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# Standard Test Method for Evaluating Emergency Response Robot Capabilities: Radio Communication:Communications Line-of-Sight Range[1]

This standard is issued under the fixed designation E2854;E2854/E2854M; 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.

## 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 communications suite of test methods.

## 1. Scope

1.1 *Purpose:* This test method is intended for remotely operated ground robots using radio communications to transmit real-time data between a robot and its remote operator interface. This test method measures the maximum line-of-sight radio communications distance at which a robot can maintain omnidirectional steering, speed control, precise stopping, visual acuity, and other functionality. This test method is one of several related radio communication tests that can be used to evaluate overall system capabilities.

1.1.1 The purpose of this test method, as a part of a suite of radio communication test methods, is to quantitatively evaluate a teleoperated robot's (see Terminology E2521) capability to perform maneuvering and inspection tasks in a line-of-sight environment.

[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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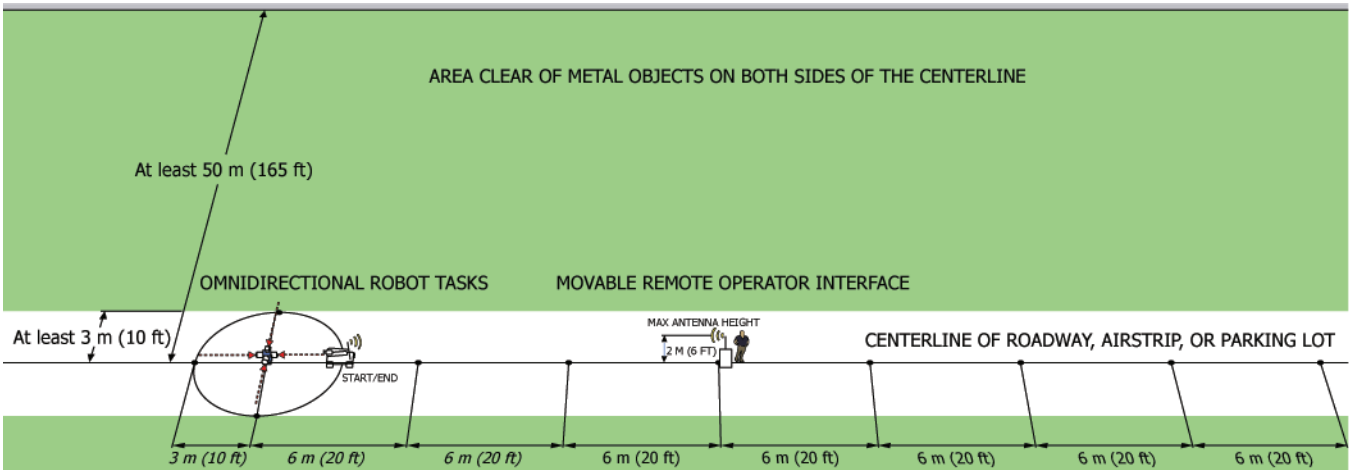



Left: The line-of-sight range test method uses an airstrip or paved road with robot test stations placed every 100 m (330 ft) along the centerline. Right: Robot test stations are prototyped with targets on the barrels for visual inspection tasks and circular paths for maneuvering tasks.Overview of the test site showing a roadway, airstrip, or parking lot with a centerline and measured incremental distances between the omnidirectional robot tasks and a movable remote operator interface.

**FIG. 1 Test Fabrication at An Air StripOverview of the Test Site**

1.1.2 Robots shall possess a certain set of radio communication capabilities, including performing maneuvering and inspection tasks in a line-of-sight environment, to suit critical operations for emergency responses. The capability for a robot to perform these types of tasks in unobstructed areas down range is critical for emergency response operations. This test method specifies a standard set of apparatuses, procedures, and metrics to evaluate the robot/operator capabilities for performing these tasks.

1.1.3 Emergency response robots shall be able to operate remotely using the equipped radios in line-of-sight (LOS) environments, in non-line-of-sight (NLOS) environments, and for signal penetration through such impediments as buildings, rubbles, and tunnels. Additional capabilities include operating in the presence of electromagnetic interference and providing link security and data logging. Standard test methods are required to evaluate whether candidate robots meet these requirements.

1.1.4 ASTM E54.08.01 Task Group on Robotics specifies a radio communication test suite, which consists of a set of test methods for evaluating these communication capabilities. This line-of-sight range test method is a part of the radio communication test suite. 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.



1.1.5 This test method establishes procedures, apparatuses, and metrics for specifying and testing the capability of radio (wireless) links used between the operator station and the testing robot in a line-of-sight environment. These links include the command and control channel(s) and video, audio, and other sensor data telemetry.

