**Designation: E2566 – 17a**

# Standard Test Method for
# Evaluating Response Robot Sensing: Visual Acuity[1]

This standard is issued under the fixed designation E2566; 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 unstructured and often hazardous environments. These missions decompose into elemental robot tasks that can be represented individually as standard test methods and practices. The associated test apparatuses and performance metrics provide a tangible language to communicate various mission requirements. They also enable repeatable testing to establish the reliability of essential robot capabilities.

The ASTM International Standards Committee on Homeland Security Applications (E54) specifies standard test methods and practices for evaluating individual robot capabilities. These standards facilitate comparisons across diverse models or multiple configurations of a single model. The 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 developed systems. User organizations leverage the resulting robot capabilities data to guide purchasing decisions, align deployment objectives, and focus training with standard measures of operator proficiency. Associated usage guides describe how such standards can be applied to support these various objectives.

The overall suite of standards addresses critical subsystems of remotely operated response robots, including maneuvering, mobility, dexterity, sensing, energy, communications, durability, proficiency, autonomy, logistics, safety, and terminology. This test method is part of the Sensing test suite and addresses the visual acuity of onboard cameras.

## 1. Scope

1.1 The purpose of this test method is to specify the apparatuses, procedures, and performance metrics necessary to quantitatively measure a robot's visual acuity as displayed to a remote operator or vision algorithm. The primary performance metric for this test method shall be a robot's possession of such a capability with a specified statistical significance level.

1.2 Secondary performance metrics are the robot's field of view and aspect ratio.

1.3 This test method can also be used to measure the operator proficiency in performing the specified task. The corresponding performance metric may be the number of completed task repetitions per minute over an assigned time period ranging from 10 to 30 minutes.

1.4 This test method is a part of the sensing suite of response robot test methods, but this test method is stand-alone and complete. This test method applies to systems operated remotely from a standoff distance appropriate for the intended mission. The system includes a remote operator in control of all functionality and any assistive features or autonomous behaviors that improve the effectiveness or efficiency of the overall system.

1.5 The apparatus, specified in Section 6, can only test a limited range of a robot's capabilities. When the robot has been tested through the limit or limits of the apparatus, a note shall be associated with the results indicating that the robot's actual capability may be outside of the limit or limits imposed by the test apparatus. For example, the robot could exceed the capabilities of the printing process used to create the charts used in the apparatus.

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

1.7 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard. Both units are referenced to facilitate acquisition of materials internationally and minimize fabrication costs.

1.8 *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.*

1.9 *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

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

2.2 *Additional Standards:*

ISO 12233 Photography – Electronic Still Picture Imaging – Resolution and Spatial Frequency Responses[3]

ISO 8596:2009 Ophthalmic Optics – Visual Acuity Testing – Standard Symbol and Its Presentation[3]

ISO/IEC 18004:2015 Information – Automatic Identification and Data Capture Techniques – QR Code Barcode Symbology Specification

## 3. Terminology

3.1 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, 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:* The following terms are used in this test method and defined below. For further discussion, please refer to Appendix X1.

3.2.1 *aspect ratio, n*—the ratio of width to height of the image produced by a *camera system*.

3.2.2 *camera system, n*—a specific camera with its associated lighting, compression, interface, display, and operator station settings that may be required to work together on the hosting robot to display the image.

3.2.3 *dynamic range, n*—a measure of the ability of a *camera system* to, in a single scene, simultaneously observe details on objects in the dark environment and in the environment or environments with certain light intensity.

3.2.4 *focal length, n*—a measure of how wide or narrow a camera's field of view is. A longer focal length provides a narrower field of view than a shorter one.

3.2.5 *foveated vision (system), n*—a *camera system* that has higher resolution (provides more information) at the center than the edges of the image.

3.2.6 *framerate, n*—a measure of the temporal resolution of a *camera system* and refers to the number of complete images per second displayed on a remote system interface.

3.2.7 *image, n*—a two-dimensional matrix of values with each of the two dimensions representing angular deviation (possibly non-linear) in orthogonal direction from the sensor's optical axis.

3.2.8 *imager, n*—a sensor, or system of sensors, that produces an image.

3.2.9 *image acuity (or acuity), n*—a measure of the resolving capability of the robot's *camera system*.

