Designation: E3125 – 17

Standard Test Method for Evaluating the Point-to-Point Distance Measurement Performance of Spherical Coordinate 3D Imaging Systems in the Medium Range[1]

This standard is issued under the fixed designation E3125; 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 test method covers the performance evaluation of laser-based, scanning, time-of-flight, single-detector 3D imaging systems in the medium-range and provides a basis for comparisons among such systems. This standard best applies to spherical coordinate 3D imaging systems that are capable of producing a point cloud representation of an object of interest. In particular, this standard establishes requirements and test procedures for evaluating the derived-point to derived-point distance measurement performance throughout the work volume of these systems. Although the tests described in this standard may be used for non-spherical coordinate 3D imaging systems, the test method may not necessarily be sensitive to the error sources within those instruments.

1.2 System performance is evaluated by comparing measured distance errors between pairs of derived-points to the manufacturer-specified, maximum permissible errors (MPEs). In this standard, a derived-point is a point computed using multiple measured points on the target surface (such as the center of a sphere). In the remainder of this standard, the term point-to-point distance refers to the distance between two derived-points.

1.3 The term "medium-range" refers to systems that are capable of operating within at least a portion of the ranges from 2 m 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 in accordance with Terminology E284.

1.4 This test method may be used once to evaluate the Instrument Under Test (IUT) for a given set of conditions or it may be used multiple times to assess the performance of the IUT for various conditions (for example, surface reflectance factors, environmental conditions).

1.5 SI units are used for all calculations and results in this standard.

1.6 This test method 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.

1.7 *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.* Some aspects of the safe use of 3D imaging systems are discussed in Practice E2641.

1.8 *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]

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
E2919 Test Method for Evaluating the Performance of Systems that Measure Static, Six Degrees of Freedom (6DOF), Pose

[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.

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2.2 *ASME Standards:*[3]

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

ASME B89.7.3.1-2001 Guidelines for Decision Rules: Considering Measurement Uncertainty in Determining Conformance to Specifications

ASME Y14.5-2009 Dimensioning and Tolerancing

2.3 *ISO Standards:*[4]

ISO 1:2016 Geometrical product specifications (GPS)—Standard reference temperature for the specification of geometrical and dimensional properties

ISO 10360-10:2016 Geometrical product specifications (GPS)—Acceptance and reverification tests for coordinate measuring systems (CMS)—Part 10: Laser trackers for measuring point-to-point distances

2.4 *JCGM Standards:*

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

JCGM 200:2012 International vocabulary of metrology—Basic and general concepts and associated terms (VIM), 3rd 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. **E2544-11a – 3.2**

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 *beam width, n*—the extent of the irradiance distribution in a cross section of a laser beam (in a direction orthogonal to its propagation path). **E2544-11a – 3.2**

3.1.3 *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**

3.1.4 *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**

3.1.5 *coverage factor, n*—numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty. **JCGM 100:2008 (GUM) – 2.3.6**

3.1.5.1 *Discussion*—A coverage factor, k, is typically in the range 2 to 3.

3.1.6 *diffuse reflectance factor, 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. **E284-13b – 4.1**

3.1.6.1 *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.

3.1.7 *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. **E284-13b – 4.1**

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

3.1.9 *limiting conditions, n*—manufacturer's specified limits on the environmental, utility, and other conditions within which an instrument may be operated safely and without damage. **ASME B89.4.19-2006 – 4**

3.1.9.1 *Discussion*—Manufacturer's performance specifications are not assured over the limiting conditions.

3.1.10 *maximum permissible measurement error (maximum permissible error), 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**

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

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

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

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

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

3.1.11.1 *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.

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

3.1.11.3 *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 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.

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

3.1.12.1 *Discussion*—The concept of 'measurement error' can be used both a) 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 b) 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.

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

3.1.13 *measurement precision, n*—closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions. **JCGM 200:2012 (VIM) – 2.15**

3.1.14 *measurement repeatability, n*—measurement precision under a set of repeatability conditions of measurement. **JCGM 200:2012 (VIM) – 2.21**

3.1.14.1 *Discussion*—See also 3.1.13, *measurement precision*, and 3.1.21, *repeatability condition of measurement*.

3.1.15 *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**

3.1.15.1 *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.

3.1.15.2 *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.

3.1.15.3 *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.

3.1.15.4 *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.

3.1.16 *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. **E2544-11a – 3.2**

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

3.1.17 *rated conditions, n*—manufacturer-specified limits on the environmental, utility, and other conditions within which the manufacturer's performance specifications are guaranteed at the time of installation of the instrument. **ASME B89.4.19-2006 - 4**

3.1.18 *reference length, n*—calibrated value of the distance between two points in space at the time and conditions when a test is performed. **ASME B89.4.19-2006 – 4**

3.1.19 *reflectance, n*—ratio of the reflected radiant or luminous flux to the incident flux in the given conditions. **E284-13b – 4.1**

3.1.19.1 *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.

3.1.20 *reflectance factor, n*—ratio of the flux reflected from the specimen to the flux reflected from the perfect reflecting diffuser under the same geometric and spectral conditions of measurement. **E284-13b – 4.1**

3.1.21 *repeatability condition of measurement, n*—condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time. **JCGM 200:2012 (VIM) – 2.20**

3.1.22 *retroreflector, n*—passive device that reflects light back parallel to the incident direction over a range of incident angles. **ASME B89.4.19-2006 – 4**

3.1.22.1 *Discussion*—Typical retroreflectors are the cat's-eye and the cube corner.

3.1.23 *spherically mounted retroreflector (SMR), n*—retroreflector that is mounted in a spherical housing. **ASME B89.4.19-2006 – 4**