visual acuity tests are applied to this test. Eye charts are scaled up to be comparable in size to, and much larger than, hazardous materials identification placards found on rail cars. The charts are positioned vertically to simulate the orientation that hazmat placards have normally on tanker cars. If conducted from an aerial platform in flight, the test targets are marked with 1.2 m square black panels with white Xs to help the robot operators find and focus on specific targets of interest within the scenario. The Xs are placed on the ground in unique groupings. The aerial operators identify such groupings by reporting the number of Xs and overall pattern and then proceed to investigate the target of interest. The test method can be conducted with the vehicle stationary on the ground at an appropriate distance from the eye charts.

Sensing – Vision Systems – Field of View

This test method addresses the responder requirement to be able to effectively perceive the surroundings of the robot as it explores an unknown area. The field of view is measured by having the operator note which markings on the wall can be viewed through the robot's camera. Vertical marks are placed on the wall subtending fields of view from the test distance of 20°-60° in increments of 10°.

Test Method Comments

Whether the camera is analog or digital must be noted in the form, as this has an effect on the results of the test method. The cosine transform used in MPEG coding picks up the sidebar of the "E" on the eyecharts and allows the direction of the character to be seen below the level at which the "E" can be distinguished as a character. This will require a change of wording to require seeing all four bars of the E.

Figure 7: Visual Acuity Test Set Up

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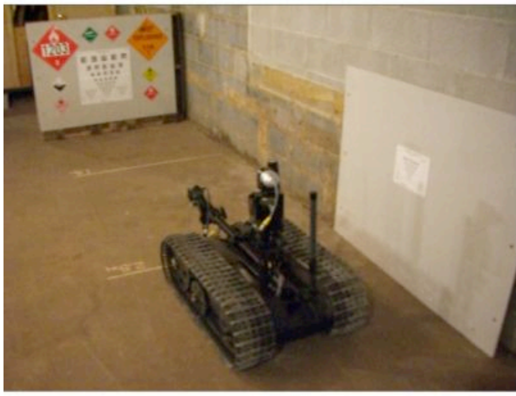
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Developing

Standard Test Methods For Response Robots

Version: 2007.4



VISUAL ACUITY and FIELD OF VIEW

ROBOT: ________________ ☐TETHER ☐RADIO

OPERATOR: ________________ ORG: _________________

TRAINING TIME: ☐ 0-24 HRS ☐ 24-100 HRS ☐ > 100 HRS

ADMINISTRATOR: 1) NOTE THE CAMERA LOCATION AND ASSOCIATED FEATURES. 2) PLACE THE SNELLEN CHARTS AT THE PROPER DISTANCES: *FAR FIELD* = 6 M AND *NEAR FIELD* = 40 CM. 3) NOTE THE LUX LEVEL OF LIGHTED AND DARK CHARTS. 4) CIRCLE THE DECIMAL EQUIVALENT FOR THE SMALLEST CORRECT LINE READ NORMALLY AND WITH ZOOM LENS IN AMBIENT LIGHT. 6) REPEAT WITH LIGHTS OUT (ILLUMINATION <1 LUX).

CAMERA: _______________ FOV:____° PAN:____° TILT:____° ZOOM:____x LIGHT: Y | N VARIABLE: Y | N

FAR FIELD TEST (DISTANCE = 6.0 METERS)

TEST DISTANCE 6 M	(20 FT)	LIGHTED CHART (_______ LUX) NORMAL	ZOOM	DARK CHART (_______ LUX) NORMAL	ZOOM
AERIAL CHART		NONE	NONE	NONE	NONE
6/90	(20/300)	0.07	0.07	0.07	0.07
6/75	(20/250)	0.08	0.08	0.08	0.08
6/60	(20/200)	0.10	0.10	0.10	0.10
6/45	(20/150)	0.13	0.13	0.13	0.13
FAR FIELD CHART (6M)					
6/30	(20/100)	0.20	0.20	0.20	0.20
6/24	(20/80)	0.25	0.25	0.25	0.25
6/18	(20/60)	0.33	0.33	0.33	0.33
6/15	(20/50)	0.40	0.40	0.40	0.40
6/12	(20/40)	0.50	0.50	0.50	0.50
6/9	(20/30)	0.67	0.67	0.67	0.67
6/7.5	(20/25)	0.80	0.80	0.80	0.80
6/6	(20/20)	1.00	1.00	1.00	1.00
6/4.8	(20/16)	1,25	1.25	1.25	1.25
6/3.8	(20/12)	1.7	1.7	1.7	1.7
6/3.0	(20/10)	2.0	2,0	2.0	2.0
6/2.4	(20/8)	2.5	2.5	2.5	2.5
6/1.7	(20/6)	3.3	3.3	3.3	3.3
6/1.5	(20/5)	4.0	4.0	4.0	4.0
NEAR FIELD CHART		(BOTTOM NINE LINES ADJUSTED TO 6M)			
6/1.25	(20/4)	5.0	5.0	5.0	5.0
6/1.00	(20/3.3)	6.0	6.0	6.0	6.0
6/0.8	(20/2.7)	7.5	7.5	7.5	7.5
6/0.6	(20/2.0)	10	10	10	10
6/0.5	(20/1.7)	12	12	12	12
6/0.40	(20/1.3)	15	15	15	15
6/0.3	(20/1.1)	20	20	20	20
6/0.25	(20/.08)	24	24	24	24
6/0.20	(20/.07)	30	30	30	30

VISUAL ACUITY RATIOS NOTED MEAN:

READABLE AT ACTUAL TEST DISTANCE

READABLE DISTANCE WITH STANDARD VISION

CIRCLE DECIMAL EQUIVALENT IN EACH COLUMN

NEAR FIELD TEST (DISTANCE = 0.40 METER)

EQUIVALENT DISTANCE 6 M	(20 FT)	LIGHTED CHART (_______ LUX) NORMAL	ZOOM	DARK CHART (_______ LUX) NORMAL	ZOOM
NEAR FIELD CHART		NONE	NONE	NONE	NONE
6/120	(20/400)	0.05	0.05	0.05	0.05
6/96	(20/320)	0.06	0.06	0.06	0.06
6/75	(20/250)	0.08	0.08	0.08	0.08
6/60	(20/200)	0.10	0.10	0.10	0.10
6/48	(20/160)	0.12	0.12	0.12	0.12
6/38	(20/125)	0.16	0.16	0.16	0.16
6/30	(20/100)	0.20	0.20	0.20	0.20
6/24	(20/80)	0.25	0.25	0.25	0.25
6/19	(20/63)	0.32	0.32	0.32	0.32
6/15	(20/50)	0.40	0.40	0.40	0.40
6/12	(20/40)	0.50	0.50	0.50	0.50
6/9.5	(20/32)	0.63	0.63	0.63	0.63
6/7.5	(20/25)	0.80	0.80	0.80	0.80
6/6.0	(20/20)	1.00	1.00	1.00	1.00
6/4.8	(20/16)	1.25	1.25	1.25	1.25
6/3.8	(20/12)	1.60	1.60	1.60	1.60
6/3.0	(20/10)	2.00	2.00	2.00	2.00

TEST LEADER DATE NOTES ☐

Figure 8: Sensing – Visual Acuity Test Method Data Capture Form

4.3 Directed Perception

(References requirement named Payload – Manipulation – Maximum Reach)

This test method addresses the responder requirement to use robotic manipulators to perform a variety of tasks in complex environments. This directed perception test captures discrete ranges of useful manipulator reach with a payload, which in this case is a camera and a light (variable illumination was very helpful in this test). The test method is meant to be flexible and extensible in terms of the payload that is being manipulated. For example, the payload could also be a chemical, biological, radiological, nuclear, or explosive sensor.

The test utilizes 3 stacks of boxes (each box is 46 cm tall x 46 cm deep x 61 cm wide) with 15 cm diameter access holes. Each box stack has one hole in the front at each level and holes in the top. Each box contains targets inside, in this case, hazard labels were used. The front access holes are vertically aligned on each box, and located on the left quarter line, requiring a skewed view to identify targets inside. The top holes are in the near-left and far-right quadrant of each stack. Each stack (left, middle, and right) thus provides a different positioning and orientation challenge to the robot and payload manipulator, even though they are identically constructed. Robot operators are asked to position the robot within the alcove formed by the three stacks of boxes and maneuver the robot's manipulator so as to be able to perceive what is inside each box through the front and top holes. Figure 9 shows a robot performing the test method.

The robot's reach ability is tested level by level. The test begins with a single level of boxes in each of the stacks, with the robot positioned outside of the directed perception area. The operator is then instructed to begin searching as many of the holes as possible and to notify the test administrator of any hazard labels they were able to identify. The search task may involve repositioning the body of the robot (translation as well as orientation) in addition to moving the manipulator. When the operator completes searching a level of boxes, s/he returned the robot back to the starting position and the next level of boxes was stacked onto the just complete set.

This data capture form contains customization choices for setting up the test configuration. There are three stacks of boxes: Left, Center, and Right. There is designed flooring in the space enclosed by the left, center, and right boxes and extending linearly beyond the enclosed space.

The test administrator is to identify the current flooring design on the forms prior to starting the test method execution. The choices are oriented planar flooring or varieties of step fields.

- Planar flooring may have a side roll with either the left or right side higher (known as "roll" configuration) or have a "pitch." A pitched floor would have an elevated center that causes a rise and a fall in the direction of approach to the center stack of boxes.
- Step fields are constructed of sets of blocks that have different heights and follow certain trends. A "diagonal" step field would have the highest blocks along the diagonal. A "hill" design step field would have the highest blocks form a ridge in the direction of approach to the center stack of boxes. Step fields can also be constructed of to have different maximum step heights. In this case, the choice is limited to "half cubic."

The form used at Disaster City and shown in Figure 10 assumes that hazardous materials labels are the targets to be searched using a camera. The form would be modified if it were a different sensor signature and marked with the appropriate choices. Also for sensors where it is applicable, distances to the center of the boxes is marked on the floor to note where a particular sensor signature was first detected. This is used, for instance, if there is a radiological or chemical target within the stacks, it may be of interest to note from how far away the sensor onboard the robot began picking up a signal. The lower left hand corner of the form shows how to mark fixed distances from the center of the box stack in order to facilitate measuring point of initial detection.

In terms of capturing performance data during execution of the test, there are several aspects that must be noted. The overall time necessary to clear all the holes accessible by the robot is captured. For each level of each stack, the following data are obtained:

- Which hazmat labels were detected and what modalities were noted: color, shape/icon, word, number,
- The number of times the robot (including its manipulator) bumped the boxes
- The time it took to complete searching a level

Test Method Deployment at Disaster City

This test method has been considerably simplified since its earlier versions. One of the key considerations is trying to minimize the number of variables in the test to reduce the combinatorial explosion and time to conduct the test.

A "level" of boxes was constructed out of four individual boxes that were taped together to form a single moveable unit. There was one hole on the front face of a level of boxes and two holes on the top of a level of boxes. Inside each of the holes was one randomly chosen hazard label out of a choice of five possible labels. The stacks of boxes were held in place by sheets of plywood joined in an L-shape to form side walls and straps were used to keep the boxes firmly in place. The test calls for a couple of different possible floor types to be used during the testing. Due to limited time constraints only a single floor style, the slanted floor, was used during this iteration. The slanted floor angles the floor to be slightly higher on the right side stack of boxes and puts the robot on a slight tilt as it sits in the test area.

A stack of practice boxes was setup in the room next to the main test area where operators could get familiar with using their manipulators to explore inside of the test boxes before beginning the actual test. Responders were given tutorials on the operation of the robot and the robot's manipulator before they began their test.

The test began with a single level of boxes in each of the stacks with the robot positioned outside of the directed perception area. The operator was then instructed to begin searching as many of the holes as possible and to notify the test administrator of any hazard labels that they were able to identify. When an operator completed the searching of a level of boxes he returned the robot back to the starting position and the next level of boxes was stacked onto the just completed boxes. The holes of the just completed boxes were covered so that the only visible holes were on the new top level of boxes.

Data that was collected included the number of correctly identified hazard labels, the time spent searching a hole, the overall time to finish each level, and the number of collisions the robot had with any of the boxes or walls. Also collected was a quad screen video of the test run which included video of the operator's screen, the operator's controls, and two different views of the robot in the test method.

Test Method Comments

All robot manufacturers and responders felt that this was a fair test for assessing the capabilities and range of a manipulator. Most responders mentioned that they would have liked to have more time getting familiar with the controls of the different robots beforehand. Some of the manufacturers said that they didn't push their robot as hard as they could have because of fear of tipping over on the slanted floor. One manufacturer expressed that a slanted floor is not a realistic environment for their robot to be operating on.

The only minor problem that arose during testing was with the way the boxes for a level are currently assembled… there is a small rectangular open square directly in the middle of where the boxes meet at the top of the level. This rectangular opening was mistaken on two occasions for being a hole that should be explored. These center squares should also be covered or the instructions should be stated that and operator only explore circular openings.

Most robots were able to search some of the front face holes and had more trouble searching the top holes especially the top hole that was farthest away. This difficulty increased with each higher level that was added. One particular robot manufacturer's operator was not able to find any targets in the holes even after trying for some time in the practice area. This may have been due to the positioning of the robot's arm camera which was often blocked by the claw on the end of the arm when trying to look in the holes or this may have been because of the manufacturer's operator was relatively new to that particular platform.

Figure 9: Directed Perception Test

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Developing

Standard Test Methods For Response Robots

DIRECTED PERCEPTION

ROBOT: ________________ ☐ TETHER ☐ RF

OPERATOR: ________________ ORG: ________________

ROBOT EXP: ☐ 0-24 HRS ☐ 24-100 HRS ☐ > 100 HRS

OPERATOR: IDENTIFY RANDOMIZED TARGETS IN HOLES AT EACH LEVEL (UP TO FOUR) WITHOUT BUMPING ANY BOXES.

