Designation: E3124 – 17

Standard Test Method for Measuring System Latency Performance of Optical Tracking Systems that Measure Six Degrees of Freedom (6DOF) Pose[1]

This standard is issued under the fixed designation E3124; 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*—This test method presents metrics and a procedure for measuring, analyzing, and reporting the system latency of an optical tracking system (OTS) that computes the pose of a rigid object.

1.2 *Usage*—System vendors may use this test method to determine or validate the system latency in their tracking systems. This test method provides a uniform way to measure and report the system latency along with the uncertainty in the system latency. System users may use this test method to verify that the system latency performance is within the user's specific requirements and within the system's rated performance.

1.3 This standard does not measure the display latency of graphical representations of the tracked objects. Display latency is external to the optical tracking system.

1.4 *Test Location*—The procedures defined in this test method shall be performed in an environment conforming to the manufacturer's rated conditions.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *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.*

1.7 *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]

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E2655 Guide for Reporting Uncertainty of Test Results and Use of the Term Measurement Uncertainty in ASTM Test Methods

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

E3064 Test Method for Evaluating the Performance of Optical Tracking Systems that Measure Six Degrees of Freedom (6DOF) Pose

2.2 *ASME Standard:*[3]

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

3. Terminology

3.1 *Definitions:*

3.1.1 *degrees of freedom, DOF, n*—any of the minimum number of translation or rotation components required to specify completely the pose of a rigid object. **E2919**

3.1.1.1 *Discussion*—

(1) In a 3D space, a rigid object's pose can be minimally represented by 6DOF, three translations and three rotations.

(2) The term "degrees 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.

3.1.2 *frame rate, n*—frequency at which a camera acquires consecutive images.

3.1.3 *integration time, n*—the length of time when the digital sensor inside a camera collects light.

[1] This test method is under the jurisdiction of ASTM Committee E57 on 3D Imaging Systems and is the direct responsibility of Subcommittee E57.50 on Optical Tracking Systems.

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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.

3.1.3.1 *Discussion*—In some systems integration time is also called exposure time.

3.1.4 *optical image event, n*—the instant in time when the OTS registers an event.

3.1.4.1 *Discussion*—In most systems, it is defined either by the beginning or the center of the image integration time.

3.1.5 *optical tracking system, n*—a tracking system that uses measurements obtained from camera images. **E3064**

3.1.6 *physical event, n*—a point in time corresponding to the physical motion of a target object tracked by the OTS in the test space (see Fig. 1).

3.1.7 *physical event latency, n*—time between an actual occurrence and OTS report of the corresponding occurrence.

3.1.8 *pose, n*—a 6DOF vector whose components represent the position and orientation of a rigid object with respect to a coordinate frame. **E2919**

3.1.9 *precision, n*—the closeness of agreement between independent test results obtained under stipulated conditions. **E177**

3.1.10 *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**

3.1.11 *standard uncertainty, n*—uncertainty reported as the standard deviation of the estimated value of the quantity subject to measurement. **E2655**

3.1.12 *system latency, n*—the elapsed time between the optical image event and the instant in time when the client receives the 6DOF pose information corresponding to that event from the optical tracking system (OTS).

3.1.12.1 *Discussion*—In Fig. 1, the optical image event time is marked by the letter "B" and the time of receipt of the pose data by a client system is marked as "D". OTS computation time is the time for the completion of the computation of the pose data by the OTS. OTS communication latency is the time between the completion of the computation of the pose data and the receipt of the data by the client.

3.1.12.2 *Discussion*—Certain optical tracking systems will observe the optical image event some amount of time after the physical event "A" happens. In the diagram of Fig. 1, OTS computation time incorporates the vendor-specific image acquisition times. As indicated in Section 9, vendors should report the operating parameters of the system including system-wide integration periods and camera frame rates.

3.1.13 *temporal pose error*—the pose error in time domain.

3.1.14 *tracking system, n*—a system that is used for measuring the pose of moving objects and supplies the data as a timely ordered sequence. **E3064**

3.1.15 *uncertainty, n*—an indication of the magnitude of error associated with a value that takes into account both systematic errors and random errors associated with the measurement or test process. **E2655**

4. Summary of Test Method

4.1 This test method provides a set of statistically-based performance metrics and a test procedure to quantitatively measure the system latency of an optical tracking system.

