Robots for Urban Search and Rescue
Performance Metrics and Standards

ASTM
E54.08.01
January 29, 2007
Scope Statement

• The scope of the task group is to specify a set of performance requirements, test methods, and associated standards for robot systems used in urban search and rescue applications. Emergency responders, pertinent technology developers, and interested government officials have defined these standards to provide an objective measure of robot performance for representative urban search and rescue applications. Results from such performance tests can be considered against specific purchaser/user performance objectives for envisioned applications.

– These standards specify a variety of performance criteria and associated test methods for urban search and rescue robots. Several representative applications of robots used in urban search and rescue have been considered in defining these test methods. These representative applications, although comprehensive, are certainly not complete.

– The standards developed by this task group will provide a means to ensure that a robot meets the performance requirements stated. Successful completion of the tests should not be construed as an ability to successfully operate in environments other than those specifically identified in the test methods.

– These standards do not address special applications outside the stated requirements, such as certain extreme weather conditions for example. To ensure performance for such applications, additional requirements need to be established along with associated standards.
US&R Robot Standards: The Big Picture

Requirements from FEMA Teams → Standard Test Methods → “Consumer’s Guide”

Responders Meet Robots Exercises

**Example Requirement:**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYSTEM ACUITY - NEAR</td>
<td>MILLIMETERS</td>
</tr>
</tbody>
</table>

**Description:** This requirement captures the responders’ expectations for real-time color 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. They suggested implementations include:

**Test Method:** TEST
<table>
<thead>
<tr>
<th>Requirements Category</th>
<th>Number of Individual Requirements</th>
<th>Category Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human-System Interaction</td>
<td>23</td>
<td>Pertaining to the human interaction and operator(s) control of the robot</td>
</tr>
<tr>
<td>Logistics</td>
<td>10</td>
<td>Related to the overall deployment procedures and constraints in place for disaster response</td>
</tr>
<tr>
<td>Operating Environment</td>
<td>6</td>
<td>Surroundings and conditions in which the operator and robot will have to operate</td>
</tr>
<tr>
<td>System</td>
<td></td>
<td>The main body of the robot, upon which additional components and capabilities may be added. This is the minimum set of capabilities (base platform)</td>
</tr>
<tr>
<td>Chassis</td>
<td>4</td>
<td>The main body of the robot, upon which additional components and capabilities may be added.</td>
</tr>
<tr>
<td>Communications</td>
<td>5</td>
<td>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</td>
</tr>
<tr>
<td>Mobility</td>
<td>12</td>
<td>The ability of the robot to negotiate and move around the environment</td>
</tr>
<tr>
<td>Payload</td>
<td>7</td>
<td>Any additional hardware that the robot carries and may either deploy or utilize in the course of the mission</td>
</tr>
<tr>
<td>Power</td>
<td>5</td>
<td>Energy source(s) for the chassis and all other components on board the robot</td>
</tr>
<tr>
<td>Sensing</td>
<td>32</td>
<td>Hardware and supporting software which sense the environment</td>
</tr>
<tr>
<td>Safety</td>
<td>1</td>
<td>Pertaining to safety of humans and potentially property in the vicinity of robots</td>
</tr>
</tbody>
</table>
## Deployment Situations

<table>
<thead>
<tr>
<th>Robot Category</th>
<th>Employment Role(s)</th>
<th>Deployment Method(s)</th>
<th>Tradeoffs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground: Peek Robots</td>
<td>Provide rapid audio visual situational awareness; provide rapid HAZMAT detection; data logging for subsequent team work</td>
<td>Tossed, chucked, thrown pneumatically, w/surgical tubing; marsupially deployed</td>
<td>Trade mobility, duration, sensing for increased expendability</td>
</tr>
<tr>
<td>Ground: Collapsed Structure--Stair/Floor climbing, map, spray, breach bots</td>
<td>Stairway &amp; upper floor situational awareness; mitigation activities; stay behind monitoring</td>
<td>Placed; lowered via tether; released: (kite) tethered LTAF launched F/W; released: balloon or F/W; placed: lowered via tether</td>
<td>Form factor for increased mobility, sensing, manipulation; mapping, spraying, variant; breach, variant</td>
</tr>
<tr>
<td>Backpacked; self driven; tethers deployed</td>
<td>Backpacked; self driven; marsupially deployed</td>
<td>Tethered; released: kite, balloon or F/W; placed: lowered via tether</td>
<td>Form factor for increased mobility, sensing, manipulation; mapping, spraying, variant; breach, variant</td>
</tr>
<tr>
<td>Trade mobility, duration, sensing for increased expendability</td>
<td>Trade mobility, duration, sensing for increased expendability</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Deployment Situations**

