



Designation: E3408/E3408M – 23

# Standard Test Method for Evaluating Ground Response Robot Capabilities: Dexterity: Linear Inspection<sup>1</sup>

This standard is issued under the fixed designation E3408/E3408M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## INTRODUCTION

The robotics community needs ways to measure whether a particular robot is capable of performing specific missions in complex, unstructured, and often hazardous environments. These missions require various combinations of elemental robot capabilities. Each capability can be represented as a test method with an associated apparatus to provide tangible challenges for various mission requirements and performance metrics to communicate results. These test methods can then be combined and sequenced to evaluate essential robot capabilities and remote operator proficiencies necessary to successfully perform intended missions.

The ASTM International Standards Committee on Homeland Security Applications (E54) specifies these standard test methods to facilitate comparisons across different testing locations and dates for diverse robot sizes and configurations. These standards support robot researchers, manufacturers, and user organizations in different ways. Researchers use the standards to understand mission requirements, encourage innovation, and demonstrate break-through capabilities. Manufacturers use the standards to evaluate design decisions, integrate emerging technologies, and harden systems. Emergency responders and soldiers use them to guide purchasing decisions, align deployment expectations, and focus training with standard measures of operator proficiency. Associated usage guides describe how these standards can be applied to support various objectives.

Several suites of standards address these elemental capabilities including maneuvering, mobility, dexterity, sensing, energy, communications, durability, proficiency, autonomy, and logistics. This standard is part of the *dexterity* suite of test methods.

## 1. Scope

1.1 This test method is intended for remotely operated ground robots operating in complex, unstructured, and often hazardous environments. It specifies the apparatuses, procedures, and performance metrics necessary to measure the capability of a robot to dexterously inspect objects of interest in the environment at various heights, depths, orientations, and confinement. This test method is one of several related *dexterity* tests that can be used to evaluate overall system capabilities.

1.2 The robotic system typically includes a remote operator in control of all functionality, so an onboard camera and remote operator display are typically required. Assistive features or autonomous behaviors may improve the effectiveness or efficiency of the overall system.

1.3 Different user communities can set their own thresholds of acceptable performance within this test method for various mission requirements.

1.4 *Performing Location*—This test method may be performed anywhere the specified apparatuses and environmental conditions can be implemented.

1.5 *Units*—The International System of Units (SI Units) and U.S. Customary Units (Imperial Units) are used throughout this test method. They are not mathematical conversions. Rather, they are approximate equivalents in each system of units to enable use of readily available materials in different countries. The differences between the stated dimensions in each system of units are insignificant for the purposes of comparing test method results, so each system of units is separately considered standard within this test method.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee E54 on Homeland Security Applications and is the direct responsibility of Subcommittee E54.09 on Response Robots.

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1.7 This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

**E2521 Terminology for Evaluating Response Robot Capabilities**

**E2566 Test Method for Evaluating Response Robot Sensing: Visual Acuity**

**E2592 Practice for Evaluating Response Robot Capabilities: Logistics: Packaging for Urban Search and Rescue Task Force Equipment Caches**

**E3349/E3349M Test Method for Evaluating Ground Robot Capabilities and Remote Operator Proficiency: Terrains: K-Rails**

## 3. Terminology

3.1 **Definitions**—The following terms are used in this test method and are defined in Terminology **E2521**: *abstain*, *administrator or test administrator*, *emergency response robot or response robot*, *fault condition*, *operator*, *operator station*, *remote control*, *repetition*, *robot*, *stepfield terrain element*, *teleoperation*, *test event or event*, *test form*, *test sponsor*, *test suite*, *testing target or target*, *testing task or task*, and *trial or test trial*.

### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *alcove*, *n*—a square area with walls on three of four sides whose sides are equal to the chosen apparatus clearance width (*W*); see Fig. 1.

3.2.2 *apparatus clearance width (W)*, *n*—a specification for the apparatus dimensions chosen from one of four possible measurements, based on the intended robot deployment environment:

(1) 240 cm ± 2.5 cm tolerance [96 in. ± 1 in. tolerance], such as open and outdoor public spaces;

(2) 120 cm ± 2.5 cm tolerance [48 in. ± 1 in. tolerance], such as indoor spaces in accessibility-compliant buildings;

(3) 60 cm ± 1.3 cm tolerance [24 in. ± 0.5 in. tolerance], residences and aisles of public transportation; or

(4) 30 cm ± 1.3 cm tolerance [12 in. ± 0.5 in. tolerance], cluttered indoor spaces, ductwork, and voids in collapsed structures.

3.2.2.1 **Discussion**—The measures for these scales are nominal and do not represent the measurement of the narrowest point in the apparatus through which the robot should pass. Consult Section 6 for the overall measurements and dimensions of the apparatus at each scale.

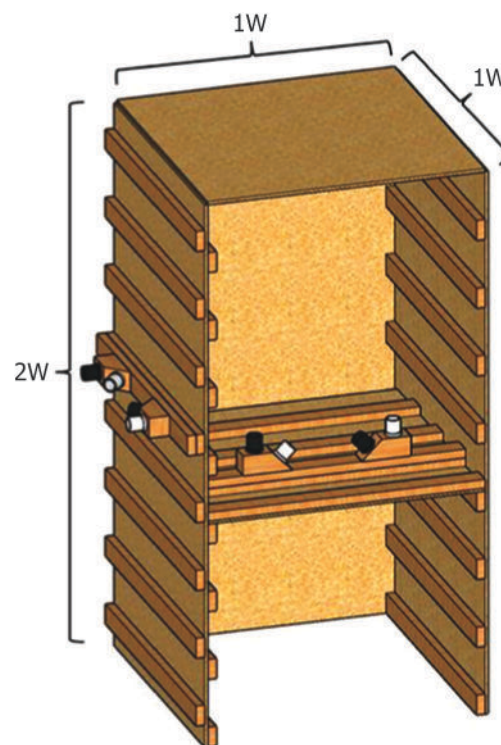


FIG. 1 Alcove Apparatus with a Linear Rail Mounted on the Outside Wall and a Linear Rail Mounted on Top of a Platform Inside of the Alcove

3.2.3 *diagonal rail*, *n*—a solid piece of dimensional lumber that is sized to fit horizontally inside a subfloor at a 45° angle to the direction of travel.

