Urban search and rescue robot performance standards: progress update

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ABSTRACT

In this paper, we describe work in performance standards for urban search and rescue (USAR) robots, begun in 2004 by the Department of Homeland Security. This program is being coordinated by the National Institute of Standards and Technology and will result in consensus standards developed through ASTM International, under the Operational Equipment Subcommittee of their Homeland Security Committee. A comprehensive approach to performance requirements and standards development is being used in this project. Formal test methods designed by several working groups in the standards task group are validated by the stakeholders. These tests are complemented by regular exercises in which responders and robot manufacturers work together to apply robots within realistic training scenarios. This paper recaps the most recent exercise, held at the Federal Emergency Management Agency (FEMA) Maryland Task Force 1 training facility, at which over twenty different robots were operated by responders from various FEMA Task Forces. The exercise included candidate standard test methods being developed for requirements in the areas of communications, mobility, sensors, and human-system interaction for USAR robots.

Keywords: urban search and rescue, robots, performance standards, performance metrics, homeland security, response robots

1. INTRODUCTION

The Department of Homeland Security (DHS) has determined that performance standards are needed for robots so that they may be applied to urban search and rescue missions. Urban Search and Rescue (USAR) is defined as "the strategy, tactics, and operations for locating, providing medical treatment, and extrication of entrapped victims."[1] This is a very dangerous and difficult. Without consistent means of defining and measuring the performance of robots, it is not possible for organizations such as the Federal Emergency Management Agency to make procurement decisions that will provide them with the best resources for their funds. To address DHS's need, the National Institute of Standards and Technology is coordinating and leading the development of requirements and test methods for urban search and rescue robots. Numerous other organizations in government, academia, and the private sector are lending their expertise and providing significant contributions to this effort.

The first phase of the project was devoted to ensuring that the responders' requirements were articulated and captured in detail. An advisory panel of FEMA USAR Task Force members participated in a structured process which captured over one hundred requirements and organized them into major categories. During this process, the responders also defined thirteen deployment situations which entail different robot capabilities. A prioritization process based on overall applicability and technological maturity resulted in selection of twenty-five requirements to address in the initial "wave" of standard test methods.

In 2005, DHS selected ASTM International[2] to host the standards that are being produced. A Task Group to develop performance standards for robots applied to USAR was formed under the Operational Equipment Subcommittee of the E54 Homeland Security Applications Committee. Working groups organized around the requirements categories were established within the Task Group. The division of labor is shown in Table 1.

Table 1: ASTM Working Groups within the E54.08.01 Task Group

ASTM E54.08.01 Working Group	Area of Responsibility and Example Requirements or Metrics
Human-System Interaction	Pertaining to the human interaction and operator(s) control of the robot
	Portability of control station. Number of operators required per robot.
Logistics	Related to the overall deployment procedures and constraints in place for disaster response
	Mean time between failures. Tools required for field maintenance.
Operating Environment	Surroundings and conditions in which the operator and robot will have to operate
	Ability to operate in extreme (hot) temperatures.
Safety	Pertaining to the safety of humans and potentially property in the vicinity of the robots
	Intrinsically safe: ability to safely operate in explosive environments.
Communications	Pertaining to the support for transmission of information to and from the robot, including commands for motion or control of payload, sensors, or other components, as well as underlying support for transmission of sensor and other data streams back to operator
	System commands must be shielded from jamming interference and encrypted.
Mobility	The ability of the robot to negotiate and move around the environment
	The ability to recover if robot tumbles and becomes inverted.
Power	Energy source(s) for the chassis and all other components on board the robot
	Amount of time system can remain active but stationary.
Sensing	Hardware and supporting software which sense the environment
	Ability to sense temperature on surface before taking action.
Terminology	Definition of terms pertaining to robots as applied to urban search and rescue

Fig. 1 illustrates the overall philosophy espoused in this standardization project. The users, developers and standards experts must work together to generate requirements and turn them into measurable specifications. In this project, the measurements occur during execution of test methods along with testing protocols, that are designed to address individual requirements. Eventually, the testing methodology is incorporated into test and evaluation programs, which could be carried out by certified testing facilities. The robot technologies are deployed, but the process is not static. As experience with using robots in the field is gained, new or modified requirements will be generated. The technologies that comprise robots will also continue to mature and evolve, hence capabilities will increase. This too will lead to changes or additions in the requirements and in the corresponding tests and protocols.