4.2 Specifically, the test procedure measures the difference between the time instant when the motion of a test apparatus causes an electric circuit to be closed and the instant when the optical tracking system has detected the event. The time instant when the electric circuit is closed is measured by a low-latency data acquisition system which is synchronized with the optical tracking system. The performance metrics include the mean, the standard deviation, the maximum, the minimum, and certain percentiles of latency measurements.

5. Significance and Use

5.1 Optical tracking systems are used in a wide range of fields including: video games, film, neuroscience, biomechanics, flight/medical/industrial training, simulation, robotics, and automotive applications.

5.2 This standard provides a common set of metrics and a test procedure for evaluating the performance of optical tracking systems and may help to drive improvements and innovations in optical tracking systems.[4]

5.3 Potential users often have difficulty comparing optical tracking systems due to the lack of standard performance metrics and test methods, and must therefore rely on the vendor claims regarding the system's performance, capabilities, and

[4] "Motion Capture Software Developers in the US: Market Research Report," IBIS World, 2014.

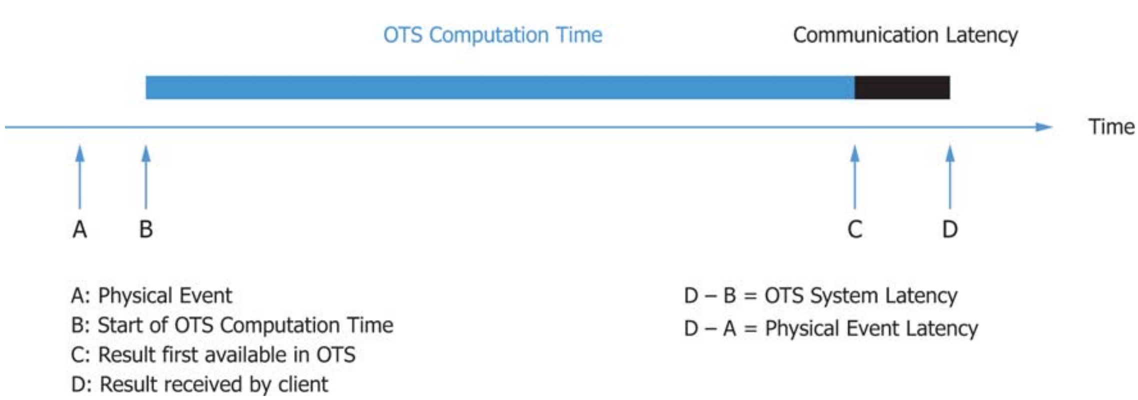

FIG. 1 OTS Latency

suitability for a particular application. This standard makes it possible for a user to assess and compare the performance of optical tracking systems, and allows the user to determine if the measured performance results are within the specifications with regard to the application requirements.

6. Apparatus

6.1 *Data Acquisition Device*—For best results, a low latency Data Acquisition Device (DAQ) should be used. Although there are no requirements on the DAQ, a device which is integrated into the computer via a PCI Express port has shown acceptable performance. Other DAQ devices may be used, but they may incur additional latency and uncertainty to the tests, which may be incorrectly construed as OTS system latency. While PCI Express devices tend to show sub-microsecond latencies, USB 3.0 and 2.0 devices, for example, have latencies between tens of microseconds to approximately one hundred microseconds nad Gigabit Ethernet devices can incur additional latencies on the order of one millisecond.[5] The user should also make sure that the operating system does not introduce significant delays into the measurements and that there are no processes running in the background during the test procedure. In general, the user should minimize instrumentation related latencies. Standalone measurement devices may also be used to avoid these issues as long as they can produce timestamps which are synchronized with those generated by the OTS.

6.2 *Hammer Device*—A device such as a hammer or pendulum shall be designed in such a way that it can be released and free fall onto a conductive plate (for example, a copper plate or other low-latency devices that can form electrical contact such as a contact switch). Although there are no strict requirements on its design, it has been found that a metal bar that rotates around a hinge point is an acceptable design. A bearing to constrain the rotation to a single axis is important to avoid adding noise to the measurements of the device motion. Fig. 2 shows a diagram of a potential apparatus. A picture of an illustrative design is given in Appendix X2. Trackable elements such as markers should be attached to the device according to the vendor requirements (for example, minimum number of markers and marker locations) so that it can be accurately tracked as a rigid body.

