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Standard Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Terrains: Crossing Pitch/Roll Ramps[1]

This standard is issued under the fixed designation E2827; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 *Purpose:*

1.1.1 The purpose of this test method, as a part of a suite of mobility test methods, is to quantitatively evaluate a teleoperated ground robot's (see Terminology E2521) capability of traversing complex terrain composed of crossing pitch/roll ramps in confined areas.

1.1.2 Robots shall possess a certain set of mobility capabilities, including negotiating complex terrains, to suit critical operations such as emergency responses. A part of the complexity is that the environments often pose constraints to robotic mobility to various degrees. This test method specifies apparatuses to standardize a confined areas terrain that is composed of crossing pitch/roll ramps and that notionally represents types of terrains containing moderate discontinuities, existent in emergency response and other environments. This test method also specifies procedures and metrics to standardize testing using the apparatus.

1.1.3 The test apparatuses are scalable to provide a range of lateral dimensions to constrain the robotic mobility during task performance. Fig. 1 shows three apparatus sizes to test robots intended for different emergency response scenarios.

1.1.4 Emergency ground robots shall be able to handle many types of obstacles and terrains. The required mobility capabilities include traversing gaps, hurdles, stairs, slopes, various types of floor surfaces or terrains, and confined passageways. Yet additional mobility requirements include sustained speeds and towing capabilities. Standard test methods are required to evaluate whether candidate robots meet these requirements.

1.1.5 ASTM Task Group E54.08.01 on Robotics specifies a mobility test suite, which consists of a set of test methods for evaluating these mobility capability requirements. This confined area terrain with crossing pitch/roll ramps is a part of the mobility test suite. Fig. 2 shows examples of other confined area terrains, along with the traversing paths. The apparatuses associated with the test methods challenge specific robot capabilities in repeatable ways to facilitate comparison of different robot models as well as particular configurations of similar robot models.

1.1.6 The test methods quantify elemental mobility capabilities necessary for ground robots intended for emergency response applications. As such, users of this standard can use either the entire suite or a subset based on their particular performance requirements. Users are also allowed to weight particular test methods or particular metrics within a test method differently based on their specific performance requirements. The testing results should collectively represent an emergency response ground robot's overall mobility performance as required. These performance data can be used to guide procurement specifications and acceptance testing for robots intended for emergency response applications.

NOTE 1—Additional test methods within the suite are anticipated to be developed to address additional or advanced robotic mobility capability requirements, including newly identified requirements and even for new application domains.

1.2 *Performing Location*—This test method shall be performed in a testing laboratory or the field where the specified apparatus and environmental conditions are implemented.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are not precise mathematical conversions to inch-pound units. They are close approximate equivalents for the purpose of specifying material dimensions or quantities that are readily available to avoid excessive fabrication costs of test apparatuses while maintaining repeatability and reproducibility of the test method results. These values given in parentheses are provided for information only and are not considered standard.

1.4 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

[1] 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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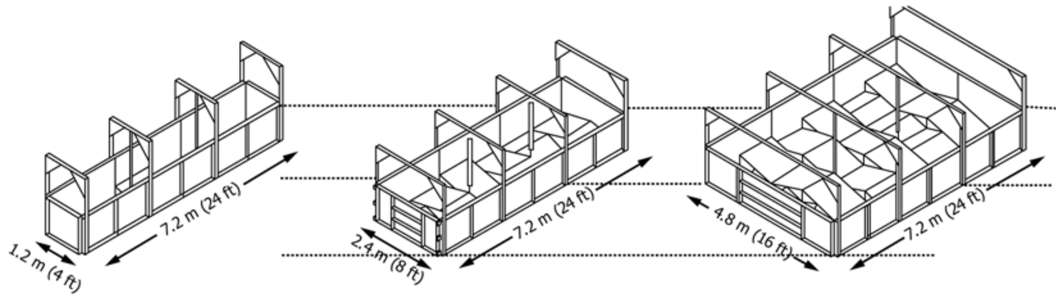

