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Digital 3D Imaging and Modeling: A Metrological Approach

Three-dimensional imaging systems are now widely available, but standards, best practices and comparative data are limited. In order to take full advantage of 3D imaging systems, one must understand not only their advantages, but also their limitations. This process has to rely on a systematic method to assess the overall performance of a system, and metrology provides such a framework.

By
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In recent years, sensors and algorithms for *digital three-dimensional (3D) imaging and modeling* (3D imaging for short) of real objects and sites have received significant attention, not only at the academic levels, but also increasingly as an important tool for documentation, analysis, inspection and visualization in application fields as diverse as manufacturing, construction, medical or cultural heritage. In the last 25 years, the National Research Council of Canada (NRCC)'s Institute for Information Technology (IIT) has been a major player behind the development of digital 3D imaging both at the research and commercial (licensees) levels (Mona Lisa study, Space Shuttle laser scanner, inspection software in major corporations, etc.). NRCC's approach to 3D has always emphasized quality through a metrological approach. Recently, a 100-square meter facility has been constructed to perform research in traceable 3D imaging metrology.

With the influx of many new users of 3D imaging, a number of concerns have been voiced. Users who are not necessarily part of the technology enthusiasts and early adopters want to be certain that a given 3D imaging system satisfies their requirements before investing. Like many other technologies relying on dimensional measurements (e.g. CMMs, laser trackers), 3D imaging has to gear up to the creation of standards. Indeed, three-dimensional imaging systems are now widely available, but standards, best practices and comparative data are limited. In order to take full advantage of 3D imaging systems, one must understand not only their advantages, but also their limitations. This process has to rely on a systematic method to assess the overall performance of a system, and metrology provides such a framework.

A 3D Imaging System

A typical 3D imaging system includes methods to extract 3D surface data (triangulation or time-of-flight: *TOF*) as well as the processing algorithms that transform the raw data into calibrated coordinates or measured features, or models that can be visualized, analyzed and compared to CAD models. A system may be complemented by a 3D search engine connected to a database and it may include a 3D printer to create solid models from the processed 3D information. All of these tasks can rely on a metrological approach. Figure 1, shows the main elements of such an approach.

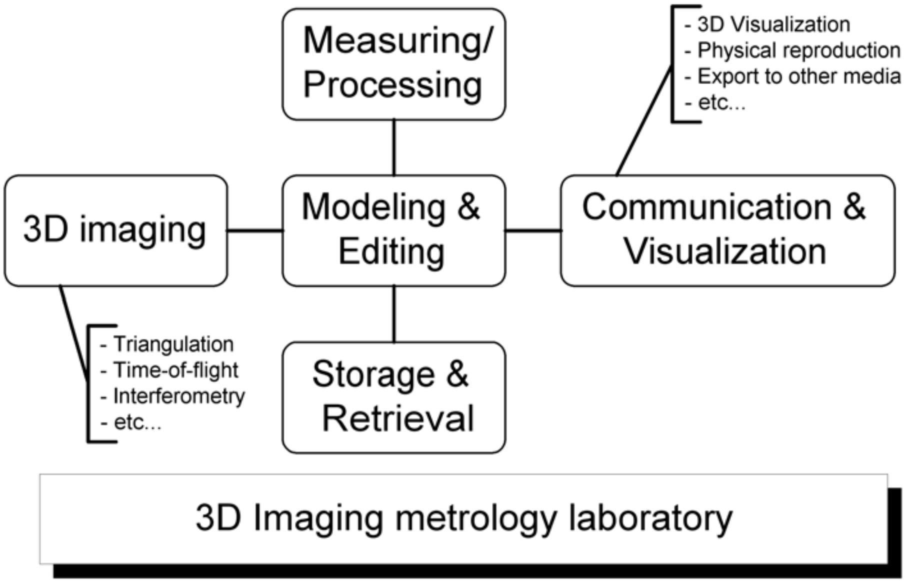

Figure 1. Digital 3D imaging and modeling.