The whole life cycle and the "ecology" into which the new technology is to be placed are taken into account. Since robots are not currently being used by USAR responders, standard operating procedures are yet to be developed. Exactly how to best utilize the robots, and how they fit into the overall existing scheme of response protocols and tools must be understood. The resulting changes in standard operating procedures will necessitate changes in training as well. The project attempts to take into account these other mission elements as it moves forward.

The project is designed to ensure that the end users' needs are captured and addressed. The robot technology providers, such as the manufacturers, researchers, and component contributors, must be full participants as well. The current state of robotics is not yet mature enough to fully meet the needs of urban search and rescue applications. It is important to be able to assess which aspects are closer to being fieldable when developing test methods. Appropriately-chosen test methods and performance standards provide concrete development goals for the solution providers. In order to familiarize developers with the domain-specific challenges and requirements, and also expose responders to available technologies, response robot exercises are regularly scheduled at FEMA USAR training facilities. FEMA USAR Task Force members experiment with applying robots within various training scenarios while working closely with the engineers from the robot manufacturers.

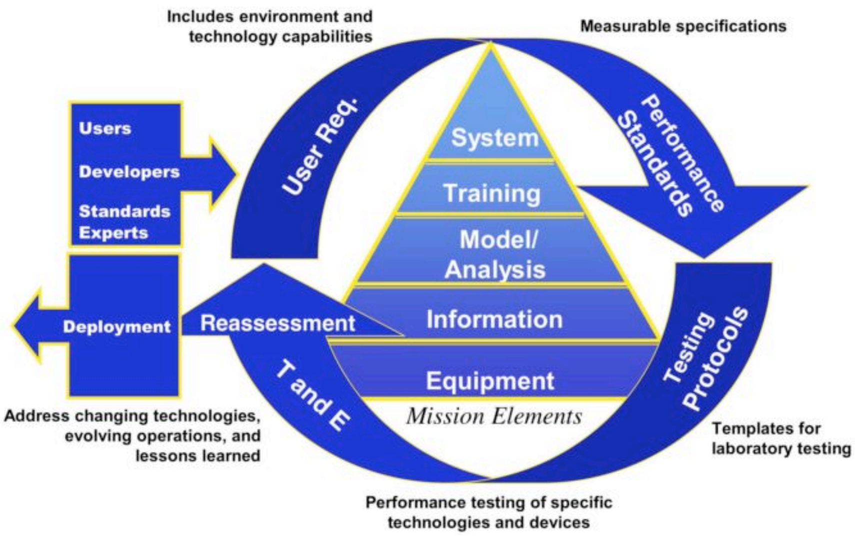


Figure 1: The Standards Process. Courtesy of Bert Coursey, Department of Homeland Security Science & Technology Directorate.

The paper is organized in the following manner: The activities of the standards task group are described in Section 2; Section 3 discusses the response robot exercises that were held thus far; Section 4 summarizes the paper.

2. STANDARD TEST METHODS

2.1. Tailoring Test Methods to different deployment missions

As discussed in previous publications[3,4,5] the foundations of the project are a set of robot performance requirements and of robot deployment categories articulated by FEMA USAR responders. Standard test methods and metrics for the various performance requirements are being developed. However, the ranges of performance which must be measured may be different, depending on the type of deployment mission to which the robot is applied. Matching performance objectives and minimum or maximum thresholds to different deployment types is an ongoing effort. The test methods that are being developed serve as measurement techniques and in and of themselves may not be sufficient to provide guidance to those who must make purchasing and usage decisions. The test method results must be interpreted according to the mission or robot type. Usage guides – also produced under the ASTM Task Group – will provide this additional necessary information. The thirteen different deployment categories do not necessarily require thirteen unique robot types, however, they each may have different expectations or assumptions in terms of what is required. The response robot exercises serve to also clarify the definition of the different categories and to refine the performance requirements for each.