**Robot Category**

- **Ground: Peek Robots**
  - Provide rapid audio visual situational awareness; provide rapid HAZMAT detection; data logging for subsequent team work
  - Tossed, chucked, thrown pneumatically, w/surgical tubing; marsupially deployed
  - Trade mobility, duration, sensing for increased expendability

**Employment Roles(s)**

- Provide rapid audio visual situational awareness; provide rapid HAZMAT detection; data logging for subsequent team work
- Tossed, chucked, thrown pneumatically, w/surgical tubing; marsupially deployed

**Deployment Method(s)**

- Placed; lowered via tether; released: (kite) tethered LTAF launched F/W; released: balloon or F/W; placed: lowered via tether
- Backpacked; self driven; marsupially deployed
- Tethered; released: kite, balloon or F/W; placed: lowered via tether
- Form factor for increased mobility, sensing, manipulation; mapping, spraying, variant; breach, variant

**Tradeoffs**

- Form factor for increased mobility, sensing, manipulation; mapping, spraying, variant; breach, variant
- Trade mobility, duration, sensing for increased expendability
## Deployment Situations

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<thead>
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<th>Tradeoffs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ground:</strong> Non-Collapsed Structure – Wide Area Survey</td>
<td><strong>Employment Roles(s)</strong></td>
<td><strong>Deployment Method(s)</strong></td>
<td><strong>Tradeoffs</strong></td>
</tr>
<tr>
<td>Long range, human access stairway &amp; upper floor situational awareness; contaminated area survey; site assessment; victim identification; mitigation activities; stay behind monitoring</td>
<td>Backpacked; self driven; marsupially deployed</td>
<td>Water traverse; rapid current station keeping; object recovery</td>
<td>Experience form factor for increased mobility, sensing, manipulation; mapping variant; spraying variant; breaching variant</td>
</tr>
<tr>
<td>Ground: Collapsed Structure – Stair/Floor climbing, map, spray, breach bots</td>
<td>Human mobility for submerge inspection; leak detection; object recovery</td>
<td>Driven across water; lowered via tether</td>
<td>Form factor for trade ground mobility at cost of other performance</td>
</tr>
<tr>
<td><strong>Ground:</strong> Collapsed Structure – Breach bots</td>
<td>Backpacked; self driven; marsupially deployed</td>
<td>Water traverse; rapid current station keeping; object recovery</td>
<td>Form factor for increased mobility, sensing, manipulation; mapping variant; spraying variant; breaching variant</td>
</tr>
<tr>
<td><strong>Ground:</strong> Ground: Non-Collapsed Structure – Wide Area Survey</td>
<td>Human mobility for submerge inspection; leak detection; object recovery</td>
<td>Driven across water; lowered via tether</td>
<td>Form factor for increased mobility, sensing, manipulation; mapping variant; spraying variant; breaching variant</td>
</tr>
</tbody>
</table>

**Robot Category**

- **Ground:** Peek Robots
- **Ground:** Collapsed Structure – Stair/Floor climbing, map, spray, breach bots
- **Ground:** Collapsed Structure – Breach bots
- **Ground:** Non-Collapsed Structure – Wide Area Survey
- **Ground:** Confined Space – Retrieval Space
- **Ground:** Confined Space – Shape Shifting Bots
- **Ground:** Confined Space – Access Bots
- **Ground:** Wall
- **Ground:** Confined Space – Breaching bots
- **Ground:** Breaching bot