FIG. 1 Mobility: Confined Area Terrains: Crossing Pitch/Roll Ramps Apparatuses

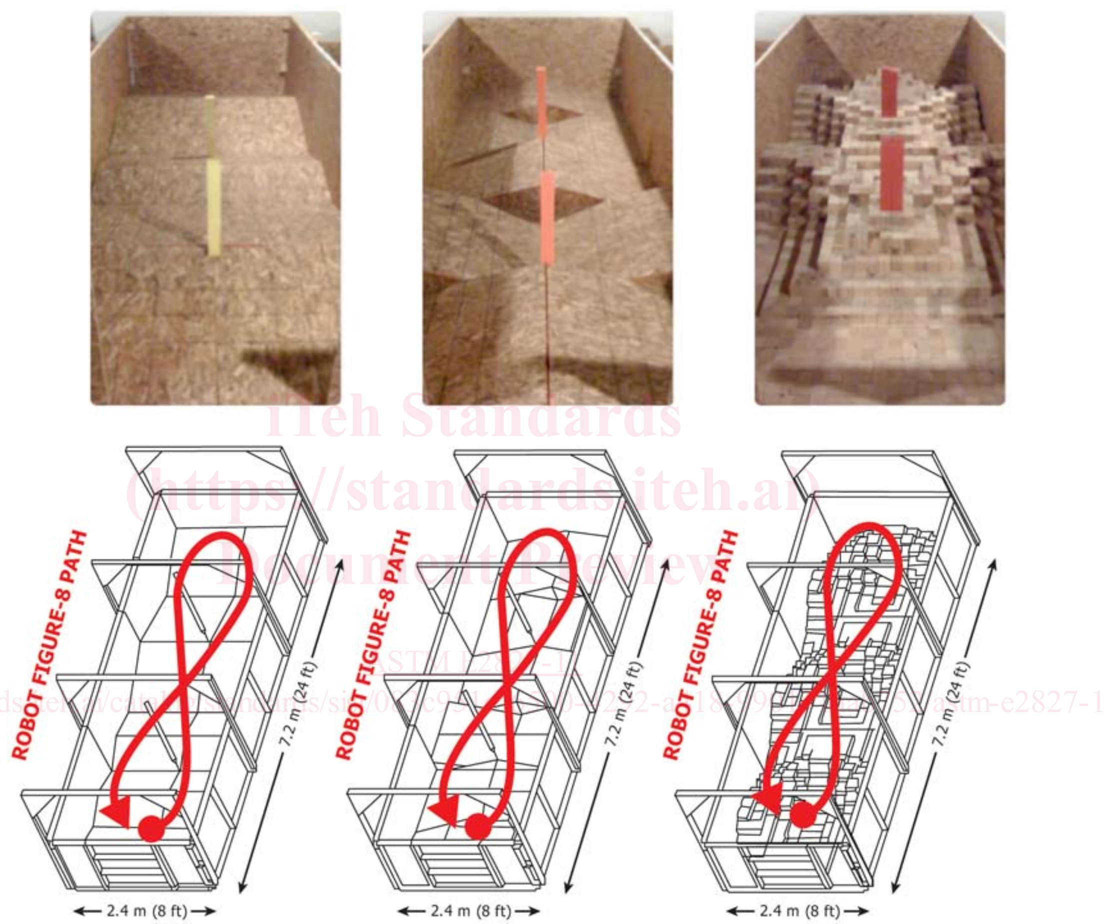

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FIG. 2 Three Confined Area Terrain Apparatuses in the Mobility Test Suite with Increasing Complexity; The Continuous Pitch/Roll Ramps Terrain is Shown on the Left. The Crossing Pitch/Roll Ramps Terrain is Shown at the Center. The Symmetric Stepfields Terrain is Shown on the Right.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E2521 Terminology for Evaluating Response Robot Capabilities

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

2.2 *Additional Documents:*

National Response Framework, U.S. Department of Homeland Security[3]

NIST Special Publication 1011–I–2.0 Autonomy Levels for Unmanned Systems ALFUS Framework Volume 1: Terminology, Version 2.0[4]

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

[3] Available from Federal Emergency Management Agency (FEMA), P.O. Box 10055, Hyattsville, MD 20782-8055, http://www.fema.gov/emergency/nrf/.