3.2.4 *Landolt Ring or Landolt C*, *n*—an optotype, or symbol, consisting of a black circular ring with a white gap or vice versa, both with specified sizes, as defined in Test Method **E2566**.

3.2.5 *linear rail*, *n*—a length of wood, plastic, or metal with four mounting points used to hold additional hardware to perform dexterity tasks; the two outermost points are each positioned normal to the rail and the two innermost points are each angled 45° to the rail.

3.2.5.1 **Discussion**—In this standard, the linear rail contains inspect tasks that consist of PVC pipes and visual acuity targets, as shown in Fig. 2. See Section 6 for more information.

3.2.6 *platform*, *n*—a flat square panel, whose sides measure one apparatus clearance width (*W*), that can hold a linear rail.

3.2.6.1 **Discussion**—See Section 6 for more information.

3.2.7 *subfloor*, *n*—an underlayment of Oriented Strand Board (OSB) or similar material with dimensional lumber borders used to affix multiple subfloors to one another and can contain apparatus elements such as terrains or obstacles.

3.2.8 *visual acuity target*, *n*—a printed graphic of nested Landolt C symbols of varying sizes and orientations. The orientation of each C is defined by the direction of the gap in the ring out from the center.

3.2.8.1 **Discussion**—This is the same type of artifact used in Test Method **E2566** – 17a. See Fig. 3.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

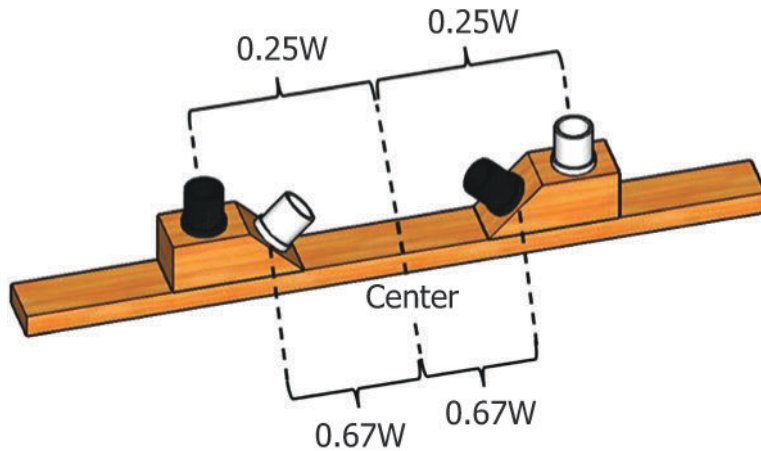


FIG. 2 Linear Rail with Inspect Tasks

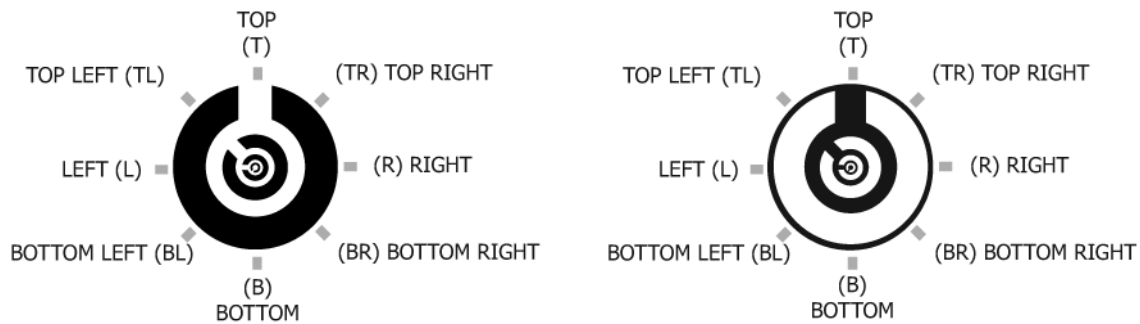


FIG. 3 Example Visual Acuity Targets and the Corresponding Ring Gap Orientations

#### 4. Summary of Test Method

4.1 This test method is performed by a remote operator who cannot see or hear the robot within the test apparatus. The robot traverses over a defined area of terrain and performs tasks on a linear rail. For a given test, a linear rail is positioned at a specified height, depth, orientation, and in an open or confined environment. Each of these variables (terrain, height, depth, orientation, and confinement) are to be selected by the test sponsor, likely with multiple tests of different combinations conducted in order to demonstrate a spread of performance. For example, the test sponsor may specify conditions that resemble target deployment scenarios (for example, reaching on top of a shelf) or allow for the robot vendor to select minimum, maximum, and median settings (for example, inspecting targets on a wall at the lowest, highest, and mid-point heights that robot is able to reach). Two test configurations are defined:

4.1.1 *Standard Apparatus*—The apparatus described in Section 6 are used for mounting the linear rail in various configurations of parameters including height, depth, orientation, and confinement.

4.1.2 *Embedded Scenario*—One or more linear rails are mounted into a real-world environment whose dimensions mimic that of the standard apparatus in one or more configurations of parameters for height, depth, orientation, and confinement.

