Designation: E2566 – 17

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[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 configurations of a particular robot model. They support robot researchers, manufacturers, and user organizations in different ways. Researchers use them to understand mission requirements, encourage innovation, and demonstrate break-through capabilities. Manufacturers use them to evaluate design decisions, integrate emerging technologies, and harden systems. User organizations leverage the resulting robot capabilities data to guide purchasing, align deployment objectives, and focus training with standard measures of operator proficiency. An associated usage guide describes how such standards can be implemented 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 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 (*1*) field of view of the camera system, (*2*) visual acuity at far distances with both ambient lighting and lighting on-board the robot, (*3*) visual acuity at near distances, again in both light and dark environments, and (*4*), if available, visual acuity in both light and dark environments with zoom lens capability.

1.2 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.

1.3 This test method is intended to be used for writing procurement specifications and for acceptance testing for robots for urban search and rescue applications.

1.4 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.

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

[1] This test method is under the jurisdiction of ASTM Committee E54 on Homeland Security Applications and is the direct responsibility of Subcommittee E54.08 on Operational Equipment.

Current edition approved Jan. 1, 2017. Published February 2017. Originally approved in 2008. Last previous edition approved in 2008 as E2566 – 08. DOI: 10.1520/E2566-17.

2. Terminology

2.1 *Definitions:*

2.1.1 *field of view, n*—angle subtended by the largest object that can be imaged with the video system.

2.1.2 *optotype, n*—character used on a chart for testing visual acuity.

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.

2.1.3 *tumbling E, 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 Fig. 1).

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.

2.1.4 *standard vision, n*—ability to resolve target features subtending 1 min of arc.

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

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.

2.1.6 *Snellen fraction, n*—a measure of visual acuity.

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.

2.1.7 *remote operation, n*—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).

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. Significance and Use

4.1 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."[2]

4.2 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 field of view or all together providing a very wide field of view.

4.3 Far Vision Visual Acuity is important for both unmanned air vehicles (UAVs) and ground vehicles for wide area survey. Zoom is required for ground vehicles for wide area survey.

4.4 Near Vision Visual Acuity is important for ground vehicles for wide area survey in examining objects at close range and also for small robots which operate in constrained spaces.

4.5 Testing in the dark is important for small robots since they must sometimes operate in spaces with no ambient lighting.

5. Hazards

5.1 There are no hazards and no environmental issues associated with this test method.

[2] Messina, E., et al., "Statement of Requirements for Urban Search and Rescue Robot Performance Standards," http://www.isd.mel.nist.gov/US&R_Robot_Standards/Requirements Report (prelim).pdf

FIG. 1 Tumbling E Optotype in Various Orientations

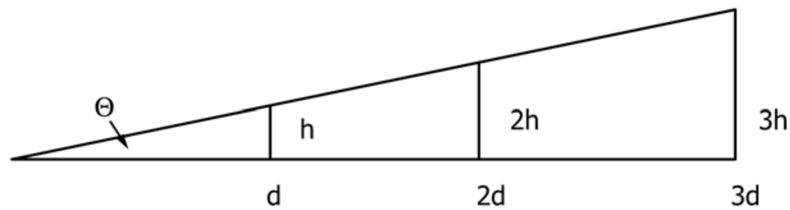

FIG. 2 Angle Subtended by Various Size Objects at Various Distances

6. Procedure

6.1 *Field of View:*

6.1.1 The test environment for 6.2 below is established, with eye charts on a wall and the robot located at a set test distance 6 m (20 ft) away from the wall (see Fig. 3). Vertical lines are drawn on the wall subtending fields of view from the test distance of 20 to 60° (or more if space allows) in increments of 10° and labeled.

6.1.2 Taking the line from the robot camera to the center of the eye chart as the center line, field of view lines need only be drawn to one side because of symmetry.