1.1.6 This test method is intended to apply to ground based robotic systems and small unmanned aerial systems (sUAS) capable of hovering to perform maneuvering and inspection tasks down range for emergency response applications.

1.1.7 This test method specifies an apparatus that is an essentially clear radio frequency channel for testing. Fig. 1 provides an illustration.

NOTE 1—Frequency coordination and interoperability are not addressed in this standard. These issues should be resolved by the affected agencies (Fire, Police, and Urban Search and Rescue) and written into the Standard Operating Procedures (SOPs) that guide the responses to emergency situations.

1.1.8 The radio communication test suite quantifies elemental radio communication capabilities necessary for robots intended for emergency response applications. As such, based on their particular capability requirements, users of this test suite can select only the applicable test methods and can individually weight particular test methods or particular metrics within a test method. The testing results should collectively represent a ground robot's overall radio communication capability. These test results can be used to guide procurement specifications and acceptance testing for robots intended for emergency response applications.

NOTE 2—As robotic systems are more widely applied, emergency responders might identify additional or advanced robotic radio communication capability requirements to help them respond to emergency situations. They might also desire to use robots with higher levels of autonomy, beyond teleoperation to help reduce their workload—see NIST Special Publication 1011-II-1.0. Further, emergency responders in expanded emergency response

~~domains might also desire to apply robotic technologies to their situations, a source for new sets of requirements. As a result, additional standards within the suite would be developed. This standard is, nevertheless, standalone and complete.~~

1.2 A remote operator is 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 to address various mission requirements.

1.4 *Performing Location*—This test method ~~shall~~may be performed ~~in a testing laboratory or the field where the specified apparatus~~anywhere the specified apparatuses and environmental conditions ~~are~~ can be implemented.

1.5 ~~*Units*—~~The ~~values stated in SI units shall be 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 facilitate testing but are not considered standard.~~International System of Units (a.k.a. SI Units) and U.S. Customary Units (a.k.a. Imperial Units) are used throughout this document. They are not mathematical conversions. Rather, they are approximate equivalents in each system of units to enable the 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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

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:*[2]

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

E2855 Test Method for Evaluating Emergency Response Robot Capabilities: Radio Communication: Non-Line-of-Sight Range



2.2 ~~*Additional*~~*Other Documents:*

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

NIST Special Publication ~~1011-I-2.0~~1011-II-1.0 Autonomy Levels for Unmanned Systems (ALFUS) Framework Volume ~~I: Terminology, Version 2.0~~I:3[3]

NIST Special Publication ~~1011-II-1.0~~1011-I-2.0 Autonomy Levels for Unmanned Systems (ALFUS) Framework Volume ~~II: Framework Models, Version 1.0~~I: Terminology, Version 2.04[3]

## 3. Terminology

~~3.1 *Definitions:*~~

~~3.1.1 *abstain, v*—the action of the manufacturer or designated operator of the testing robot choosing not to enter the test. Any decision to take such an action shall be conveyed to the administrator 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.~~

[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/.~~

[3] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov/el/isd/ks/autonomy_levels.cfm.

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

3.1.2 *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; and the administrator shall call the operator to start the test and record the performance data and any notable observations during the test.

3.1.3 *emergency response robot, or response robot, n*—a remotely deployed device intended to perform operational tasks at operational tempos to assist the operators to handle a disaster.

3.1.3.1 *Discussion—*
A response robot is designed to serve as an extension of the operator for gaining improved remote situational awareness and for accomplishing the tasks remotely through the equipped capabilities. The use of a robot 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; mobile in complex environments; sufficiently hardened against harsh environments; reliable and field serviceable; durable and/or cost effectively disposable; and equipped with operational safeguards.

3.1.4 *fault condition, n*—a certain situation or occurrence during testing whereby the robot either cannot continue without human intervention or has performed some defined rules infraction.

3.1.4.1 *Discussion—*
Fault conditions include robotic system malfunctions such as de-tracking, task execution problems such as excessive deviation from a specified path, or uncontrolled behaviors and other safety violations which require administrative intervention.



3.1.5 *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.

3.1.5.1 *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.



3.1.6 *line-of-sight communications, n*—propagating electromagnetic energy with a direct path between a transmitting radio antenna and a receiving radio antenna which are in visual contact with each other with no obstructions between them. In the ideal case, the only paths that the radio waves can take in the line-of-sight case are the direct path either between the transmitter and receiver or a path that corresponds to a single reflection of the radio wave off of the ground before it encounters the receiving antenna.

3.1.7 *non-line-of-sight communications, n*—propagating electromagnetic energy with no direct path between a transmitting radio antenna and a receiving radio antenna which are not in visual contact with each other due to obstructions between them. Radio waves propagate between the transmitting and the receiving antennas via reflections off structures, diffraction around structures, and/or passage through structures with attenuation.

