Designation: ~~E2566 – 17~~ E2566 – 17a

Standard Test Method for ~~Determining Visual Acuity and Field of View of On-Board Video Systems for Teleoperation of Robots for Urban Search and Rescue Applications~~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 ~~robot models, or across various~~ diverse models or multiple configurations of a ~~particular robot model. They~~ single model. The standards support robot researchers, manufacturers, and user organizations in different ways. Researchers use ~~them~~ the standards to understand mission requirements, encourage innovation, and demonstrate break-through capabilities. Manufacturers use ~~them~~ the standards to evaluate design decisions, integrate emerging technologies, and harden developed systems. User organizations leverage the resulting robot capabilities data to guide ~~purchasing,~~ purchasing decisions, align deployment objectives, and focus training with standard measures of operator proficiency. ~~An associated usage guide describes~~Associated usage guides describe how such standards can be ~~implemented~~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~~Sensing test suite and addresses the visual acuity of onboard cameras.

1. Scope

1.1 ~~This test method covers the measurement of several key parameters of video systems for remote operations. It is initially intended for applications of robots for Urban Search and Rescue but is sufficiently general to be used for marine or other remote platforms. Those parameters are (~~The purpose of this test method is to specify ~~1) field of view of the camera system, (~~the apparatuses, procedures, ~~2) visual acuity at far distances with both ambient lighting and lighting on-board the robot, (~~and performance metrics necessary to quantitatively~~3) visual acuity at near distances, again in both light and dark environments, and (~~ measure a robot's visual acuity as displayed to a remote operator or vision algorithm. The primary performance~~4), if available, visual acuity in both light and dark environments with zoom lens capability.~~ 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.

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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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1.3 ~~These tests measure only end-to-end capability, that is, they determine the resolution of the images on the display screen at the operator control unit since that is the important issue for the user.~~ 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 ~~intended to be used for writing procurement specifications and for acceptance testing for robots for urban search and rescue applications.~~ 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.

1.6 *Performing Location—*This test method ~~will use the Snellen fraction to report visual acuity; readers may wish to convert to decimal notation to improve intuitive understanding if they are more familiar with that notation. Distances will be given in metres with English units in parentheses following.~~ may be performed anywhere the specified apparatuses and environmental conditions can be implemented.

1.7 *Units*—~~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.~~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 ~~*field of view,*~~ *aspect ratio, n*—~~angle subtended by the largest object that can be imaged with the video~~ the ratio of width to height of the image produced by a *camera system*.

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[2] ~~Messina, E., et al., "Statement~~ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For ~~*of Requirements for*~~*Annual Book of ASTM Standards* ~~Urban Search and Rescue Robot Performance Standards," http://www.isd.mel.nist.gov/US&R_Robot_Standards/Requirements Report (prelim).pdf~~ 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.

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 ~~*optotype,*~~ *dynamic range, n*—~~character used~~ a measure of the ability of a *camera system*~~on a chart for testing visual acuity.~~ to, in a single scene, simultaneously observe details on objects in the dark environment and in the environment or environments with certain light intensity.

~~2.1.2.1 *Discussion—*~~

~~Optotypes are generally built on a 5 by 5 grid, with the size for "standard" vision subtending a square 5 min of arc on a side. This makes one grid element 1 min of arc square.~~

3.2.4 ~~*tumbling E,*~~*focal length, n*—~~specific optotype that can be drawn in various orientations (facing left, right, up, or down) and in various sizes to create an eye chart (see~~a measure of how wide or narrow a camera's field of view is. A longer focal length ~~Fig. 1).~~provides a narrower field of view than a shorter one.

~~2.1.3.1 *Discussion—*~~

~~This optoptype is reported in the literature as being maximally distinguishable. Eye charts with Tumbling Es are available commercially for use at different distances.~~

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 ~~*standard vision,*~~ *framerate, n*—~~ability~~ a measure of the temporal resolution of a *camera system*~~to resolve target features subtending 1 min of arc.~~ and refers to the number of complete images per second displayed on a remote system interface.

3.2.7 ~~*visual acuity,*~~ *image, n*—~~ability to resolve features subtending some angle, as compared with "standard" vision measured at the same distance.~~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.

~~2.1.5.1 *Discussion—*~~

~~An angle Θ subtends a feature of size h at a distance d, of size 2h at a distance of 2d, of size 3h at a distance 3d, and so on. If 2d is the "standard" measurement distance of 6 m (20 ft), an eye chart for use at 3 m (10 ft) would have characters of h high rather than 2h high and the measurement of visual acuity would be the same. See Fig. 2 for an illustration of the angle/distance relationship.~~

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 ~~*Snellen fraction,*~~*image resolution, n*—a measure of ~~visual acuity.~~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.