6.1.3 Determine field of view and record the result.

6.1.4 If the camera lens has a field of view beyond 60°, and test site space does not allow further reference marks, the field of view can be calculated using trigonometry (see Fig. 4).

$$Field\ of\ View = 2\ \phi = 2\ \ tan^{-1}(h/d)$$

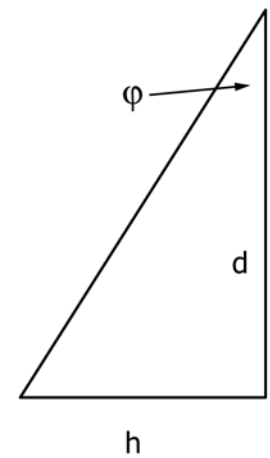

FIG. 4 Geometry of Field of View Determination

FIG. 3 Test of Visual Acuity and Field of View

6.1.4.1 Beyond 100° h becomes very large and using trigonometry may be impractical. The vendor will generally know the field of view of the lens provided with the camera, or an estimate may be made. High precision is not important in determining the field of view since this only provides an indication as to the limitations of the view of the operator when driving the robot. 10° resolution is adequate.

6.1.5 If the robot is equipped with multiple cameras, all cameras used for remote driving shall be measured.

6.2 *Visual Acuity—Far Vision with Ambient Illumination:*

6.2.1 This test determines the visual acuity available to the operator at the operator control unit when the camera on the robot is focused on distant objects (more than a few metres or so distant from the robot). The display on the screen at the operator control unit integrates the effects of camera, the sensor within the camera, digitization of the signals, transmission of the data, reconstruction of the images, and resolution of the display screen. Since the visual image as presented to the operator is the key issue in remote operation, there is no need from the user's perspective to resolve these various contributing factors. Developers of robots, on the other hand, may need to analyze each of these factors separately. This standard is written from the standpoint of evaluation and procurement by the user.

6.2.2 Eye charts are placed on a wall with illumination >1000 lux (typical of room lighting). The optotypes of a standard eye chart for use at 3 m (10 ft) or 6 m (20 ft) typically cover a range from 6/3 to 6/60 or 6/100 (20/10 to 20/200 or 20/300; 2.0 to 0.1 or 0.07). The optotypes thus subtend 2.5 min of arc at the smallest to 50 or 75 min of arc at the largest. As noted earlier, a 3 m eye chart can be used at 6 m and the results scaled (the 6/6 line on a chart designed for 3 m represents 6/3 acuity when used at 6 m). If necessary, larger optotypes can be printed to extend the measurement range to 6/180 (20/600; 0.03), at which point the optotoypes would subtend 2.5°. If the robot has zoom capability, a close range eye chart (for testing reading ability, typically for use at 40 cm (16 in.)) should be mounted below the larger eye chart. Using the 40 cm chart at 6 m and successfully reading the 6/4.5 (20/15, 1.33) line with a zoom lens would be equivalent to 6/0.3 (20/1, 20.0) vision since 600/40 = 15; 15 × 1.33 = 20.0.

6.2.3 The robot is placed so that the camera under test is 6 m (20 ft) from the eye charts. The lowest line that can be read on the operator control unit screen without zoom is determined and recorded.

6.2.4 If the robot has a zoom lens, the lens is run to maximum zoom and the lowest line that can be read is recorded.

6.2.5 When mpeg coding is used for video compression, the operator should report only the lowest line at which all four bars of the "E" are distinguishable. The discrete cosine transform used in mpeg coding highlights the asymmetric side bar of the "E" with the lowest spatial frequency filter and allows interpretation of the orientation of the characters below the level at which the character can actually be distinguished. Care should be taken not to introduce a bias in this case.

6.3 *Visual Acuity—Near Vision with Ambient Illumination:*

6.3.1 This test establishes the ability of the operator to use the robot to examine objects at close distances.

6.3.2 An eye chart designed for testing visual acuity for reading is used. The typical test distance is 40 cm (16 in.).

6.3.3 Place the eye chart at the distance for which it was designed from the camera. The eye chart should be mounted at the height of the camera. Illumination at the eye chart should be >1000 lux.

6.3.4 Read the lowest line that can be distinguished on the operator control unit screen and record the result.

6.3.5 Use the zoom and read the lowest line that can be resolved and record the result. Zoom lenses can lose focus at close ranges, so only a portion of the full zoom capability will be available.

