Designation: E2938 – 15

Standard Test Method for Evaluating the Relative-Range Measurement Performance of 3D Imaging Systems in the Medium Range[1]

This standard is issued under the fixed designation E2938; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard describes a quantitative test method for evaluating the range measurement performance of laser-based, scanning, time-of-flight, *3D imaging systems* in the medium range. The term "medium range" refers to systems that are capable of operating within at least a portion of ranges from 2 to 150 m. The term "time-of-flight systems" includes phase-based, pulsed, and chirped systems. The word "standard" in this document refers to a *documentary standard* as per Terminology E284. This test method only applies to 3D imaging systems that are capable of producing a *point cloud* representation of a measured target.

1.1.1 As defined in Terminology E2544, a *range* is the distance measured from the origin of a 3D imaging system to a point in space. This range is often referred to as an absolute range. However, since the origin of many 3D imaging systems is either unknown or not readily measurable, a test method for absolute range performance is not feasible for these systems. Therefore, in this test method, the range is taken to be the distance between two points in space on a line that passes through the origin of the 3D imaging system. Although the error in the calculated distance between these two points is a *relative-range error*, in this test method when the term range error is used it refers to the relative-range error. This test method cannot be used to quantify the constant offset error component of the range error.

1.1.2 This test method recommends that the first point be at the manufacturer-specified *target 1 range* and requires that the second target be on the same side of the instrument under test (IUT) as the first target. Specification of *target 1 range* by the manufacturer minimizes the contribution to the relative range measurement error from the target 1 range measurement.

1.1.3 This test method may be used once to evaluate the IUT for a given set of conditions or it may be used multiple times to better assess the performance of the IUT for various conditions (for example, additional ranges, various reflectances, environmental conditions).

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard. SI units are used for all calculations and results in this standard.

1.3 The method described in this standard is not intended to replace more in-depth methods used for instrument calibration or compensation, and specific measurement applications may require other tests and analyses.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Some aspects of the safe use of 3D Imaging Systems are discussed in Practice ASTM E2641.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E284 Terminology of Appearance

E1164 Practice for Obtaining Spectrometric Data for Object-Color Evaluation

E1331 Test Method for Reflectance Factor and Color by Spectrophotometry Using Hemispherical Geometry

E2544 Terminology for Three-Dimensional (3D) Imaging Systems

E2641 Practice for Best Practices for Safe Application of 3D Imaging Technology

2.2 *ASME Standards:*[3]

ASME B89.1.9-2002 Gage Blocks

ASME B89.4.19-2006 Performance Evaluation of Laser-Based Spherical Coordinate Measurement Systems

ASME B89.7.2-1999 Dimensional Measurement Planning

[1] This test method is under the jurisdiction of ASTM Committee E57 on 3D Imaging Systems and is the direct responsibility of Subcommittee E57.02 on Test Methods.

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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 American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.

2.3 *ISO Standards:*[4]

ISO 14253-1:1998 Geometrical Product Specifications (GPS)—Inspection by measurement of workpieces and measuring equipment—Part 1: Decision rules for proving conformance or non-conformance with specifications

ISO 14253-2:1999 Geometrical Product Specifications (GPS)—Inspection by measurement of workpieces and measuring equipment—Part 2: Guide to the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification

2.4 *JCGM Standards:*

JCGM 200:2012 International vocabulary of metrology—Basic and general concepts and associated terms (VIM), 3rd edition

JCGM 100:2008 Evaluation of measurement data—Guide to the expression of uncertainty in measurement (GUM), 1st edition

3. Terminology

3.1 *Definitions:*

3.1.1 *3D imaging system, n*—a non-contact measurement instrument used to produce a 3D representation (for example, a point cloud) of an object or a site. **E2544**

3.1.1.1 *Discussion*—Some examples of a 3D imaging system are laser scanners (also known as LADARs or LIDARs or laser radars), optical range cameras (also known as flash LIDARs or 3D range cameras), triangulation-based systems such as those using pattern projectors or lasers, and other systems based on interferometry.

3.1.1.2 *Discussion*—In general, the information gathered by a 3D imaging system is a collection of *n*-tuples, where each *n*-tuple can include but is not limited to spherical or Cartesian coordinates, return signal strength, color, time stamp, identifier, polarization, and multiple range returns.

3.1.1.3 *Discussion*—3D imaging systems are used to measure from relatively small scale objects (for example, coin, statue, manufactured part, human body) to larger scale objects or sites (for example, terrain features, buildings, bridges, dams, towns, archeological sites).

3.1.2 *calibration, n*—operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication. **JCGM 200:2012 (VIM) – 2.39**

3.1.3 *combined standard uncertainty, n*—standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes in these quantities. **JCGM 100:2008 (GUM) – 2.3.4**

3.1.4 *compensation, n*—the process of determining systematic errors in an instrument and then applying these values in an error model that seeks to eliminate or minimize measurement errors. **ASME B89.4.19**

3.1.5 *covariance*—the covariance of two random variables is a measure of their mutual dependence. **JCGM 100:2008 (GUM) – C.3.4**

3.1.6 *coverage factor, n*—numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty.

3.1.6.1 *Discussion*—A coverage factor, *k*, is typically in the range 2 to 3. **JCGM 100:2008 (GUM) 2.3.6**

3.1.7 *diffuse reflectance factor, R_d, n*—the ratio of the flux reflected at all angles within the hemisphere bounded by the plane of measurement except in the direction of the specular reflection angle, to the flux reflected from the perfect reflecting diffuser under the same geometric and spectral conditions of measurement. **E284 Section 3.1**

3.1.7.1 *Discussion*—The size of the specular reflection angle depends on the instrument and the measurement conditions used. For its precise definition the make and model of the instrument or the aperture angle or aperture solid angle of the specularly reflected beam should be specified.