ADMINISTRATOR: CHECK TERRAIN TYPE AND TRACE ELEVATIONS (IF ANY). FOR EACH LEVEL, CIRCLE TARGETS IDENTIFIED WITH TWO OF FOUR FEATURES (COLOR/ICON/WORD/NUMBER); COUNT BUMPS; ELAPSED TIME. USE SQUARE AROUND TARGETS WITH CHEMICAL/EXPLOSIVE/RADIATION.

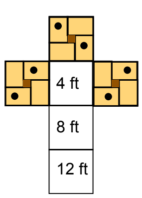
LEVEL 4 START TIME: _______
LEVEL 4 END TIME: _______
LEVEL 4 ELAPSED: _______ m:s
BUMPS: ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

LEVEL 3 START TIME: _______
LEVEL 3 END TIME: _______
LEVEL 3 ELAPSED: _______ m:s
BUMPS: ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

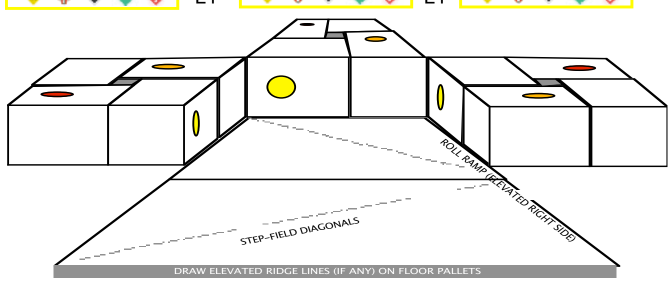
LEVEL 2 START TIME: _______
LEVEL 2 END TIME: _______
LEVEL 2 ELAPSED: _______ m:s
BUMPS: ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

LEVEL 1 START TIME: _______
LEVEL 1 END TIME: _______
LEVEL 1 ELAPSED: _______ m:s
BUMPS: ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

FIRST DETECTION:
-- CHEMICAL
-- EXPLOSIVE
-- RADIATION



TEST LEADER



☐ FLAT FLOORING ☐ ROLL RAMPS ☐ STEP-FIELDS (HALF CUBIC) ☐ STEP-FIELDS (FULL CUBIC)

DATE NOTES

Figure 10: Sensing – Directed Perception Test Method Data Capture Form

4.4 Grasping/Manipulator Dexterity

(References Requirement Labeled Payload – Manipulation – Retrieval)

This test method addresses the responder requirement to retrieve objects, not necessarily configured for robot manipulators, within complex environments. This manipulator dexterity test setup is similar to the Directed Perception test in that it involves positioning a robot within an alcove formed by 3 stacks of shelves with which the robot must interact. Each shelf contains items that must be picked up and/or placed by the robot and are centered on a 3x3 grid, with consistent orientations to challenge particular gripping approaches. The majority of the items to be picked up are wooden blocks, which are 4x4 posts cut into three cubic lengths, so are larger than most grippers can grab in at least one dimension. Other items may be available to be grasped (especially if the test is aimed at bomb-disposal robots rather than US&R robots). These include mineral water bottles and simulated pipe bombs.

Just like for Directed Perception, this test is conducted on a "layer by layer" basis. The lowest layer of shelves is arranged to represent three different types of spatial approach challenges for the robot manipulator. On the right, the blocks are placed on an open surface (like a table top). The middle stack shelf presents a shelf-like configuration, with the surface on which the blocks are placed being covered by another sheet of plywood at about a 25-30 cm above it. The left stack presents a "reach over" challenge by having the front plane covered by a sheet of plywood, thus requiring the robot manipulator to reach over and down to grasp or place the blocks. Each of the stacks is raised by one shelf height and the test is repeated until the robot can no longer grasp any of the blocks. Figure 11 shows a robot performing the test method at the second layer.

Robot operators approach the shelf stack alcove and remove as many blocks as possible from the current shelf levels as possible. They may optionally be asked to place the blocks in a corresponding location on a shelf in the adjacent stack. They perform the task on non-flat flooring to complicate robot orientations and mobility. The number and locations (x, y, z) of all blocks removed from any given side are noted. The data capture form is shown in Figure 12.

This data capture form contains customization choices for setting up the test configuration. There are three stacks of shelves: Left, Center, and Right. There is designed flooring in the space enclosed by the left, center, and right shelves and extending linearly beyond the enclosed space. Oriented planar flooring was used in this test method. Planar flooring may be flat, have a side roll with either the left or right side higher (known as "roll" configuration) or have a "pitch." A pitched floor would have an elevated center that causes a rise and a fall in the direction of approach to the center stack of boxes.

In terms of capturing performance data during execution of the test, there are several aspects that must be noted. The overall time necessary to remove all the blocks accessible by the robot is captured. For each level of each stack, the following data are obtained:

- Each block that is removed from each level is marked on the figure. A distinction is made between the perimeter angled blocks ("B") and the center blocks ("O"). Total number of blocks removed at each level is computed.
- The total time it took for the robot to remove all of the blocks it was able to. The blocks may be dropped on the floor once they have been picked up by the robot.

Test Method Comments

During the grasping dexterity test at Disaster City, data was collected on only three robots that had manipulators. Data was only collected during the first phase of testing when the robots were operated by the expert operators/vendors. This test provided the operators with a long and difficult test, with only one of the robots capable of advancing past the first level. On average it took the operators over 20 minutes to clear the first table and less than 45 minutes for the only operator to successfully complete the first level.

The test at this exercise used non-flat flooring which added a degree of difficulty to the operators when repositioning the robots in order to reach the blocks. One of the operators made negative comments to the validity of the test due to the non-flat flooring, while others appreciated the difficulty saying that the non-flat flooring added another dimension to the test because they had to worry about the stability of the platform. The test needs may need to be administered with non-flat flooring using different operators on multiple runs to separate operator error from robot design.

Most of the robots failed to place blocks on the third and final platform, when reaching over the closed face to place blocks in the box. This failure point was primarily due to the configuration of the arm and not operator error (meaning that the arm or a camera on the arm collided with part of the test setup's frame).. Two other factors in the test method that were tweaked were the orientation and location of the blocks. The orientation of the blocks seemed to have significant impact of the operators' ability to grab the blocks and the location of the blocks would sometimes impede the operator if they were not careful on the order in which they grabbed the blocks.

Figure 11: Manipulator/Grasping Dexterity Test Method

NIST
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Technology Administration, U.S. Department of Commerce

Developing

Standard Test Methods For Response Robots

Version: 2007.4

GRASPING DEXTERITY

ROBOT: ________________ ☐TETHER ☐RADIO

OPERATOR: ________________ ORG: _________________

TRAINING TIME: ☐ 0-24 HRS ☐ 24-100 HRS ☐ > 100 HRS

INSTRUCTIONS: 1) TRACE GROUND TERRAIN AND STACK HEIGHTS. 2) TIME SEQUENCE TO REMOVE AS MANY BLOCKS FROM EACH LEVEL AS POSSIBLE (DROPPING BLOCKS ONTO FLOOR IS OKAY). 3) TRACE WHICH ANGLED BLOCKS ("B") AND CENTERED OBJECTS ("O") ARE REMOVED. 4) NOTE ELAPSED TIME.

START TIME: _______

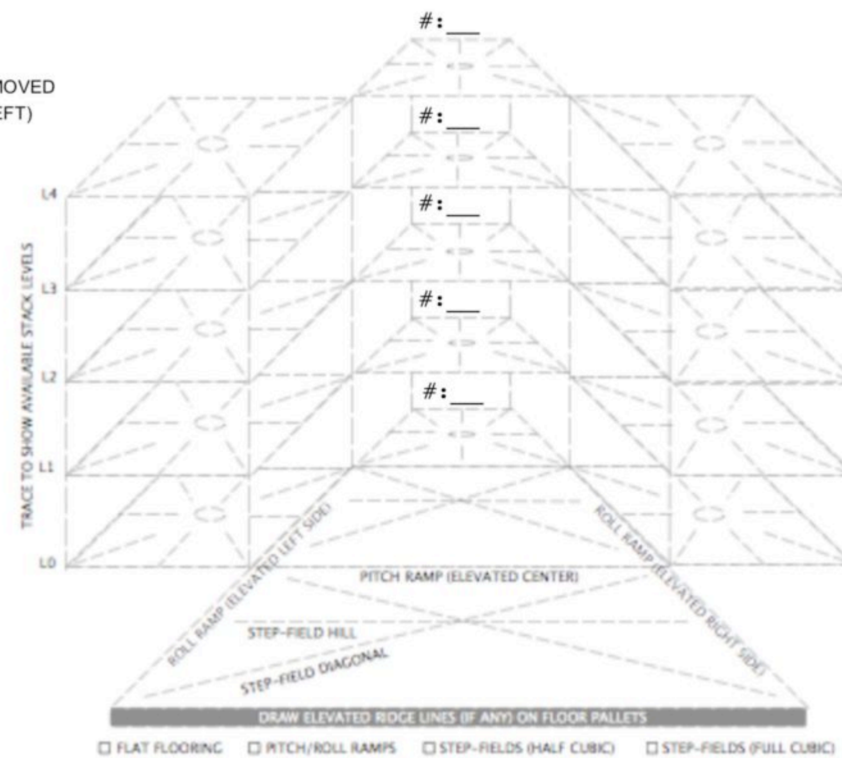
END TIME: _______

ELAPSED: _______ s

BLOCKS REMOVED BY LEVEL (CENTER)

BLOCKS REMOVED BY LEVEL (LEFT)

BLOCKS REMOVED BY LEVEL (RIGHT)



LEFT: #:___ #:___ #:___ #:___ #:___

RIGHT: #:___ #:___ #:___ #:___ #:___

☐ FLAT FLOORING ☐ PITCH/ROLL RAMPS ☐ STEP-FIELDS (HALF CUBIC) ☐ STEP-FIELDS (FULL CUBIC)

TEST LEADER DATE NOTES ☐

Figure 12: Manipulator/Grasping Dexterity Test Method Data Capture Form

4.5 Human/System Interaction – Acceptable Usability

This test method addresses the responder requirement to operate robotic systems simply and effectively. The metric measures the percent of timed tasks operators can successfully complete. The operators are to navigate a maze-like course from one given location to another. They are to note hazardous materials labels that have been placed on the walls of the maze. This test also measures the situational awareness of the operator as s/he navigates through an unknown environment using only the onboard sensors of the robot or any assistive technologies such as map-building or sensor fusion that may be available. Figure 13 shows the data capture form and a diagram of the maze that was built for the exercise. The total amount of time required to traverse the maze was captured, along with the decision points and time necessary for the operator to select which direction to go. The hazmat labels identified by the operator are marked on the form. Issues, such as "bumping" the walls and going in the wrong direction are noted on the form.

Test Method Comments

As occurred during a previous (Montgomery County, Maryland) maze data collection attempt, data collected at the Disaster City site included time to complete a maze, and also that necessary for gaining situation awareness when entrapped in either of two predetermined dead-ended isolation points. Data also included recordings of maze wall encounters, and errors made in direction of traverse. At the Texas site, digital video recordings were taken to enable post hoc analyses, however these have not been reviewed to date. Again, Texas participants operating the robots were engineering professionals representing a respective product, thus each possessed extensive experience in operation. A second group attempting to traverse this maze were emergency response professionals, not necessarily familiar with whichever robot they may have been asked to operate but skilled in urban search techniques.

During the first maze experiment (Mont. Co.), significant differences in time to gain situation awareness, encounters with walls, and errors made in direction of traverse were uncovered. However, no significant differences were revealed among robots concerning total times taken to traverse the maze. This first experimental attempt was an effort to assess the theory of employing a maze, and as all dependent measures other than one did in fact elicit sufficient performance data the second maze (Disaster City) was constructed taking this into account by extending travel distances and maze complexity. Also found during the first maze attempt was that increased times spent in making decisions were correlated with erroneous directions of traverse selected subsequently (i.e., the longer it took to make a navigational direction decision, the more this decision was found to be incorrect). Wall encounters were similarly found highly correlated with errors made in direction of traverse (revealing confusion, probably as a result of post-collision trauma). In keeping these measures comparable during the second maze attempt, it is expected that results should be analogous.

Preliminary results of observations made during tests in Texas appear to reveal that this particular maze distance and complexity demanded greater mental attention for navigation, thus it may be expected that the variable (previously found not significant) will return statistically significant results once analyzed and be of value in performance assessment as intended. General results (to include comments made by test participants) show the maze test approach for evaluating robot teleoperation performance effective, pragmatic, and rational.

During Texas testing, maze test validity was observed using a predictive approach (criterion-oriented, the goal being to navigate to a target within an environment void of terrain characteristics for use as aids). Few, if any, test participants were able to reach designated targets without encountering inconveniences in the form of necessary directional changes or retracing a previously traveled route, revealing test legitimacy in assessment of the objective. Dependent upon the amount of usable data collected, test reliability may also be established, thus statements as to whether this type examination measures consistently or not should eventually be available. With this, it is expected that modest statements may be made as to desired level of operator experience (per a demographics questionnaire administered), and possibly advantageous personality traits (via a modified personality inventory, also administered) which may assist during future operator selection.

Prior to submission as a test standard, mathematical formulas aiding in maze construction should be developed for use by those not capable of testing at a NIST designated arena.