3.1.8 *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.

3.1.8.1 *Discussion—*
An emergency responder would be a typical operator in emergency response situations.

3.1.9 *operator station, n*—apparatus for hosting the operator and her/his operator control unit (OCU, see NIST Special Publication 1011-I-2.0) to teleoperate (see Terminology E2521) the robot. The operator station shall be positioned in such a manner as to insulate the operator from the sights and sounds generated at the test apparatuses.

3.1.10 *radio interference, n*—adverse effect on the transfer of data when unrelated external signals are received by a robot receiver or an operator station receiver.

3.1.10.1 *Discussion*—

In licensed frequency bands such as those used by the public safety community, each radio transmitter and receiver is assigned a unique frequency channel typically with limits on power emissions. Some radio systems are designed to work effectively when multiple systems operate in the same frequency band at the same time. Many of these systems can be found in the unlicensed Industrial, Scientific, and Medical (ISM) frequency bands.

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

3.1.11.1 *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 tested capability to a certain degree of statistical significance as specified by the test sponsor.

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

3.1.13 *test form, n*—a collection of data fields or graphics used to record the testing results along with the associated information. A single test form shall not be used to record the results of multiple trials.

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



3.1.15 *test suite, n*—a 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-system interaction (HSI), logistics, safety and operating environment, and aerial or aquatic maneuvering.

3.1.16 *testing target, or target, n*—a designed physical feature to be used by the testing robotic subsystem for evaluating the subsystem capabilities. The feature may be an operationally relevant object, a notional object, or one designed specifically for exercising the subsystem features to its full extent.



3.1.17 *testing task, or task, n*—a set of activities well defined in a test method for testing robots and the operators to perform in order for the system's capabilities to be evaluated according to the corresponding metric(s). A test method may specify multiple tasks. A task corresponds to the associated metric(s).

3.1.18 *trial, n*—the number of repetitions to be performed for a test to reach required statistical significance. The repetitions may be recorded on a single test form.

3.1 The following terms are used in this test method and are defined in Terminology E2521: *lists additional definitions**emergency response robot* relevantor *to this**response robot,* *test**fault condition,* *method.**Landolt C,line-of-sight communications,non-line-of-sight communications,optotype,* and *radio interference.*

3.2 The following terms are used in this test method and are defined in ALFUS Framework Volume I:3: *autonomous*,*autonomy*, *level of autonomy*,*operator control unit (OCU)*, and *semi-autonomous*, and *remote teleoperation*.

## 4. Summary of Test Method

4.1 This test method uses remote maneuvering and inspection tasks to measure the is intended for remotely operated ground robots using radio communications to transmit real-time data between a robot and its remote operator interface. This test method specifies robot maneuvering and camera pointing tasks performed from designated standoff distances between the robot and remote operator interface (see Fig. 1line-of-sight range of a robot using its equipped radio communication system. This test represents the least complicated propagation environment with ground effects that will be encountered by radio linked robotic systems.). This test


*Left)* The robot maneuvering tasks include a circular robot path with 3 m [10 ft] radius for the robot to straddle and follow.
*Middle)* The center buckets are perpendicular and limit the viewing angles of the interior targets.
*Right)* Each bucket target has an inscribed ring (shown as green) to evaluate successful alignment along with five increasingly small concentric ring gap orientations to evaluate visual acuity.

**FIG. 2 Robot Maneuvering Tasks**

method measures the maximum line-of-sight radio communications range at which a robot can complete omnidirectional tasks including continuous steering, speed control, precise stopping, visual acuity, and other functionality. This test method is conducted in an environment with no radio frequency interference and minimal radio propagation effects. The same test can be conducted at any operationally significant environment (with representative radio interference) as a practical measure of line-of-sight radio communications range.

4.2 ~~The test course shall be a flat paved~~ This test method is conducted on a straight and flat surface at least ~~1000 m (3300 ft) long by 20 m (65 ft) wide with a centerline robot path. A minimum of 50 m (165 ft) on each side~~ 6 m [20 ft] wide and longer than the maximum radio communications range of the robotic system being evaluated, or longer than the operationally significant range of the intended application. There must be no obstructions on the paved surface or radio reflective metal objects within 50 m [165 ft] of the centerline ~~robot path shall be clear of any obstructions or reflecting objects to minimize multi-path effects.~~ to minimize effects from multi-path radio transmissions. A roadway, airstrip, or parking lot can be used depending on the overall length required (see Fig. 2).