Table 2 summarizes the robot deployment categories. Due to space limitations, the tradeoffs that were defined for each are not shown. As part of the process to prioritize which of the requirements should be addressed within the initial set of test methods, the USAR responders were asked to note which requirements applied to which robot category. This activity produced a set of cross-cutting requirements that would be applicable to most types of response scenarios. The set of “wave 1” test methods, which is the first set of test methods to be submitted into the standards process, was largely determined by a statistical analysis of the applicability of requirements to robot categories. The analysis process is fully described in the Preliminary Statement of Requirements[2].

At a subsequent workshop, held after responders had experimented with a wide range of different robots in scenarios, three categories were selected as being the closest to being usable in real responses. The categories that drive the initial set of test method designs are: Ground: Peek robots, Ground: Non-collapsed Structure--Wide area Survey Robots, and Aerial, Survey/Loiter Robots. The original category description for the aerial robots was "high altitude loiter." This has been modified to more accurately reflect the fact that, according to responders' needs, the robots need not go higher than a few hundred meters, which is not considered "high altitude" in aerial vehicle parlance.

Table 2: Robot Deployment Categories

Robot Category	Employment Role(s)
Ground: Peek Robots	Provide rapid audio-visual situational awareness; provide rapid HAZMAT detection; data logging for subsequent team work
Ground: Collapsed Structure--Stair/Floor climbing, map, spray, breach Robots	Stairway & upper floor situational awareness; mitigation activities; stay behind monitoring
Ground: Non-collapsed Structure--Wide area Survey Robot	Long range, human access stairway & upper floor situational awareness; contaminated area survey; site assessment; victim identification; mitigation activities; stay behind monitoring
Ground: Wall Climbing Deliver Robots	Deliver Payloads to upper floors; provide expanded situational awareness when aerial platforms are unavailable or untenable
Ground: Confined Space, Temporary Shore Robots	Adaptive, temporary shoring; provide stay behind monitoring; victim triage & support
Ground: Confined Space Shape Shifters	Search; provide stay behind monitoring
Ground: Confined Space Retrieval Robots	Retrieve objects from confined spaces; provide stay behind monitoring
Aerial: Survey/Loiter Robots	Provide overhead perspective & sit. awareness; provide HAZMAT plume detection; provide communications repeater coverage
Aerial: Rooftop Payload Drop Robots	Payload delivery to rooftops; provide overhead perspective; provide communications repeater coverage
Aerial: Ledge Access Robot	Object retrieval from upper floors; crowd control with a loudspeaker object attached, provide situational awareness
Aquatic: Variable Depth Sub Robot	Structural inspection; leak localization/mitigation; object (body) recovery
Aquatic: Bottom Crawler Robot	Water traverse; rapid current station keeping; object recovery

