Designation: E2919 – 22

Standard Test Method for Evaluating the Performance of Systems that Measure Static, Six Degrees of Freedom (6DOF), Pose[1]

This standard is issued under the fixed designation E2919; 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 *Purpose*—In this test method, metrics and procedures for collecting and analyzing data to determine the performance of a pose measurement system in computing the pose (position and orientation) of a rigid object are provided.

1.2 This test method applies to the situation in which both the object and the pose measurement system are static with respect to each other when measurements are performed. Vendors may use this test method to establish the performance limits for their six degrees of freedom (6DOF) pose measurement systems. The vendor may use the procedures described in 9.2 to generate the test statistics, then apply an appropriate margin or scaling factor as desired to generate the performance specifications. This test method also provides a uniform way to report the relative or absolute pose measurement capability of the system, or both, making it possible to compare the performance of different systems.

1.3 *Test Location*—The methodology defined in this test method shall be performed in a facility in which the environmental conditions are within the pose measurement system's rated conditions and meet the user's requirements.

1.4 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *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]

E456 Terminology Relating to Quality and Statistics

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

2.2 *ANSI/NCSL Standard:*[3]

ANSI/NCSL Z540.3:2006 Requirements for the Calibration of Measuring and Test Equipment

2.3 *ASME Standard:*[4]

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

2.4 *ISO/IEC Standards:*[5]

JCGM 100:2008 Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement (GUM)

JCGM 106:2012 Evaluation of measurement data – The role of measurement uncertainty in conformity assessment

JCGM 200:2012 International Vocabulary of Metrology—Basic and General Concepts and Associated Terms (VIM), 3rd edition

IEC 60050-300:2001 International Electrotechnical Vocabulary—Electrical and Electronic Measurements and Measuring Instruments

3. Terminology

3.1 *Definitions from Other Standards:*

3.1.1 *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**

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

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

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

3.1.1.1 *Discussion—*

(1) A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

(2) Calibration should not be confused with either adjustment of a measuring system, often mistakenly called "self-calibration," or verification of calibration.

(3) Often, the first step alone in 3.1.1 is perceived as being calibration.

3.1.2 *maximum permissible measurement error, maximum permissible error, and limit of 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**

3.1.2.1 *Discussion—*

(1) Usually, the terms "maximum permissible errors" or "limits of error" are used when there are two extreme values.

(2) The term "tolerance" should not be used to designate "maximum permissible error."

3.1.3 *measurand, n*—quantity intended to be measured. **JCGM 200:2012**

3.1.3.1 *Discussion—*

(1) 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.

(2) In the second edition of the VIM and IEC 60050-300, the measurand is defined as the "quantity subject to measurement."

(3) 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.

(a) 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.

(b) 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.

(4) 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.

3.1.4 *measurement error, error of measurement, and error, n*—measured quantity value minus a reference quantity value. **JCGM 200:2012**

3.1.4.1 *Discussion—*

(1) 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.

(2) Measurement error should not be confused with production error or mistake.

3.1.5 *measurement sample and sample, n*—group of observations or test results, taken from a larger collection of observations or test results, that serves to provide information that may be used as a basis for making a decision concerning the larger collection. **E456**

3.1.6 *measurement uncertainty, uncertainty of measurement, and 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**

3.1.6.1 *Discussion—*

(1) 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.

(2) 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) 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.

(4) 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.

3.1.7 *precision, n*—closeness of agreement between independent test results obtained under stipulated conditions. **E456**

3.1.7.1 *Discussion—*

(1) Precision depends on random errors and does not relate to the true value or the specified value.

(2) The measure of precision is usually expressed in terms of imprecision and computed as a standard deviation of the test results. Less precision is reflected by a larger standard deviation.

(3) "Independent test results" means results obtained in a manner not influenced by any previous result on the same or similar test object. Quantitative measures of precision depend

critically on the stipulated conditions. Repeatability and reproducibility conditions are particular sets of extreme stipulated conditions.

3.1.8 *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**

3.1.9 *reference quantity value and reference value, n*—quantity value used as a basis for comparison with values of quantities of the same kind. **JCGM 200:2012**

3.1.9.1 *Discussion*—

(1) A reference quantity value can be a true quantity value of a measurand, in which case it is unknown, or a conventional quantity value, in which case it is known.