~~4.3 Test stations shall be placed every 100 m (330 ft) down range along the centerline. Each test station consists of eight visual and audio targets for inspection tasks along with circular robot paths marked on the ground for maneuvering tasks.~~

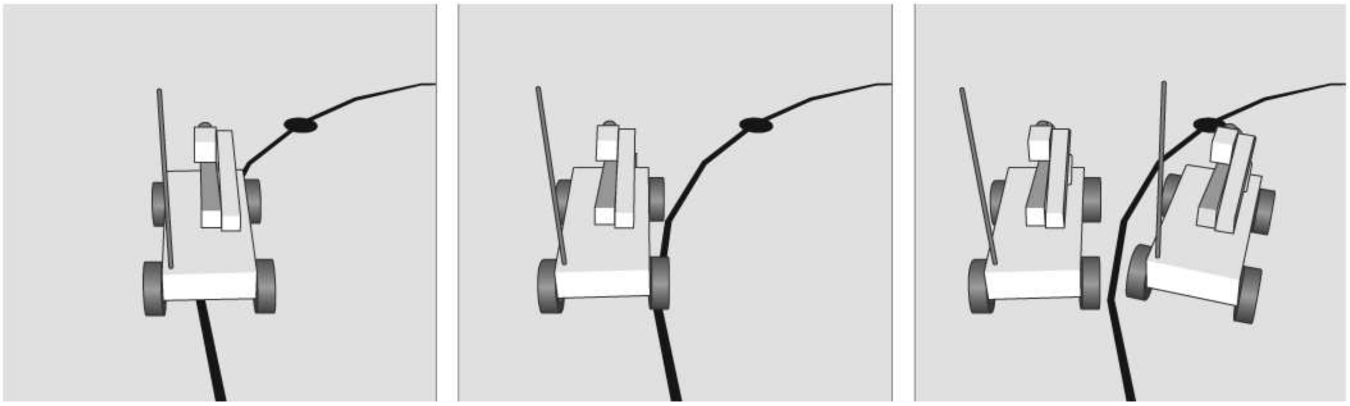
~~4.4 At each test station, the robot shall perform a maneuvering task to follow the circular path to locate each of the visual and audio targets.~~

4.3 The ~~visual and audio targets shall be identified using the robot's forward facing cameras, requiring~~ maneuvering tasks require the robot to straddle and follow a circular path marked on the ground with 3 m [10 ft] radius to demonstrate continuous steering and speed control. The robot also aligns with four perpendicular buckets in the center using a designated forward-facing camera on or over the robot chassis. These tasks require the robot to face ~~all~~ four ~~compass~~ different directions relative to the ~~direction of travel~~ operator interface to ensure that there are no directionality issues with transmitting or receiving communication signals. Each recessed bucket target has an inscribed ring with a limited viewing angle to evaluate successful alignment. A 5-point score records successful completion of the robot maneuvering tasks (see Fig. 3 and Fig. 4).

4.4 The ~~robot's line-of-sight range capability is measured as the maximum distance downrange at which the robot completes all the tasks at a test station to verify the functionality of line-of-sight control, video and audio transmissions.~~ visual acuity tasks require identifying up to five increasingly small concentric ring gap orientations in each bucket. A separate 5-point acuity score per target across four different targets totals 20 points for overall acuity.

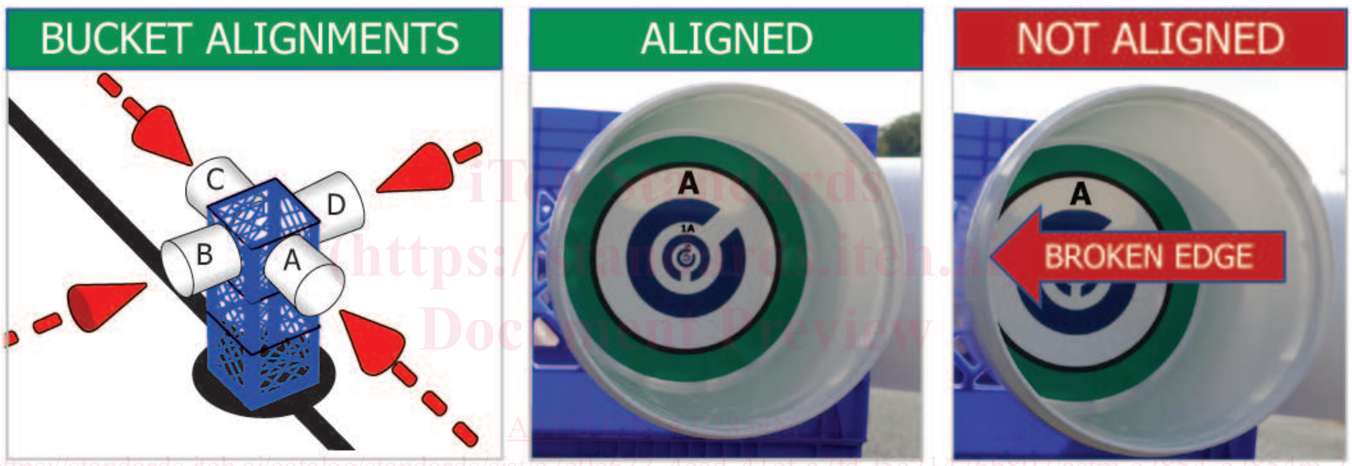
4.5 ~~Teleoperation shall be used from the operator station specified by the administrator to test the~~ There are four performance metrics to consider when calculating the results of a test trial. They should be considered in the following order of importance: ~~*robots using an OCU*~~ *line-of-sight radio communications range,reliability,* ~~*provided by*~~ *average visual acuity,* ~~the operator. The operator station shall be positioned~~ and ~~*implemented*~~ *efficiency.* ~~in such a manner as to insulate the operator from the sights and sounds generated at the test apparatus.~~