3.2.10 *image field of view (or field of view), n*—a measure of the extent of the robot's environment that may be observed in a single visual image, measured in terms of degrees in the horizontal and vertical directions.

3.2.11 *image resolution, n*—a measure of the amount of visual information that the robot's *camera system* is capable of conveying to the operator (regardless of the *field of view* of the system) and is measured as the number of black and white lines that can be clearly resolved, per image height, in the horizontal, vertical and diagonal directions. Reporting relative to image height normalizes for variations in aspect ratio.

3.2.12 *Landolt Ring or Landolt C, n*—a *symbol* consisting of a black circular ring with a white gap, both with specified sizes, as defined in ISO 8596:2009.

3.2.13 *QR Code (or Quick Response Code), n*—a pattern of black squares that encodes digital information and is designed to be read by a computer.

3.2.14 *resolution wedge, n*—a series of lines that decrease in size and spacing and are used to measure the *image resolution* of a *camera system*. The point along the resolution wedge at which the lines are no longer distinct indicates the *image resolution* of the *camera system*.

3.2.15 *resolve, v*—the act of discerning the presence of a marking or object.

## 4. Summary of Test Method

4.1 This test method uses standard symbols of incrementally small sizes viewed by a robot from specified distances to

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[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 International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

measure the far-field and near-field visual acuity of each onboard camera as displayed on a remote operator interface. The metric is the size of the smallest object that can be resolved, in millimeters, at the far-field and near-field. Attributes of aspect ratio and field of view are also measured for each camera.

4.2 The apparatuses required to perform the measurements are visual acuity test charts displayed at a far-field distance of 6 m [20 ft] and a near-field distance of 40 cm [16 in.] from the robot. The remote operator identifies Landolt C symbols with gaps in any of eight different orientations. Autonomous systems with image processing capabilities identify machine readable symbols known as quick response codes (QR codes).

4.3 The conditions include lighted and darkened room or hallway of sufficient length and width to accommodate the robot and the charts at the specified distances (see Fig. 1). Illumination from the robot is allowed. A light meter shall be available to measure the light conditions.

## 5. Significance and Use

5.1 Various levels of visual acuity are essential when remotely operating robots in unstructured and often hazardous environments. Missions typically include establishing situational awareness, finding available paths, maneuvering through obstacles, identifying objects of interest, and performing detailed inspections. This test method measures robot system far-field and near-field visual acuity which are applicable to virtually every mission. These quantitative measures of performance provide a common language that allows robot users to better understand and express their own requirements and improve the way visual sensing capabilities are specified.

5.2 Multiple cameras could be incorporated into remotely operated robotic systems since a single camera is unlikely to be effective for all aspects of a mission. For example, cameras with zoom lenses are often used for far-field tasks. Cameras with close focus capabilities are often used for near-field tasks. Wide-angle lenses are often used for driving and obstacle avoidance. This test method characterizes each onboard camera to understand overall system capabilities.

5.3 This test method provides a way to unambiguously specify robot requirements in terms of the related measures of visual acuity and field of view. This helps quantify the trade-offs and general usefulness of optical versus digital zoom cameras and fixed versus variable focus lenses. The visual acuity charts can also help provide quantitative measures of performance within other test methods and training scenarios. See Figs. 2-4 for illustrations.

5.4 This test method helps evaluate the effect of illumination on visual acuity. In dark environments, robots typically need to illuminate the scene to be effective. Far-field objects downrange require much greater light intensity than near-field objects close to the robot. Variable illumination helps ensure the scene is neither too dark nor overwhelmingly lighted so as to thwart the camera's ability to discern visual details (so-called "washout" of the image). Variable illumination is especially important when quickly transitioning from far-field to near-field and back again.

5.5 Key features of response robots are that they are remotely operated from safe standoff distances, deployable at operational tempos, capable of operating in complex environments, sufficiently hardened against harsh environments, reliable and field serviceable, durable or cost-effectively disposable, and equipped with operational safeguards. As such, a major advantage of using robots in response operations is to enhance the safety and effectiveness of responders or soldiers.

5.6 This test method aligns user expectations with actual capabilities to understand the inherent trade-offs in deployable systems at any given cost. For example, an increase in image resolution typically results in improved field of view or acuity, but not necessarily both. An increase in both may not be possible for robots of a desired weight, endurance, or cost.