6.3 *Other Materials*—This test method also requires a computer (that is, the client system), a solid surface, two wires, and a conductive plate (Fig. 2). Additionally, depending on the specifications provided by the DAQ manufacturer, a pull-down resistor (that is, resistor to ground connection) or a pull-up resistor (that is, resistor to power supply connection) may be necessary. The resistance of the pull-down/pull-up resistor should be defined according to the DAQ manufacturer recommendation (10,000 Ohm is a typical value). To ensure repeatable contact conditions, the conductive plate should not move relative to the hard surface on which it is set even under the action of the hammer striking the conductive plate.

7. Measurement and Test Procedure

7.1 *Introduction*—This section describes the basic procedure for measuring the latency of an optical tracking system. Latency measurements shall be carried out with a single trackable object without other objects in the background. Optinally, vendors may choose to carry out additional tests with multiple trackable objects, in which case object count shall be included in the report.

7.1.1 *Setup*—Attach a wire to the head of the hammer device and another wire to a conductive plate. Connect the wires from the hammer and the conductive plate to a DAQ device connected directly into the computer. In the optical tracking system software make the hammer device a trackable object and start streaming its positional data.

7.1.2 *Client Program*—Create a client program that records a "DAQ time" value on the computer when the hammer device makes contact with the conductive plate. This time corresponds to time instant "A" in Fig. 1. Since the hammer might rebound after initial contact with the conductive plate, the DAQ sampling rate should be sufficiently high to capture brief contact times. Although there are no requirements for the DAQ sampling rate, it has been found that 10,000 samples per

[5] Instrument Bus Performance – Making Sense of Competing Bus Technologies for Instrument Control, Nov. 2016, http://www.ni.com/white-paper/3509/en/

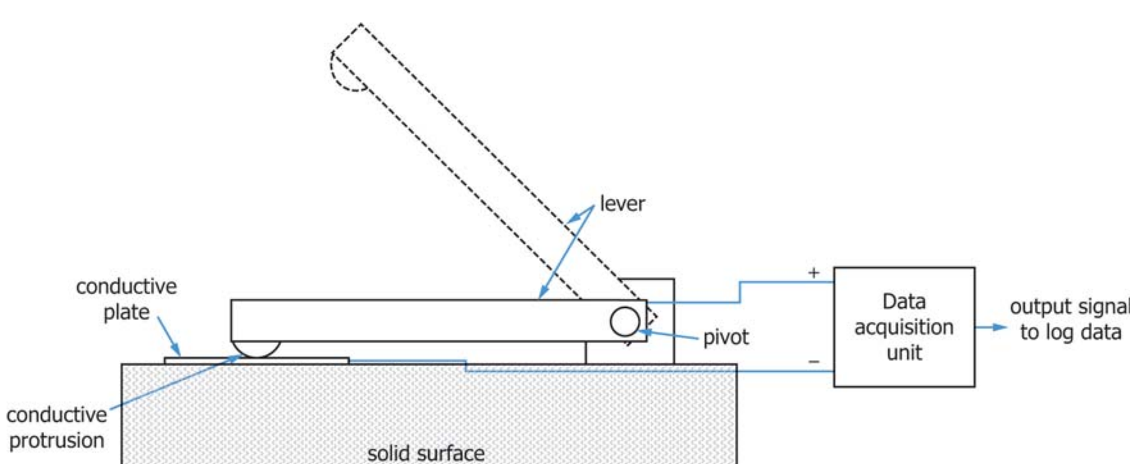

FIG. 2 Schematic Diagram of the Suggested Apparatus

second produces acceptable results. The client program should also record the positional data of the tracked hammer. Define a parameter that will cause the client to measure an "OTS time," that is, the time instant when the movement of the hammer device matches this parameter. As Fig. 3 indicates, the parameter that triggers the "OTS time" event corresponds to the first significant change of slope of the motion of the hammer (note that the magnitude of the change of slope will be dependent upon the settings of the OTS and the design of the hammer device and that in high frame rate systems, multiple changes of slope might be observed when the hammer rebounds from its initial impact). The "OTS time" represents time instant "D" in Fig. 1. Appendix X3 includes the description of a suggested algorithm to detect the change of slope. Appendix X4 shows one example of experimental data.