4.2 In either configuration, the robot traverses into the test environment, crossing from the A-side to the B-side and then

onto the terrain; the test begins once the full body of the robot is contained on the terrain. The robot attempts to inspect all possible targets from the four available on the linear rail positioned in the apparatus. See Fig. 4.

4.3 This test evaluates linear dexterity, wherein all targets to be inspected are on linear rails which require varying degrees of freedom in order to be completed. The position (height or depth, or both), orientation (viewable from the front, below, or above), and confinement (open, rectangular, or square confinement) of the linear rails is varied in order to represent increasingly complex robotic dexterity capabilities (for example, longer manipulators in order to reach high or deep set targets, additional degrees of freedom in order to inspect targets at varying orientations using the robot's camera, confined space for constrained dexterity evaluation). Dexterity tests can be performed in a standard apparatus (which features diagonal rail terrain) or as part of an embedded scenario (using the available terrain of the scenario or standard terrain elements that are added to the environment, such as diagonal rails or ramps, or combinations thereof).

4.4 Based on the selected apparatus clearance width ( $W$ ), apparatus dimensional settings are defined such as the size of the alcove, the dimensions of the linear rails, and the size of the visual acuity targets; see Section 6 and Table 1 for more details.

4.5 For this test method, each linear rail contains four visual acuity targets mounted recessed inside of PVC pipes (see Fig. 2) such that they are only viewable

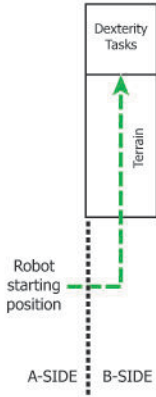
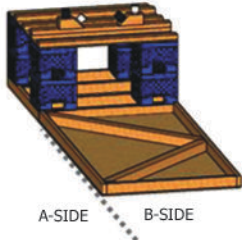
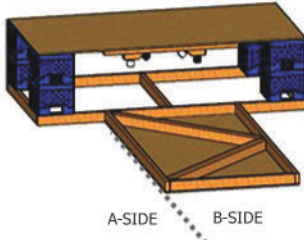
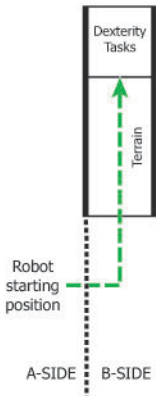
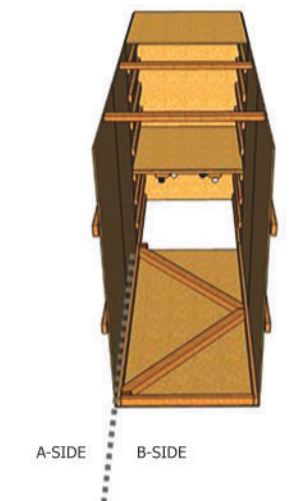
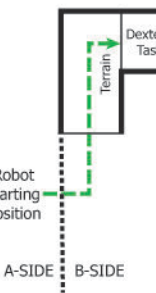
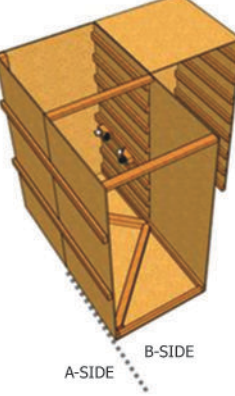
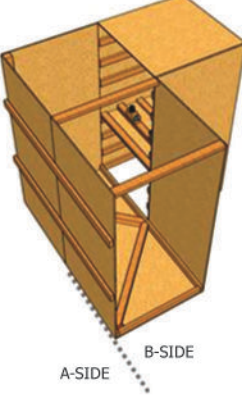
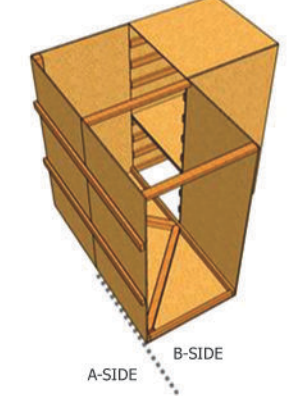
|                         | Layout                                                                              | Viewable from front                                                                 | Viewable from above                                                                  | Viewable from below                                                                   |
|-------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Open                    |    |    |    |    |
| Rectangular confinement |   |   |   |   |
| Square confinement      |  |  |  |  |

FIG. 4 Layout of the Standard Apparatuses in Various Configurations

camera is approximately aligned/centered with the target. Based on test sponsor specifications, the height, depth, orientation, and confinement of the linear rail is positioned in the apparatus from a set of predefined settings as follows (additional detail is provided in Section 6):

4.5.1 *Height*—Based on the selected apparatus clearance width, starting from 0/ground level and increasing by 0.25W (for example, 0.25W, 0.5W, 0.75W, etc.).

4.5.2 *Orientation*—Set to be either viewable from the front (mounted on the wall), viewable from above (mounted on top

**TABLE 1 All Possible Combinations of Test Settings**

NOTE 1—“Etc.” implies that the values continue increasing as high or deep as needed based on test sponsor specifications.

| Orientation             | Height Range                                 | Confinement                  | Depth Range                 |
|-------------------------|----------------------------------------------|------------------------------|-----------------------------|
| Viewable from the front | 0/ground level, 0.25W, 0.5W, 0.75W, 1W, etc. | Open, rectangular, or square | 0                           |
| Viewable from above     | 0/ground level, 0.25W, 0.5W, 0.75W, 1W, etc. | Open, rectangular, or square | 0, 0.25W, 0.5W, 0.75W, etc. |
| Viewable from below     | 0.25W, 0.5W, 0.75W, 1W, 1.25W, etc.          | Open, rectangular, or square | 0, 0.25W, 0.5W, 0.75W, etc. |

of a shelf), or viewable from below (mounted underneath a shelf; only applicable when confined).