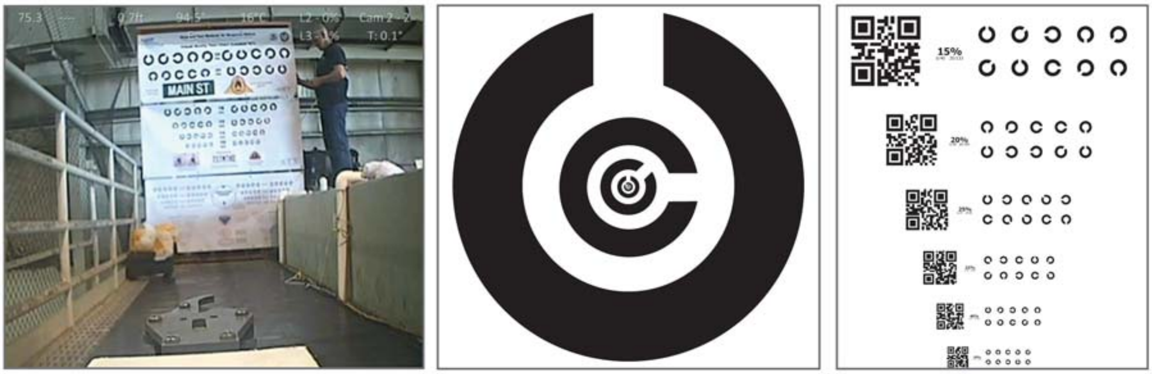

**FIG. 1** (*A*) An example of a far-field visual acuity chart as viewed by a robot 6 m [2 ft] away and displayed on a remote operator interface. The chart contains lines of ten standard symbols in incrementally small sizes along with items of interest to highlight the applicability of different levels with acuity (road signs, hazmat placards, shipping labels, etc.). (*B*) The standard symbols to identify are called Landolt Rings with gaps in any of eight different orientations. Concentrically displayed Landolt Rings contain increasing small symbols within each other. (*C*) Similarly, increasingly small QR codes are used to evaluate the acuity of autonomous systems with image processing capabilities.

FIG. 2 This Baseline Image is Used for Purposes of Comparisons Below

FIG. 3 Three Images of the Same Scene with the Same Image Resolution. Top Row Shows Field of View Increasing from Left to Right (the image "zooms out") While Bottom Row Shows Acuity Decreasing (features of the same size become harder to clearly observe)

Appropriate levels of understanding can help ensure that requirement specifications are articulated within the limit of current capabilities.

5.7 This test method provides a tangible representation of essential robot capabilities with quantifiable measures of performance. When considered with other related test methods in the suite, it facilitates communication among communities of robot users and manufacturers. As such, this test method can be used to:

5.7.1 Inspire technical innovation and guide manufacturers toward implementing combinations of capabilities necessary to perform essential mission tasks.

5.7.2 Measure and compare essential robot capabilities. This test method can establish the reliability of the system to perform specified tasks, highlight break-through capabilities, and encourage hardening of developmental systems.

5.7.3 Inform purchasing decisions, conduct acceptance testing, and align deployment objectives with statistically

FIG. 4 Three Images of the Same Scene with the Same Field of View. The Top Row Shows the Field of View is Unchanged While Bottom Row Shows Both Resolution and Acuity Increasing (features become clearer)

significant robot capabilities data captured through repeated testing and comparison of quantitative results.

5.7.4 Focus operator training and measure proficiency as a repeatable practice task that exercises actuators, sensors, and operator interfaces. The test method can be embedded into training scenarios to capture and compare quantitative scores even within uncontrolled environmental variables. This can help develop, maintain, measure, and track very perishable skills over time and enable comparisons across squads, regions, or national averages.

5.8 Although this test method was developed as part of a suite of sensing tests for response robots, it may be applicable to other domains. Different user communities can set their own thresholds of acceptable performance within the test method for various mission requirements.

5.9 It is recommended that users of this test method consider their particular robot requirements when interpreting the test results. The capability evaluated in this test method alone shall be interpreted according to the scope of this test method and shall not be considered as an overall indication of the capability of the robot's mobility subsystem nor of the entire robotic system. A single test method only captures the specified single aspect of a robot's capabilities. A more complete characterization of a robot's capabilities requires test results from a wider set of test methods.