[4] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov/customcf/get_pdf.cfm?pub_id=824705.

3. Terminology

3.1 Terminology E2521 lists additional definitions relevant to this test method.

3.2 *Definitions:*

3.2.1 *abstain, v*—prior to starting a particular test method, the robot manufacturer or designated operator shall choose to enter the test or abstain. Any abstention shall be granted before the test begins. The test form shall be clearly marked as such, indicating that the manufacturer acknowledges the omission of the performance data while the test method was available at the test time.

3.2.1.1 *Discussion*—Abstentions may occur when the robot configuration is neither designed nor equipped to perform the tasks as specified in the test method. Practice within the test apparatus prior to testing should allow for establishing the applicability of the test method for the given robot.

3.2.2 *administrator, n*—person who conducts the test—The administrator shall ensure the readiness of the apparatus, the test form, and any required measuring devices such as stopwatch and light meter; the administrator shall ensure that the specified or required environmental conditions are met; the administrator shall notify the operator when the safety belay is available and ensure that the operator has either decided not to use it or assigned a person to handle it properly; and the administrator shall call the operator to start and end the test and record the performance data and any notable observations during the test.

3.2.3 *emergency response robot, or response robot, n*—a robot deployed to perform operational tasks in an emergency response situation.

3.2.3.1 *Discussion*—A response robot is a deployable device intended to perform operational tasks at operational tempos during emergency responses. It is designed to serve as an extension of the operator for gaining improved remote situational awareness and for projecting her/his intent through the equipped capabilities. It is designed to reduce risk to the operator while improving effectiveness and efficiency of the mission. The desired features of a response robot include: rapid deployment; remote operation from an appropriate standoff distance; mobility in complex environments; sufficient hardening against harsh environments; reliable and field serviceable; durable or cost effectively disposable, or both; and equipped with operational safeguards.

3.2.4 *fault condition, n*—during the performance of the task(s) as specified by the test method, a certain condition may occur that renders the task execution to be failed and such a condition is called a fault condition. Fault conditions result in a loss of credit for the partially completed repetition. The test time continues until the operator determines that she/he can not continue and notifies the administrator. The administrator shall, then, pause the test time and add a time-stamped note on the test form indicating the reason for the fault condition.

3.2.4.1 *Discussion*—Fault conditions include robotic system malfunction, such as de- tracking, and task execution problems, such as excessive deviation from a specified path or failure to recognize a target.

3.2.5 *full-ramp terrain element, n*—1.2 by 1.2 m (4 by 4 ft.) surface ramp with 15° slope using solid wood support posts with angle cuts. The material used to build these elements shall be strong enough to allow the participating robots to execute the testing tasks.

3.2.5.1 *Discussion*—The material that is typically used to build these elements, oriented strand board (OSB) is a commonly available construction material. The frictional characteristics of OSB resemble that of dust covered concrete and other human improved flooring surfaces, often encountered in emergency responses. Solid wood posts with 10- by 10-cm (4- by 4-in.) cross-section dimensions typically support the ramped surface.

3.2.5.2 *Discussion*—Similar elements like this type are used, sometimes mixed and assembled in different configurations, to create various levels of complexities for robotic functions such as orientation and traction.

3.2.6 *half-ramp terrain element, n*—0.6- by 1.2-m (2- by 4-ft) surface with the shorter dimension ramped at 15° using solid wood posts with angle cuts. The material used to build these elements shall be strong enough to allow the participating robots to execute the allow tasks.

3.2.6.1 *Discussion*—See the discussions under **full-ramp terrain element**.

3.2.7 *human-scale, adj*—used to indicate that the objects, terrains, or tasks specified in this test method are in a scale consistent with the environments and structures typically negotiated by humans, although possibly compromised or collapsed enough to limit human access. Also, that the response robots considered in this context are in a volumetric and weight scale appropriate for operation within these environments.

3.2.7.1 *Discussion*—No precise size and weight ranges are specified for this term. The test apparatus constrains the environment in which the tasks are performed. Such constraints, in turn, limit the types of robots to be considered applicable to emergency response operations.