NIST
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Technology Administration, U.S. Department of Commerce

Developing

Standard Test Methods For Response Robots

Version: 2007.4

the MAZE (Traverse *and* Search)

Robot: ______________________

Operator: ______________________

Skill Level: NOVICE ☐ INTER ☐ CONT. EX. ☐ E. RESP. PROF. ☐

Course *Time*: Start _______ End _______ = TOTAL _______

Time Decision point ***A*** ________ Correct Exit?: "Y" "N"

Time Decision point ***B*** ________ Correct Exit?: "Y" "N"

Time Decision point ***C*** ________ Correct Exit?: "Y" "N"

Time Decision point ***D*** ________ Correct Exit?: "Y" "N"

Time Decision point ***E*** ________ Correct Exit?: "Y" "N"

Time Decision point ***F*** ________ Correct Exit?: "Y" "N"

Time Decision point ***G*** ________ Correct Exit?: "Y" "N"

Time Decision point ***H*** ________ Correct Exit?: "Y" "N"

Time Decision point ***I*** ________ Correct Exit?: "Y" "N"

MAZE Configuration #***2***

Date __________

Run __________

Forward ☐ *Reverse* ☐

Hits = _______

Targets = _____ *of* _____

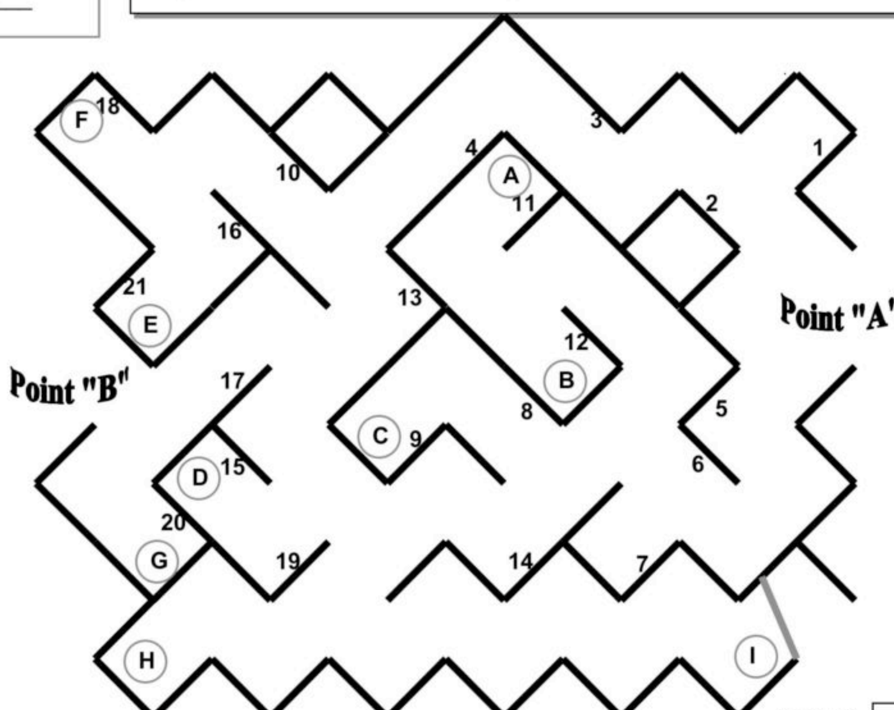
FLAMMABLE: 1 - 8 - 14 - 19

NON-FLAMMABLE GAS: 2 - 10 - 12 - 17

CORROSIVE: 3 - 6 - 15 - 18 - 21

OXIDIZER 5.1: 4 - 9 - 11 - 16

5 - 7 - 13 - 20



COMMENTS:

PROCTOR: ______________

TEST LEADER

DATE

NOTES:

Figure 13: Human-System Interaction - Acceptable Usability Test Method Data Capture Form

4.6 Communications – Range – Line of Sight (LOS)

This test method addresses the responder requirement to project remote situational awareness at some standoff distance with line of sight. The robot's communications frequencies for transmission (Tx) and reception (Rx) were noted. There could be two different channels – one for command information and one for data.

During this test, the operator navigated a robot down a linear path with direct line of sight to the control station. Along the way, there were some visual targets (eye charts) placed for the operator to view through the robot's camera(s) as a way of capturing the quality of the video transmission at the given distance. For this test, the distance from the start point to each target was noted, as was the smallest line of the eye chart that could be read by the operator. Time to navigate to each target location was noted.

Figure 15 shows the data collection form for this communications test.

Test Method Comments

The line-of-sight test track was set up on the nearby Texas A&M Riverside Campus. This is an old airfield that is no longer used for aircraft and includes several long (1.5 km) runways. The asphalt-paved runway is about 150 meters wide and essentially clear of obstacles. Figure 14 shows the test setup at the runway. The dense vegetation (trees, bushes) that lined the sides of the runway probably did not cause strong reflections or multipath signals to interfere with the direct communications link from the control to the robot. However, we did not have the means to verify this assumption. We set up along the centerline of one of these runways to test the unobstructed or line-of-sight radio communications. The test points began at 200 meters from the control operator station and repeated every 200 meters up to 1000 meters. The final test point was at 1150 meters where we ran out of runway. The remote location of the runway meant that radio interference was minimal, which we verified with spectrum analyzer measurements. We were only able to test three different robots due to logistics and weather conditions (lightning and rain).

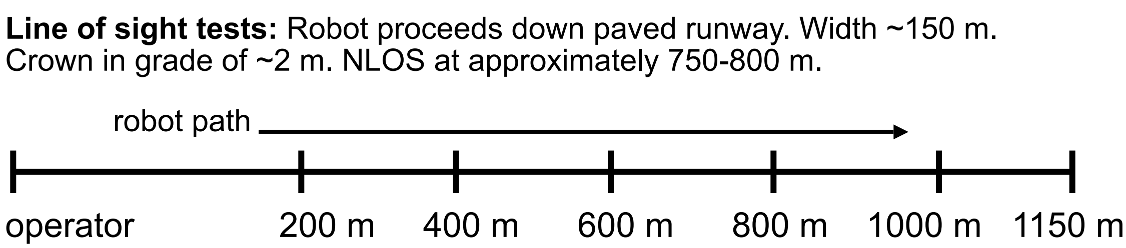


Figure 14: Line of Sight Radio Communications Test. Right image shows robot reading eye chart

Some issues with this test course were noted:

The runway had a slight crown (rise) that peaked in the 700-800 meter range that obscured the visual (line-of-sight) path from the robot to the control station. This probably affected the down-range performance, especially for robots with antennas located very close to the ground.

There was an interesting structure at about the 1050 meter location. Two metal poles about 15 meters tall were positioned symmetrically on either side of the centerline of the runway about 30 meters apart. There was a steel cable stretched between the tops of these poles. This structure was essentially a large steel loop perpendicular to the long axis of the runway. The purpose of this structure is unknown. The interaction of this structure with the robot communications at higher frequencies (above 400 MHz) is not known, but we did see an effect with one robot using 35 MHz. The robot lost control signals when trying to pass though this loop and would stop. This happened when the control unit was well within normal operating range at about 100-120 meters distance. It appeared that the loop cancelled the 35 MHz signal at that position. The lesson here is to avoid such structures for the line-of-sight test.

Robot Performance

The following table summarizes the results of the LOS tests. Multiple listings indicate repeat measurements of the same robot but with somewhat different configurations.

Table 2: Robot Performance in Line-of-sight Test

Robot	LOS
1	800 m
2	--
3	--
4	1000 m
5	--
6	800 m (degraded) 1000 m (total range)
7	--
8	--
9	--
10	--

General Observations (apply to line-of-sight and non-line-of-sight)

- All of the robots were controlled by expert operators during these tests. These operators were able to anticipate and, to some degree, compensate for degradations in the communications quality. For example, one symptom of poor signal strength is a time lag in the video (since the data rate is reduced) but measuring this parameter was not part of the test procedure.
- The design and placement of the communications antennas on the robot had a large effect on the down-range performance. The larger and taller antenna systems had greater range, as expected. Also, the radiation pattern of the antennas on the robot was not necessarily omni-directional (the same in all azimuth directions). This means that signal strength could change significantly if the robot changed direction. In one example the video communications was lost going directly away from the operator but by rotating the robot about 45 degrees the video was fully recovered.

- A more thorough performance test at each test position may address the previous two bullet points. A possibility is to include a timed maneuverability exercise such as a figure-8 around two markers in addition to locating and reading the visual chart. This may provide some indication of the video lag time and antenna pattern effects, especially in areas of weak signal strength. As well, tests could be performed by both expert and novice users to study ease of use in the field.

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RADIO COMMS (LINE-OF-SIGHT)

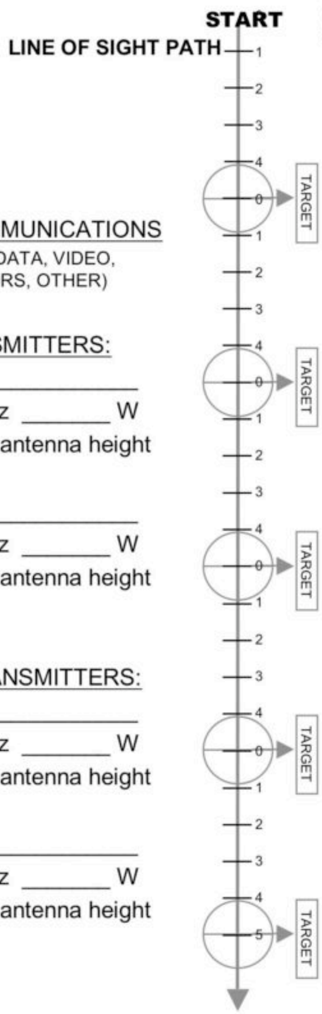
ROBOT: ________________ ☐TETHER ☐RADIO

OPERATOR: ________________ ORG: ________________

TRAINING TIME: ☐ 0-24 HRS ☐ 24-100 HRS ☐ > 100 HRS

INSTRUCTIONS: WHILE TRAVERSING THE PATH SHOWN, STOP AND READ THE SMALLEST COMPLETE LINE ON THE VISUAL ACUITY TARGETS UNTIL PERFORMANCE DEGRADES TO UNUSABLE. THEN RETURN READING ALL THE SAME TARGETS IN REVERSE ORDER. ANTENNA HEIGHT < 2 METERS.

ADMINISTRATOR: 1) NOTE ALL RADIO INFORMATION. 2) NOTE THE DISTANCES FROM THE START POINT TO EACH EQUALLY SPACED TARGET. 3) NOTE THE TIME ON TARGET TO POINT TO AND READ THE SMALLEST CORRECT LINE. 4) CIRCLE LAST LINE MARKER IF FARTHEST RANGE IS BETWEEN TARGETS.



START TIME: ________

RADIO COMMUNICATIONS
(COMMANDS, DATA, VIDEO, AUDIO, SENSORS, OTHER)

OCU TRANSMITTERS:
Content: ____________
_______ MHz _______ W
_______ cm antenna height

Content: ____________
_______ MHz _______ W
_______ cm antenna height

ROBOT TRANSMITTERS:
Content: ____________
_______ MHz _______ W
_______ cm antenna height

Content: ____________
_______ MHz _______ W
_______ cm antenna height

	OUTBOUND	INBOUND	
1ST TARGET:	_______ meters		
ARRIVAL TIME:	_______	_______	m:s
TIME ON TARGET:	_______	_______	m:s
SMALLEST ACUITY:	_______	_______	(decimal)
2ND TARGET:	_______ meters		
ARRIVAL TIME:	_______	_______	m:s
TIME ON TARGET:	_______	_______	m:s
SMALLEST ACUITY:	_______	_______	(decimal)
3RD TARGET:	_______ meters		
ARRIVAL TIME:	_______	_______	m:s
TIME ON TARGET:	_______	_______	m:s
SMALLEST ACUITY:	_______	_______	(decimal)
4TH TARGET:	_______ meters		
ARRIVAL TIME:	_______	_______	m:s
TIME ON TARGET:	_______	_______	m:s
SMALLEST ACUITY:	_______	_______	(decimal)
5TH TARGET:	_______ meters		
ARRIVAL TIME:	_______	_______	m:s
TIME ON TARGET:	_______	_______	m:s
SMALLEST ACUITY:	_______	_______	(decimal)

TEST LEADER DATE NOTES ☐

Figure 15: Communications - Wireless Line of Sight Test Method Data Capture Form

4.7 Communications – Range – Beyond Line of Sight (BLOS)

This test method addresses the responder requirement to project remote situational awareness at some standoff distance around corners of buildings and into compromised or collapsed structures. The robot's communications frequencies for transmission (Tx) and reception (Rx) were noted. There could be two different channels – one for command information and one for data. This test method is also referred to as non-line-of-sight.

In this test, the operator navigated the robot down a linear path towards a building. The operator was to try maneuvering the robot to the end of the far side of the building. There were visual targets (eye charts) placed at regular intervals on the side of the building, intended to capture the quality of the video transmission at each location. The robot path was to be within 1 m of the side of the building. The distance to the first turn around a corner (which was the transition from having line of sight to non-line of sight, was captured on the form. Also noted were the distances to each of the visual targets and the smallest line that could be read by the operator. Times required to reach the first corner of the building and each of the targets was captured.

Figures 17 show the data collection form for this communications test.

Test Method Comments

A test track for the non-line-of-sight communications test was set up on the Disaster City grounds (Figure 16). The idea was to include some stand-off distance prior to the robot passing behind a large obstacle. Hence, the operator station was located on the northeast end of Main Street at 183 meters (600 feet) from the southwest corner of the strip mall on 2nd Street. This test included a line-of-sight section along Main Street from the operator station to the corner of the strip mall and a non-line-of-sight section behind the one story concrete structure. The robot had to travel from the operator control station to the corner of the building and then along the sidewalk behind and adjacent to the structure. There were visual acuity charts positioned on the wall of the structure at one meter above the ground level and about 6 meters apart. At these predefined test points, the video and control radio links were evaluated. The evaluation test was to simply locate the visual chart, position the camera, and read the chart. We tested nine different robots. This test course presented a reasonable challenge to the robots with only the most robust communications systems able to negotiate the entire distance and some not able to complete the LOS stand-off distance.