**4.5.3 Depth**—Based on the selected apparatus clearance width, starting from 0 and increasing by 0.25W (for example, 0.25W, 0.5W, 0.75W, etc.).

**4.5.4 Confinement**—The artifact is mounted in open space or in confined space (rectangular or square confinement).

**4.6** See Fig. 4 for examples of each type of dexterity test. Some combinations of test settings are not possible due to dimensional limitations of the apparatus and real-world applicability (for example, an artifact oriented to be viewable from below cannot be mounted at ground level); see Table 1 for all possible combinations of test settings.

**4.7** To inspect the visual acuity targets, the operator shall use the robot’s camera to identify the targets that are viewable by the robot’s camera, moving the robot and manipulator(s) as necessary. Some targets may not be able to be inspected due to limitations in the robot’s capability such as its camera resolution, reach of its inspection camera, or its manipulator degrees of freedom. To successfully inspect a visual acuity target, the operator must first be able to see the entire black or white ring inside of the colored ring (outside of the Landolt Cs) on the OCU display of the robot’s camera (see Fig. 5 for examples of correct and incorrect alignment). The operator then must correctly discern the orientation of the gap in the Landolt Cs relative to the top of the target (marked by a number/letter), for example, top, top-right, bottom, etc., doing so down to the smallest Landolt C that they are able to.

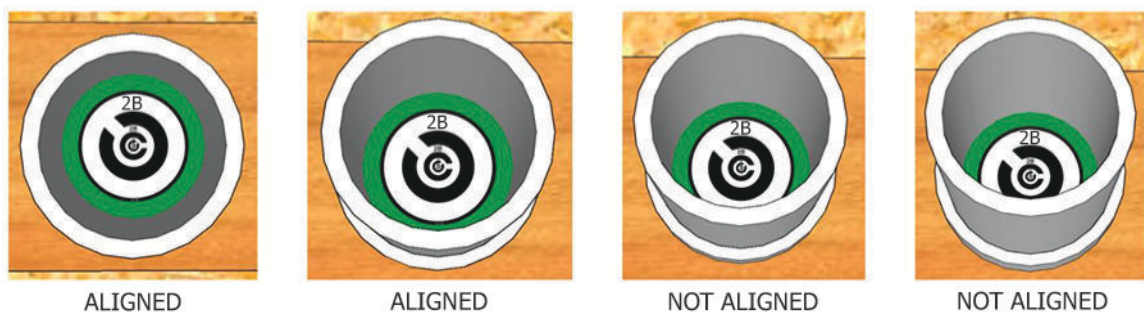
**4.8** Two sizes of visual acuity targets (V) are available, identified by the diameter of the outer edge of the black ring (inside of the colored ring): 4 cm [1.5 in.] and 2.1 cm [0.8 in.]. Target size is determined based on the selected apparatus clearance width (W); more information is provided in Section 6. The corresponding levels of acuity for the available Landolt C symbols for each target size are shown in Table 2. The Landolt C symbols are labeled C1 (largest) through C5 (smallest); note that the corresponding acuity for some Landolt C symbols (that is, the size of the opening in the C) are marked as “N/A” due to limitations in printing the targets, which prevents some of the smallest Landolt Cs from being printed legibly. The orientations observed by the operator shall be compared to an answer key after the test is complete in order to determine the level of acuity achieved.

**4.9** Outside of the alcove is terrain where the robot is positioned while performing the dexterity task. For the standard apparatus, the K-Rails terrain (specified in Test Method E3349/E3349M) is used (see Fig. 6). For the embedded scenario, the terrain that already exists in the environment can be used (for example, carpet, concrete).

**4.10** Metrics are recorded for each test conducted and across a set of tests (see Section 9 for more information):

**4.10.1 Per Test**—For each test, metrics recorded include (in order of priority): completeness (number of visual acuity targets inspected), acuity (visual acuity level achieved per inspected target and average across all targets), and time (time to complete the test). The heights, depths, orientations (viewable from the front, above, or below), and confinement (open or confined) of the linear rails, as well as the terrain, shall also be recorded in the test report along with the metrics.

**4.10.2 Across Tests**—Additional metrics are reported across a set of tests. These metrics are only applicable to tests that evaluate dexterity at the same orientation (viewable from the front, above, or below), in the same type of confinement (open or confined), and the same terrain, but with variable heights and depths. For example, two tests using standard apparatus test configurations with linear rails oriented to be viewable from the front, in rectangular confinement, set at two different heights for the lowest and highest position achievable. Across a set of tests, metrics recorded include: minimum height, maximum height, height range, minimum depth, maximum depth, depth range, and acuity (average across all targets from



NOTE 1—Correct alignment is defined as when the operator is able to see the entire black or white outer ring outside of the Landolt Cs (inside of the colored ring), as shown in the left and middle image.

**FIG. 5 Examples of Correct and Incorrect Alignment**

**TABLE 2 Levels of Acuity Achievable for Each Target Size**

NOTE 1—N/A indicates Landolt Cs that cannot be printed legibly, meaning they cannot be inspected.

| Landolt C | Visual acuity target size (V) |                   |
|-----------|-------------------------------|-------------------|
|           | 4 cm [1.5 in.]                | 2.1 cm [0.8 in.]  |
| C1        | 5.0 mm [0.2 in.]              | 2.6 mm [0.1 in.]  |
| C2        | 2.0 mm [0.08 in.]             | 1.0 mm [0.04 in.] |
| C3        | 0.8 mm [0.03 in.]             | 0.4 mm [0.02 in.] |
| C4        | 0.3 mm [0.01 in.]             | N/A               |
| C5        | N/A                           | N/A               |

all tests). Only a subset of these metrics may be applicable depending on the tests that are run. For example, any depth metrics are only applicable to tests that use the viewable from above or below orientations.

