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Performance evaluation of 3D imaging systems based on GD&T

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ABSTRACT

In this paper, we present a method for evaluating the performance of short-range non-contact 3D imaging systems. This method is intended to address the lack of internationally-recognized standards for the characterization of these systems. We begin by presenting characterization-specific terminology before introducing a geometrical and dimensional tolerancing-based approach for the characterization of these systems. This approach focuses on what these systems are typically used for rather than being designed specifically for specific classes of 3D imaging systems. A Portable Characterization Target (PCT) is then presented as an artifact that provides a simple way to perform the characterization of short-range non-contact 3D imaging systems.

KEYWORDS:

3D Imaging Systems • Performance • Characterization • Geometrical and Dimensional Tolerancing • 3D Metrology

INTRODUCTION

In the past few years we have seen an increase in the number of non-contact 3D imaging systems available on the market, as well as a growing interest in 3D data capture in general. The theory behind the operation of 3D imaging systems is well understood so it is now possible to produce them affordably. This is especially true for short-range 3D imaging systems. Both industrial and consumer-type applications are benefiting from lower-cost hardware and software. Furthermore, these 3D data capture systems for the manufacturing sector are mature enough to benefit from the establishment of standardized methods for evaluating their performance.

Suppliers and manufacturers of non-contact 3D imaging systems need to verify the performance of their systems so that they can deliver useful and accurate specifications to clients that reflect the expected performance of their systems. The manufacturer will then have assurance that they are providing a system that will suit the needs of their clients.

From the user's perspective (e.g. in the manufacturing sector), verifying the performance of non-contact 3D imaging systems is critical for comparing different systems to choose the one that is best-suited for a specific application (Beraldin 2011) [1]. The user also needs a way to periodically confirm that the system's performance conforms to the specifications provided by the manufacturer.

It is clear that, from both a manufacturer's and user's perspective, it is important to develop standardized methods to assess the performance of non-contact 3D imaging systems so that common test methods, procedures and algorithms can be used for system assessment. There is currently no published internationally-recognized standard for assessing the performance of non-contact 3D imaging systems. The German guideline VDI 2634 includes a part devoted to acceptance and re-verification testing of non-contact 3D imaging systems [2]; however, it is limited to systems that perform area scanning from a single viewpoint. Moreover, the VDI 2634 is a guideline, not a standard. The ISO 10360-8 standard is currently being developed but only addresses optical distance sensors mounted on a CMM. Meanwhile, manufacturers currently provide performance specifications based on their own test procedures. As a result, users often don't know how values provided in these specifications were obtained so it can be difficult to compare systems or determine whether a system is suitable for a specific application.

This paper proposes a method for characterization and verification of the performance of short-range non-contact 3D imaging systems, referred to in this paper as 3D imaging systems. Suggested terminology is detailed in Section 1, followed by descriptions of geometrical and dimensional tolerancing–based test procedures in Section 2. Section 3 presents a proposed test artifact and related test procedures.

This work builds on previously-published work on artifact-based and geometric dimensioning and tolerancing (GD&T)-based characterization of 3D imaging systems [3] [4] [5].

1. Terminology for Characterization

It is important that a common terminology be used to describe the performance of 3D imaging systems. Researchers and manufacturers have each used many different terms to describe system performance: accuracy, precision, resolution, range noise, standard deviation, etc. Some of these terms are used inconsistently, and sometimes different terms are used to describe similar performance metrics. This makes it difficult for users of the technology to compare the performance of different systems based solely on what is available in research and commercial literature. In this paper, we have selected a terminology that conforms to the International Vocabulary of Metrology (VIM) [6]. This standard, developed by the Joint Committee for Guides in Metrology (JCGM), defines basic metrology concepts and related terms.

The performance of a 3D imaging system is based on two concepts:

1. By how much does the measured value differ from the value that should have been generated?
2. How variable are the measured values?

The first concept is represented by the term accuracy. According to the VIM [6], **measurement accuracy** is the *closeness of agreement between a measured quantity value and a true quantity value of a measurand*; however, it is impossible to know the true value of a measurand in practice so we use a **reference quantity value** [6] as a best estimate of the true value. The VIM defines a reference value as the *quantity value used as a basis for comparison with values of quantity of the same kind*. Each reference value has associated with it a **measurement uncertainty** [6] that indicates how well it approximates the true value. The difference between a measured value and a reference value is the **measurement error** [6], defined in the VIM as the *measured quantity value minus a reference quantity value* (Fig. 1). This provides us with a way to quantify the first concept as a performance metric.