6.3.6 As noted above, only the line at which all four bars of the "E" can be distinguished should be reported.

6.4 *Visual Acuity—Far Vision with Illumination from the Robot:*

6.4.1 This test determines the visual acuity available to the operator at the operator control unit when the robot is operating in the dark.

6.4.2 The same test as 6.2 is run in a dark environment (ambient illumination at the eye chart of <1 lux) and the results recorded.

6.4.3 As noted above, only the line at which all four bars of the "E" can be distinguished should be reported.

6.5 *Visual Acuity—Near Vision with Illumination from the Robot:*

6.5.1 Test 6.3 is repeated in the dark environment (illumination <1 lux) and the results recorded.

NOTE 1—Variable illumination from the robot is necessary to successfully image both the distant vision eye chart 6 m (20 ft) and the near vision eye chart 40 cm (16 in.) since light intensity necessary for viewing the distant chart will typically overwhelm the automatic gain control of the camera at the close distance.

6.5.2 As noted above, only the line at which all four bars of the "E" can be distinguished should be reported.

7. Report

7.1 The data collection form used by NIST, shown in Fig. 5, provides spaces for entry of all measured data. Use of this form is not a requirement of this test method.

8. Precision and Bias

8.1 Proper use of this field of view test method to measure the field of view will result in an uncertainty of ±5°, one half the spacing of the indicator lines used to make the measurement.

8.2 *Precision of Visual Acuity Tests:*

8.2.1 Eye charts are all quantized. The measurement reported is the lowest line that can be read. Repeatability tests show that almost all operators will report one of two adjacent values.

8.2.2 The lines on the Tumbling E eye charts used in this test method are not strictly proportional, the heights being chosen to provide as close to one significant figure resolution as possible while maintaining correlation between English and metric charts. For example, one significant figure resolution

Data Collection Form

Standard Test Methods For Response Robots

Visual Acuity and Field of View

Robot Model: ________________ ☐ Tether ☐ RF

Company/Org: ______________ Operator: ________________

Skill Level: ☐ Novice ☐ Intermediate ☐ Expert

INSTRUCTIONS: 1) Note optical capabilities of robot. 2) Note the lux level of lighted and dark charts. 3) Place the *far field* Snellen charts at a distance of 6 m. 4) Place *near field* Snellen chart at a distance of 40 cm. 5) Circle the decimal equivalent for the smallest correct line read normally and with zoom. 6) Repeat with lights out (lighting levels less than 1 lux).

FOV:____° Pan:____° Tilt:____° Zoom:____*x* Illumination: Y | N Variable: Y | N

Far Field Test (Distance = 6.0 m)

TEST DISTANCE 6 m	(20 Ft.)	LIGHTED CHART (______ LUX) NORMAL	ZOOM	DARK CHART (______ LUX) NORMAL	ZOOM
LARGER CHARACTER EXTENSION TO FAR FIELD CHART					
6/90	(20/300)	0.07	0.07	0.07	0.07
6/75	(20/250)	0.08	0.08	0.08	0.08
6/60	(20/200)	0.10	0.10	0.10	0.10
6/45	(20/150)	0.13	0.13	0.13	0.13
FAR FIELD CHART (6 m)					
6/30	(20/100)	0.20	0.20	0.20	0.20
6/24	(20/80)	0.25	0.25	0.25	0.25
6/18	(20/60)	0.33	0.33	0.33	0.33
6/15	(20/50)	0.40	0.40	0.40	0.40
6/12	(20/40)	0.50	0.50	0.50	0.50
6/9	(20/30)	0.67	0.67	0.67	0.67
6/7.5	(20/25)	0.80	0.80	0.80	0.80
6/6	(20/20)	1.00	1.00	1.00	1.00
6/4.8	(20/16)	1.25	1.25	1.25	1.25
6/3.8	(20/12)	1.7	1.7	1.7	1.7
6/3.0	(20/10)	2.0	2.0	2.0	2.0
6/2.4	(20/8)	2.5	2.5	2.5	2.5
6/1.7	(20/6)	3.3	3.3	3.3	3.3
6/1.5	(20/5)	4.0	4.0	4.0	4.0
NEAR FIELD CHART (Bottom Nine Lines Adjusted To 6 m)					
6/1.25	(20/4)	5.0	5.0	5.0	5.0
6/1.00	(20/3.3)	6.0	6.0	6.0	6.0
6/0.8	(20/2.7)	7.5	7.5	7.5	7.5
6/0.6	(20/2.0)	10	10	10	10
6/0.5	(20/1.7)	12	12	12	12
6/0.40	(20/1.3)	15	15	15	15
6/0.3	(20/1.1)	20	20	20	20
6/0.25	(20/.08)	24	24	24	24
6/0.20	(20/.07)	30	30	30	30