~~NOTE 3—Separate, autonomous radio communications test methods will be separately specified in the future as per community requirements. This standard is, nevertheless, standalone and complete.~~



*Left)* The robot is shown successfully straddling the circular line by having at least one ground contact on both sides.
*Middle)* When ground contacts are touching the circular line the robot is still considered successfully straddling.
*EachRight)* robot test station includes a maneuvering task to follow marked circular paths around two sets off our targets facing compass directions relative to the direction of travel.All the ground contacts are on one side of the circular line, so the task is considered unsuccessful. Alternatively, the robot could have left the circular line toward the inside which would also be considered unsuccessful.

**FIG. 23 Test StationSuccessful Straddling and Unsuccessful Attempt**




A) An example of a visual acuity eye chart and an audio speaker playing a series of computer generated, single digit numbers. B) A prototype test station apparatus shows two barrels with only four targets total and half circular robot paths. A complete test station shall have full circular paths around each barrel with four targets facing all compass directions totaling eight total targets per test station.Successful alignment with each bucket requires visibility of a continuously inscribed ring on the interior bottom of the bucket. The inscribed ring is shown as green with a black inner edge to increase contrast. When the inner black edge is clearly broken the robot is considered NOT ALIGNED.

**FIG. 34 Test Station ImplementationSuccessful Alignment and Unsuccessful Alignment**

4.6 This test method is performed with appropriate safety precautions to mitigate any potentially dangerous robot behaviors due to lost communications. The operator performs the maneuvering and visual acuity tasks from a standoff distance near where loss of either control or video is evident. The test is then repeated closer to the robot along the centerline at incremental distances of 6 m [20 ft] until all omnidirectional maneuvering and visual acuity tasks are performed successfully. The maximum distance from the remote operator interface and its co-located antenna to the center of the circle is considered the maximum line-of-sight radio communications range.

4.7 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 describing the targets as seen by the operator, 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.*Potential Faults Include:*

4.7.1 Any contact by the robot with the apparatus that requires adjustment or repair to return the apparatus to the initial condition.

4.7.2 Any visual, audible, or physical interaction that assists either the robot or the remote operator.

4.7.3 Leaving the apparatus during the trial.

~~NOTE 4—Practice within the test area is could help establish the applicability of the robot for the given test method. It allows the operator to gain familiarity with the test method and environmental conditions. It also helps the test administrator to establish the initial apparatus setting for the test.~~

4.8 ~~The test sponsor has the authority to establish the testing policy, including the robot participation, testing schedules, test site at which this test method is implemented, associated environmental conditions, the apparatus settings, and statistical reliability and confidence levels of the testing results.~~Test trials shall produce enough successful repetitions to demonstrate the reliability of the system capability or the remote operator proficiency. A complete trial of 10 to 30 repetitions should take 30 to 60 min to complete. When measuring system capabilities, it is important to allow enough time to capture a complete trial with an expert operator. When measuring operator proficiency, it is important to limit the time of the trial so that novice and expert operators are similarly fatigued.

4.9 Various other operationally significant targets can be incorporated into this test method to evaluate color acuity, thermal acuity, audio acuity, latency, signal/packet loss, etc.

## 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 perform the specified types of tasks and thus provide emergency responders sufficiently high levels of confidence to determine the applicability of the robot.~~

5.1 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 capabilities 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 in National Response Framework.~~is part of an overall suite of related tests that provide reproducible measures of radio communications for remotely operated robots. It measures the maximum line-of-sight radio communications range between a robot and its remote operator interface using omnidirectional robot maneuvering and visual acuity tasks to evaluate the degradation of essential mission capabilities due to communications latency and loss.

5.2 This test method is inexpensive, easy to fabricate, and simple to conduct so it can be replicated widely. This enables comparisons across various testing locations and dates to determine best-in-class system capabilities and remote operator proficiency.