4.11 Test completion is defined as when the operator determines that they have attempted to inspect all targets possible (for example, if the robot is not able to physically reach a high target, then it may not be possible to inspect that target) and announces this to the test administrator. The test may also end prematurely if the maximum test time (set by the test sponsor) is exceeded. Setting a maximum test time as criteria for a successful test is optional.

#### 4.12 Potential faults include:

4.12.1 Any contact by the robot with the apparatus that requires adjustment or repair to return the apparatus to the initial condition. If a linear rail or the visual acuity targets, or both, are moved or damaged significantly by the robot during testing, the operator will be instructed to pause robot operation while the test administrator repairs the apparatus and notes the fault on the report form. The test timer will continue to count time while the repair is made. If part of the apparatus (for example, walls, terrain) is moved or damaged significantly by the robot during testing, the operator will be instructed to pause robot operation while the test administrator repairs the apparatus and notes the fault on the report form. The test timer will be paused until the repairs have been made. If necessary, the robot shall be extracted from the test apparatus in order for the repair to be made, and then returned to the position where the fault occurred to continue testing.

4.12.2 Any visual, audible, or physical interaction that assists either the robot or the remote operator. For example, if the robot has a failure that would require it to be manually reset (for example, if the robot's tracks fall off, then the operator would have to enter the test apparatus to repair them), this would constitute a fault. However, if the robot has a failure that can be repaired while the operator remains remote (for example, if the robot's software has to be reset and this can be performed without the operator entering the test apparatus), this would not constitute a fault.

## 5. Significance and Use

5.1 This test method is part of an overall suite of related test methods that provide repeatable measures of human-system interaction capability including robotic system mobility, dexterity, inspection, remote operator proficiency, and situational awareness. In particular, the operator control unit

(OCU) design and interface features may impact the operator's ability to perform movement and inspection tasks with the robot.

5.2 The test apparatuses are low cost and easy to fabricate so they can be widely replicated. The procedure is also simple to conduct. This eases comparisons across various testing locations, dates, and times to determine best-in-class systems and operators.

5.3 *Evaluation*—This test method can be used in a controlled environment to measure baseline capabilities. It can also be embedded into operational training scenarios to measure degradation due to uncontrolled variables in lighting, weather, radio communications, GPS accuracy, etc.

5.4 *Procurement*—This test method can be used to identify inherent capability trade-offs in systems, make informed purchasing decisions, and verify performance during acceptance testing. This aligns requirement specifications and user expectations with existing capability limits.

5.5 *Training*—This test method can be used to focus operator training, as a repeatable practice task or as an embedded task within training scenarios. The resulting measures of remote operator proficiency enable tracking of perishable skills over time, along with comparisons of performance across squads, regions, or national averages.

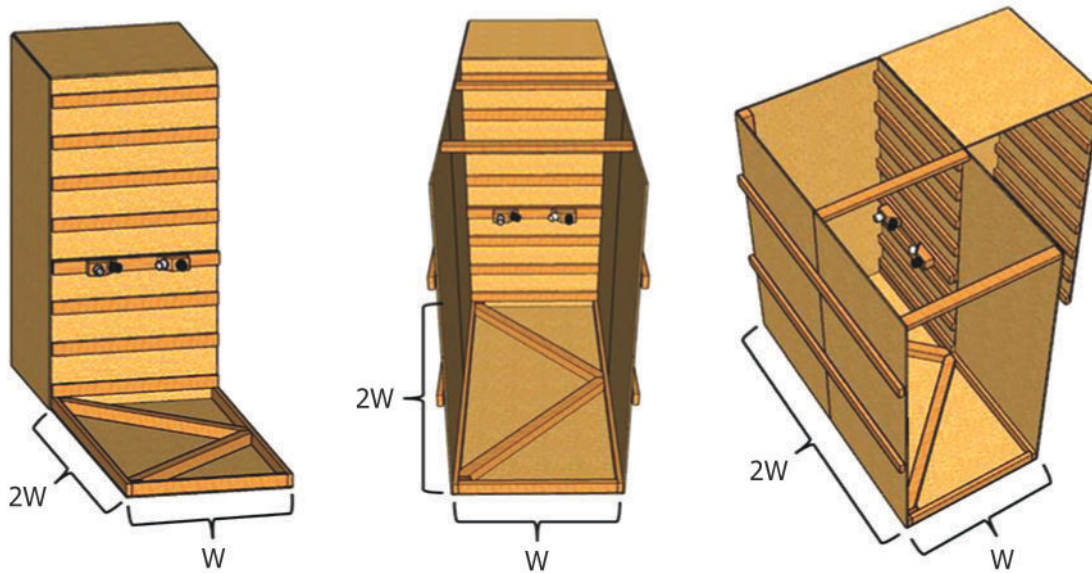
5.6 *Innovation*—This test method can be used to inspire technical innovation, demonstrate break-through capabilities, and measure the reliability of systems performing specific tasks within an overall mission sequence. Combining or sequencing multiple test methods can guide manufacturers toward implementing the combinations of capabilities necessary to perform essential mission tasks.