**Deployment Method(s)**

- Thrown
- Dropped into water
- Dropped into water; lowered via tether
- Deployed
- Marsupially deployed
- Backpacked
- Self driven
- Self driven; marsupially deployed
- Marsupially deployed
- Pneumatically
- Chucked
- Tossed
- Teamwork

**Tradeoffs**

- Form factor for increased mobility, sensing, manipulation; mapping variant; spraying variant; breaching variant
- Form factor for increased mobility, sensing, mapping, manipulators, sensing)
- Form factor for increased mobility, sensing, mapping, manipulators, sensing)
# Example Requirements

<table>
<thead>
<tr>
<th>Logistics</th>
<th>Cache packaging--Setup Time</th>
<th>Time from on-site delivery to operation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logistics</td>
<td>Cache packaging--Volume</td>
<td>Scale defined: 1=Pelican 1650 box; 3=Hardigg box checkable on commercial aircraft; 5=Rpack model 4048, 4039 with drop door</td>
</tr>
<tr>
<td>Logistics</td>
<td>MTBF</td>
<td>Operating hours.</td>
</tr>
<tr>
<td>Logistics</td>
<td>Field Maintenance: Spares and Supplies</td>
<td>Self sustaining for 72 hours.</td>
</tr>
<tr>
<td>Logistics</td>
<td>Field Maintenance: Tools</td>
<td>Scale Defined: 1=Requires special tools, 3=Simple tools (e.g., screwdriver), 5= No tools required</td>
</tr>
<tr>
<td>Logistics</td>
<td>Field Maintenance: Intervals</td>
<td>Mean time between routine maintenance.</td>
</tr>
<tr>
<td>Power</td>
<td>Power: Working Time</td>
<td>Must have sufficient power to operate for specified number of hours. Assumes one power charge. One out and back mission.</td>
</tr>
<tr>
<td>Power</td>
<td>Power: Runtime Indicator</td>
<td>Must be able to inform operator of remaining power level (percent).</td>
</tr>
<tr>
<td>Power</td>
<td>Power: Sustainment</td>
<td>Amount of time system must be able to operate in field before re-supply is needed.</td>
</tr>
<tr>
<td>Sensing</td>
<td>Video: Real time remote video system (Far)</td>
<td>Resolution of the image will be tested using visual acuity tests at given range. Limiting case could be assessment of structural integrity of the building. Image should be in color and resolution. Operator must read eye chart through entire imaging system</td>
</tr>
</tbody>
</table>
Integrating the Two Views

Robot Application 6

Logistics - Standard Test Method 1:
Resulting values must be within range (y3, y4)

Logistics - Standard Test Method 5:
Resulting values must be within range (y3, y4)

Sensing - Standard Test Method 3: Resulting values must be at least X3

Sensing - Standard Test Method 5, Protocol A:
Resulting values must be less than X4

Robot Application 1

Logistics - Standard Test Method 1:
Resulting values must be within range (y1, y2)

Sensing - Standard Test Method 3: Resulting values must be at least X

Sensing - Standard Test Method 5, Protocol B:
Resulting values must be less than X2

DHS Standard Test Methods for Performance and Use of US&R Robots!

Comms

Standard Test Method 1:

Chassis

Standard Test Method 1:

Sensing

Standard Test Method 1:

Standard Test Method 2:

Standard Test Method 11:
Working Groups within E54.08.01

- **Logistics** - Bob McKee, FEMA TF-1
- **Operating Environment** - Glen Keller, Allentown Fire Department
- **Communications** - Kate Remley, NIST
- **Human-System Interaction** - Sal Schipani, NIST
- **Sensing** - John Evans, John Evans LLC
- **Mobility** - Bill McBride, SwRI
- **Safety** - Mark Micire, UML and American Standard Robotics
- **Power** - TBD
- **Terminology** - Hui-Min Huang, NIST
Status