## 6. Apparatus

6.1 The components required to perform this test method are visual acuity test charts described below and devices to hold the test charts at specified distances from the robot. For lighted conditions, outdoor daylight testing is preferable. Indoor testing requires a room or hallway of sufficient length and width to accommodate the robot and the charts at the far-field distance and lighting equipment. For darkened conditions, the same room can be used if windowless. A light meter is required to measure both lighting conditions. Fig. 5 shows an example of the apparatus.

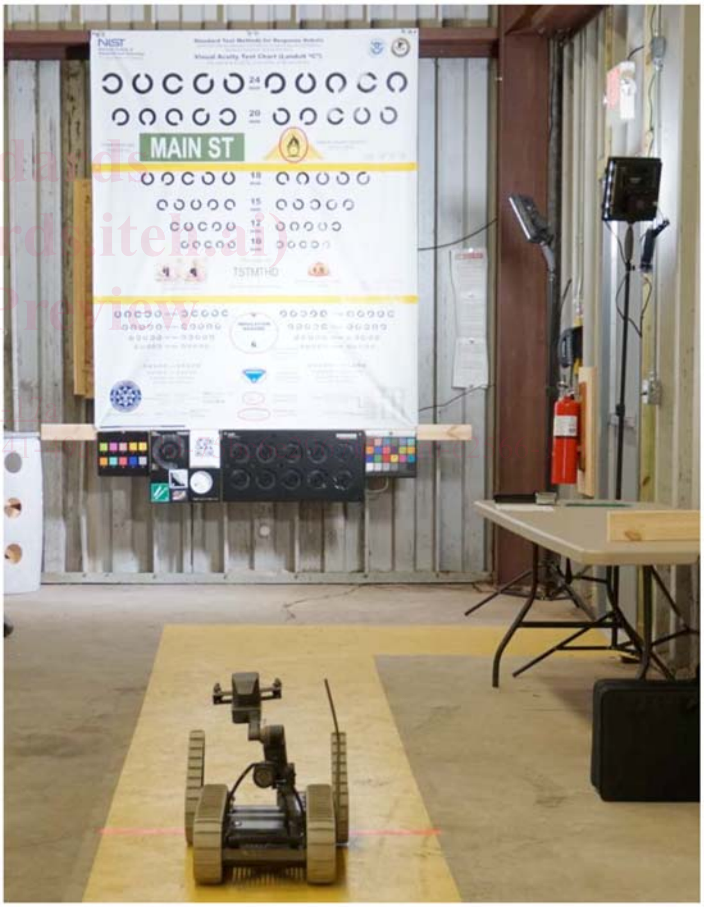

FIG. 5 An Example of a Robot Positioned in Front of the Visual Acuity Test Apparatus. The LED Studio Lights to the Right are Set Up to Provide an Even Illumination Across the Chart. For Space Reasons, Only 10 or 20 Symbols are Visible Here. Multiple Charts are Used to Achieve the Prescribed 30 Symbols

6.2 For robotic systems with camera images displayed on a remote operator interface, human-readable symbols shall be used to measure visual acuity. Landolt Ring symbols are used as described in ISO 8596 (see Figs. 6 and 7). Each symbol consists of a black ring with an outer diameter equal to five times the ring thickness displayed on a white background 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° intervals starting from straight up. Correctly identifying a series of randomly oriented symbols within defined error rates provides statistically significant measures of visual acuity.

6.2.1 Correctly discerning the gap orientations of multiple symbols with a specified error rate represents the ability to resolve features the size of the gap. The gap orientations shall be identified relative to the top of the camera image in terms of compass directions as follows: 0°/North (N), 45°/Northeast (NE), 90°/East (E), 135°/Southeast (SE), 180°/South (S), 225°/Southwest (SW), 270°/West (W), and 315°/Northwest (NW).

6.2.2 Although the test is performed with a single sequence of 30 symbols at a selected size, multiple sizes may be provided on one chart to facilitate repeated testing at larger or smaller sizes.

6.2.3 The chart may be scaled to provide for various levels of acuity for robots under test depending on testing requirements. Typical charts will have symbols for testing at a scale of 0.25 to 5 mm [0.01 to 0.2 in.] for testing at the near field distance of 40 cm [16 in.] and 0.5 to 25 mm [0.02 to 1 in.] for testing at the far field distance of 6 m [20 ft].