7.1.3 *Method*—Drop the hammer device on the conductive plate to complete the circuit. The hammer should be dropped from a height that allows the tracking system to accurately measure its trajectory but that minimizes bouncing effects or permanent deformations of the conductive plate. Although there are no requirements on the height, it has been found that a height of approximately 0.2 m produces acceptable results in several tracking systems. Take the difference between the point in time when the circuit was completed ("DAQ time") and when data was received showing that the optical tracking system fulfilled its trigger parameter ("OTS time"). This time difference will be used to approximate the system latency of an optical tracking system. The latency corresponds to the time interval D – B in Fig. 1, but since that interval cannot be directly measured (other than by the optical tracking system vendor), the minimum difference (D – A) over repeated observations will be taken as an approximation of the system latency (see 8.1, Eq 3).

8. Latency Measurement and Metrics

8.1 This section describes the methods for computing latency. The statistics of these measurements include the mean, the standard deviation, the maximum, the minimum, and certain percentiles.[5,6] The mean latency is calculated as:

$$\text{Mean Latency Measurement} \quad \mu = \frac{1}{N} \Sigma_{i=1}^{N} l_i \tag{1}$$

The latency standard deviation is calculated as:

[6] NIST/SEMATECH e-Handbook of Statistical Methods, April 2012, http://www.itl.nist.gov/div898/handbook/.

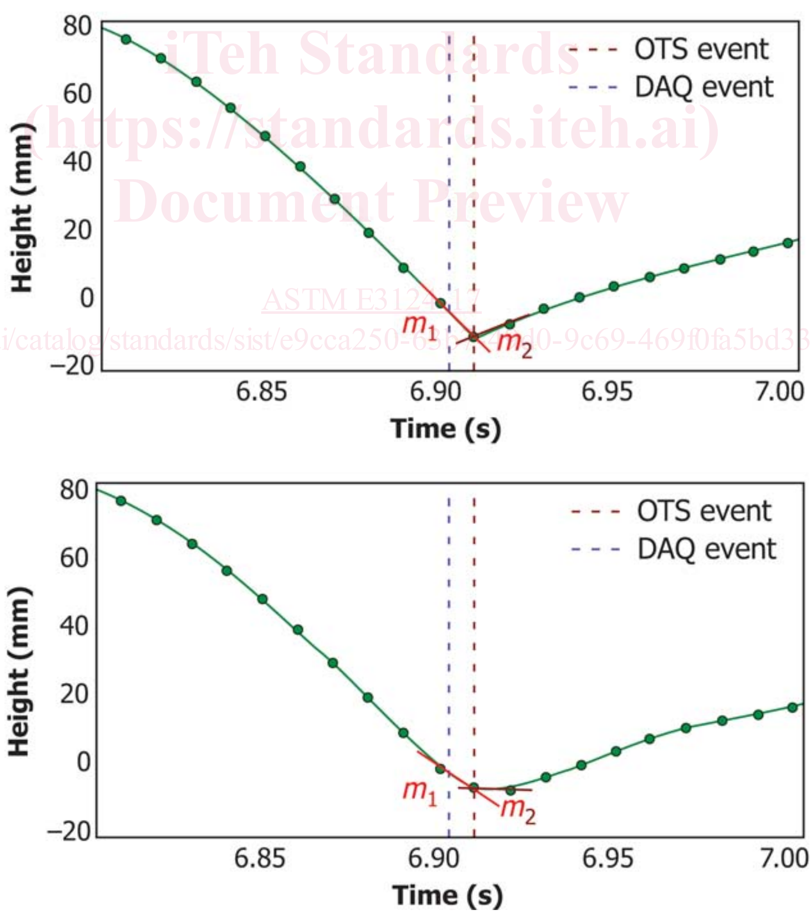

FIG. 3 Change of Slope Illustration

The green points represent the samples collected by the optical tracking system. The top figure shows an example in which there is a change of sign from slope m_1 to m_2. The bottom figure shows a less pronounced change of slope in which the sign of the slope does not change. The OTS event is determined by the significant change of slope from m_1 to m_2.