3.2.8 *operator, n*—person who controls the robot to perform the tasks as specified in the test method; she/he shall ensure the readiness of all the applicable subsystems of the robot; she/he through a designated second shall be responsible for the use of a safety belay; and she/he shall also determine whether to abstain the test.

3.2.9 *operator station, n*—apparatus for hosting the operator and her/his operator control unit (OCU, see ALFUS Framework Volume I: Terminology) to teleoperate (see Terminology E2521) the robot; the operator station shall be positioned in such a manner so as to insulate the operator from the sights and sounds generated at the test apparatuses.

3.2.10 *repetition, n*—robot's completion of the task as specified in the test method and readiness for repeating the same task when required.

3.2.10.1 *Discussion*—In a traversing task, the entire mobility mechanism shall be behind the START point before the traverse and shall pass the END point to complete a repetition. A test method can specify returning to the START point to complete the task. Multiple repetitions, performed in the same test condition, may be used to establish the robot performance

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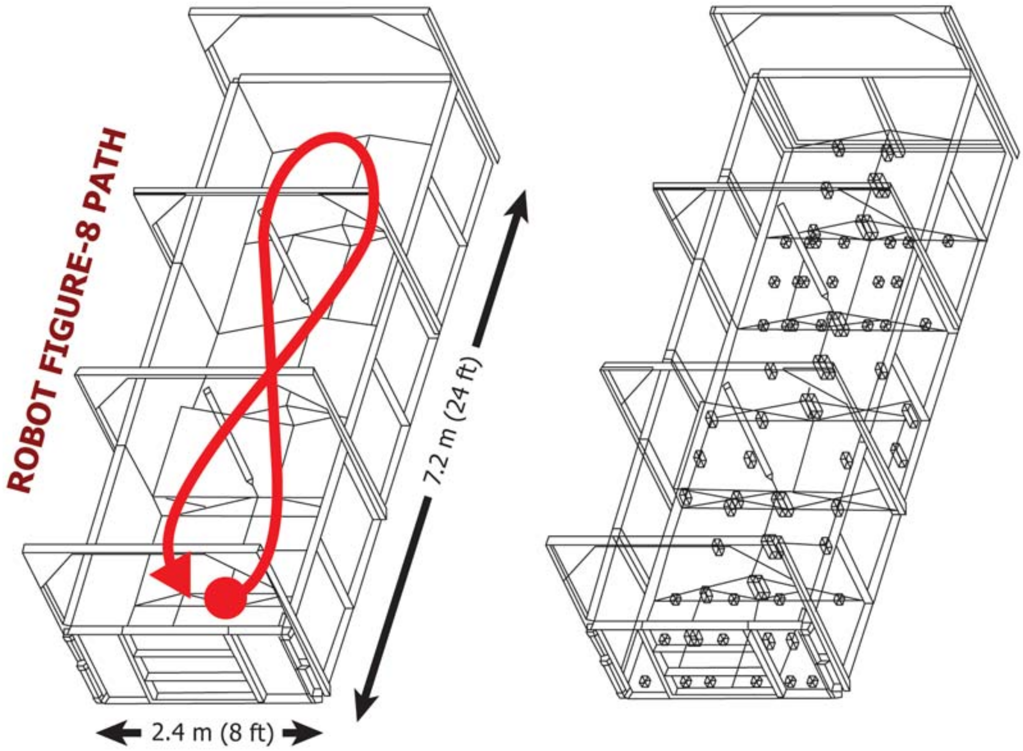

FIG. 3 Mobility: Confined Area Terrains: Crossing Pitch/Roll Ramps Apparatuses (Perspective View)

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of a particular test method to a certain degree of statistical significance as specified by the testing sponsor.

3.2.11 *test event or event, n*—a set of testing activities that are planned and organized by the test sponsor and to be held at designated test site(s).

3.2.12 *test form, n*—form corresponding to a test method that contains fields for recording the testing results and the associated information.

3.2.13 *test sponsor, n*—organization or individual that commissions a particular test event and receives the corresponding test results.