2.2. Test method example: visual acuity and field of view

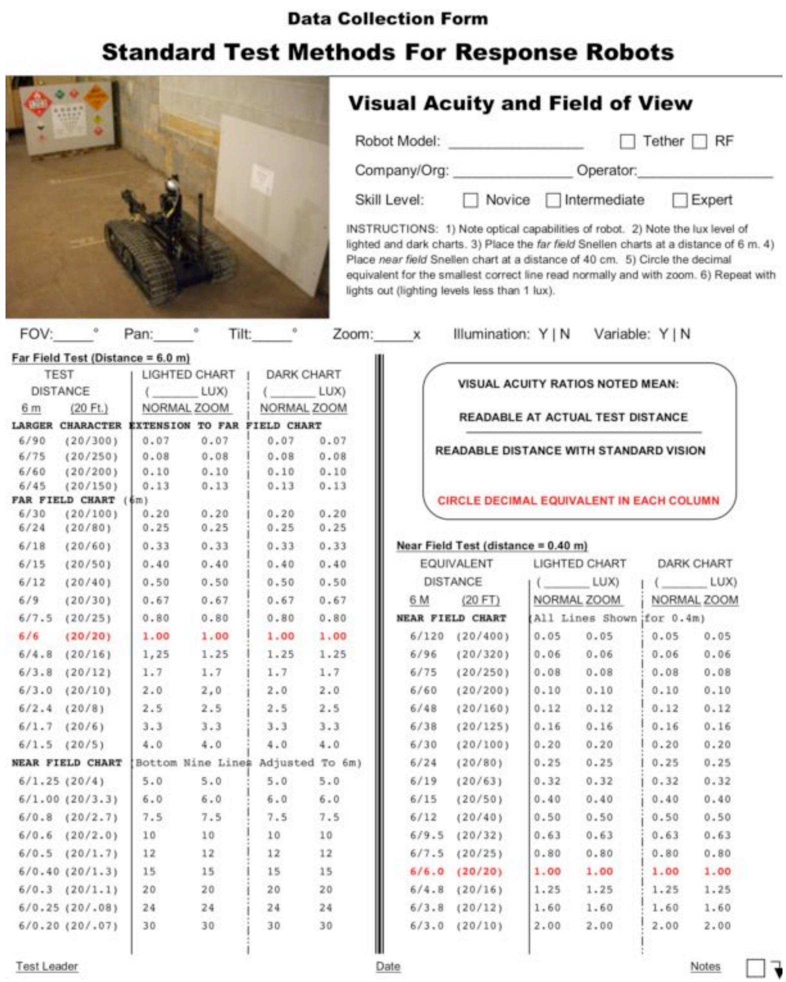
To illustrate the effect of different robot categories on the performance requirements, we will discus the visual acuity and field of view test method. This test method captures performance to address the responders' performance requirements listed in Table 3. The specifics of the test set up were designed to address specifically the three types of robot deployments selected as highest priority.

Figure 2 shows an example of the draft data capture form that can be used when conducting the test. Note that the test method was submitted for balloting to the ASTM E54 Committee in the the Fall of 2006, but at the time of writing this paper, has not been formally approved. Hence, the form is subject to modifications.

The test method utilizes the Tumbling E optotype (character) in the eye charts that are to be viewed by the operator at the control station remotely located from the robot, which is positioned at specified distances from two eye charts (near and far). Far Vision Visual Acuity is important for both unmanned air vehicles (UAVs) and ground vehicles for wide area survey. Zoom is required for ground vehicles for wide area survey. Near Vision Visual Acuity is important for ground vehicles for wide area survey in examining objects at close range and also for small robots which operate in constrained spaces. Fig. 3 shows a sample line of tumbling E's. The operator is to indicate which side of the letter E is open (top, left, right, bottom) for each letter in a row. The smallest row that is correctly read in its entirety is the one that is noted on the form. The test is conducted in both ambient light and dark conditions (both of which are measured and noted). If the robot is traversing dark areas (which is likely in USAR missions), onboard illumination is necessary. However, if the illumination is not adjustable, close by objects will be "washed out" by the strong lighting. This case will become evident if the robot illumination enables reading the far-field chart, but precludes viewing the near-field one.

Table 3: Requirements Addressed by Visual Acuity and Field of View Test Method

Type	Sub-Type	Requirement
Chassis	Illumination	Adjustable
Sensing	Video	Real time remote video system (Near)
Sensing	Video	Real time remote video system (Far)
Sensing	Video	Field of View
Sensing	Video	Pan
Sensing	Video	Tilt



Data Collection Form

Standard Test Methods For Response Robots

Visual Acuity and Field of View

Robot Model: ______________ ☐ Tether ☐ RF

Company/Org: ______________ Operator: ______________

Skill Level: ☐ Novice ☐ Intermediate ☐ Expert

INSTRUCTIONS: 1) Note optical capabilities of robot. 2) Note the lux level of lighted and dark charts. 3) Place the *far field* Snellen charts at a distance of 6 m. 4) Place *near field* Snellen chart at a distance of 40 cm. 5) Circle the decimal equivalent for the smallest correct line read normally and with zoom. 6) Repeat with lights out (lighting levels less than 1 lux).