Non line of sight tests: Robot proceeds in LOS condition ~183 m. Turns behind single story concrete structure (strip mall). Reads eye chart located 1 m above ground. Six eye charts are spaced approximately 6 m apart.

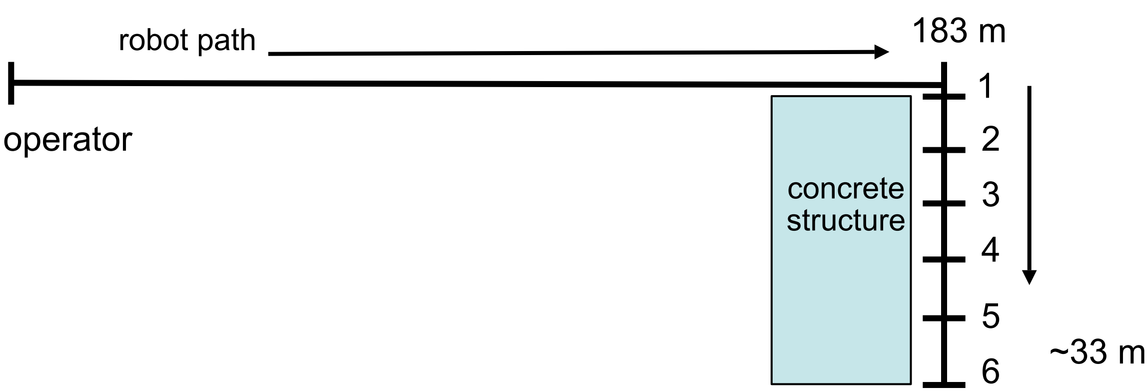


Figure 16: Non-line-of-sight radio communications Test Method. The start of the course is shown on the left. The far side of the building is shown on the right.

Table 3: Robot Performance in Non-line-of-sight Test

Robot	NLOS (stand-off + eye charts)
1	--
2	183 m + chart 1 183 m + chart 3
3	183 m + chart 6
4	183 m + chart 6
5	152 m (LOS only) 183 m (LOS only) 183 m + chart 2
6	183 m + chart 6
7	183 m + chart 6
8	106 m (LOS only) 30 m + chart 1
9	183 m + chart 3
10	107 m (LOS only)

Several issues with the test course were noted:

- The strip mall was too small to fully shadow the radio signals and had other leakage paths through the structure. This allowed significant radio-frequency energy to leak through, over, and around the structure. This was evident in that the responses near both building ends (position 1 and 6) and near an open garage doorway (position 3) were usually better than the other positions. The disadvantage of this set-up is that it is difficult to replicate at other test sites. The ideal would be a structure with more predictable, and perhaps complete, shadowing.

- The stand-off section (line-of-sight) was partially lined on either side with trees and small structures. The overall effect on the communications was probably slight but it does raise the question about the configuration of the stand-off part of this test. Should the test replicate an urban canyon or an open field? These scenarios do not necessarily present the same issues for radio communications.

- Radio interference from other robots operating in the area may have affected this test even though an effort was made to schedule and place robots so as to minimize conflicts. One example of interference happened just as a robot was arriving at the corner of the strip mall and preparing to turn the corner. For a few moments the received video at the control station was from another robot navigating the maze in the auditorium next door to the strip mall. Since this is strictly a range test, and not radio interference and compatibility, an RF-quiet zone would be optimal.

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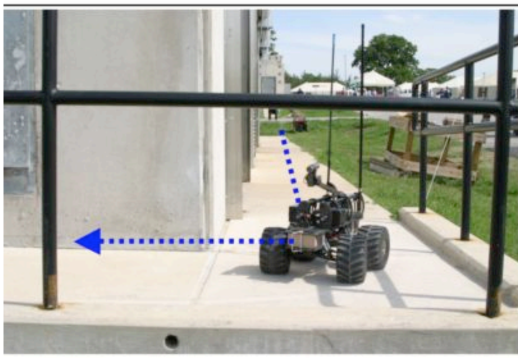


RADIO COMMS (NON-LINE-OF-SIGHT)

ROBOT: ________________ ☐TETHER ☐RADIO

OPERATOR: ________________ ORG: ________________

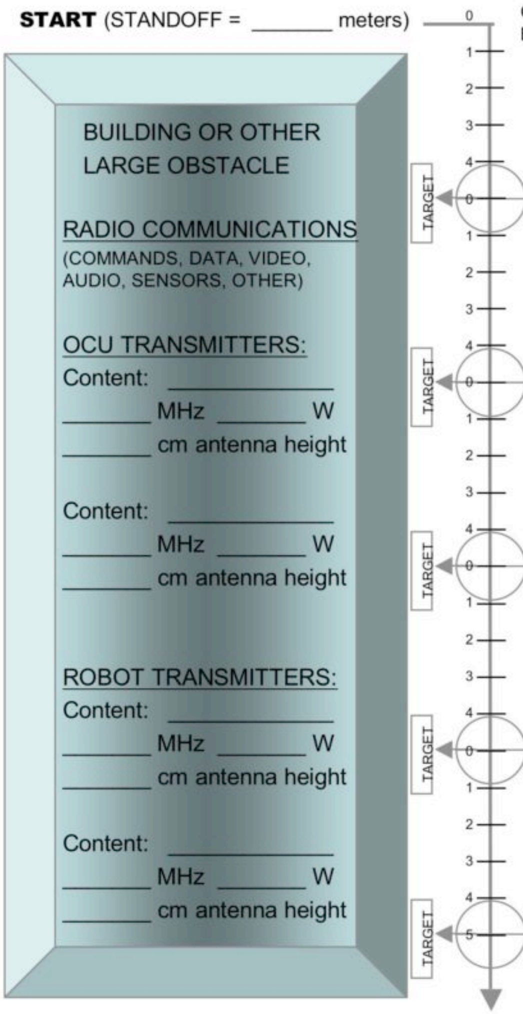
TRAINING TIME: ☐ 0-24 HRS ☐ 24-100 HRS ☐ > 100 HRS

INSTRUCTIONS: WHILE TRAVERSING THE PATH SHOWN, STOP AND READ THE SMALLEST COMPLETE LINE ON THE VISUAL ACUITY TARGETS UNTIL PERFORMANCE DEGRADES TO UNUSABLE. THEN RETURN READING ALL THE SAME TARGETS IN REVERSE ORDER. ANTENNA HEIGHT < 2 METERS.

ADMINISTRATOR: 1) NOTE ALL RADIO INFORMATION. 2) NOTE THE DISTANCES FROM THE START POINT TO EACH EQUALLY SPACED TARGET. 3) NOTE THE TIME ON TARGET TO POINT TO AND READ THE SMALLEST CORRECT LINE. 4) CIRCLE LAST LINE MARKER IF FARTHEST RANGE IS BETWEEN TARGETS.

START (STANDOFF = _______ meters)

START TIME: _______



	OUTBOUND	INBOUND	
1ST TARGET:	_______ meters		
ARRIVAL TIME:	_______	_______	m:s
TIME ON TARGET:	_______	_______	m:s
SMALLEST ACUITY:	_______	_______	(decimal)
2ND TARGET:	_______ meters		
ARRIVAL TIME:	_______	_______	m:s
TIME ON TARGET:	_______	_______	m:s
SMALLEST ACUITY:	_______	_______	(decimal)
3RD TARGET:	_______ meters		
ARRIVAL TIME:	_______	_______	m:s
TIME ON TARGET:	_______	_______	m:s
SMALLEST ACUITY:	_______	_______	(decimal)
4TH TARGET:	_______ meters		
ARRIVAL TIME:	_______	_______	m:s
TIME ON TARGET:	_______	_______	m:s
SMALLEST ACUITY:	_______	_______	(decimal)
5TH TARGET:	_______ meters		
ARRIVAL TIME:	_______	_______	m:s
TIME ON TARGET:	_______	_______	m:s
SMALLEST ACUITY:	_______	_______	(decimal)

TEST LEADER DATE NOTES ☐

Figure 17: Communications - Wireless Non-Line of Sight Test Method Data Capture Form

4.8 Mobility/Endurance

(References Requirements Labeled Mobility – Locomotion – Sustained Speed, Logistics – Mean Time Between Failures, Logistics – Field Maintenance – Duration, Power – Working Time)

This test method provides the means by which to measure performance of robots against several different requirements. The artifacts used in the test method can be used to

- measure robot speeds and basic maneuverability on different surfaces while maintaining a proscribed course. The courses required predictable changes in direction over different ground surfaces, for example oriented wooded ramps (pitch/roll), grass (long or short), gravel, pavement, or NIST's random stepfields. The stepfields are designed to be an abstracted, but repeatable, rubble-like terrain. The form associated with this test method is shown in Figure 19.
- measure the duration of the robot's batteries while it traverses the Figure 8 version of the test method.
- capture failures that occur during continuous robot operation over non-flat terrain
- measure the duration of field repairs performed in response to any failures that occur during the test

There were three dashes set up for the exercise: unpaved, paved, and red stepfields. The red stepfields provide more challenging terrain to negotiate than the orange ones which were used in other test methods primarily to present changes in orientation to the robot platform, rather than actual mobility tests. In terms of customization of the forms, the test leader had to mark the dominant features of the step fields (by darkening the appropriate lines: diagonals, mid-field hills, etc.). For each run (a single zig zag) attempted, the test leader timed the robot as it went through the course in one direction and then back towards the start point. If the robot was unable to complete the course, the test leader noted the furthest location it attained. Any bumping of the side walls was noted as well.

Test Method Comments

The endurance test was conducted in two parts. Part A consisted of a figure 8 pattern constructed within a 3.6 m^2 space with pitch and roll ramps placed to force a repeated pattern of travel. Part B was similar in construction to part A with the exception that the traversed surface was constructed of step fields. In both cases laps were counted until the onboard power supply of the vehicle was exhausted (and occasionally the operator). Figure 18 shows the 2 courses.

Figure 18: Mobility (left) and Endurance (right) Figure 8 Test Methods

Although few robots actually completed testing, in general, the test was well received by vendors and responders. Responders generally used part A to learn to operate the vehicle and part B as a way of determining what the vehicle could actually do. Part B of the test was much more physically challenging than part A with most robots achieving only minimal success and sustaining some level of damage. There were several comments indicating that the tests were helpful in determining the performance capabilities of the vehicles tested and should allow comparisons between "apples and apples and oranges and oranges".

It should be noted that not all robots can or should be tested for endurance in this way. Small robots tend to be disadvantaged and should be excluded from testing unless mobility on rubble or other difficult surfaces is one of the claims of the vendor of the vehicle. While the test vehicles tend to become damaged in the test bays, this is also true of the test surfaces. It is good practice for future test administrators to arrive armed with many drywall screws, Cable ties and a power drill.

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MOBILITY/ENDURANCE

ROBOT: ______________ ☐TETHER ☐RADIO

OPERATOR: ______________ ORG: ______________

TRAINING TIME: ☐ 0-24 HRS ☐ 24-100 HRS ☐> 100 HRS

INSTRUCTIONS: TRAVERSE THE FIGURE-8 WITHOUT BUMPING THE WALLS FOR ONE COMPLETE BATTERY CYCLE. REPAIRS ARE ALLOWED BUT MUST BE DONE IN PLACE TO CONTINUE TEST.

ADMINISTRATOR: 1) COUNT THE NUMBER OF LAPS (16 PALLETS PER LAP). 2) NOTE THE ELAPSED TIME. THE CLOCK SHOULD STOP FOR SWITCHING OF OPERATORS AND REPAIRS. 3) NOTE THE NUMBER OF REPAIRS, TYPE OF REPAIRS, AND TOOLS USED.

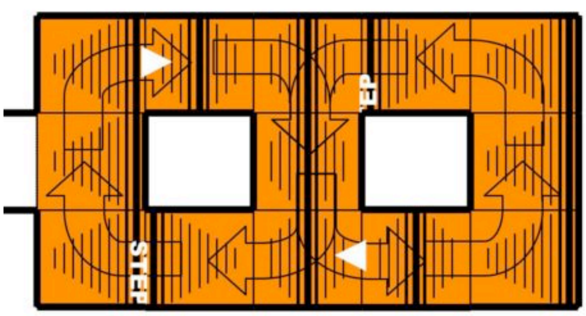
PITCH/ROLL RAMPS

START TIME: ________

END TIME: ________

ELAPSED TIME: ________ m:s

TOTAL PALLETS: ________



REPAIRS

TYPE	TIME		TOOLS
________	______	m:s	☐ NONE ☐TYPICAL ☐ SPECIAL
________	______	m:s	☐ NONE ☐TYPICAL ☐ SPECIAL
________	______	m:s	☐ NONE ☐TYPICAL ☐ SPECIAL
________	______	m:s	☐ NONE ☐TYPICAL ☐ SPECIAL
________	______	m:s	☐ NONE ☐TYPICAL ☐ SPECIAL

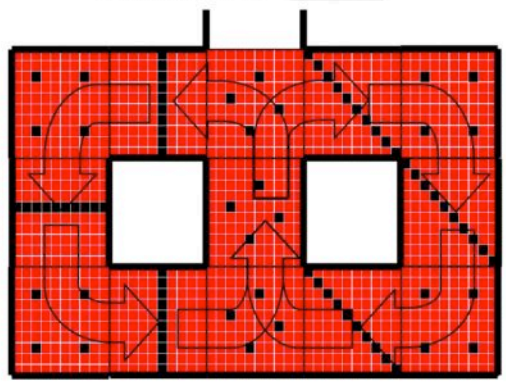
FULL CUBIC (RED) STEPFIELDS

START TIME: ________

END TIME: ________

ELAPSED TIME: ________ m:s

TOTAL PALLETS: ________



REPAIRS

TYPE	TIME		TOOLS
________	______	m:s	☐ NONE ☐TYPICAL ☐ SPECIAL
________	______	m:s	☐ NONE ☐TYPICAL ☐ SPECIAL
________	______	m:s	☐ NONE ☐TYPICAL ☐ SPECIAL
________	______	m:s	☐ NONE ☐TYPICAL ☐ SPECIAL
________	______	m:s	☐ NONE ☐TYPICAL ☐ SPECIAL

TEST LEADER　　DATE　　NOTES ☐

Figure 19: Mobility – Endurance Test Method Data Capture Form

4.9 Mobility – Stair Climbing

This test method addresses responder requirements for mobility climbing and descending stairs. The test uses artifacts that are readily available in the training facility's scenarios. In this instance, the staircase in the steel structure was utilized. NIST also used smaller, specially constructed stairs, to be able to measure climbing performance that could be reproducible. The specific stair artifacts may not be formally submitted to the standards process, however, fabricated versions of stairs or a description of the desirable characteristics for stairs used in the test procedures will be included in the proposed test methods. There are a multiplicity of combinations of materials and stair configurations so an exhaustive set of "reference test stairs" is not achievable.

