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Firearms and Toolmarks 3D Measurement Systems and Measurement Quality Control

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Foreword

This document was revised, prepared, and finalized as a standard by the Firearms and Toolmarks Consensus Body of the AAFS Standards Board. The draft of this standard was developed by the Firearms and Toolmarks Subcommittee of the Organization of Scientific Area Committees (OSAC) for Forensic Science This document is part of a series of documents to include:

— ANSI/ASB Standard 061*, Firearms and Toolmarks 3D Measurement Systems and Measurement Quality Control*

— ANSI/ASB Standard 062*, Standard for Topography Comparison Software for Firearm and Toolmark Analysis*

— ANSI/ASB Standard 063*, Implementation of 3D Technologies in Forensic Firearm and Toolmark Comparison Laboratories*

The purpose of this document is to ensure the production of reliable data and statistically based conclusions and is applicable to all forensic science service providers that provide conclusions regarding toolmark-related evidence. The documents establish performance expectations for new technologies while allowing legacy systems to coexist in the lab. The hardware document specifically refers to 3D scanning hardware and does not apply to legacy 2D type systems. The software document specifies three categories (levels) of software. Legacy systems are Category 0 whereas systems which provide validated statistical measures are Category 2. The implementation document outlines the necessary steps to ensure the proper implementation of 3D technologies.

The ANSI/ASB Standard 061, *Firearms and Toolmarks 3D Measurement Systems and Measurement Quality Control* applies to all 3D imaging systems which capture data beyond a flat 2D photographic image. This document is intended to ensure the instrument's accuracy, to conduct instrument calibration, and to estimate measurement uncertainty for each axis (X, Y, and Z).

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All hyperlinks and web addresses shown in this document are current as of the publication date of this standard.

Keywords: *3D, topography, measurement, quality assurance, traceability, firearms, toolmarks, identification*

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Firearms and Toolmarks 3D Measurement Systems and Measurement Quality Control

1 Scope

This document provides guidelines for the measurements systems which capture data beyond a flat 2D photographic image for Firearm and Toolmark Analysis; in this document these systems are referred to as 3D systems. This document provides guidelines to ensure the instrument's accuracy, to conduct instrument calibration, and to estimate measurement uncertainty for each axis (X, Y, and Z). Included in the standard are procedures for validation of 3D system hardware. The focus of this standard is on the hardware and resulting measurement data, this standard does not include the guidelines for measurement systems software.

2 Normative References

The following references are documents that are indispensable for the application of the standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ANSI/ASB Standard 063, *Implementation of 3D Technologies in Forensic Firearm and Toolmark Comparison Laboratories*[a]

ISO 25178-72, *Geometrical product specifications (GPS)—Surface texture: Areal—Part 72: XML file format x3p063*[b]

3 Terms and Definitions

For purposes of this document, the following definitions apply.

3.1
areal-topography method[c]
Surface measurement method that produces a topographical image of a surface, which may be represented mathematically as a height function z (x, y) of two independent variables (x, y).

3.2
Coherence Scanning Interferometry[c]
CSI
Surface topography measurement method wherein the localization of interference fringes during a scan of optical path length provides a means to determine a surface topography map.

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[a] Available from: http://www.asbstandardsboard.org/published-documents/
[b] Available from: https://www.iso.org/standard/62310.html
[c] ISO 25178-6:2010, *Geometrical product specifications (GPS)—Surface texture: Areal—Part 6: Classification of methods for measuring surface texture*

3.3
confocal microscopy[c]
Surface topography measurement method whereby a pinhole object illuminated by the light source is imaged by a lens onto the surface being studied and the light is reflected back through the lens to a second pinhole placed in front of a detector and acting as a spatial filter.

3.4
confocal chromatic microscopy[c]
Surface topography measurement method consisting of a confocal microscope with chromatic objective integrated with a detection device (e.g., spectrometer) whereby the surface height at a single point is sensed by the wavelength of light reflected from the surface.

3.5
dropouts
Ordinate values within a dataset that did not receive enough signal during the measurement for a height measurement to be acquired. These are often represented as NaN, zero, blank, or the minimum measured value.

3.6
focus variation microscopy[c]
Surface topography measurement method whereby the sharpness of the surface image (or another property of the reflected light at optimum focus) in an optical microscope is used to determine the surface height at each position along the surface.

3.7
measurement coordinate system[c]
System of coordinates that represent the geometry of the measured surface.

NOTE If the nominal surface is a plane (or portion of a plane), it is common to use a rectangular coordinate system in which the axes form a right-handed Cartesian set, the X-axis being the direction of tracing co-linear with the mean line, the Y-axis also lying on the nominal surface, and the Z-axis being in an outward direction (from the material to the surrounding medium).

3.8
noise
High frequency signals caused by the instrument electronics, vibrations, and environmental factors. This is often determined by measuring a flat surface (e.g., mirror) which establishes the minimum feature height (z) that the instrument is capable of measuring. Also known as "Noise Floor".

3.9
ordinate value z (x, y) [c]
Height of the surface at position (x, y).