VISUAL ACUITY RATIOS NOTED MEAN:

READABLE AT ACTUAL TEST DISTANCE

READABLE DISTANCE WITH STANDARD VISION

CIRCLE DECIMAL EQUIVALENT IN EACH COLUMN

Near Field Test (distance = 0.40 m)

EQUIVALENT DISTANCE 6 m	(20 FT)	LIGHTED CHART (______ LUX) NORMAL	ZOOM	DARK CHART (______ LUX) NORMAL	ZOOM
NEAR FIELD CHART (All Lines Shown for 0.4 m)					
6/120	(20/400)	0.05	0.05	0.05	0.05
6/96	(20/320)	0.06	0.06	0.06	0.06
6/75	(20/250)	0.08	0.08	0.08	0.08
6/60	(20/200)	0.10	0.10	0.10	0.10
6/48	(20/160)	0.12	0.12	0.12	0.12
6/38	(20/125)	0.16	0.16	0.16	0.16
6/30	(20/100)	0.20	0.20	0.20	0.20
6/24	(20/80)	0.25	0.25	0.25	0.25
6/19	(20/63)	0.32	0.32	0.32	0.32
6/15	(20/50)	0.40	0.40	0.40	0.40
6/12	(20/40)	0.50	0.50	0.50	0.50
6/9.5	(20/32)	0.63	0.63	0.63	0.63
6/7.5	(20/25)	0.80	0.80	0.80	0.80
6/6.0	(20/20)	1.00	1.00	1.00	1.00
6/4.8	(20/16)	1.25	1.25	1.25	1.25
6/3.8	(20/12)	1.60	1.60	1.60	1.60
6/3.0	(20/10)	2.00	2.00	2.00	2.00

Test Leader Date Notes ☐

FIG. 5 Example Data Collection Form for Visual Acuity and Field of View Tests

with metric ratios only would be 6/6, 6/7, 6/8, 6/9—but English charts run 20/20, 20/25, 20/30—so the metric charts use the sequence 6/6, 6/7.5, 6/9. The ratio of 6/6 to 6/7.5 is 0.80. With strictly proportional spacing the next higher line would be 6/9.375, which is rounded to 6/9.

8.2.3 The average ratio is 0.8, a scaling for a given line 20 % smaller than the line above. The standard deviation has been measured with different robots and operators as no more than 13 % of the mean value. For a single measurement, the two standard deviation error is ±26 %.

NOTE 2—"+" is worse visual acuity and "–" is better visual acuity than that measured.

8.3 *Bias:*

8.3.1 One variable that was found to introduce a possible bias was lighting level. Significant degradation in visual acuity was seen at light levels less than 100 lux. The light level specified in the test method is >1000 lux, which corresponds to typical good indoor lighting.

8.3.2 A second source of bias is introduced when mpeg coding is used for compressing the video for transmission. The discrete cosine transform used in mpeg coding picks up the asymmetric side bar of the "E" with the lowest spatial frequency filter and allows interpretation of the orientation at a level below which the four bars of the "E" can be distinguished. This is particularly noted when the camera lens has zoom capability as operators are observed moving the zoom back and forth to match the spatial filter size to the character size. As noted in Section 6, the operator must be directed to report only the level at which all four bars of the "E" character can be distinguished.

9. Keywords

9.1 field of view; remote operation; robots; teleoperation; urban search and rescue; video systems; visual acuity