- 5 Work Items introduced; 2 balloted
  - Visual Acuity and Field of View
  - Terminology
    - Human-System Interaction: Usability
    - Logistics, Cache Packaging
    - Communications: Line of sight and Non-line of sight wireless

- Additional ones in queue
  - Mobility
  - Safety
Status

• 11 test methods (some covering multiple requirements) have been piloted at least once
• Today, we will have more in-depth discussions regarding
  – Sensing, Visual Acuity and Field of View
  – Communications, Wireless LOS and NLOS
### Requirements Addressed in Wave 1

<table>
<thead>
<tr>
<th>Requirement #‡</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>Logistics-Cache Packaging-Volume</td>
</tr>
<tr>
<td>34</td>
<td>Logistics-Cache Packaging-Weight</td>
</tr>
<tr>
<td>36</td>
<td>Logistics-Cache Packaging-Setup Time</td>
</tr>
<tr>
<td>96</td>
<td>Sensing-Vision System-Acuity, Near</td>
</tr>
<tr>
<td>99</td>
<td>Sensing-Vision System-Acuity, Far</td>
</tr>
<tr>
<td>101</td>
<td>Sensing-Vision System-Field of View</td>
</tr>
<tr>
<td>14</td>
<td>Human-System Interaction - Acceptable Usability</td>
</tr>
<tr>
<td>3</td>
<td>Chassis - Adjustable Illumination</td>
</tr>
<tr>
<td>6</td>
<td>Communications-Range NLOS</td>
</tr>
<tr>
<td>8</td>
<td>Communications-Range LOS</td>
</tr>
</tbody>
</table>

‡ References original requirements in Preliminary Report. See http://www.isd.mel.nist.gov/US&R_Robot_Standards

DHS Standard Test Methods for Performance and Use of US&R Robots
### Requirements Addressed in Wave 1

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<tbody>
<tr>
<td>59</td>
<td>Payload-Manipulation</td>
</tr>
<tr>
<td>65</td>
<td>Payload-Retrieval</td>
</tr>
<tr>
<td>60</td>
<td>Payload-Manipulation-Sensor Manipulation</td>
</tr>
<tr>
<td>45-47</td>
<td>Mobility-Locomotion-sustained speed</td>
</tr>
<tr>
<td>44</td>
<td>Mobility-Aerial-Stationkeeping</td>
</tr>
<tr>
<td>new</td>
<td>Mobility-Vertical Climbing</td>
</tr>
<tr>
<td>new</td>
<td>Mobility-Locomotion-Random Step Fields</td>
</tr>
<tr>
<td>new</td>
<td>Mobility-Stair Climbing</td>
</tr>
<tr>
<td>new</td>
<td>Mobility-Ramps</td>
</tr>
<tr>
<td>new</td>
<td>Mobility-Confined Space Access</td>
</tr>
<tr>
<td>new</td>
<td>Sensing-Vision System-Acuity, Aerial</td>
</tr>
</tbody>
</table>

*References original requirements in Preliminary Report. See http://www.isd.mel.nist.gov/US&R_Robot_Standards*
Responders Meet Robots Exercises

Refining Requirements
Understanding Operational Scenarios
Encouraging Information Flow: Manufacturers & End Users
Evaluating Draft Test Methods and Artifacts

1. FEMA Nevada TF1 Training Facility August 5-9, 2005
   - Diverse set of robots: ground, aerial, underwater, and amphibious brought by manufacturers and researchers
   - Responders operated robots in scenarios within rubble pile, freeway collapse, and using NIST test artifacts (simulated victims, mobility, vision, and other tests)
   - Responders and vendors critiqued draft test methods, artifacts

2. FEMA Texas TF1 Training Facility April 4-7, 2006
   - Disaster City - a 52 acre facility with diverse and rich training scenarios
   - Numerous small aerial vehicles participated
   - Initial piloting of Wave 1 test methods