## 6. Apparatus

6.1 This section specifies the apparatuses used in both the *standard apparatus* and *embedded scenario* configurations. For both configurations, the dimensional characteristics specified for the linear rails and visual acuity targets shall be followed. For the *standard apparatus*, all other dimensional characteristics specified in this section shall be used when fabricating the apparatuses in order to run the test. For the *embedded scenario*, all other dimensional characteristics (except for the terrain) shall be used to characterize the real-world environment used, with some variance allowed.

6.2 The *standard apparatus* consists of diagonal rails set into subfloors to form the terrain, an alcove, a platform, confinement walls, and a linear rail. The alcove and confinement walls are only required if dexterity in confinement is being evaluated. If dexterity in the open configuration is being evaluated, then only a wall panel is needed; however, the outside wall of an alcove can be used if desired.

6.3 The main apparatus dimension to consider is the apparatus clearance width (W) for the robot, which can be set to 120 cm  $\pm$  2.5 cm tolerance [48 in.  $\pm$  1 in. tolerance], 60 cm  $\pm$  1.3 cm tolerance [24 in.  $\pm$  0.5 in. tolerance], or 30 cm  $\pm$  1.3 cm tolerance [12 in.  $\pm$  0.5 in. tolerance]. The dimension chosen for W should represent the



NOTE 1—The K-Rails terrain used in the standard apparatus configurations shown with the linear rails oriented to be viewable from the front. The terrain is positioned outside of the alcove adjacent to the wall in the open configuration (left), outside of the alcove adjacent to the wall with two additional walls in the rectangular confinement condition (middle), and adjacent to the alcove with three additional walls in the square confinement configuration (right).

FIG. 6 K-Rails Terrain Used in the Standard Apparatus

environment or be based on the size of the robot (that is, the robot shall be able to maneuver within the selected dimensions of the apparatus), or both. All apparatus dimensions scale proportionally with  $1W$ ; the width of the terrain is  $1W$ , the length of the terrain is  $2W$ , the position of the linear rails is selected from a set of predefined heights and depths based on  $W$  (starting from 0/ground level and increasing by  $0.25W$ ; for example,  $0.25W$ ,  $0.5W$ ,  $0.75W$ , etc.), the area of the alcove and the platform are both  $1W$  by  $1W$ , and the position of the targets on the linear rails are based on  $W$  (the two outer targets normal to the rail are each  $0.25W$  distance from the center of the rail and the two inner targets angled  $45^\circ$  to the rail are each  $0.67W$  distance from the center of the rail). The diagonal rail height ( $H$ ) for the terrain, the size of the visual acuity targets ( $V$ ), and the length ( $L$ ) and width ( $T$ ) of the pipes used on the linear rails also scales with  $W$ . See Table 3 for all apparatus dimensions at

each apparatus clearance width ( $W$ ). See Figs. 7-11 for dimensional diagrams of the apparatus.

**6.4 Visual Acuity Targets**—Visual acuity targets are mounted at the bottom of the PVC pipes. The dimensions of the PVC pipes ( $T$  and  $L$ ) and visual acuity targets ( $V$ ) change based on the value of  $W$  (see Table 3). The visual acuity targets consist of Landolt C symbols, which are used as described in Test Method E2566 (see Fig. 12). Each symbol consists of a ring with an outer diameter equal to five times the ring thickness displayed on a background of inverted color compared to the ring, to maximize contrast. The ring contains a gap with parallel edges equal to the ring thickness. The size of the gap represents the smallest discernible feature when measuring visual acuity and is reported as the metric. The gap appears in one of eight radial orientations around the ring at  $45^\circ$  intervals.

TABLE 3 Apparatus Dimensions Based on Apparatus Clearance Width

| Intended Deployment Environment                                     | Apparatus Clearance Width ( $W$ ) | Terrain Width ( $1W$ ) | Terrain Length ( $2W$ ) | Height/Depth Increments ( $0.25W$ ) | Alcove Area ( $1W$ by $1W$ )           | Linear Rail Outer Target Distance from Center ( $0.25W$ ) | Linear Rail Inner Target Distance from Center ( $0.67W$ ) | Diagonal Rail Height ( $H$ ) | Visual Acuity Targets ( $V$ ) | Target Pipes Length ( $L$ ) | Target Pipes Width ( $T$ ) |
|---------------------------------------------------------------------|-----------------------------------|------------------------|-------------------------|-------------------------------------|----------------------------------------|-----------------------------------------------------------|-----------------------------------------------------------|------------------------------|-------------------------------|-----------------------------|----------------------------|
| Open: Rooms<br>Confined: Hallways, bathrooms, and closets           | 120 cm<br>[48 in.]                | 120 cm<br>[48 in.]     | 240 cm<br>[96 in.]      | 30 cm<br>[12 in.]                   | 120 cm by 120 cm<br>[48 in. by 48 in.] | 30 cm<br>[12 in.]                                         | 20 cm<br>[8 in.]                                          | 10 cm<br>[4 in.]             | 4 cm<br>[1.5 in.]             | 10 cm<br>[4 in.]            | 5 cm<br>[2 in.]            |
| Open: Public transportation<br>Confined: Cluttered interiors        | 60 cm<br>[24 in.]                 | 60 cm<br>[24 in.]      | 120 cm<br>[48 in.]      | 15 cm<br>[6 in.]                    | 60 cm by 60 cm<br>[24 in. by 24 in.]   | 15 cm<br>[6 in.]                                          | 10 cm<br>[4 in.]                                          | 5 cm<br>[2 in.]              | 2.1 cm<br>[0.8 in.]           | 5 cm<br>[2 in.]             | 2.5 cm<br>[1 in.]          |
| Open: Constrained spaces<br>Confined: Voids in collapsed structures | 30 cm<br>[12 in.]                 | 30 cm<br>[12 in.]      | 60 cm<br>[24 in.]       | 7.5 cm<br>[3 in.]                   | 30 cm by 30 cm<br>[12 in. by 12 in.]   | 7.5 cm<br>[3 in.]                                         | 5 cm<br>[2 in.]                                           | 2.5 cm<br>[1 in.]            | 2.1 cm<br>[0.8 in.]           | 2.5 cm<br>[1 in.]           | 2.5 cm<br>[1 in.]          |