(2) A reference quantity value with associated measurement uncertainty is usually provided with reference to:

(a) A material, for example, a certified reference material;

(b) A device, for example, a stabilized laser;

(c) A reference measurement procedure; and

(d) A comparison of measurement standards.

3.1.10 *registration, n*—process of determining and applying to two or more datasets the transformations that locate each dataset in a common coordinate system so that the datasets are aligned relative to each other. **E2544**

3.1.10.1 *Discussion*—

(1) A three-dimensional (3D) imaging system generally collects measurements in its local coordinate system. When the same scene or object is measured from more than one position, it is necessary to transform the data so that the datasets from each position have a common coordinate system.

(2) Sometimes the registration process is performed on two or more datasets that do not have regions in common. For example, when several buildings are measured independently, each dataset may be registered to a global coordinate system instead of to each other.

(3) In the context of this definition, a dataset may be a mathematical representation of surfaces or may consist of a set of coordinates, for example, a point cloud, a 3D image, control points, survey points, or reference points from a computer-aided drafted (CAD) model. Additionally, one of the datasets in a registration may be a global coordinate system (as in 3.1.10.1*(2)*).

(4) The process of determining the transformation often involves the minimization of an error function, such as the sum of the squared distances between features (for example, points, lines, curves, and surfaces) in two datasets.

(5) In most cases, the transformations determined from a registration process are rigid body transformations. This means that the distances between points within a dataset do not change after applying the transformations, that is, rotations and translations.

(6) In some cases, the transformations determined from a registration process are nonrigid body transformations. This means that the transformation includes a deformation of the dataset. One purpose of this type of registration is to attempt to compensate for movement of the measured object or deformation of its shape during the measurement.

(7) Registration between two point clouds is sometimes referred to as cloud-to-cloud registration, between two sets of control or survey points as target-to-target, between a point cloud and a surface as cloud-to-surface, and between two surfaces as surface-to-surface.

(8) The word alignment is sometimes used as a synonymous term for registration. However, in the context of this definition, an alignment is the result of the registration process.

3.1.11 *true quantity value, true value of a quantity, and true value, n*—quantity value consistent with the definition of a quantity. **JCGM 200:2012**

3.1.11.1 *Discussion*—

(1) In the error approach to describing measurement, a true quantity value is considered unique and, in practice, unknowable. The uncertainty approach is to recognize that, owing to the inherently incomplete amount of detail in the definition of a quantity, there is not a single true quantity value but rather a set of true quantity values consistent with the definition. However, this set of values is, in principle and practice, unknowable. Other approaches dispense altogether with the concept of true quantity value and rely on the concept of metrological compatibility of measurement results for assessing their validity.

(2) In the special case of a fundamental constant, the quantity is considered to have a single true quantity value.

(3) When the definitional uncertainty associated with the measurand is considered to be negligible compared to the other components of the measurement uncertainty, the measurand may be considered to have an "essentially unique" true quantity value. This is the approach taken by JCGM 100 and associated documents in which the word "true" is considered to be redundant.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *absolute pose, n*—pose of an object in the coordinate frame of the system under test.

3.2.2 *degree of freedom, DOF, n*—any of the minimum number of translation or rotation components required to specify completely the pose of a rigid body.

3.2.2.1 *Discussion*—

(1) In a 3D space, a rigid object can have at most 6DOFs, three translation and three rotation.

(2) The term "degree of freedom" is also used with regard to statistical testing. It will be clear from the context in which it is used whether the term relates to a statistical test or the rotation/translation aspect of the object.

3.2.3 *pose, n*—a 6DOF vector whose components represent the position and orientation of a rigid object with respect to a coordinate frame.

3.2.4 *pose measurement system, n*—a 3-D imaging system that measures the pose of an object.

3.2.4.1 *Discussion*—This system can consist of both hardware and software.

3.2.5 *reference system, n*—a measurement instrument or system used to generate a reference value or quantity.

3.2.6 *relative pose, n*—change of an object's pose between two poses measured in the same coordinate frame.