~~2.1.6.1 *Discussion—*~~

~~The subject is placed a standard distance from an eye chart, typically 6 m (20 ft). The subject is asked to identify the line with the smallest characters that he can resolve. The Snellen fraction is the ratio of the distance at which that line would be resolved by a subject with standard vision to the standard test distance. Thus, a subject with standard vision would have 6/6 (20/20) vision.~~

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 ~~*remote operation,*~~ *resolve, ~~n~~—v—*~~act of controlling a distant robot on a continuous or intermittent basis via tethered or radio-linked devices while being provided with sensory information (for example, visual information through cameras onboard the robot).~~the act of discerning the presence of a marking or object.

~~2.1.7.1 *Discussion—*~~

~~Remote operation includes teleoperation as well as forms of intermittent autonomy or assisted autonomy.~~

~~3. Units for Reporting Visual Acuity~~

~~3.1 The commonly used distance for measuring visual acuity is 20 ft in the United States. This leads to the "Snellen fraction" as the common measure of visual acuity: 20/20, 20/40, and so on. The Snellen fraction is also used in England, referred to 6 m as the standard measurement distance (6/6, 6/12, etc.), while the rest of Europe generally used the decimal fraction equivalent: 20/20 = 6/6 = 1.0; 20/40 = 6/12=0.5, etc. Measurements may be taken at any distance and the result scaled to the common distance.~~

~~3.2 The meaning of 6/12 (20/40 or 0.5) is that features that can be resolved at 6 m (20 ft) by the test subject are of a size such that a person with "standard" visual acuity could resolve them at 12 m (40 ft). The characters on the 6/12 (20/40, 0.5) line of an eye chart are twice the size of the characters on the 6/6 (20/20, 1.0) line. The best human vision is not 6/6 (20/20, 1.0), resolving 1 min of arc (1/60° = .016°) but more like 6/3.6 (20/12, 1.7), resolving about 0.01°.~~

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 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.

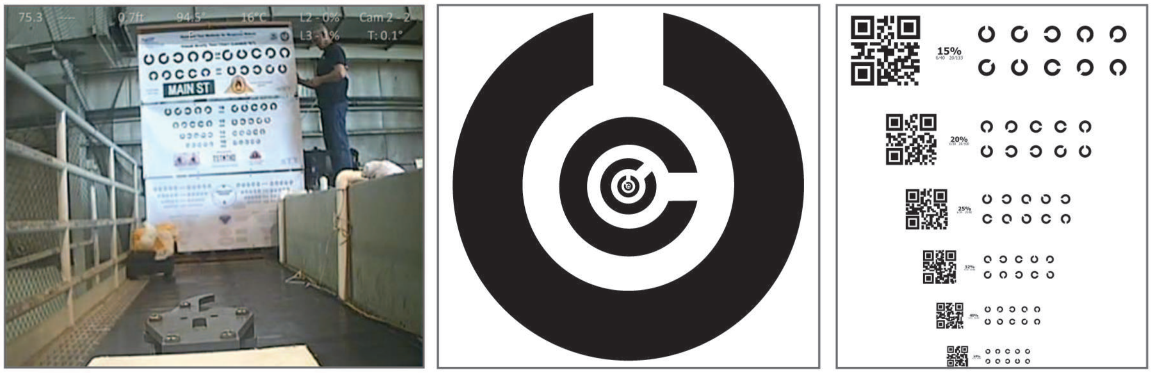

FIG. 1 ~~Tumbling~~(*A* ~~E Optotype in Various Orientations~~) An example of a far-field visual acuity chart as viewed by a robot 6 m [2 ft] away and displayed on a remote operator interface. The chart contains lines of ten standard symbols in incrementally small sizes along with items of interest to 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.

5.2 ~~Responder-defined requirements for these test methods are documented in a preliminary document entitled "Statement of Requirements for Urban Search and Rescue Robot Performance Standards."~~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 ~~Field of View is important in terms of the ability of the operator to drive the robot. Looking at the world through a zoom lens is like "looking through a soda straw." Looking with a 30 or 40° field of view lens is like "driving with blinders on." On the other hand, using a very wide field of view lens (with a field of view of 120 or 150°), the operator's use of optic flow to cue depth perception is severely degraded and navigating in a tight environment is very difficult. Multiple cameras are recommended, with one providing a very wide~~ 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 ~~all together providing a very wide field of view.~~acuity, but not necessarily both. An increase in both may not be possible for robots of a desired weight, endurance, or cost. Appropriate levels of understanding can help ensure that requirement specifications are articulated within the limit of current capabilities.

FIG. 2 ~~Angle Subtended by Various Size Objects at Various Distances~~ This Baseline Image is Used for Purposes of Comparisons Below

FIG. ~~4~~3 ~~Geometry of~~ Three Images of the Same Scene with the Same Image Resolution. Top Row Shows Field of View ~~Determination~~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)

FIG. ~~3~~4 ~~Test of Visual Acuity and Field of View~~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)

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 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.