Figure 21 shows the form used for the test method. The test leader has to note the geometry of the staircase in use. The average height of the risers and treads is measured. Whether the risers have kick plates or not is noted. The left and right sides of the stairs are marked as being either open or closed. Whether risers or sides of the steps are open or closed is important because some robot algorithms or tele-operative techniques may rely on there being solid material in the riser portion or adjacent to the steps. The number of steps between landings is counted.

The test method entails having the operator navigate the robot up the stairs and back down. The total number of steps completed is counted and the amount of time required is noted. As with the other test methods, a time limit was imposed due to logistical considerations, but the intended test method would allow as much time as necessary to complete a round trip on the stairs. An average rate (time/step) is calculated for the test.

Test Method Comments

The stairs test was set up in an L formation as shown in the diagram below with steel stairs on one side and wooden stairs on the other. Both sets of stairs had 40-degree rises with 5 steps including the upper landing. The test also used the steel staircase part of the structure as an advanced course. To minimize the risk of having robots tumble and become damaged, a safety belay was used, as shown in Figure 20.

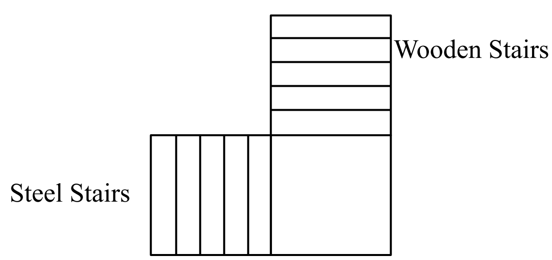


Figure 20: Stairs Test Method. Left image shows the advanced course and belay safety mechanism used to ensure robots were not harmed. Wooden stairs are shown also.

The metric of the test is the time required for the robot to make it up one set of stairs and down the other set of stairs, or the time and number of stairs achieved if the robot is not able to complete the full sets of stairs. For the advanced course, the metric is a combination of the time required and the number of steps climbed by the robot.

The test seemed very well accepted by the developers and responders as a quite accurate representation of real world problem of traversing stairs in a US&R environment. All robots that came down to the test method were able to traverse the main set of stairs, while only a few robots tried the advanced course; none of the robots made it up more than halfway up the advanced set of stairs.

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STAIRS

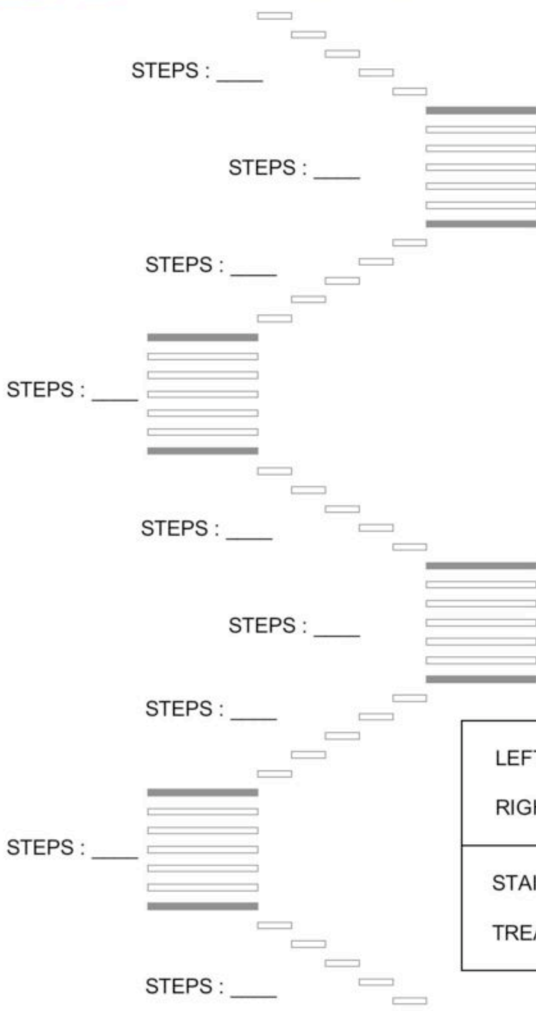
ROBOT: ________________ ☐TETHER ☐RADIO

OPERATOR: ________________ ORG: _________________

TRAINING TIME: ☐ 0-24 HRS ☐ 24-100 HRS ☐ > 100 HRS

INSTRUCTIONS: ASCEND THE STAIRS TO THE TOP, TURN AND DESCEND BACK TO THE START POINT.

ADMINISTRATOR: 1) NOTE THE AVERAGE STEP RISER AND TREAD DIMENSIONS. 2) NOTE THE WALL CONDITIONS AS SOLID OR OPEN. 3)NOTE THE NUMBER OF STAIRS AND LANDINGS (SHOWN IN GREY). 4)TIME THE SEQUENCE.



	ASCENDING	DESCENDING
START TIME:	________	________
END TIME:	________	________
ELAPSED TIME:	________ s	________ s
TOTAL STEPS:	________	________
	(COUNT LANDINGS AS A STAIR)	
AVG RATE:	________	________
	(COUNT LANDINGS AS A STAIR)	

LEFT WALL (ASCENDING): ☐ SOLID ☐ EMPTY W/ RAILING

RIGHT WALL (ASCENDING): ☐ SOLID ☐ EMPTY W/ RAILING

STAIR HEIGHT: ________ cm ☐ SOLID RISER

TREAD DEPTH: ________ cm ☐ EMPTY RISER

TEST LEADER DATE NOTES ☐

Figure 21: Mobility - Stair Climbing Test Method Data Capture Form

4.10 Mobility – Inclined Plane

This test method addresses responder requirements for mobility on sloped surfaces, including roofs. Rather than submitting a single formal artifact into the standards process, it is envisioned that a range of angles and surface types will be included in the test method definition.

As can be seen in the data collection form in Figure 23, the angle of the ramp must be measured. Ideally, the material and/or coefficient of friction will also be another quality that is captured on the test method form. The robot is to traverse a sequence of waypoints as shown on the schematic in the form. The waypoints are marked upon the ramp to guide the operator. The operator must start at location 1 and move the robot to location 2, then 3, and so on, in sequence. This forces there to be different combinations of robot orientation and direction of travel with respect to slope of the ramp. The distances between each leg of the pattern is measured and the time it takes for the robot to complete the whole circuit is measured. In practical implementations, the angle of the ramp would be raised each time the robot successfully completes a circuit. The data collection is continued until the ramp reaches an angle that is too steep for the robot to complete the entire circuit.

Test Method Comments

Two 15º ramps were used for the inclined plane test at Disaster City. The surface of the first was unfinished plywood whilst the second was loose gravel. Painted plywood markers were screwed into the ramps to mark out squares of approximately 25 cm^2 (Fig. 22). Robot operators were asked to drive their robots in a given pattern across the markers in order to test their ability to drive across, along and diagonally over the ramps, and their ability to execute sharp turns on the ramps.

In general the test was reasonably well executed by most robots, the only exceptions being robots with wheels that were physically too small to drive over the markers or cut through the gravel. As a way of discriminating between robots however, as conducted, the test on both ramps was probably too easy as most robots were able to complete the circuits in around the same time. Past tests were conducted on a steeper 25º plywood ramp with grip strips applied to it to vary the surface friction across the ramp, that test seemed better at separating out the robots. Although not apparent in the completion times, the gravel ramp did show qualitative differences between the abilities of the operators to control the robot whilst sliding. It may be useful to apply position tracking to the gravel ramp test via trackers or overhead cameras in order to capture this.

Figure 22: Inclined Plane Test Method

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INCLINED PLANE

ROBOT: ________________ ☐TETHER ☐RADIO

OPERATOR: ________________ ORG: ________________

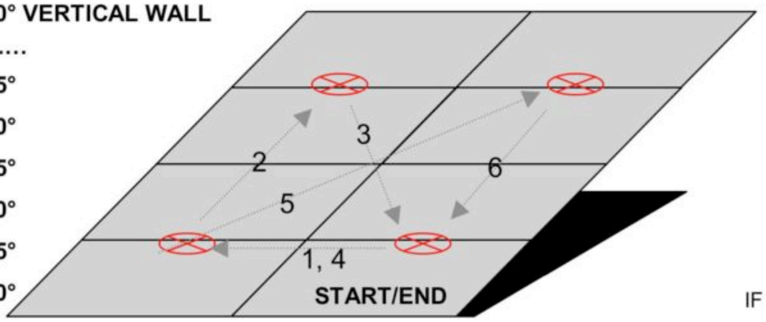
TRAINING TIME: ☐ 0-24 HRS ☐ 24-100 HRS ☐ > 100 HRS

INSTRUCTIONS: TRAVERSE THE TWO PATTERNS SHOWN WITH THE CENTER OF GRAVITY OF THE ROBOT ROUGHLY PASSING OVER EACH TARGET.

ADMINISTRATOR: 1) FOR EACH ANGLE, CHECK IF COMPLETE OR NOTE THE NUMBER OF SEGMENTS COMPLETED IN ORDER. TARGETS TOUCHED OUT OF ORDER IS INCOMPLETE. 2) TIME THE SEQUENCE. 4) INCREASE THE ANGLE UNTIL INCOMPLETES REPEAT. THE PREVIOUS COMPLETE ANGLE WILL BE CONSIDERED AS THE MAXIMUM.

INCLINE (CHECK ONE):

- ☐ **90° VERTICAL WALL**
- **......**
- ☐ **45°**
- ☐ **40°**
- ☐ **35°**
- ☐ **30°**
- ☐ **25°**
- ☐ **20°**



SURFACE TYPE:

☐ OSB PANELS

☐ OTHER: ______________

START TIME: __________

END TIME: __________

ELAPSED __________ m:s

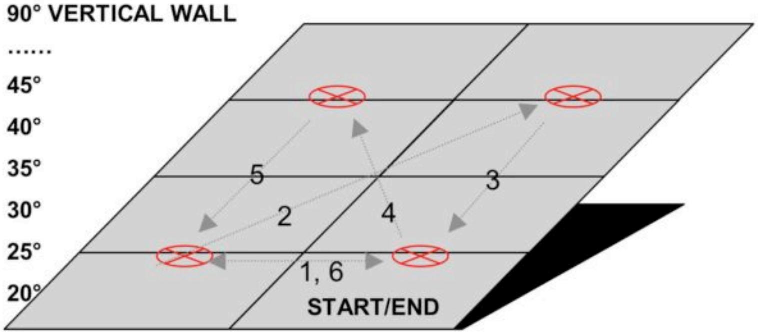
☐ COMPLETE?

(YES = √ , NO = X)

IF NO, SEGMENTS COMPLETED WERE _______ OF 6 (DRAW ON GRAPHIC)

INCLINE (CHECK ONE):

- ☐ **90° VERTICAL WALL**
- **......**
- ☐ **45°**
- ☐ **40°**
- ☐ **35°**
- ☐ **30°**
- ☐ **25°**
- ☐ **20°**



SURFACE TYPE:

☐ OSB PANELS

☐ OTHER: ______________

START TIME: __________

END TIME: __________

ELAPSED __________ m:s

☐ COMPLETE?

(YES = √ , NO = X)

IF NO, SEGMENTS COMPLETED WERE _______ OF 6 (DRAW ON GRAPHIC)

TEST LEADER DATE NOTES ☐

Figure 23: Mobility - Inclined Plane Test Method Data Capture Form

4.11 Mobility – Confined Space Access

The confined space access test methods addresses responder requirements for access to tight spaces. This test uses a variant of the NIST step fields that has an inverted set of step fields projecting from above to narrow the traversable volume.

Figure 25 shows the test method data capture sheet for the test. The artifact employed is a confined space cube. As with most other test methods, the artifacts for this are constructed from pallet-sized units. The customization allowed for necessitates that the test leader capture the following information on the test form for each pallet unit:

- The dominant (highest) geometry of the random step fields for both the roof and floor: flat, diagonal, or hill. This is marked directly on the schematic representation
- The post heights for each cube (in terms of multiples of a unit cube).
- Total number of pallets

For the test data capture, the robot is to traverse the length of the set of confined cubes. The number of pallets it can traverse is noted along with the time for it to do so.