5.3 *Evaluations*—This test method ~~is part of a test suite and is intended to provide a capability baseline for the robotic communications systems based on the identified needs of the emergency response community. Adequate testing performance will not ensure successful operation in all emergency response environments due to possible extreme communications difficulties. Rather, this standard is intended to provide a common comparison that can aid in choosing appropriate systems. This standard is also intended to encourage development of improved and innovative communications systems for use on emergency response robots.~~can be conducted in a controlled environment with no radio frequency interference and minimal radio propagation effects to measure baseline capabilities that can be compared widely across robotic systems. It also can be embedded into any operational training scenario as a practical measure of line-of-sight radio communications range with additional degradation due to uncontrolled variables such as radio frequency interference, weather, etc. The results of these scenario tests can be compared across robotic systems only when conducted in the same environment in similar conditions. However, the results cannot be compared reliably to results from other venues or environmental conditions due to the uncontrolled variables.

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. Operators can learn system behaviors during radio communication degradation and refine techniques to mitigate issues while performing tasks. The resulting measures of remote operator proficiency enable tracking of perishable skills over time, along with comparisons of performance across organizations, regions, or national averages.

5.6 *Innovation—*~~The standard apparatus is specified to be easily fabricated to facilitate self-evaluation by robot developers and provide practice tasks for emergency responders to exercise robot actuators, sensors, and operator interfaces. The standard apparatus can also be used to support operator training and to establish operator proficiency.~~ 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 tests can guide manufacturers toward implementing the combinations of capabilities necessary to perform essential mission tasks.

~~5.5 Although the test method was developed first for emergency response robots, it may be applicable to other operational domains, such as law enforcement and armed services.~~

## 6. Apparatus

6.1 *Test Environment:*

6.1.1 This test method is conducted in an environment with no radio frequency interference near the frequency bands used by the robot being evaluated. This requires radio frequency monitoring equipment to ensure there is no interference from other sources. Variants of this test method should also be performed in environments with other known or unknown radio frequency emissions in the vicinity. Robots should be evaluated using this test method in operational scenarios with powerful radio transmitters nearby such as emergency response vehicles, cell phone towers, and even hand-held radios as a source of potentially significant radio interference. These test variants are less repeatable but can still provide performance comparisons for various systems tested in the same environment at roughly the same time.



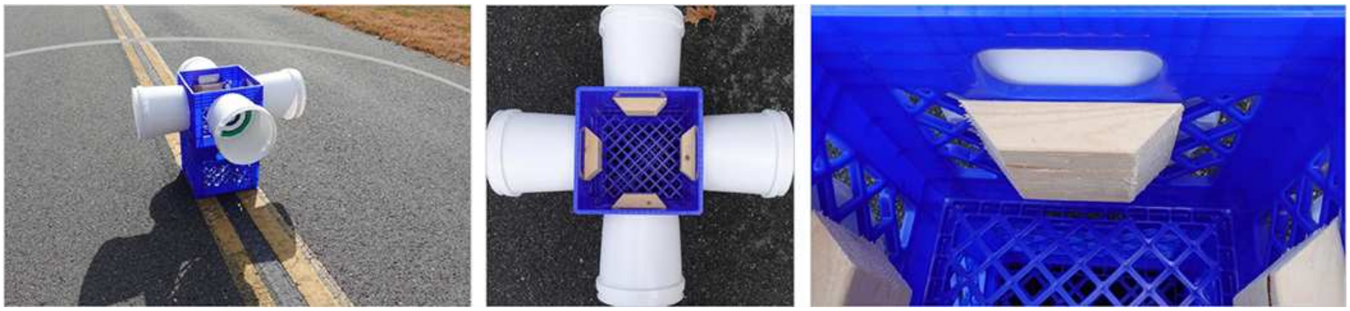
6.2 ~~The test apparatus is a straight, flat section of airstrip, roadway or other paved asphalt or concrete surface at least 1000 m (3300 ft) long and 20 m (65 ft) wide. It shall have no obstructions or reflective objects within at least 50 m (165 ft) on either side of the centerline.~~ *Test Site (see Fig. 1):*

6.2.1 The test site must be a flat paved surface at least 6 m [20 ft] wide with an overall centerline length longer than the maximum radio communications range of the robotic system being evaluated, or longer than the operationally significant range of the intended application. It must be flat and straight enough to maintain an unobstructed view between the robot and the remote operator interface antenna throughout the test. A slight incline or decline can be tolerated as long as there is no depression along the centerline that obscures the direct line-of-sight path from the robot to the operator interface antenna. The top of the antenna is limited to a maximum height of 2 m [6 ft] from the ground. There must also be no obstructions or reflecting metal objects within 50 m [165 ft] of the centerline to minimize effects from multi-path radio transmissions to only reflections off the ground. A roadway, airstrip, or parking lot can be used depending on the system capabilities being evaluated as long as there are no metal buildings, vehicles, guardrails, signs, etc. Operationally significant variants of this test method performed on absorptive ground surfaces such as grass and with reflective metal objects in the vicinity, or with antennas mounted on vehicles or structures such that they exceed 2 m [6 ft] in height, or combinations thereof, are less repeatable but can still provide points of comparison for various systems tested in the same environment in similar conditions.