FOV:_____° Pan:_____° Tilt:_____° Zoom:_____x Illumination: Y | N Variable: Y | N

Far Field Test (Distance = 6.0 m)

TEST DISTANCE 6 m	(20 Ft.)	LIGHTED CHART (______ LUX) NORMAL	ZOOM	DARK CHART (______ LUX) NORMAL	ZOOM
LARGER CHARACTER EXTENSION TO FAR FIELD CHART					
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 m)

EQUIVALENT DISTANCE 6 M	(20 FT)	LIGHTED CHART (______ LUX) NORMAL	ZOOM	DARK CHART (______ LUX) NORMAL	ZOOM
NEAR FIELD CHART (All Lines Shown for 0.4m)					
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 2: Draft Data Collection Form for Visual Acuity Test Method

Figure 3: Tumbling E Optotype in Various Orientations

2.3. Other Wave 1 Standards

Several other requirements have corresponding test methods that have been developed and are being actively refined and documented by working groups under the ASTM Task Group. A parallel standardization effort has been undertaken for terminology that is relevant to robotics and urban search and rescue. An initial set of terms was approved as a standard in early 2007[6]. It must be noted that interoperability is a priority for USAR robots. Since the Joint Architecture for Unmanned Systems (JAUS)[7], focusing on interoperability for unmanned systems, was already underway when the USAR standards effort was initiated, it seemed appropriate to reference the results from that group. JAUS standards are being developed under the Society for Automotive Engineers. The remainder of this section presents a brief overview of the developing test methods within ASTM.

2.3.1. Common Artifacts and Precepts

Some common artifacts and philosophies apply to multiple test methods and are described up front. Common terrain artifacts are used in several of the test methods. They are meant to provide reproducible and repeatable mobility or orientation challenges.

Step Field Pallets (Figure 4) provide repeatable surface topologies with different levels of “aggressiveness.” Half-cubic stepfields (referred to as “orange”) provide orientation complexity in static tests, such as Directed Perception. Full-cubic step fields (“red”) provide repeatable surface topologies for dynamic tests, such as for locomotion. The sizes of the steps and width of the pallets are scaleable according to the robot sizes. Small size robots can use pallets that are made of 5 cm by 5 cm posts. Mid-sized robots can use pallets made of 10 cm by 10 cm posts. Large-sized robots use pallets made of clusters of four 10 cm by 10 cm posts. The topologies of the posts can be arranged to be biased in three main ways: flat, hill, and diagonal configurations.

Pitch/Roll Ramps provide non-flat flooring for orientation complexity. As implied by the name, the orientation of the ramp can be along the direction of robot travel or perpendicular to it. Different types of ramps are concatenated as well. The angles of the ramps can be 5°, 10°, or 15°.

Figure 4: Step Fields provide repeatable terrain challenges.

Certain visual targets are used in multiple test methods. Far-field and near-field charts provide easy to recognize “tumbling E’s” with standard metrics to measure an operator’s ability to discern details in the video image when viewed remotely through the operator interface and communications link. Various hazardous materials labels provide operationally significant targets in the environment to identify colors, shapes, icons, numbers and letters, which relate directly back to the visual acuity charts.

Most of the tests have many possible configurations (e.g., types of terrains or visual targets). The data capture form therefore must include specification of the exact configuration of the test set up when the test is conducted.

In terms of how the performance is measured in these test methods, we also note that there is a wide variance in the abilities and levels of experience of the operators. Therefore each form includes a selection of the operator's self-declared experience level (novice, intermediate, or expert). When the "official" data is collected for a robot (once the test method is a standard), the robot manufacturer will supply the operator(s) that will conduct the test. We expect to strive for statistically significant numbers of trials, so that the data is averaged over numerous repetitions. Ideally, the performance data will include the level of expertise and can thus be further analyzed for disparities by this particular demographic.

A process by which the key aspects of the test procedure are captured in time-tagged, multi-image format is being refined at NIST. We have been using a quad-screen capture device to merge images from four sources into a single video stream. The sources are typically video streams of the robot performing the test, of the operator's actions on the control, and of the operator control screen (i.e., what the operator would see). Additional, computer-generated or other images can be included in the fourth quadrant, such as the track of the robot if it is performing a test that involves significant motion. All images are captured simultaneously and are time-tagged to permit post analysis. Figure 5 illustrates an example of a quad screen capture. The high resolution digital video includes an introductory screen describing the exact configuration of the test.