3.2.14 *test suite, n*—designed collection of test methods that are used, collectively, to evaluate the performance of a robot's particular subsystem or functionality, including mobility, manipulation, sensors, energy/power, communications, human-robot interaction (HRI), logistics, safety, and aerial or aquatic maneuvering.

3.2.15 *testing task, or task, n*—a set of activities specified in a test method for testing robots and the operators to perform in order for the performance to be evaluated according to the corresponding metric(s). A test method may specify multiple tasks.

4. Summary of Test Method

4.1 The task for this test method, crossing pitch/roll ramp terrain traversing, is defined as the robot traversing from the START point along the specified path which ends back at the START point, thus enabling continuous repetitions. The default path shall be a figure-eight, also known as a continuous "S," around two pylons installed in the test course as described in Section 6. The START and END points are the same, located beside the first pylon upon entering the gate. See Fig. 3 for an illustration.

4.2 The robot's traversing capability of this type of terrain is defined as the robot's ability to complete the task and the associated effective speed. Further, the test sponsor can specify the statistical reliability and confidence levels of such a capability and, thus, dictate the number of successful task performance repetitions that is required. In such a case, the average effective speed shall be used, instead, as the robot's capability.

4.3 Teleoperation shall be used from the operator station specified by the administrator to test the robots using an OCU provided by the operator. The operator station shall be positioned and implemented in such a manner so as to insulate the operator from the sights and sounds generated at the test apparatus.

4.4 The operator is allowed to practice before the test. She/he is also allowed to abstain from the test before it is started. Once the test begins, there shall be no verbal communication between the operator and the administrator regarding the performance of a test repetition other than instructions on when to start and notifications of faults and any safety related conditions. The operator shall have the full responsibility to determine whether and when the robot has completed a repetition and notify the administrator accordingly. However, it is the administrator's authority to judge the completeness of the repetition.

NOTE 2—Practice within the test apparatus could help establish the applicability of the robot for the given test method. It allows the operator to gain familiarity with the standard apparatus and environmental conditions. It also helps the test administrator to establish the initial apparatus setting for the test when applicable.

4.5 The test sponsor has the authority to select the size for the specified confined area apparatus. The test sponsor also has the authority to select the test methods that constitute the test event, to select one or more test site(s) at which the test methods are implemented, to determine the corresponding statistical reliability and confidence levels of the results for each of the test methods, and to establish the participation rules including the testing schedules and the test environmental conditions.

5. Significance and Use

5.1 A main purpose of using robots in emergency response operations is to enhance the safety and effectiveness of emergency responders operating in hazardous or inaccessible environments. The testing results of the candidate robot shall describe, in a statistically significant way, how reliably the robot is able to traverse the specified types of terrains and thus provide emergency responders sufficiently high levels of confidence to determine the applicability of the robot.

5.2 This test method addresses robot performance requirements expressed by emergency responders and representatives from other interested organizations. The performance data captured within this test method are indicative of the testing robot's capabilities. Having available a roster of successfully tested robots with associated performance data to guide procurement and deployment decisions for emergency responders is consistent with the guideline of, "Governments at all levels have a responsibility to develop detailed, robust, all-hazards response plans," as stated National Response Framework.

5.3 This test apparatus is scalable to constrain robot maneuverability during task performance for a range of robot sizes in confined areas associated with emergency response operations. Variants of the apparatus provide minimum lateral clearance of 2.4 m (8 ft) for robots expected to operate around environments such as cluttered city streets, parking lots, and building lobbies; minimum lateral clearance of 1.2 m (4 ft) for robots expected to operate in and around environments such as large buildings, stairwells, and urban sidewalks; minimum lateral clearance of 0.6 m (2 ft) for robots expected to operate within environments such as dwellings and work spaces, buses and airplanes, and semi-collapsed structures; minimum lateral clearance of less than 0.6 m (2 ft) with a minimum vertical clearance adjustable from 0.6 m (2 ft) to 10 cm (4 in.) for robots expected to deploy through breeches and operate within sub-human size confined spaces voids in collapsed structures.