3.10
outliers
Ordinate values within a dataset that received an erroneous signal during the measurement and no longer represent the real surface. These often appear as spikes in the dataset. Detection methods include local slope and neighboring height thresholding.

3.11
Phase-Shifting Interferometric Microscopy[c]
PSI
Surface topography measurement method whereby an optical microscope with illumination of a known effective wavelength is integrated with an interferometric attachment and produces multiple successive optical images with interferometric fringes from which the profile or areal surface topography image is calculated.

3.12
photometric stereo
Surface topography measurement method in computer vision for measuring the surface normals of a surface by observing that surface under different lighting conditions. Given sufficient independent light sources, the surface normals, and thus surface geometry, can be determined for every position on the surface.

3.13
processed data
Ordinate values that have been processed (e.g., trimmed, filtered, and/or interpolation applied).

3.14
raw data
Ordinate values that come directly from the instrument which have not been manipulated (e.g., trimmed, filtered, and/or interpolation applied).

3.15
reference datafile
A reference measurement of a flat surface (e.g., mirror) which includes the errors and optical aberrations of the measurement system. This data file can be stored and subtracted from all subsequent measurements.

3.16
structured light projection[c]
Surface topography measurement method whereby a light image with a known structure or pattern is projected on a surface and the pattern of reflected light together with knowledge of the incident structured light allows one to determine the surface topography.

3.17
surface profile[c]
Profile that results from the intersection of the real surface by a specified plane.

4 Requirements

4.1 Developmental Validation (Mandatory)

As per ANSI/ASB Standard 063, *Implementation of 3D Technologies in Forensic Firearm and Toolmark Comparison Laboratories*, a developmental validation shall be completed by at least one organization with appropriate knowledge and/or expertise. The developmental validation of imaging hardware typically consists of identifying and citing previously published scientific literature establishing the underlying imaging technology. The methods defined above of coherence scanning interferometry, confocal microscopy, confocal chromatic microscopy, focus variation microscopy, phase-shifting interferometric microscopy, photometric stereo, and structured light projection all have ample published scientific literature which can be cited to establish the underlying imaging technology.

4.2 Deployment Validation (Mandatory)

4.2.1 General

As per ANSI/ASB Standard 063, *Implementation of 3D Technologies in Forensic Firearm and Toolmark Comparison Laboratories*, the laboratory shall complete and document a deployment validation prior to use in casework. **The laboratory shall retain the deployment validation documentation.**

4.2.2 Personnel

Personnel responsible for deployment validation shall at a minimum have a bachelor's degree or equivalent degree with a natural science-based or applied science-based major field of study. To the extent possible, a single individual should conduct all components of the deployment validation to minimize sources of operator uncertainty.

4.2.3 Environmental Conditions

To help ensure quality measurements, the instrument should be in a low noise and low vibration environment. Air vents and high traffic areas of the building should be avoided. Some instruments (e.g., interferometry) are extremely sensitive to vibrations and should reside on a vibration isolation table. To determine the "noise floor" of the instrument, see 4.2.5.2.

4.2.4 Instrument Calibrations

The laboratory shall have the instrument calibrated by the manufacturer or instrument provider upon installation.

4.2.5 Minimum Requirements for Establishing/Verifying Instrument Performance

4.2.5.1 General

The deployment validation for a new 3D measurement instrument shall verify and document the instrument's performance. These tests are required after initial installation and after any subsequent hardware modification, or change that affects the scanning process (e.g., after the installation of a new objective or relocation to a new environment). The deployment validation includes the following.

4.2.5.2 Instrument Noise Floor Testing

Noise floor testing shall be conducted using a flat surface (e.g., mirror) with flatness better than $\lambda/10$, where λ is the wavelength of the light source. Ten measurements shall be performed consecutively without changing the measurement setup. Ten measurements shall also be performed daily over ten days. The calculated average roughness (*Sa*) value shall be within manufacturer specifications. For 3D instruments that rely on a minimum level of roughness to resolve the surface (i.e., focus variation), the noise floor should be tested using manufacturer suggested standards and protocols.

4.2.5.3 Instrument Repeatability Measurement

4.2.5.3.1 General

Using calibrated geometric standards (e.g., sine wave, pitch, step heights), measurements shall be conducted to check the X and Y lateral scales as well as the vertical Z scale. Ten measurements shall be performed consecutively without changing the measurement setup (i.e., not taking the sample off the instrument, not changing the operator, and not varying any measurement parameters). The measurement uncertainty of the repeatability measurements shall overlap with the certified value and uncertainty of the geometric standard used.

4.2.5.3.2 X and Y Lateral Scale Check

The X and Y lateral scales shall be checked using a geometric standard calibrated for a length scale parameter such as pitch or *RSm* (wavelength) in standard units.

4.2.5.3.3 Z Vertical Scale Check

The Z scale shall be checked using a geometric standard calibrated for height in standard units.