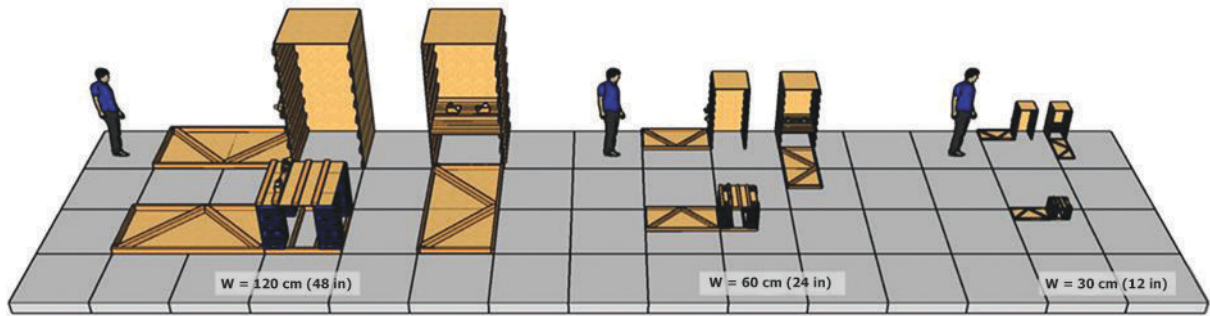


FIG. 7 Standard Apparatus Shown at Each Apparatus Clearance Width (W) in Various Example Configurations

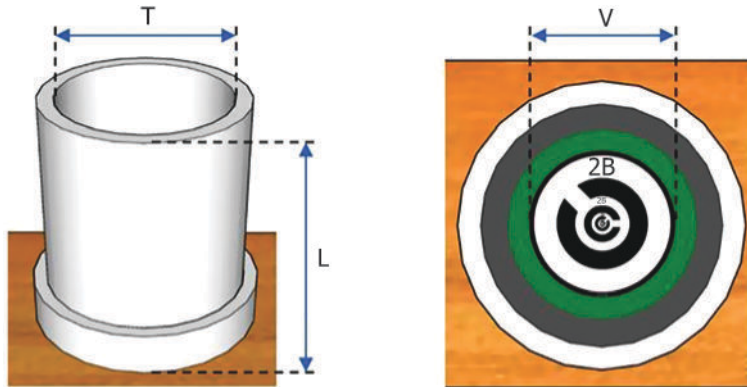


FIG. 8 Dimensional Layout of the Pipes and Visual Acuity Targets on the Linear Rail

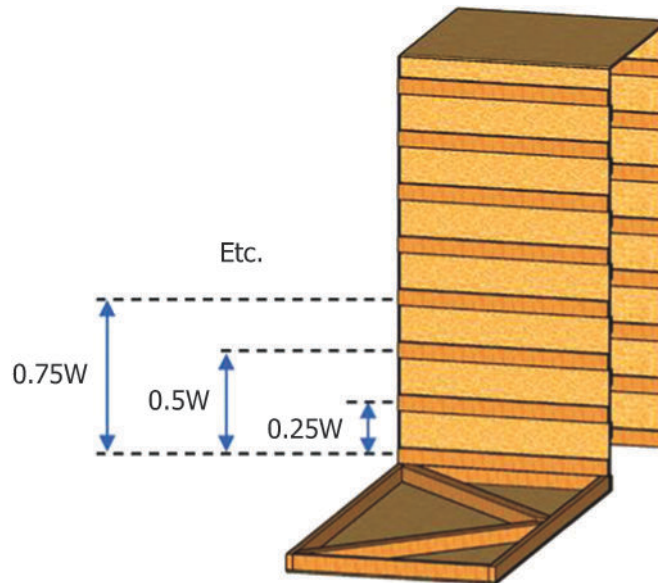


FIG. 9 Height Settings Outside of the Alcove in the Open Configuration for Linear Rails Oriented to be Viewable from the Front

Identifying gap orientations of Landolt C symbols with gaps of a particular size is related to the ability to resolve visual identification of objects of that size. Five Landolt C symbols are arranged in a concentric manner, with the largest 50 % of the diameter of the overall target and each successive symbol is 40 % of the diameter of the previous. The smallest optotype that can be resolved with the desired level of statistical significance represents the measured visual acuity of the system in the context of this test. The visual acuity targets used

in this test method can be downloaded.<sup>3</sup> Note that all targets must be printed at actual size and shall not be scaled; otherwise, the associated acuity measures for each target will be impacted. The report form provided in Section 10 includes an answer key to use when comparing the orientations the operator discerns during test performance.