5.4 The standard apparatus is specified to be easily fabricated to facilitate self-evaluation by robot developers and provide practice tasks for emergency responders that exercise robot actuators, sensors, and operator interfaces. The standard apparatus can also be used to support operator training and establish operator proficiency.

5.5 Although the test method was developed first for emergency response robots, it may be applicable to other operational domains.

6. Apparatus

6.1 The test apparatuses specify three scaled sizes of confined areas fully covered with full-ramp and half-ramp terrain elements. The three sizes are 7.2 m (24 ft) long by 4.8 m (16 ft), 2.4 m (8 ft), or 1.2 m (4ft) wide. Two pylons define the figure-eight path. They are posted at the 2.4- and 4.8-m (8- and 16-ft) distances from either end and along the centerline between the two sidewalls. The ramps are paired up and connected at different heights to form ridges or valleys with discontinuities, thus they are called "crossing" ramps. The resulting topology causes jaggedly recurring orientation complexities for robots. The terrain is surrounded with a 1.2 m (4 ft) tall wall. A gate opens in the front to allow robot entry. See Figs. 3 and 4. Each repetition for the figure eight path is nominally considered to be 15 m long. Section 5.3 specifies the scalability of the apparatuses.

NOTE 3—The material that is typically used to build the test apparatuses, OSB, is a commonly available construction material. The frictional characteristics of OSB resemble that of dust covered concrete and other improved flooring surfaces often encountered in emergency responses.

6.2 Various test conditions such as apparatus surface types and conditions, including wetness and friction levels, temperature, types of lighting, smoke, humidity, and rain shall be facilitated when the test sponsor requires. For example, for a test run in the dark environment, a light meter shall be used to read 0.1 lux or less. The darkness shall be re-measured when the lighting condition might have changed. The actual readings of these conditions should be recorded on the test form.

NOTE 4—The testing apparatus can be implemented in a standard International Standards Organization (ISO) specified shipping container, in which some of the testing conditions can be furnished. To achieve the specified darkness, first turn off all the lighting sources inside and entirely cover the entrance with light-blocking drapes. The darkness is specified as 0.1 lux due to the implementation cost concerns for the apparatuses and due to the fact that robotic cameras are less sensitive than human eyes, such that any darkness below 0.1 lux would not make a difference in the cameras' functioning. It is recognized that the environments in real applications may be darker than the specified test condition.

6.3 A stopwatch shall be provided to measure the timing performance.

7. Hazards

7.1 Besides 1.4 that addresses the human safety and health concerns, users of the standard shall also address the equipment preservation concerns and human-robot coexistence concerns.

NOTE 5—The environmental conditions, such as high or low temperatures, excessive moisture, and rough terrains can be stressful to the humans, can damage the robotic components, or can cause unexpected robotic motions.

8. Calibration and Standardization

8.1 The robot configuration as tested shall be described in detail on the test form, including all subsystems and components and their respective features and functionalities. The configuration shall be subjected to all the applicable test methods as determined by the test sponsor. Any variation in the configuration shall cause the resulting robot variant to be