4.2.5.4 Instrument Reproducibility Measurement

4.2.5.4.1 General

Using calibrated geometric standards (e.g., sine wave, pitch, step heights), check measurements shall be conducted to test the X and Y lateral scales as well as the vertical Z scale. Daily measurements shall be performed over ten days by the same operator. The measurement setup shall be varied each day (i.e., taking the sample on and off the instrument and manually setting up each measurement). The measurement uncertainty of the reproducibility measurements shall overlap with the certified value and uncertainty of the geometric standard used.

4.2.5.4.2 X and Y Lateral Scale Check.

The X and Y lateral scales shall be checked using a geometric standard calibrated for a length scale parameter such as pitch or *RSm* (wavelength) in standard units.

4.2.5.4.3 Z Vertical Scale Check.

The Z scale shall be checked using a geometric standard calibrated for height in standard units.

4.2.5.5 Instrument Measurement Uncertainty.

The laboratory shall document the instrument's X, Y, and Z measurement uncertainties in accordance with the "Evaluation of measurement data — Guide to the expression of uncertainty in measurement"[d] . Laboratories may also have to comply with their accrediting body requirements for uncertainty in measurement. These uncertainties can often be determined using the procedures stated in 4.2.5.3 and 4.2.5.4.

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[d] BIPM, *Evaluation of measurement data—Guide to the expression of uncertainty in measurement*, JCGM 100:2008

4.3 Ongoing Performance Checks (Mandatory)

4.3.1 General

As per ANSI/ASB Standard 063, *Implementation of 3D Technologies in Forensic Firearm and Toolmark Comparison Laboratories*, the laboratory shall document and demonstrate measurement Quality Control (QC) procedures and measurement traceability. **The laboratory shall retain the performance check documentation.**

4.3.2 Check and Re-check Measurement

The check and re-check measurements bracket regular measurements. These measurements shall be conducted at the beginning and end of the data acquisition session. These should include at a minimum a check and re-check for the X, Y, and Z scale. The purpose is to ensure that regular measurements are traceable and that the instrument did not drift during the measurements.

4.3.3 Control Chart

The laboratory shall maintain a control chart [1] tracking all measured re-check measurement values. The control chart shall display the calibrated uncertainty values for each standard and the dated re-check measurement results. Out of spec re-check measurements shall be documented in the control chart.

4.3.4 Quality Control Failure Protocol (Mandatory)

If the measured check and re-check value falls out of the control limits, a minimum of two repeat measurements shall be made to eliminate the chance of an outlier. The failed check values shall be noted on the control chart.

If the error persists, then the hardware shall be removed from service until it can be remedied and a performance validation has been completed. The data collected while in noncompliance of the quality control check (i.e., the compromised measurement session) cannot be guaranteed and shall not be used. The qualified personnel that conducted the instrument validation should, to the best of their ability, diagnose and correct the source(s) of error (e.g., environment, algorithm, protocol, measurement/sample quality, user). If the error diagnosis is inconclusive, the instrument manufacturer or qualified expert should be involved in the investigation.

4.4 Measurement Traceability (Mandatory)

The geometric standards used for instrument performance validation (see 4.2.5) and quality control measurements (Section 4.3) shall be metrologically traceable to the SI unit of length. Metrological traceability is defined as a result that can be related to a reference through an unbroken chain of calibrations, each contributing to the measurement uncertainty. For more information on traceability, see BIPM, *International vocabulary of metrology—Basic and general concepts and associated terms (VIM)*, JCGM 100:2008.

The laboratory shall document the traceability chain of the geometric standards used. This can be supplied by the manufacturer or the accredited calibration laboratory.

4.5 Data Exchange Format XML 3D Profile (X3P) (Mandatory)

Any imaging hardware that collects data of dimensions greater than two shall have the capability to read and write full resolution raw data in XML 3D Profile (X3P) format in accordance to ISO 25178-72. More information as well as minimum metadata requirements can be found in ANSI/ASB Standard 062, *Standard for Topography Comparison Software for Firearm and Toolmark Analysis* standard.

Annex A
(informative)

Bibliography

This is not meant to be an all-inclusive list as the group recognizes other publications on this subject may exist. At the time this standard was drafted, these were the publications available for reference. Additionally, any mention of a particular software tool or vendor as part of this bibliography is purely incidental, and any inclusion does not imply endorsement.

1] ANSI/ASB Standard 062, *Standard for Topography Comparison Software for Firearm and Toolmark Analysis.* First Edition 2021[e].

2] ASQ Control Charts." *American Society for Quality (ASQ)* 2019[f].

3] Evaluation of measurement data—Guide to the expression of uncertainty in measurement, JCGM 100:2008." *BIPM*[g].

4] International vocabulary of metrology—Basic and general concepts and associated terms (VIM), JCGM 100:2008. *BIPM*[h].

5] ISO 25178-6:2010, *Geometrical product specifications (GPS)—Surface texture: Areal—Part 6: Classification of methods for measuring surface texture*[i].

[e] Available from: www.asbstandardsboard.org/published-documents/
[f] Available from: http://asq.org/learn-about-quality/data-collection-analysis-tools/overview/control-chart.html
[g] Available from: www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf
[h] Available from: www.bipm.org/en/publications/guides/vim.html
[i] Available from: www.iso.org/standard/42896.html

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