6.3 ~~Test stations, specified below, shall be placed every 100 m (330 ft) down range from the operator station along the centerline robot test path (see Fig. 1).~~ *Incremental Standoff Distances (see Fig. 1):*

6.3.1 The incremental standoff distances along the centerline locate the remote operator interface relative to the center of the circular robot tasks. Each incremental distance is 6 m [20 ft]. The overall length must extend beyond the maximum line-of-sight radio communications range of the robotic system being evaluated. The centerline can be a roadway lane marker line, pavement seam, or measuring tape pulled taught and secured to the ground. Each measured increment should be marked with spray chalk or other means to clearly identify the location and distance from the center of the circular robot path.

6.4 ~~Each test station shall have two circular robot paths marked on the ground each with a 2 m (6.5 ft) radius (see Fig. 2 and Fig. 3). The circular robot paths shall be tangent to each other, with the connection point marking the measured distance downrange from the operator station. Markings on the circular paths shall show the location at which the robot must turn and face the targets to identify them.~~ *Circular Robot Path (see Fig. 2):*



*Left)* The elevation of the buckets needs to align with various size robots, so some vertical adjustment is necessary.
*Middle)* Stackable crates provide excellent perpendicular mounting surfaces and easy adjustment of elevation.
*Right)* Wood blocks inside the crates enable the buckets to be affixed to the outside surfaces with screws. Bolts, washers, and wingnuts through the bucket and crate can also be used to enable quick set up and stowing.

**FIG. ~~4~~5 ~~Example of a Test Form (Blank)~~Perpendicular Buckets**

6.4.1 The circular robot path marked on the ground provides a 3 m [10 ft] radius line for the robot to straddle and follow. The circle can be marked using a fixed length rope tied between a spray chalk roller wand and center stake or weight. Pull the rope taught to ensure the radius is correct, then pull continuously outward away from the center while marking. Four additional markings at 90-degree increments around the circle designate the locations where the robot rotates inward to align with the perpendicular buckets. The locations for bucket A and bucket C are the intersection of the circle and the centerline with Bucket A closer to the remote operator interface and C further from the remote operator interface. The locations for bucket B and bucket D are 90-degrees from the centerline with bucket B to the left when viewed from the operator interface and bucket D to the right. Use the correct alignment position of bucket B and bucket D to mark the locations.

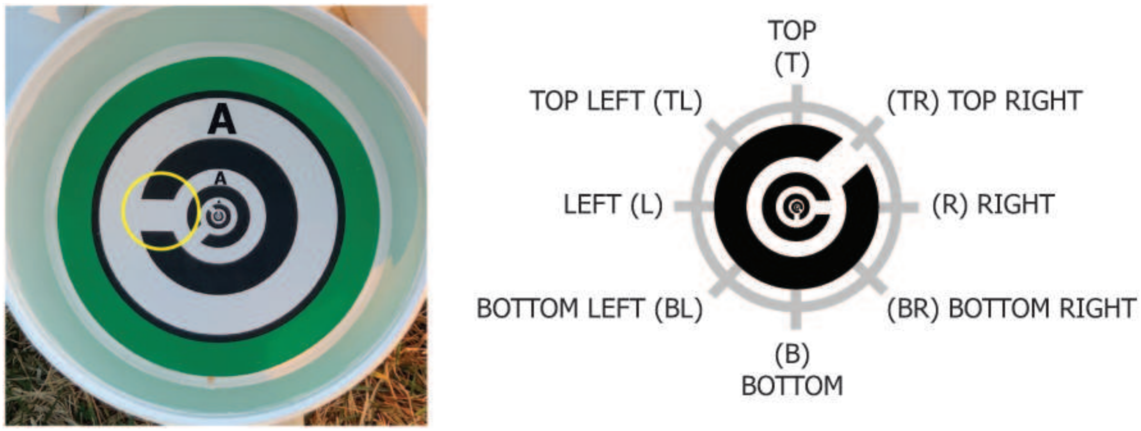


6.5 ~~Each test station shall have eight unique visual targets to be identified through the equipped communications channel. The visual targets shall be placed at the center of the circular robot paths facing all four compass directions (north, south, east, and west) relative to the direction of travel on the centerline path.~~*Perpendicular Buckets (see Fig. 5):*