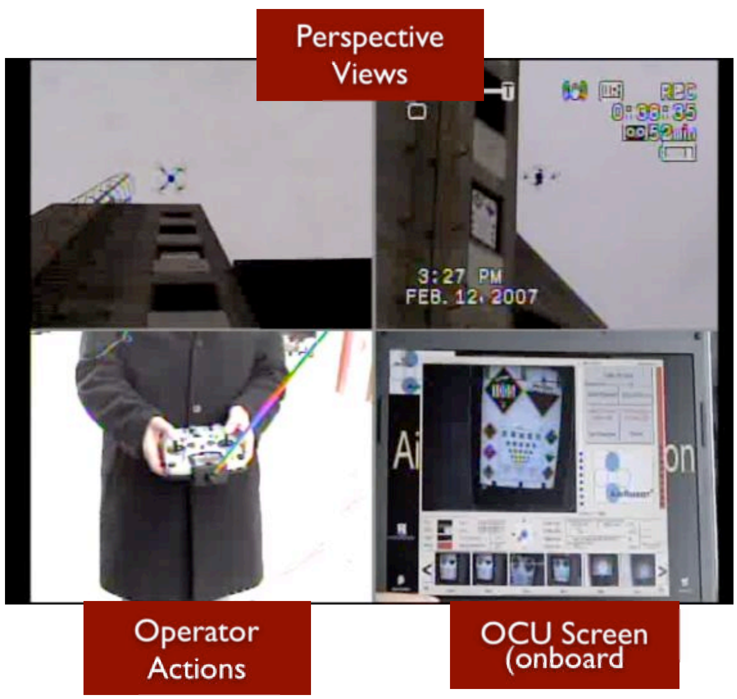


Figure 5: Quad-screen capture during test method execution. In this instance, top 2 quadrants show different views of robot during test. Bottom left captures operator's actions during robot control. Bottom right directly inputs the operator control unit (OCU) video display, which includes views from onboard cameras and whatever else operator would see.

2.3.2. Logistics

In order to ensure that any robots adopted by FEMA USAR teams fit into their well-established logistics procedures, several aspects of the robots are captured in a logistics test method. The items to be noted or measured are:

- Volume of packaging for the robot and all other associated peripherals. Since FEMA has standardized on certain transportation cases, the volume is expressed in terms of type and number of case.
- Weight of packaging for the robot and all other associated peripherals.

- Weight of the robot downrange. This refers to the unpackaged weight for the robot chassis, onboard sensors, operator control unit, and any other required equipment for deploying the robot. Responders may have to carry this equipment downrange.
- The time required to unpackage the robot and associated peripherals and make it ready for deployment.
- The types of tools required for conducting field service on the robot.

2.3.3. Directed Perception

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 sensor. The test artifact consists of an "alcove" formed by three sets of stacked boxes with cutout holes. Inside the boxes are "targets" for different sensors. They could be eye charts, heating blankets (for thermal sensors), trace explosives or simulants, radiation sources, etc. The robot enters the alcove and the operator is to clear as many holes as possible. The maximum reach and range is measured, as well as how effectively the items inside the boxes are sensed and how long the process takes. Fig. 6 shows a sample set up. Note that the flooring is not necessarily flat, so as to induce additional, realistic challenges.

Figure 6: Left: Directed Perception Test Method; Right: three views of Grasping Dexterity Test Method. Both are shown with Pitch Ramps and Orange Step Fields

2.3.4. Grasping Dexterity

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 three stacks of shelves forming an alcove that the robot enters, typically with non-flat flooring. Each shelf contains items (typically blocks), centered on a 3 x 3 grid, that must be picked up by the robot. The number of blocks that can be removed within each shelf is noted, along with the amount of time required to complete the test.

2.3.5. Human-System Interaction -- Acceptable Usability

Since humans will be controlling the robots most, if not all, of the time, measuring the usability and effectiveness of the operator control unit and robot platform is an essential need. The metric measures the percent of timed tasks operators can successfully complete. The operators are to control a robot to navigate a maze-like course from start to finish. The test mission's goal may be to reach a specified exit point or to exhaustively explore the entire 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. The progress of the robot through the maze can be captured using ultra-wide band tracking technology. Figure 7 shows an image of a robot's trail as it traverses a maze. Time stamp information is associated with each recorded location for post-analysis (e.g., how long was the operator stuck in a cul-de-sac?).