<sup>3</sup> Link:

<https://drive.google.com/file/d/1sUsX4rlm24LqcEe37BnSvY8vYjDn0w7d0t/view>

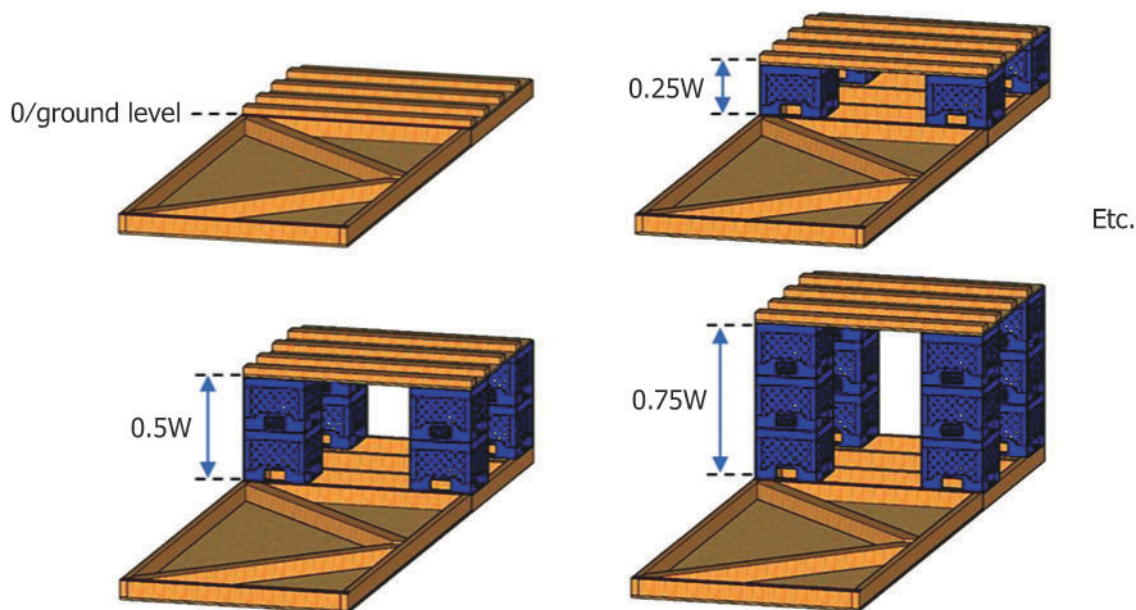


FIG. 10 Platform Height Settings for Linear Rails Oriented to be Viewable from Above in the Open Configuration in an Example Apparatus Using Plastic Crates

**6.5 Linear Rail**—The linear rail is a length of wood, plastic, or metal measuring between  $0.75W$  and  $1W$  with four PVC pipes mounted to it; the two outer PVC pipes (one black and one white) are mounted normal to the rail and each is  $0.25W$  distance from the center of the rail, while the two inner PVC (one black and one white) pipes are mounted  $45^\circ$  to the rail and each is  $0.67W$  distance from the center of the rail. Two pieces of wood, plastic, or metal, each with one  $45^\circ$  angled end, are attached to the rail; each piece has two PVC pipes mounted to it (one black and one white, one normal to the piece/rail and one angled  $45^\circ$  to the piece/rail). See Fig. 13 for a dimensional layout of the linear rail.

**6.6 Platform**—The platform is a panel of OSB or similar material measuring  $1W$  wide by  $1W$  long with four  $1W$  length rails made of wood, plastic, or metal mounted on top of the panel with each rail  $0.25W$  apart from each other as shown in Fig. 14. In the open configuration, the platform can be elevated using a variety of methods, including on top of crates, a table, and a stack of pallets. Regardless of the elevation method used, the robot shall not position any part of itself underneath the elevated platform.

**6.7 Alcove**—The alcove apparatus with a platform inside is used to hold a linear rail when oriented to be viewable from above or below (rectangular or square confinement); the exterior wall of the alcove can also be used to hold a linear rail when oriented to be viewable from the front (open configuration). The walls of the alcove are made out of OSB panels or similar material measuring  $1W$  wide by  $2W$  tall. A series of rails made out of wood, plastic, or metal are attached to the two left and right interior wall panels and on one exterior wall. The rails in the interior side walls are used to mount the platform. The rails on the exterior wall are used to mount a linear rail. See Fig. 15 for the dimensional layout of the alcove. Note that all rails shown in Fig. 15 are not required to be fabricated; for

example, one may choose to position rails in  $0.5W$  increments rather than the  $0.25W$  increments shown in order to reduce fabrication costs. Additionally, similar alternative mounting methods to those shown in Fig. 14 can be used instead of the fabricated alcove apparatus, so long as they conform to the specified dimensional layout.

**6.8 Confinement Boundaries**—The rectangular and square confinement configurations use boundaries to confine the movement of the robot while performing the dexterity tasks. Physical or virtual boundaries can be used in these conditions. If virtual, then the test administrator shall ensure that no part of the robot exceeds the horizontal space allotted for each configuration during task performance. If physical, the confinement boundaries are fabricated out of wood panels made of OSB panels or similar material measuring  $1W$  wide by  $2W$  tall, connected together using horizontal wooden posts on the outside of the apparatus and vertical wooden posts on the inside of the apparatus to form corners with other wall panels. Wooden posts measuring either  $1W$  or  $2W$  in length are used to connect wall panels on either side of the apparatus along the top for structural stability. See Fig. 16.

NOTE 1—If shipping containers are used as the apparatus, the metal walls of the containers are not required to be covered with OSB panels, unless so desired.

**6.9 K-rail Terrain Panel**—For the standard apparatus configuration, the K-Rails terrain (from Test Method E3349/E3349M) is used. It consists of diagonal rails, which are wooden rails measuring  $10\text{ cm}$  by  $10\text{ cm}$  [ $4\text{ in.}$  by  $4\text{ in.}$ ] on the ground. They present obstacles to the robot that must be negotiated while traversing through the apparatus. The K-rail terrain panel consists of a rectangular subfloor measuring  $2W$  by  $1W$  with two diagonal rails. The surface of the subfloor is constructed of OSB or similar material with dimensional lumber along the outside edges. The diagonal rails are made of