The performance of a system may be evaluated using quality parameters like resolution, uncertainty and accuracy with particular attention to the effects of object material and local surface features on the measured coordinates. Some definitions of such terms can be found in ISO-VIM (International vocabulary of basic and general terms in metrology, www.iso.org). This is necessary because three-dimensional imaging systems are measurement instruments and the spatial coordinates they provide will only be an estimate of the 3D surfaces being sampled. The coordinates need to be completed by a quantitative statement about their uncertainty. The statement of uncertainty is generally based on comparisons with standards traceable to the national units (SI units). Figure 2, summarizes the most important factors that impact on the uncertainty in a 3D imaging system. In any case, the use of accepted terminology, methodology whereby measurements and artifacts are traceable and neutral test facilities will be instrumental for user confidence.

Defining Standards

Some work in defining standards in 3D imaging has started around the world and more specifically in North America. In Germany, a guideline called VDI/VDE 2634 has been prepared for close range optical 3D vision systems. It contains acceptance testing and monitoring procedures for evaluating the accuracy of optical 3D measuring systems based on area scanning. In the U.S., a standards committee known as E57 has been formed by the American Society for Testing and Materials (ASTM) (West Conshohocken, PA). It has the mandate to work on the development of standards for 3D imaging systems specification and performance evaluation for applications like construction, surveying, manufacturing, historic preservation and forensics to name a few. A research group at the National Institute of Standards and Technology (NIST) (Gaithersburg, MD) in the U.S. has been active in the area of 3D imaging system performance evaluation and a facility has been constructed for long range 3D imaging systems.

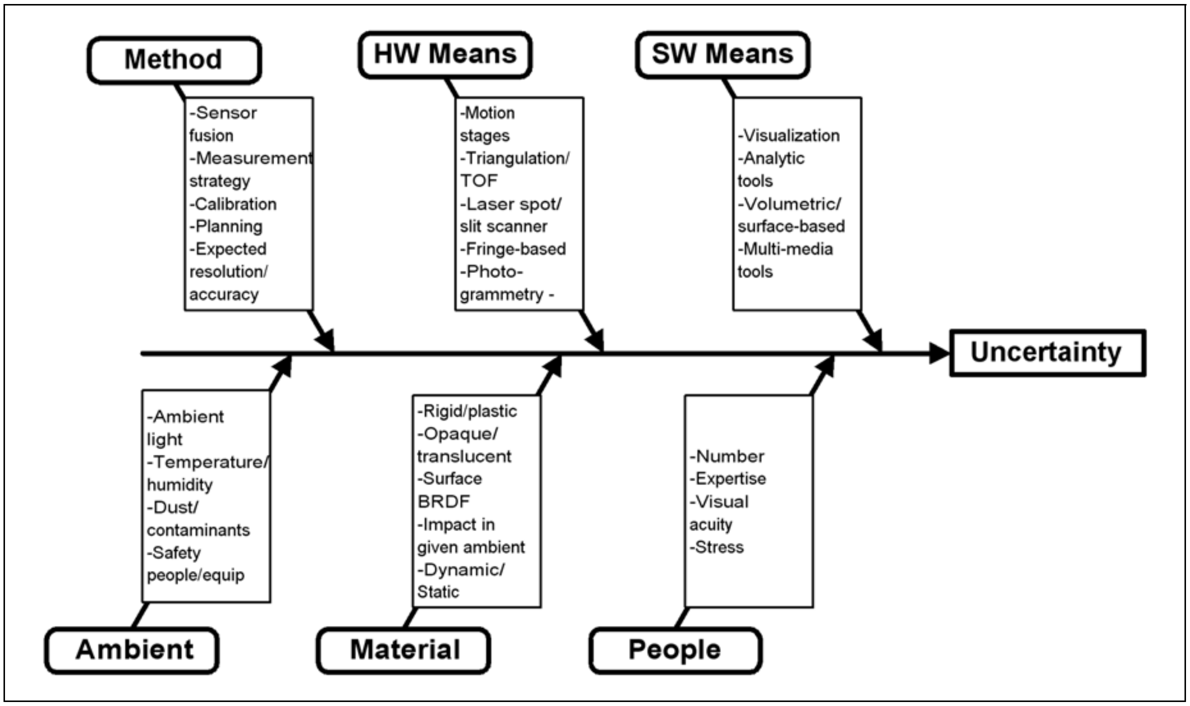

Figure 2. Uncertainty in 3D imaging and modeling systems.