3. FEMA Maryland TF1 Training Facility August 19-21, 2006
   - Piloting of test methods prior to submission to standards organization
   - Initial integration of radiation sensors and other hazmat sensors in test methods and operational scenarios

DHS Standard Test Methods for Performance and Use of US&R Robots
Participating Robots (thus far)

**WALL CLIMBERS**
- Vortex (suction)
- Nanomag (magnetic)

**AERIAL**
- Aerovironment Wasp
- ARA Nighthawk
- Aerovironment Raven
- BAI/L-3 Evolution
- Cyberdefense Cyberbug
- UAH Flying Bassett Helicopter
- AirRobot Helicopter
- ARACAR Tethered Blimp

**GROUND**
- Remington EyeBall (throwable, panning camera)
- Omnitech Toughbot (throwable, maneuverable)
- Inuktun VGTV (shape shifter), VGTV Extreme
- M–Bots Sneaky (low profile search)
- ARA LRV (stair climbing)
- Automatika DragonRunner (wheeled)
- WVHTC Bombot (wheeled)
- Exponent Marbot (wheeled)
- Robotic FX Negotiator (flipper, tracks)
- Toin University Iris
- Toin University Hibiscus
- Toin University Cpeha
- International Rescue Systems Soryu
- University Electro Communications Shinobi
- ASI Chaos (four flipper)
- Packbot Explorer (with infrared)
- Packbot Scout
- Packbot EOD (with manipulator)
- Mesa Robotics Marv (double track)
- Mesa Robotics Matilda
- Mesa Robotics Matilda EOD (with manipulator)
- INL ATRV-mini
- Foster–Miller Talon (with manipulator)
- Remotec Andros F6A (with manipulator)
- Remotec Andros Minim (with manipulator)
- Boz Robots Boz I

**WATER**
- VideoRay Sea Sprite
- Video Ray Pro III

**ROBOT SIMULATORS/ VISUALIZERS**
- Acroname Symonym
- USARSim
Participating FEMA Task Forces (thus far)

Arizona TF1
California TF1
California TF2
California TF3
California TF6
California TF7
California TF8
Colorado TF1
Indiana TF1
Massachusetts TF1
Maryland TF1
Missouri TF1
Nebraska TF1
Nevada TF1
New York TF1
Ohio TF1
Pennsylvania TF1
Tennessee TF1
Texas TF1
Utah F1
Virginia TF1
Virginia TF2
Washington TF1
Responder-Driven Scenarios
Responsers Meet Robots Exercises
Example

Logistics - Cache Packaging;
Logistics - Field Maintenance - Tools

DHS Standard Test Methods for Performance and Use of US&R Robots
## DHS Standard Test Methods for Performance and Use of US&R Robots

### Example

#### Payload – Manipulation - Sensor Manipulation

| DIRECTED PERCEPTION |
|---------------------|------------------|
| Robot:             | Operator:        |
| Skill Level:       |                  |
| NOVICE | INTERMEDIATE | EXPERT |
|                  |
| Start Time:       |                  |
| End Time:         |                  |
| Elapsed:          |                  |

**TARGETS (C)**
- O: ___of___
- E: ___of___
- AVG: ___ of ___
- T: ___ of ___

**TARGETS (L)**
- O: ___of___
- E: ___of___
- AVG: ___ of ___
- T: ___ of ___

**TARGETS (R)**
- O: ___of___
- E: ___of___
- AVG: ___ of ___
- T: ___ of ___

DISTANCE FROM CENTER STACK:

- 12.8 ft

PROCTOR:

NOTES: ___
Example Movie of Robot Performing Directed Perception Test Method
Partnering

• Within ASTM
  – F32 - Search and Rescue
  – F38 - Unmanned Aerial Systems
  – F41 - Unmanned Underwater Vehicles
  – E54.01 - CBRNE
  – E54.92 - Terminology

• With Other SDO’s
  – Leverage wherever possible
  – IEEE communications standards