Test Method Comments

The confined space test was set up down at the structure using the standard red step fields as flooring in a line of five. The step fields were set up in the following configuration: flat, diagonal, flat, hill, flat. The ceilings in this configuration were diagonal, flat, hill, flat, and an empty ceiling piece with a triangular hole. The ceilings are held up by frames of variable height such that the ceilings are at a height of 10 or 12 step field units. The purpose of the test is to simulate a sort of tunnel with protrusions from the floor and ceiling. Figure 24 shows the configuration at Disaster City. The test method saw very few robots during the event, but seemed to be well accepted by the developers and responders who saw it and were told of its purpose and reasoning.

Figure 24: Confined Space Access Test Method

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Developing

Standard Test Methods For Response Robots

Version: 2007.4

CONFINED SPACE CUBES

ROBOT: ________________ ☐TETHER ☐RADIO

OPERATOR: ________________ ORG: ________________

TRAINING TIME: ☐ 0-24 HRS ☐ 24-100 HRS ☐ > 100 HRS

INSTRUCTIONS: TRAVERSE THE CONFINED SPACE DASH TO FAR END AND BACK. TURNING IN PLACE AT FAR END IS OPTIONAL.

ADMINISTRATOR: 1) TRACE THE ELEVATED TERRAIN RIDGES BOTH ON FLOOR PALLETS AND ROOF PALLETS. 2) NOTE THE POST HEIGHTS FOR EACH PALLET IN CENTIMETERS. 3) TIME THE SEQUENCE. 4) NOTE TOTAL PALLETS TRAVERSED IF INCOMPLETE.

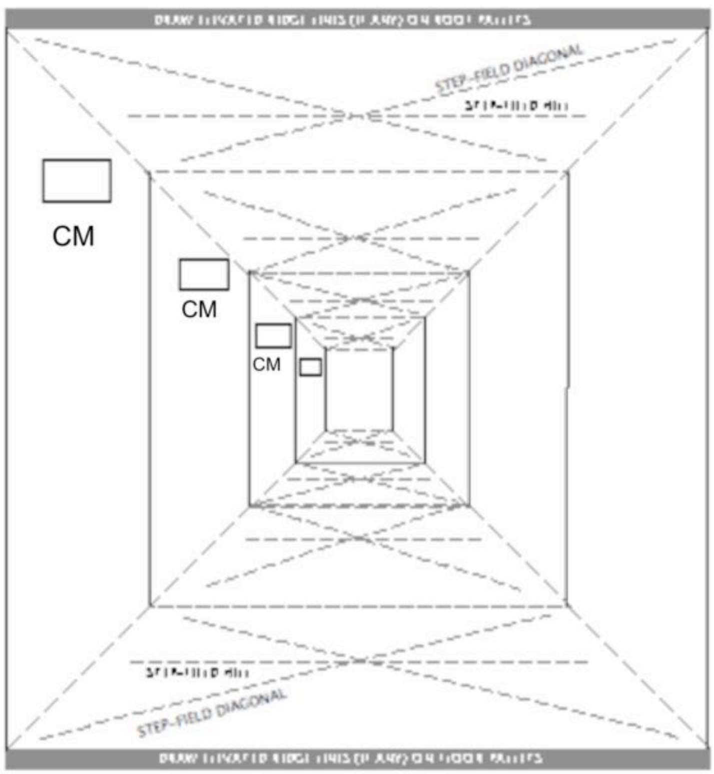
START TIME: __________

END TIME: __________

ELAPSED: _________m:s

☐ COMPLETE? (YES = √ , NO = X)

IF NO, TOTAL PALLETS COMPLETED WERE ____ OF 10



TEST LEADER DATE NOTES ☐

Figure 25: Mobility - Confined Space Access Test Method Data Capture Form

4.12 Mobility – Step/Gap Test Method

This test method addresses responder requirements for mobility across discontinuous surfaces which may have gaps or large steps.

A single data collection form for both types of test methods is shown in Figure 27. There are four groups of tests to be performed. The step test is conducted with and without pipes on the edge of the raised platform. The pipes provide an additional challenge to the robot's mobility, as they have less friction and can rotate freely. Without the pipes, there is an edge that the robot may be able to "grab" onto, especially if it has tracks. The gap test is conducted across an even height as well as across a gap that includes a step. Multiple (5) repetitions must be performed for each height or gap distance. The height or gap distance is increased until the robot cannot perform the test successfully. Average time over 5 repetitions to complete each test is noted. Ideally, the material and/or coefficient of friction will also be another quality that is captured on the test method form.

Test Method Comments

The step/gap test was set up down at the structure in a variable set-up using 1.2m x 1.2m x 10cm "pallets." The basic step part of the setup consists of a tall stack of (n+1) pallets next to a single pallet to create a (n*10) cm step. This test is performed once with an exposed corner and then a second time with a 10 cm PVC pipe held against the vertical face as shown below. The gap portion of the test is set up first using two pallets set on the ground at a set distance from each other. The final iteration of this test is set up using a stack of 3 pallets and a single pallet at a set distance from each other like the gap test. Figure 26 shows one configuration.

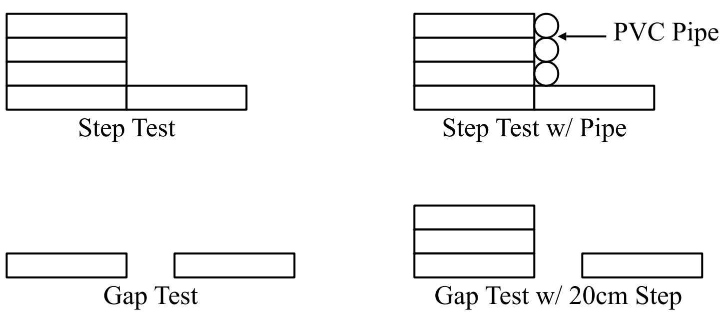


Figure 26: Step & Gap Test Method

The metrics for this set of tests is based upon the successful completion of 5 cycles of each test. A cycle of the step test is once up and down the step, while a cycle on the gap test is once across the gap and back. If the robot completes 5 cycles at a certain level, they proceed to the next level until they find the first level that cannot be completed. For the step test, each pallet added to the tall stack is a new level, while for the gap test, widening the gap by 10cm is a new level. The highest level that the robot completes 5 cycles of is the score for the test.

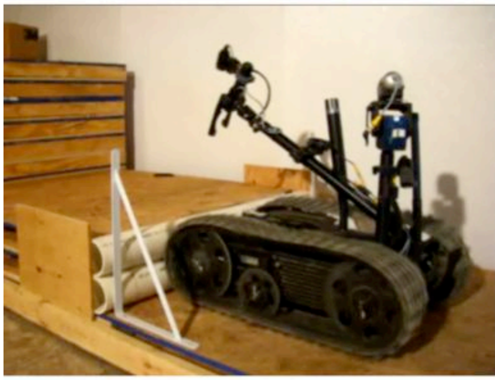
The test method seemed well accepted by the developers and even resulted in the discovery of a new climbing technique for one of the robots in order to make it across the gap test.

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Developing

Standard Test Methods For Response Robots

Version: 2007.4



STEP/GAP

ROBOT: ________________ ☐TETHER ☐RADIO

OPERATOR: ________________ ORG: ________________

TRAINING TIME: ☐ 0-24 HRS ☐ 24-100 HRS ☐ > 100 HRS

INSTRUCTIONS: TRAVERSE THE OBSTACLE AND RETURN TO START POINT (ONE REPETITION). REPEAT FIVE TIMES CONTINUOUSLY.

ADMINISTRATOR: 1) FOR EACH OBSTACLE, INCREASE OBSTACLE UNTIL UNSUCCESSFUL IN ONE OF FIVE REPETITIONS. CIRCLE THE MAXIMUM OBSTACLE DIMENSION WITH FIVE CONTINUOUS REPETITIONS. 2) NOTE THE ELAPSED TIME FOR FIVE CONTINUOUS TRAVERSES.

STEP WITH EDGE

	HEIGHT	1	2	3	4	5	ELAPSED TIME
☐	100 cm	☐	☐	☐	☐	☐	________ m:s
☐	90 cm	☐	☐	☐	☐	☐	________ m:s
☐	80 cm	☐	☐	☐	☐	☐	________ m:s
☐	70 cm	☐	☐	☐	☐	☐	________ m:s
☐	60 cm	☐	☐	☐	☐	☐	________ m:s
☐	50 cm	☐	☐	☐	☐	☐	________ m:s
☐	40 cm	☐	☐	☐	☐	☐	________ m:s
☐	30 cm	☐	☐	☐	☐	☐	________ m:s
☐	20 cm	☐	☐	☐	☐	☐	________ m:s
☐	10 cm	☐	☐	☐	☐	☐	________ m:s

STEP WITH PIPE

	HEIGHT	1	2	3	4	5	ELAPSED TIME
☐	100 cm	☐	☐	☐	☐	☐	________ m:s
☐	90 cm	☐	☐	☐	☐	☐	________ m:s
☐	80 cm	☐	☐	☐	☐	☐	________ m:s
☐	70 cm	☐	☐	☐	☐	☐	________ m:s
☐	60 cm	☐	☐	☐	☐	☐	________ m:s
☐	50 cm	☐	☐	☐	☐	☐	________ m:s
☐	40 cm	☐	☐	☐	☐	☐	________ m:s
☐	30 cm	☐	☐	☐	☐	☐	________ m:s
☐	20 cm	☐	☐	☐	☐	☐	________ m:s
☐	10 cm	☐	☐	☐	☐	☐	________ m:s

GAP WITH NO STEP

	HEIGHT	1	2	3	4	5	ELAPSED TIME
☐	100 cm	☐	☐	☐	☐	☐	________ m:s
☐	90 cm	☐	☐	☐	☐	☐	________ m:s
☐	80 cm	☐	☐	☐	☐	☐	________ m:s
☐	70 cm	☐	☐	☐	☐	☐	________ m:s
☐	60 cm	☐	☐	☐	☐	☐	________ m:s
☐	50 cm	☐	☐	☐	☐	☐	________ m:s
☐	40 cm	☐	☐	☐	☐	☐	________ m:s
☐	30 cm	☐	☐	☐	☐	☐	________ m:s
☐	20 cm	☐	☐	☐	☐	☐	________ m:s
☐	10 cm	☐	☐	☐	☐	☐	________ m:s

GAP WITH 20CM STEP

	HEIGHT	1	2	3	4	5	ELAPSED TIME
☐	100 cm	☐	☐	☐	☐	☐	________ m:s
☐	90 cm	☐	☐	☐	☐	☐	________ m:s
☐	80 cm	☐	☐	☐	☐	☐	________ m:s
☐	70 cm	☐	☐	☐	☐	☐	________ m:s
☐	60 cm	☐	☐	☐	☐	☐	________ m:s
☐	50 cm	☐	☐	☐	☐	☐	________ m:s
☐	40 cm	☐	☐	☐	☐	☐	________ m:s
☐	30 cm	☐	☐	☐	☐	☐	________ m:s
☐	20 cm	☐	☐	☐	☐	☐	________ m:s
☐	10 cm	☐	☐	☐	☐	☐	________ m:s

TEST LEADER DATE NOTES ☐

Figure 27: Mobility – Step and Gap Traversal Test Method Data Capture Form

4.13 Towing Test Method (Initial Trials)

An emerging test method to assess the towing capacity of robots was initially evaluated at Disaster City. Although a requirement for towing was not part of the initial set defined at the outset of this project, it is a capability that could provide many advantages to US&R responders. The ability of a robot to carry significant loads can help serve as a "pack mule," hauling heavy payloads for the responders. If configured appropriately, a robot could carry responders downrange, especially if they are outfitted in cumbersome protective suits, which constrict mobility. If victims are found, a robot outfitted with a litter or sked stretcher can transport victims that are found back to the base of operation. Figure 28 illustrates examples of how this would be potentially used.

The metrics for this test are envisioned to include
- weight being towed (kg)
- distance towed
- terrain type, incline angle if hilly

Figure 28: Different Towing and Carrying Configurations: Carrying lumber for shoring, transporting victims

5. Data Collection

This event provided a focused opportunity to capture feedback from responders and manufacturers. On-site discussions captured the impressions of all the stake-holders. Further feedback was collected from the participants during an after-action review held the final day as part of the informal standards meeting. Copious images and video of the robots in action were also collected. This section describes briefly the data collected.

5.1 Images and Video

The organizers collected images and videos of robots and personnel participating in the event. Each robot developer receives all media related to their robots. Highlight images and generally successful robot videos can be found on the NIST project home page: http://www.isd.mel.nist.gov/US&R_Robot_Standards/. Sections 5.3 and 5.4 provide more detail on specific video capture of robot locations as well as multi-stream data collection.

5.2 Test Results

Robots were assigned to run through all tests that were relevant or feasible for their particular design. Most robots were able to attempt all of the tests for which they were eligible. Test proctors collected data per the draft test methodology on the appropriate data sheets, which were shown in Section 4. Video and tracking information augmented the capture of performance data and is included in the materials provided to the robot developers.

The process of capturing data was evaluated by the test proctors and others. Critiques of the test methodology and artifacts from responders and robot developers were solicited. The actual data collected was analyzed post facto, primarily to establish ranges of performance for finalizing the test methods prior to submitting them to the standards balloting process.

NIST is not releasing the results of the test methods from this exercise. The test methods are still under development, hence it is premature to officially measure robot performance. Robot developers have voluntarily participated in this event, knowing that this was a learning opportunity for all and it would not be fair to publish test results at this time.

5.3 Robot Tracking Data Collection within Test Methods

NIST personnel have continued to capture robot position data to enhance quantitative performance evaluations during test methods/scenarios using an Ultra Wide Band (UWB) tracking system, developed by MultiSpectral Solutions, Inc. [8] Antennas (also known as receivers) are placed around the perimeter of the test method/scenario and their positions are measured to enable the system's multilateration algorithms to locate active UWB tags that are attached to the robot(s). The tracking system is used to capture 2D or 3D position data over time to compare specific implementations, approaches, and/or deployment techniques. This data facilitates the collection of performance metrics including deviations from desired routes, dwell sites and durations, percent of area covered, thoroughness of team searches, etc.