NRCC-IIT

The main objectives of the research at NRCC-IIT are to perform research in traceable 3D imaging metrology that will lead to establishing standards and expanding the use of the 3D imaging and modeling technologies. We are actively collaborating with both the NIST and NRCC-Institute for National Measurement Standards (INMS) Dimensional Metrology group. The latter provides comprehensive calibration services for highest accuracy dimensional measurements in Canada and develops state-of-the-art instrumentation for custom measurements, conducts and coordinates investigations, fundamental research and scientific studies in-house as well as with colleagues worldwide. Most of the work will use the laboratory space to allow accurate and stable measurements of 3D shapes as small as 100 nm and as large as 10 meters.

Precise ambient temperature and relative humidity control is paramount in metrology. A laminar flow of air is maintained at constant temperature, 20°C±0.1°C. This is the required temperature according to ISO 1 (Geometrical Product Specifications - Standard reference temperature for geometrical product specification and verification). The total volume of air in the lab is circulated every 30 seconds and the air cleanliness is exceptionally good (Class 1000). The target tolerance for relative humidity is 45 percent ± 5 percent in the winter and at 55 percent ± 5 percent in the summer. Within the laboratory, the researchers are able to adjust the set points by physically overriding output points from the control cabinets as required by the research work. Along with our own laser scanners designed and built at NRC-IIT, high quality metrology equipment and other laser scanners are also used.

Our research is aimed at

1) Performing precise calibration of various types of 3D imaging systems
2) Monitoring systems stability over time and under variations in environmental conditions such as ambient temperature, relative humidity and ambient light
3) Evaluating measurement accuracy and uncertainty using a wide range of specially designed standard objects, 3D measuring equipment and high-precision positioning devices
4) Validating computer vision algorithms, such as target and edge measurement, fitting algorithms, multi-view registration, model-based recognition and sensor fusion
5) Helping in the definition of international standards by testing methodologies related to known standards within a traceability chain

The Future

While 3D imaging systems are more widely available, standards, best practices and comparative data are still almost inexistent. Specifications stated by the manufacturers of these 3D imaging systems still generate a lot of confusion. A metrology-based approach is required to provide a clearer picture in order to improve the use of 3D imaging in industrial and non-industrial applications. In particular, the creation of standards and the establishment of neutral test facilities will be critical for the generation of user confidence. Standards for 3D imaging systems should address the whole measuring chain from acquisition, processing, to methodology, as well as the user skill level.

Industry Links

ISO VIM (DGUIDE 99999): International vocabulary of basic and general terms in metrology: www.iso.org

ISO/IEC 17025:2005: General requirements for the competence of testing and calibration laboratories: www.iso.org

ASME B89: www.asme.org

VDI/VDE : www.vdi.de/vdi/english

ASTM E57 : www.astm.org/COMMIT/SUBCOMMIT/E57.htm

CMSC Coordinate Metrology Systems Conference www.cmsc.org

ACMC Association for Coordinate Metrology Canada: www.acmc-canada.ca

NIST: www.bfrl.nist.gov/861/CMAG/publications/index.htm

NRC-INMS: http://inms-ienm.nrc-cnrc.gc.ca/calserv/dimensional_metrology_e.html

NRCC-IIT 3D: http://iit-iti.nrc-cnrc.gc.ca/about-sujet/vit-tiv_e.html

SME 3D Data Capture/Reverse Engineering Tech Group: www.sme.org/capture