6.2.4 The incremental size of each scale shall be no more than 20 % smaller or larger than the next closest scale. The symbols shall range from easily readable at the largest scale to unambiguously unreadable at the smallest scale. All symbols shall be printed with sufficient resolution to maintain smoothly contoured symbols. The metric used shall be in millimeters (inches).

6.2.5 At each scale, 30 randomly oriented symbols shall be identified with at least one vertical, one horizontal, and one diagonal. One or more test charts may contain sets of multiple symbols at various scales. Alternatively, a single symbol at each scale can be rotated and identified sequentially.

6.2.6 For testing near-field visual acuity at a distance of 40 cm [16 in.], high quality conventional office printers or commercially available charts shall be used to ensure small symbols with features as small as 0.25 mm are printed with sufficient resolution and contrast.

6.2.7 For testing far-field visual acuity at a distance of 6 m [20 ft], much larger symbols may be required. Large-format printers or commercially available charts shall be used to ensure smoothly contoured symbols with sufficient resolution and contrast.

6.2.8 Eq 1 may be used to compute the appropriate visual acuity for a particular size symbol viewed from a given distance and may be reported as a convenience. Table 1 provides the conversion between metric ratios (6/6), imperial ratios (20/20 ft), decimal (1.0), and percentage of average human vision (100 %), along with examples of objects that may be approximately discernible from the given distances.

$$\%\,\text{Human Vision} = 100 \times \frac{\text{Chart Distance} \times \tan(1/60\,°)}{\text{Landolt Ring gap size}} \qquad (1)$$

6.2.9 For robotic systems with image processing capabilities, a visual acuity test chart with machine-readable symbols is used to measure visual acuity. Increasingly small symbols called "quick response codes" or "QR codes" are used, which are two-dimensional bar codes described in ISO/IEC 18004:2015 (see Fig. 8). Each QR code consists of a grid of black and white squares arranged in a pattern that encodes information. The ability to successfully read a QR code requires resolving features equal to the size of the individual squares in the grid. It is the sizes of the individual black and white squares that is reported as the metric.

6.2.10 Grids can range from 11×11, 21×21, up to 57×57 or larger than encode more information and contain embedded error checking. Smaller 11×11 grids suffice for the purpose of testing visual acuity because they encode sufficient information to identify the acuity measurement and some additional identification words such as they chart name or number, for example. At each scale, 30 randomly oriented symbols shall be identified with at least one vertical and one diagonal. One or more test charts may contain sets of multiple symbols at

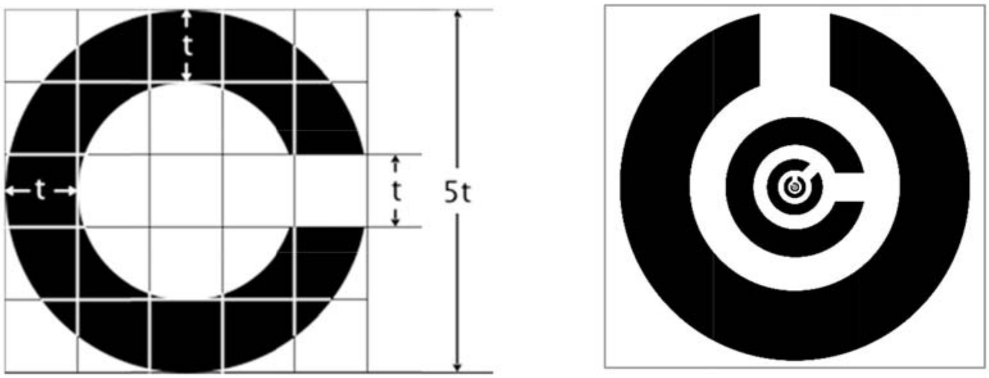

**FIG. 6** (*A*) **The relative dimensions of the human-readable symbol used to measure visual acuity of systems as displayed on a remote operator interface. (*B*) A concentric set of increasingly small symbols enables measurement of different levels of acuity within a compact size that is particularly useful for embedding into training scenarios. But multiple concentric sets are required to achieve the granularity desired for testing acuity. This chart can be rotated to produce all eight orientations of the symbol.**