3.1.8 *documentary standard, n*—document, arrived at by open consensus procedures, specifying necessary details of a method of measurement, definitions of terms, or other practical matters to be standardized. **E284**

3.1.9 *expanded test uncertainty, n*—product of a combined standard measurement uncertainty and a factor larger than the number one. **JCGM 200:2012 (VIM) – 2.35**

3.1.10 *flatness, n*—the minimum distance between two parallel planes between which all points of the measuring face lie. **ASME B89.1.9 – 3.5**

3.1.11 *limiting conditions, n*—the manufacturer's specified limits on the environmental, utility, and other conditions within which an instrument may be operated safely and without damage. **ASME B89.4.19**

3.1.11.1 *Discussion*—The manufacturer's performance specifications are not assured over the limiting conditions.

3.1.12 *maximum permissible error (MPE), n*—extreme value of measurement error, with respect to a known reference quantity value, permitted by specifications or regulations for a given measurement, measuring instrument, or measuring system. **JCGM 200:2012 (VIM) – 4.26**

3.1.12.1 *Discussion*—Usually, the term "maximum permissible errors" or "limits of error" is used where there are two extreme values.

3.1.12.2 *Discussion*—The term "tolerance" should not be used to designate 'maximum permissible error'.

3.1.13 *measurand, n*—quantity intended to be measured. **JCGM 200:2012 (VIM) – 2.3**

3.1.13.1 *Discussion*—The specification of a measurand requires knowledge of the kind of quantity, description of the state of the phenomenon, body, or substance carrying the quantity, including any relevant component, and the chemical entities involved.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.1.13.2 *Discussion*—In the second edition of the VIM and in IEC 60050-300:2001, the measurand is defined as the 'quantity subject to measurement'.

3.1.13.3 *Discussion*—The measurement, including the measuring system and the conditions under which the measurement is carried out, might change the phenomenon, body, or substance such that the quantity being measured may differ from the measurand as defined. In this case, adequate correction is necessary.

Example 1—The potential difference between the terminals of a battery may decrease when using a voltmeter with a significant internal conductance to perform the measurement. The open-circuit potential difference can be calculated from the internal resistances of the battery and the voltmeter.

Example 2—The length of a steel rod in equilibrium with the ambient Celsius temperature of 23°C will be different from the length at the specified temperature of 20°C, which is the measurand. In this case, a correction is necessary.

3.1.13.4 *Discussion*—In chemistry, "analyte", or the name of a substance or compound, are terms sometimes used for 'measurand'. This usage is erroneous because these terms do not refer to quantities.

3.1.14 *measurement accuracy, n*—closeness of agreement between a measured quantity value and a true quantity value of a measurand. **JCGM 200:2012 (VIM) – 2.13**

3.1.14.1 *Discussion*—The concept 'measurement accuracy' is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.

3.1.14.2 *Discussion*—The term "measurement accuracy" should not be used for measurement trueness and the term measurement precision should not be used for 'measurement accuracy', which, however, is related to both these concepts.

3.1.14.3 *Discussion*—'Measurement accuracy' is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

3.1.15 *measurement error, n*—measured quantity value minus a reference quantity value. **JCGM 200:2012 (VIM) – 2.16**

3.1.15.1 *Discussion*—The concept of 'measurement error' can be used both: *(1)* when there is a single reference quantity value to refer to, which occurs if a calibration is made by means of a measurement standard with a measured quantity value having a negligible measurement uncertainty or if a conventional quantity value is given, in which case the measurement error is known; and *(2)* if a measurand is supposed to be represented by a unique true quantity value or a set of true quantity values of negligible range, in which case the measurement error is not known.

3.1.15.2 *Discussion*—Measurement error should not be confused with production error or mistake.

3.1.16 *measurement uncertainty, n*—non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used. **JCGM 200:2012 (VIM) – 2.26**

3.1.16.1 *Discussion*—Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated.

3.1.16.2 *Discussion*—The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

3.1.16.3 *Discussion*—Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

3.1.16.4 *Discussion*—In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

3.1.17 *point cloud, n*—a collection of data points in 3D space (frequently in the hundreds of thousands), for example as obtained using a 3D imaging system. **E2544**

3.1.17.1 *Discussion*—The distance between points is generally non-uniform and hence all three coordinates (Cartesian or spherical) for each point must be specifically encoded.

3.1.18 *range, n*—the distance, in units of length, between a point in space and an origin fixed to the 3D imaging system that is measuring that point. **E2544**

3.1.18.1 *Discussion*—In general, the origin corresponds to the instrument origin.

3.1.19 *rated conditions, n*—manufacturer-specified limits on environmental, utility, and other conditions within which the manufacturer's performance specifications are guaranteed at the time of installation of the instrument. **ASME B89.4.19**

3.1.20 *repeatability (of results of measurements), n*—closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement. **JCGM 200:2012 (VIM) – 3.6**

3.1.20.1 *Discussion*—These conditions are called repeatability conditions.

3.1.20.2 *Discussion*—Repeatability conditions include: the same measurement procedure; the same observer; the same measuring instrument used under the same conditions; the same location; and repetition over a short period of time.

3.1.20.3 *Discussion*—Repeatability may be expressed quantitatively in terms of the dispersion characteristics of the results.

3.1.21 *reflectance, n*—ratio of the reflected radiant or luminous flux to the incident flux in the given conditions. **E284 Section 3.1**

3.1.21.1 *Discussion*—The term reflectance is often used in a general sense or as an abbreviation for reflectance factor. Such usage may be assumed unless the above definition is specifically required by context.