6.5.1 Four perpendicular buckets are located at the center of the circular robot path to restrict the viewing angles of targets affixed to their inside bottom surfaces. They are aligned with positions every 90-degrees around the circular robot path starting where the circle intersects the centerline. The buckets are incrementally elevated using the crates shown or other non-metallic apparatus to ensure different sized robots can see the entire inscribed ring when in the correct location around the circle. The buckets shown are 7.5 L [2 gal] with 20 cm [8 in.] inner diameter so they fit letter/A4-size target stickers. White buckets are used to reflect light and illuminate the recessed targets. Other bucket sizes and colors can work as long as the recessed targets are clearly visible to the robot being evaluated. Each bucket is uniquely named with letters (A, B, C, D) to identify the different robot orientations for scoring purposes. The bucket labeled "A" is viewable from the intersection of the circular robot path and the centerline closest to the remote operator station. The other letters continue leftward or clockwise from there.

6.6 ~~Each test station shall also have two audio sources to be identified through the equipped communications channel. The center of each circular robot path shall have an audio source and speaker playing a continuous series of single digit numbers for the identification task. The numbers shall be articulated using a computer-generated voice with a volume of at least 60 to 80 dB.~~*Bucket Targets (see Fig. 4, Fig. 5, and Fig. 6):*

6.6.1 Each bucket contains a recessed target affixed to the interior bottom surface. Targets include an inscribed ring to verify robot alignment. The inscribed ring shown is 2.5 cm [1 in.] thick and green, but any contrasting color can be used. The visual acuity target contains five increasingly small concentric rings with various gap orientations to correctly identify. These are concentric Landolt-C optotypes (see Test Method E2566 – 17a or later). Each ring gap can be in eight different orientations making the overall visual acuity target randomizable with a unique answer key. The naming convention for the different gap orientations are: top (T), top right (TR), right (R), bottom right (BR), bottom (B), bottom left (BL), left (L), top left (TL). The ring gaps are the following sizes from largest (outer) to smallest (inner):




Left) Visual acuity targets affixed to the interior bottom of the buckets have increasingly small concentric ring gap orientations.
Right) The associated naming convention for each ring gap orientation.

**FIG. ~~5~~6 ~~Example of a Test Form (Filled out)~~Bucket Targets**

| | | |
|---|---|---|
| Largest | Ring 1<br>Gap Size = 20 mm [0.8 in.] | 5 % Human Vision<br>from 3 m [10 ft] |
| | Ring 2<br>Gap Size = 8.0 mm [0.3 in.] | 11 % Human Vision<br>from 3 m [10 ft] |
| | Ring 3<br>Gap Size = 3.2 mm [0.125 in.] | 27 % Human Vision<br>from 3 m [10 ft] |
| | Ring 4<br>Gap Size = 1.3 mm [0.05 in.] | 67 % Human Vision<br>from 3 m [10 ft] |
| Smallest | Ring 5<br>Gap Size = 0.5 mm [0.02 in.] | 175 % Human Vision<br>from 3 m [10 ft] |



6.7 *Timer:*

6.7.1 A timer is used to measure the elapsed time for the robot to perform each set of maneuvering and visual acuity tasks.



6.8 *Optional Time-synced Clocks:*



6.8.1 Two time-synced digital clocks can be used to detect and measure latency and loss issues due to degraded radio communications. These latency and loss issues can last several seconds and increase the difficulty of the tasks. One time-synced clock should be placed with the remote operator interface display and the other time-synced clock placed so it is viewable by the robot's camera when the robot is aligned with the buckets. The time-synced clock with the buckets needs to be large enough to be viewable through the remote operator interface and easily comparable to the time-synced clock with the remote operator interface display.

6.9 *Optional Still-image Camera:*

6.9.1 A still-image camera can be used to capture images of the remote operator interface display at each bucket alignment to pictorially document both the alignment and visual acuity score with static examples of video degradation. The camera must have sufficient quality to record the pixels of the remote operator interface display to ensure the camera does not add uncertainty to the image degradation. Similarly, a "screenshot" of the remote operator interface display can be used for scoring. However, any images captured by the robot but not transmitted via the radio communications link cannot be used for scoring. If a system recording of a video feed from the remote operator interface is available to be captured, it shall be marked "streamed" to make it clear to the viewer that the effect of the remote operator interface screen (for example, a small or low-resolution screen reducing the acuity of the system) will not be represented in the resulting recording. Any video captured by the robot but not transmitted via the radio communications link cannot be used for scoring.

6.10 *Optional Video Cameras:*

6.10.1 Two video cameras can be used to simultaneously record the remote operator interface and robot behaviors to capture more detailed performance of the communications link. Watching the two videos side by side is ideal to see subtle issues of latency and