UWB tracking has been used successfully for several years within fabricated robot test arenas to capture 2D paths of individual robots, teams of collaborative robots, and dogs being trained. Efforts to track assets within realistic training scenarios have produced mixed results. At a previous event, several responders were tracked moving through an intact building structure pre-equipped with antennas to produce data and videos of each responder's 2D path overlaid onto the building floor plan. Assets were also tracked in line-of-sight of the antennas across a large concrete rubble pile. However, attempting to track assets located in tunnels under the concrete rubble pile, or within surface voids on the pile, was unsuccessful due to the overall density of concrete rubble along with the limited power levels of the active radio tags (30mW) at that time. At Disaster City in 2006, the tracking system was deployed around the wood pile, which provided a more porous prop than the concrete rubble, and used higher power radio tags (1000mW). During the wood pile deployment, robots could be tracked as they performed initial reconnaissance on the street around the pile, yet the tracking data disappeared as they entered the wood pile through buried concrete culverts. Once inside the pile, tracking remained unsuccessful due to the robots' low ground position while surrounded by the densely-packed wood pile perimeter.

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[8] www.multispectral.com

For the 2007 exercise in Disaster City, the UWB tracking system was deployed around the maze test method located in the theatre building. Six receivers were set up around the perimeter of the 12m x 9m wooden-walled maze at various heights (Figure 29) with the reference tag (necessary to synchronize the system's internal counter functions) placed on top of a centrally-located maze wall.

Once the receivers were wired back to the tracking hub, the location for each of them and for the reference tag were measured from a common coordinate origin. After these steps were completed, the coordinate data was input into the hub and some final calibration steps were undertaken to ensure adequate data was being captured.

Figure 29 - UWB tracking system receiver positions (circled in red) around the maze test method

NIST has developed software to display the output of the tracking system. The data from multiple tags can be filtered, both spatially and temporally. The most recent position or a customizable "tail" of past positions, which is the track of the robot can be shown. A ground truth map or overhead image of the environment through which the robot is traversing can be imported into the tool, enabling the robot track to be overlaid onto the image or map to facilitate visualization of the robot's movements through a test method or scenario. For example, the user-generated map of the maze configuration used at Disaster City is shown in Figure 30, with the robot's trail overlaid onto this ground truth.

Each robot that challenged the maze was outfitted with one to three (depending upon available space on the robot) tracking tags (see Figure 30). Low power (30mW with an update rate of 60Hz) tags were used as opposed to high power (1000mW with an update rate of 1Hz) tags because most of the robots could easily 'outrun' the slower update rate of the higher-powered tags, resulting in irregular tracks (using both types of tags during calibration produced a negligible difference in static accuracy). Tracks were obtained from multiple robots while they performed variations of the maze test throughout the week. Figure 2b shows a track of a robot whose task was to navigate from Point "B" to Point "A." Other maze tasks that were tracked included moving from Point "A" to Point "B" and performing a complete search of the maze. During the exhaustive search, robot operators declared when they believed they had completely searched the maze. The maze ground truth was compared against the UWB system's generated track that displayed the actual visited regions.

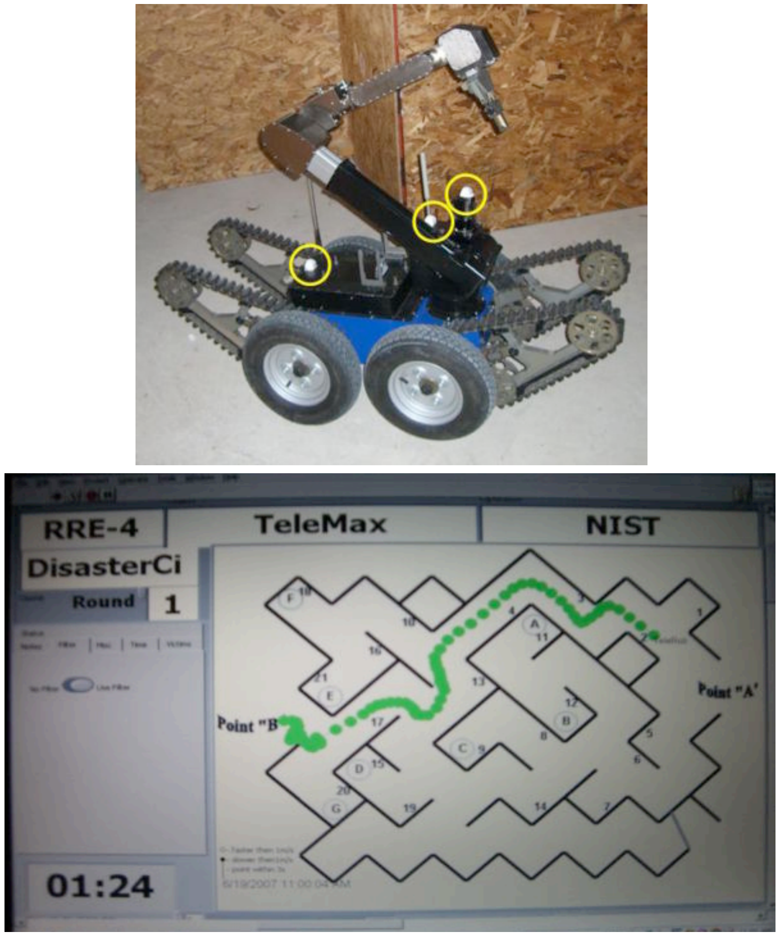

Figure 30 - a) Robot with tracking tags (circled in yellow), b) UWB track of a robot having negotiated the maze

The tracking data gathered throughout the week was very promising. For the most part, the system was able to track robots as they moved from one part of the maze to another with minimal visible error. There were a few instances where the tracking system incorrectly displayed robots 'ghosting' through walls. It is believed that these occurrences can be minimized in future evaluations through more accurate placement of maze walls and through the creation of a more precise map of the maze that was integrated with the tracking software (not only was time a constraint during the setup process, but the maze was placed on the theater's sloped floor). Another issue that arose was when robots moved maze walls inadvertently. Since the tracking interface maintains a user-defined static image of the maze, the system was unable to recognize when walls were moved thereby showing the robots in inaccurate positions with respect to the updated wall positions. This issue is addressed through fusing the tracking data with synchronously captured video data (discussed later) where the real time video data would show a robot's interactions with the maze walls). Another solution that was investigated during the week was connecting adjacent maze walls to one another. This turned the entire maze into four large, heavy components which minimized the robots' ability to rearrange the walls.

Further experiments are underway including additional characterizations of the tracking system's performance within one of NIST's resident maze configurations. Tags are being statically placed within the maze walls at varying heights for specified periods of time. Data is collected at multiple locations and will be analyzed for accuracy and precision. A drift analysis is also planned to determine how the system's accuracy and precision changes, if any, over time.

5.4 Audio/Visual Quad Data Collection

For this specific event, when a robot attempted either endurance, grasping dexterity, directed perception or maze test methods additional performance data was captured through Audio/Visual (A/V) quad data collection. A quad video and single audio collection system is managed to depict a clear representation of both the operator's and robot's actions during these test methods. This A/V data collection system is composed of the control and display hub and supported by *in situ* cameras and an operator station-based microphone. A computer-output splash screen showing the pertinent run information initiates the A/V collection and displays the robot, operator, test method, etc. While a robot operates within a test method, video is captured of the robot from multiple perspectives (includes a combination of ground-based and/or ceiling-mounted cameras), the operator's hand interactions with the robot's control system, the robot's visual user interface, and the display output of the robot tracking system (maze test method, only). A microphone mounted next to the operator, captures everything the operator says throughout their performance. Date and time information is also captured on the screen to allow *post facto* analysis of the test method and robot performance.

The video and audio feeds are sent into the quad data collection system (Figure 31). While the audio is directly output to the digital recording device, the video signals go through preview monitors and switchers before the final four video outputs are fed into the quad compressor and split out to large display monitor and the digital recording device. Typically, the A/V manager has more than four video sources per test method, but only has the ability to pick the two most opportune robot video sources (displayed in the upper-right and upper-left quadrants) while the other two video sources default to the operator's control (lower-left quadrant) and robot interface (lower-right quadrant). The only exception is that the robot tracking system output is displayed in the upper-left quadrant (replacing a robot perspective) during the maze test method.

Figure 31 - Quad Data Collection System

This system was extremely effective in capturing audio/visual data in the test methods in which it was integrated. Since the four output video sources to the quad were recorded together on a single device, there was no need to synchronize the clocks of the various video devices. Following the event, DVD videos were burned of the videos to not only organize the raw footage, but also to create highlights. This data greatly facilitates a more complete understanding of both the robot's and operator's capabilities within a specific test method enabling vendors to realize how and why their robots were successful (or not successful), operator's to recognize their strengths and weaknesses, robot operator trainers to see which skills require additional/augmented training, and the evaluation team to iterate and improve upon the impetus of the test methods.

6. Technology Initiatives

During this event, a technical initiative was held that consisted of several presentations and a series of small working groups that were geared at introducing advanced technologies with assistive capabilities to first responders. It also provided an opportunity for the researchers and responders to discuss the utility of these technologies, refining the assumptions, and discussing practical application of these technologies. These are technologies that are candidates for either future test method development or for providing infrastructural support to performance evaluation and standards efforts.

One thrust of the technical initiative was the use of simulation as a robotic training tool for first responders. Simulation provides a means to introduce, train, and critique emergency responders on emerging and existing technologies in specific scenarios. The development of high-fidelity models gives responders virtual access to existing training scenarios and the ability to develop customizable scenarios that are repeatable and safe. The use of simulation also provides the means for responders to enhance user competencies of existing operator interfaces, understand the control modalities of different robotic platforms, and experiment with new interfaces. Potentially, high-fidelity simulations could assist in performance capture techniques. Figure 32 shows images of portions of the Theater building at Disaster City that were modeled in USARSim.[9]

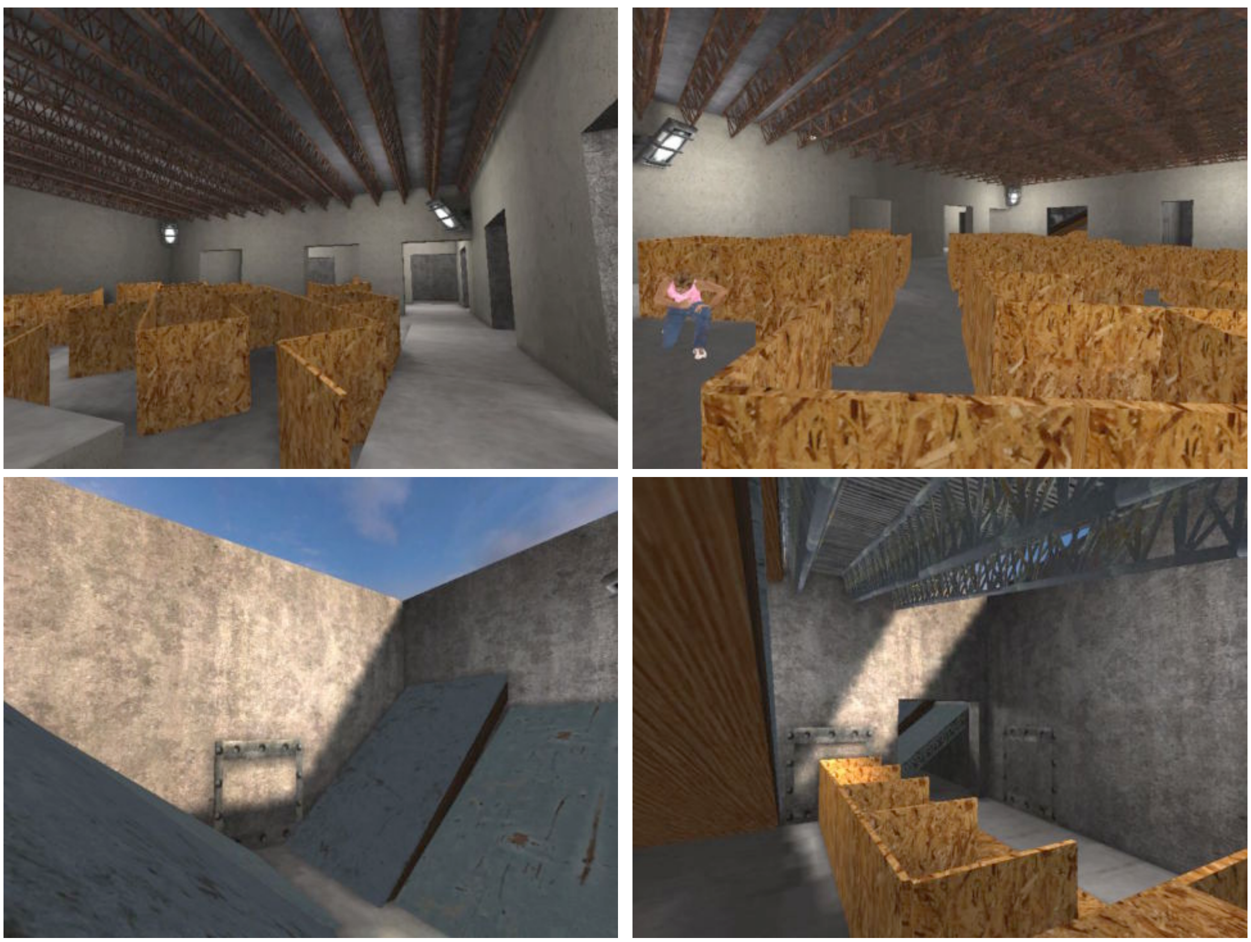

Figure 32: Images of portions of the Disaster City Theater building modeled in USARSim. The top images are of the main room, where the maze test method was housed. Other areas are shown in the bottom.