Figure 7: Image of robot path as it traverses a maze during the Usability Test Method. The trail shows locations tracked using ultra-wide band technology.

2.3.6. Radio Communications - Range

Robots will be functioning remotely from the control station and human operator. Wireless radio communications range is measured by this test method, for both line of sight and beyond. During the line-of-sight test, the operator navigates a robot down a linear path with direct line of sight to the control station. Along the way, there are stations with 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. The distance to each target and the best (smallest) line legible are noted, as well as the time to reach each station. The beyond line of sight test is similar, except that the robot is to circumnavigate a building. The robot's communications frequencies for transmission and reception are noted, since there may be interference issues[8]. There could be two different channels – one for command information and one for data.

2.3.7. Ground Mobility Test Methods

Basic robot speeds and maneuverability on different terrains are measured in a series of tests. To measure basic locomotion abilities and sustained speeds, the robots are to traverse a prescribed course. The terrain types may be paved, unpaved (including vegetated), or a variant of abstracted, but repeatable, rubble-like terrain. The course may be a zig-zag pattern or a figure 8. For a zig-zag course, the test proctor notes the time it takes the robot to reach the end in one direction, and then proceed back to the origin. For a figure 8 course, the robot may be required to complete a given number of laps. A variant of these mobility tests is one that measures the ability of a robot to traverse confined spaces. In this test, step field pallets are inverted and placed over another set of pallets (see Fig. 8). This test measures the ability of robots to maneuver in very small spaces.

Special cases of mobility are tested using ramps and stairs. A pattern of way points is marked on a ramp (at a variable angle), which the robot is to follow on an inclined plane. Ability to do so and time to complete is noted for each angle, which is gradually increased until the robot may no longer accomplish this safely. For robots that are able to climb walls or move while inverted, the test can be extended to accommodate these configurations For the mobility on stairs, the ability of the robot to ascend and descend several flights of stairs of different steepness is measured. Whether the stairs have enclosing walls or just railings, as well as whether they have risers or are open, are among the variables.

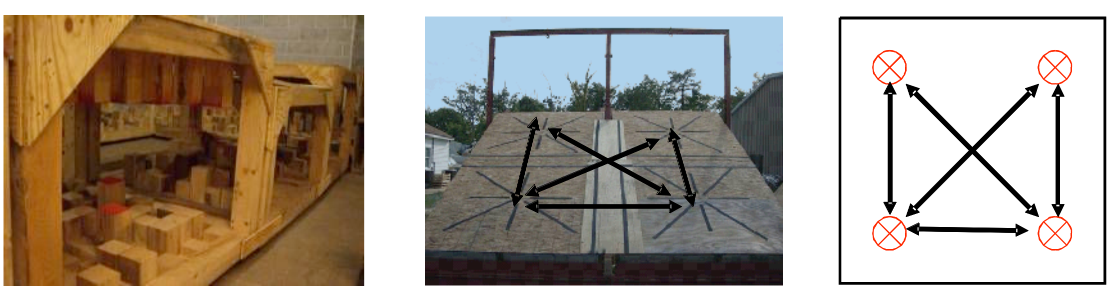


Figure 8: Mobility Tests. Left: Confined Space Cubes; Right: Inclined Plane with way point pattern

2.3.8. Aerial Stationkeeping

Since responders expressed an interest in aerial robots that are able to loiter, a test method that measures this capability has been devised. Figure 9 shows a version of this test, which entails having the robot move to specified locations in three dimensions, typically relative to a feature in the environment, and hover. While they hover, the operator is to read visual targets through the operator control station.