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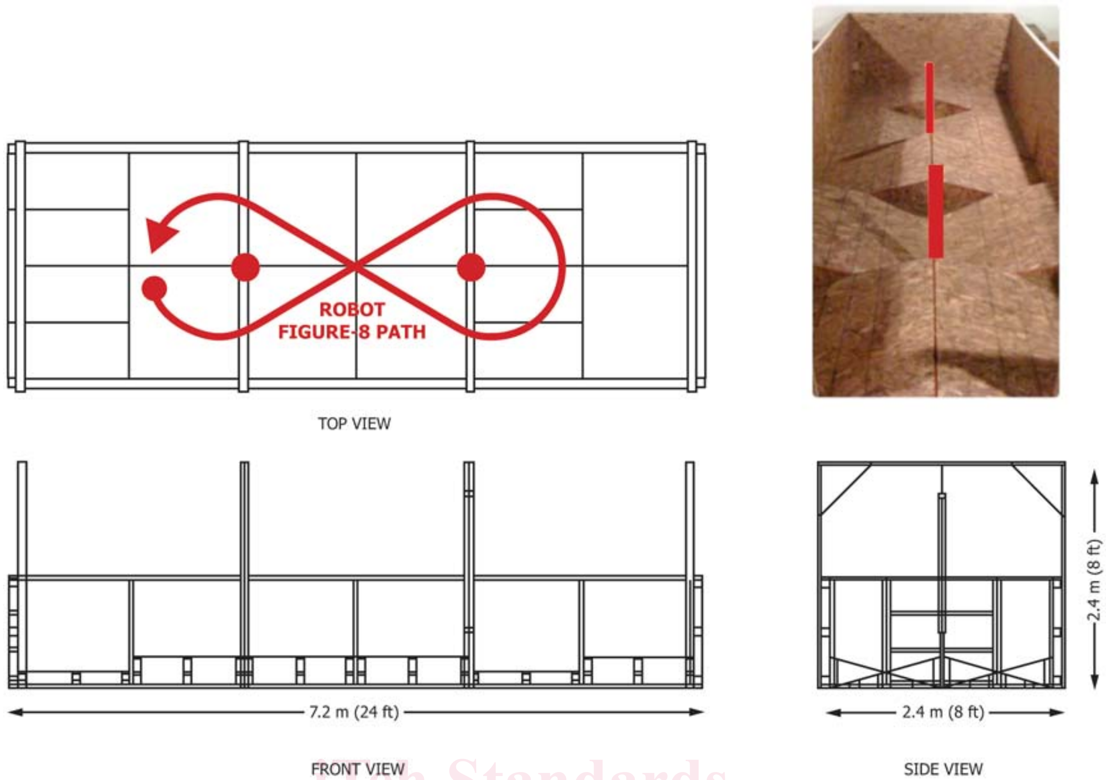

FIG. 4 Mobility: Confined Area Terrains: Crossing Pitch/Roll Ramps Apparatuses (Projection View)

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retested across all those applicable test methods to provide a consistent and comprehensive representation of the performance. Practice E2592 shall be used to record the robotic configuration.

8.2 Once a robot begins to be teleoperated to execute a specified task, the task shall be performed for the specified number of repetitions through completion without leaving the apparatus. During the process, any human physical intervention with the robot, such as replenishing the energy/power source or adjusting, maintaining, or repairing any component shall be designated as a fault condition.

8.3 The metric for this test method is the completeness of the prescribed path successfully traversed for the specified number of continuous repetitions.

8.4 In addition, the elapsed time for successfully traversing the path, or effective speed in meters per minute, is a performance proficiency index reflecting the combination of the robot's capability and efficiency, the OCU's ease of use, and the operator's skill level. Therefore, this temporal aspect is a part of the test and the results shall be recorded on the test form.

NOTE 6—The term "effective" is used because the speed is calculated based on the designed length of the path and not on the actual path of the traverses, which can deviate from the designed path.

8.5 Although the metric is based on teleoperation, autonomous behaviors are allowed as long as the testing procedure is followed, with the associated effects reflected in the testing scores. See ALFUS Framework Volume I: Terminology for the definition of autonomy.

8.6 The test sponsor has the authority to specify the lighting condition and other environmental variables, which can affect the test results. All environmental settings shall be noted on the test form.

8.7 A robot's reliability (R) of performing the specified task at a particular apparatus setting and the associated confidence (C) shall be established. The required R and C values dictate the required number of successful repetitions and the allowed number of failures during the test. With a given set of the R and C values, more successes will be needed when more failures are allowed. A test sponsor has the authority to specify the R and C values for her/his testing purposes, otherwise she/he can elect to use the default values for this standard. The factors to be considered in determining the values are mission requirements, consistency with the operating environments, ease of performing the required number of repetitions, and testing costs such as time and personnel. To meet the statistical significance established by the standards committee, which is 80 % reliability (probability of success) with 85 % confidence at any given setting of a test apparatus, the number of failures (incomplete repetitions or the occurrence of the fault conditions) in the specified set of repetitions shall be no more than the following:

zero failures in 10 repetitions
one failure in 20 repetitions
three failures in 30 repetitions
four failures in 40 repetitions
six failures in 50 repetitions
eight failures in 60 repetitions