[9] http://usarsim.sourceforge.net/

The Symonym[10] high-fidelity simulation system was shown to the responders as well. Three-dimensional point clouds gathered using a Hokuyo laser were imported into Symonym for dynamic visualization. The Hokuyo (a higher-power new version) was mounted on a tilt plate that allowed the laser to automatically be tilted. This allowed for full 3-D scans of areas in and around the disaster scenarios where the robots were operating.

The idea behind these 3-D laser scans is to provide a rapid model of a space that is completely unknown for responders and robots alike to use in better understanding the dynamics of a building, cave, or structure that is completely unknown to the responders. The scans can be used by structural engineers in these response teams to assess structural integrity, they can be used by responders cutting shoring in the field to secure the structure for entry, and finally, the scans can be used to determine sizes, shapes, and types of structures in an unknown space.... including potential victims. Figures 33 show an example scan from the Hokuyu displayed in Symonym, alongside a color picture of the scene.


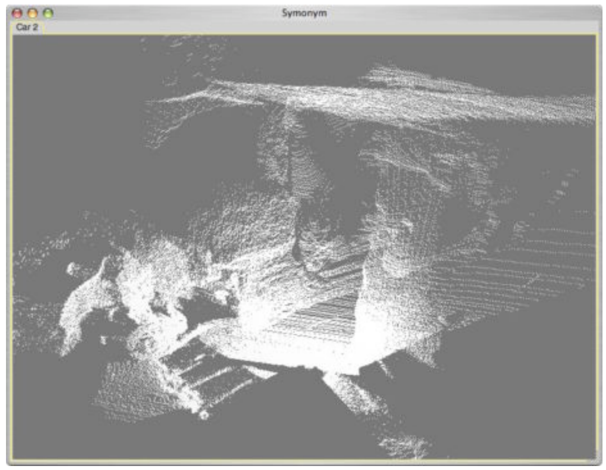

Figure 33: Left image shows the scene to be scanned and the setting up of the sensor. Right image shows the 3-D point cloud displayed within Symonym.

The other thrust of the technical initiative was to present the development of assistive technologies that could be employed to increase the utility of robotic platforms to safely assess disaster situations. These technologies primarily relied on the fusion of sensor data to provide visualization tools, mapping utilities, and autonomous capabilities that are aimed at enhancing the overall utility and performance of robotic platforms in the urban search and rescue environment.

Figures 34 and 35 show screen shots from a Rapid Assessment Tool (R.A.T.)[11] developed by the Environmental Protection Agency (EPA) Region 5 Field Environmental Decision Support (FIELDS) team. This tool combines global positioning information from a GPS device with single point or continuous field sample data (from a variety of sensors). R.A.T. stores the sample data with its GPS location in a flat file and plots these results in a dynamic, two-dimensional display in real-time. In the software, data can be viewed with aerial photography, polygon boundaries, and sample designs to allow for immediate data availability, analysis, and use in the field. The collected data can also be exported using standard U.S. EPA data formats such as SCRIBE and ESRI Shapefile. Sensors were carried by the HERO robot as it circumnavigated the passenger train. Triggers for the sensors were placed in the environment. Figure 34 shows the locations where the sensor samples were taken. The calculated plume is shown in Figure 35.

A tool such as R.A.T. can provide facilities for capturing data from sensors onboard robots and displaying the resulting readings, along with ground truth in future performance test methods for hazardous materials sensors.

10 http://www.symonym.com/

11 http://epa.instepsoftware.com/rat/

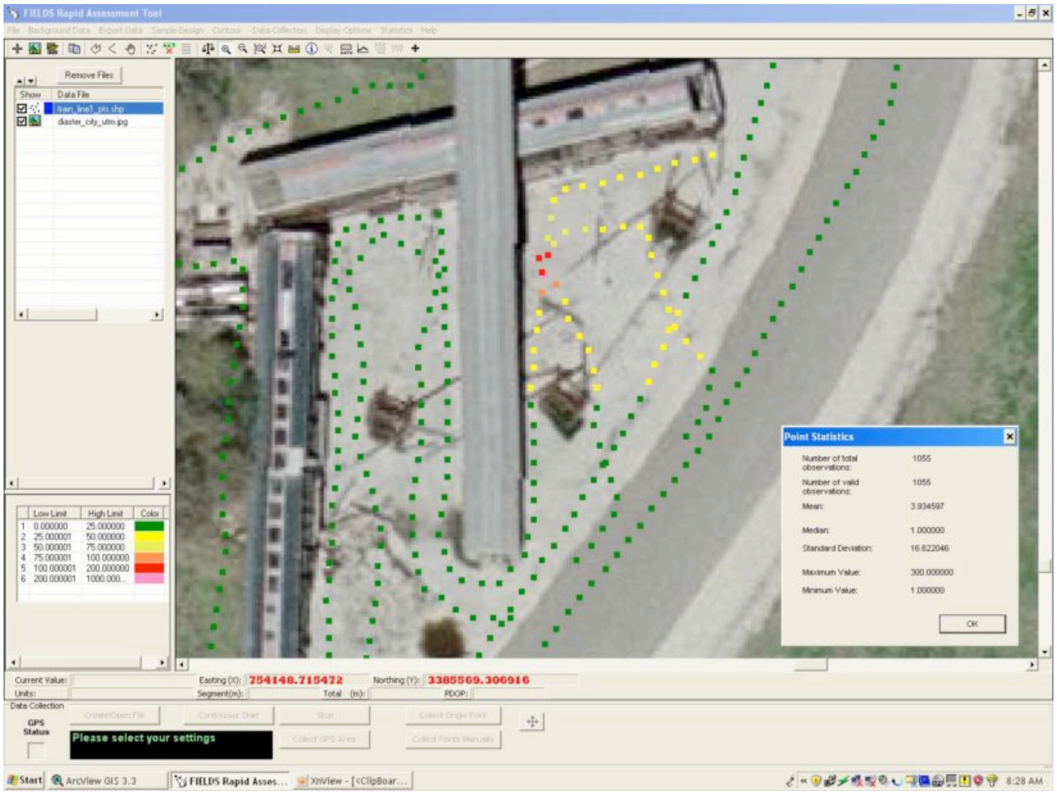

Figure 34: Data Collected using sensors and GPS around Passenger Train and displayed on overhead imagery of Disaster City site by the EPA Rapid Assessment Tool.

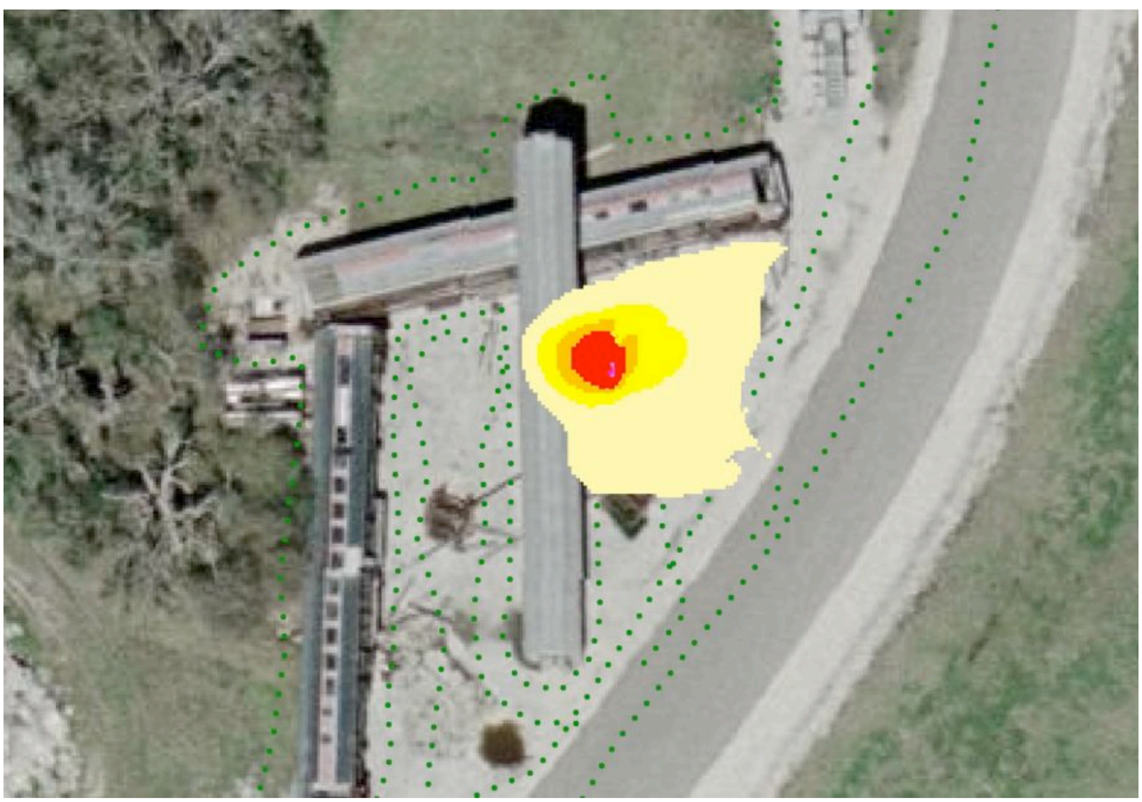

Figure 35: Plume calculated by the EPA Rapid Assessment Tool

7. Standards Task Group Meeting (ASTM E54.08.01)

On June 22, an informal meeting of the ASTM E54.08.01 Task Group on Performance Standards for Urban Search and Rescue Robots was held. The meeting allowed all participants to comment on the overall exercise and provide specific feedback on test methods that were assessed during the week.

7.1 Overall Event Comments

- Overall, participants favored the new event scheduling, where robot developers were on site prior to the responders. This allowed developers to focus on running through the test methods and increased the availability of robots for scenario usage once the responders arrived.
- Instruct developers to bring "beater" robots and engineers to fix them while learning what breaks.
- Others wanted the latest and greatest robots available, even if fragile.
- Responders would like to be able to start scenarios with robots still in their cache packaging. This way, they would get to experience unpackaging and readying the robot for its mission.
- In general, note in detail the configuration of the robots at test time for "gaming" of test. For example, the discussion regarding the robot's ability to bring and deploy equipment to cross gaps. The consensus was that if the robot carried and deployed a "kit" it should be okay, but would need to be asterisked in the data that it requires the optional "kit." We need to capture all the options used in the robot spec sheets.
- Look into lighting up Disaster City with Wi-Max to allow RoboCupRescue[12]-like support for radios to support development of other capabilities.

7.2 Comments on Specific Test Methods

The discussions covered both the test methodology and artifacts as well as the data capture form.

7.2.1 Radio Communications

Test Method:

- Add slalom (with cones) to catch latency issues in control channel. Maybe add 5-10 cones near each interim measurement location. Be careful that each cone implies the side the robot should pass so that counting bumps and misses is consistent. Also, varying slaloms would prevent canned paths from being used. Color-coded pass through tasks could also be used (pass between the two red cones along the line).
- Develop a new electro magnetic compatibility interference test in an anechoic chamber to isolate issues with expected conflicts with response radios nearby (fire, ambulance, etc).

Data Form:

- Add checkbox for antenna type (directional vs omni) and note height of antenna
- Add checkbox for signal type (analog vs digital)
- Remove the "tether" checkbox? Will we never test tether range? Should these be simply COMMUNICATIONS tests, not necessarily a radio communications test?

7.2.2 Visual Acuity

Test Method:

[12] International competition in which robots perform US&R tasks within arenas that incorporate the ASTM draft test methods, along with more advanced challenges. http://www.robocuprescue.org/

- Repeatability data is needed for completing this standard test method. ASTM requires a statement on intra-lab repeatability for test methods.
- Need to develop new POINTING test to capture situational awareness in open space (on various surfaces). This would be a different test method than visual acuity.

Data Form:

- Add checkbox for signal type (analog vs digital)

7.2.3 Directed Perception

Data Form:

- Note the brand of sensors used in DIRECTED PERCEPTION test.

7.2.4 Miscellaneous

Operating Environment

- For new Operating Environment test method, initial concepts were discussed. We had originally intended to have a demonstration of a new “wash down” test method at this event, but the working group chair’s schedule prevented him from traveling to Texas. The test initially needs to cover “wash down” conditions using existing cache brushes, 10% chlorine solution, and foaming peroxide (two complete cycles and keep working). If the robot is exposed to a real hazmat, it will probably be staying on site anyway and may not need wash down. Alternatively, certain components (such as tracks) may need to be replaced.

Audio

- One of the high-priority sensors for the next wave of standards is audio. Audio filtering should be tested to be compatible with Delsar seismic sensors nearby. An entire two-way audio test needs to be developed. The RoboCup Rescue competition currently includes such a test, which may be useful as a starting point.

Appendix A -- Participants

Steve Richards	Acroname Inc.
Thomas Meyer	Airrobot US, Inc.
Alex Campbell	Blitz Solutions
Rory Rehbeck	Colorado Task Force I
Norman Smith	CTEH
Jon Nelson	Dynamic Protection Solutions
Michael Asimor	Dynamic Protection Solutions Intl.
Mike Cardarelli	First Response Robotics, LLC.
Martin Foley	Foster-Miller,Inc.
Robert Morehead	Foster-Miller,Inc.
Ryan Wall	Innovative Response Technologies, Inc
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Lee Haus	LAFD - Sepulveda
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