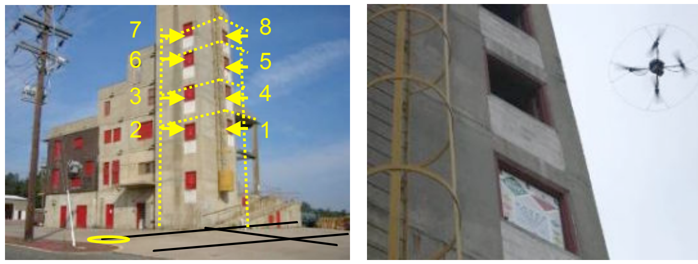


Figure 9: Aerial Stationkeeping Test Method. Robot is to follow the pattern indicated in yellow on the left image and the operator reads eye charts and hazardous materials labels at prescribed locations.

3. RESPONSE ROBOT EXERCISES

The robot manufacturers and researchers 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 USAR 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. In each instance, search scenarios are devised using facilities available at the training facility. NIST-built simulated victims are placed within the scenarios. These may exhibit several signs of life, including human form (typically partial), heat, sound, and movement. Robot providers are encouraged to work closely with responders to determine the best way to deploy robots into these scenarios. Operation of the robots by the responders by the end of the exercise is a key goal. This enables responders to familiarize themselves with the capabilities of the robots and to provide direct feedback to the robot manufacturers and researchers about strengths and weaknesses of robots applied to this domain. Three exercises have been held to date at FEMA USAR Task Force training facilities and are briefly described in this section.

In August of 2005, the first response robot exercise for this project was held in the desert training facility for Nevada Task Force 1. Fifteen ground (including throw-able, wall-climbing, confined space, complex terrain reconnaissance, and other sub-categories), 3 aerial, 2 aquatic, and 2 amphibious robots participated. FEMA Task Force members from the local team, as well as from several other areas of the country devised search scenarios and operated robots through them. At this time, there was one nascent test method - visual acuity - that was piloted.

The second exercise was hosted by Texas Task Force 1 at Disaster City® in April 2006.[9,10] More than 30 robots participated in 10 scenarios at this 21 hectare facility. The robot demographics spanned 16 models of ground vehicles, 2 models of wall climbers, 7 models of aerial vehicles including a helicopter, and 2 underwater vehicles. The scenarios included aerial survey of a rail accident using a variety of small and micro aerial vehicles (primarily fixed wing). Fig. 10 shows some of the scenarios. At this point, there were several emerging test methods available to be evaluated. A standards task group meeting was held after the exercise to gather input and test method critiques from the responders and vendors. At a separate meeting, the responders selected the three focus robot categories discussed above and provided an assessment of the robot maturity levels and relative strengths and weaknesses.

Maryland Task Force 1 hosted an exercise in August 2006[11] (Fig. 11). This event placed heavy emphasis on evaluation of the 11 draft test methods. This exercise included 24 models of ground robots, 2 models of wall climbers, and 2 models of aerial robots, which had to run through all relevant test methods before proceeding to the scenarios. In addition to the search and rescue training scenarios, there was an *ad hoc* experiment integrating portable radiation sensors with robots. Collaborating with NIST researchers who are working on radiation sensor standards, sensor vendors participated, providing sensors that were integrated with robots and deployed in a test method (directed perception) and in a scenario. Standards working group meetings for the communications, human-system interaction, and sensor teams were held, to capture lessons learned during the piloting of the test methods.

Figure 10: Two scenarios from the Texas exercise. Left: The passenger train derailment (the legs of a simulated victim are visible). Right: The House of Pancakes, containing reconfigurable structure collapse.

Figure 11: Scenarios from Montgomery County Fire Rescue Training Academy. Left: Section of the Rubble Pile. Right: School Bus where simulated victims and a radiation source were placed.

4. SUMMARY

Robots may become a valuable tool for emergency responders. DHS and NIST have been working closely with industry, academia, and other government agencies to define performance requirements and measures for robots applied to urban search and rescue. Through the use of exercises, in which responders work with robots in operationally relevant training scenarios, appropriate and potential deployments of various types of robots are becoming more clearly understood. This clarifies desirable operating conditions for the robots and permits the definition of test methods for evaluating robot performance in different categories. Working through the ASTM International standards body, consensus development and approval of test methods and usage guides for robots is progressing. Having known and measurable performance goals to strive for, robot developers can ensure that their products will meet the responders' needs and enable a new generation of rescue tools to be fielded.

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