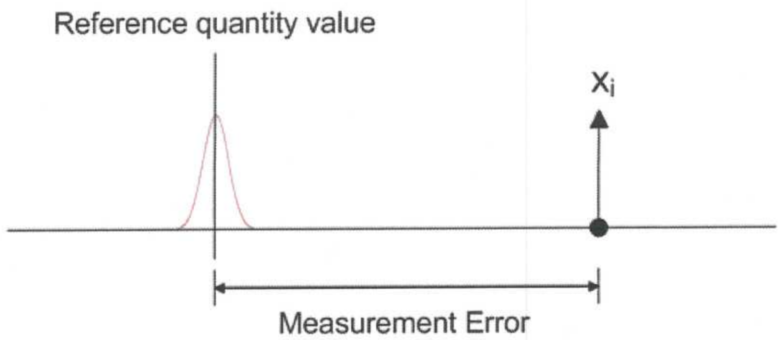

Fig. 1: Measurement Error

The second concept is represented in the VIM by **measurement precision** [6], defined as the *closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions* (Fig. 2). Measurement precision is often quantified by the standard deviation, which can be approximated by the RMS value if the number of measured values is sufficiently large. This is typically the case with measured results obtained by 3D imaging systems. Standard deviation and RMS values provide us with two ways to quantify the second concept.

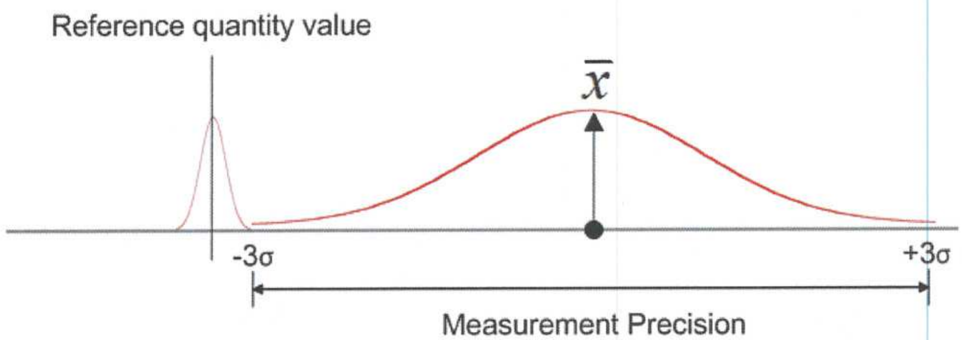

Fig. 2: Measurement Precision represented as the 6σ spread where σ is the standard deviation of the measurement results.

2.GD&T Approach

Current efforts toward standardizing the performance characterization and verification of 3D imaging systems have drawn heavily from the CMM world and are system specific. The approach presented in this paper uses what will be measured as a basis for assessing the performance of 3D imaging systems. 3D imaging systems are typically used for design, manufacturing, quality inspection or reverse engineering. The primary language used in these applications to describe an object, and to facilitate transferring information about the physical characteristics of that object, is often based on the ASME Y14.5-2009 standard [7], what is referred to as GD&T.

There are, in fact, two different standards that describe geometrical and dimensional tolerancing. One is the aforementioned ASME Y14.5-2009 [7] and the other is a set of ISO documents [8] [9] [10] [11] [12] [13] included in the Geometrical Product Specification (GPS) category. We mostly draw our terminology and related performance-assessment tests from GD&T but all the tests presented here have their equivalent in GPS. As a result, our approach is compatible with both GD&T and GPS.

Five categories of tolerance are needed to fully define the geometry of an object: dimension, form, orientation, location and profile. A 3D imaging system may be required to assess tolerances from one or more of these categories. Using GD&T-based terminology to define a set of tests for the characterization of 3D imaging systems makes it possible to create a performance limit for 3D imaging systems that is closely linked to the assessment of a specific type of tolerance. For the user, it links the performance metric to what the system is able to measure or verify on an object. Characterization of the performance of a 3D imaging system can then be described using a set of tolerance-specific characteristic values rather than of a single accuracy value that may have less practical significance to the user.

Fig. 3 shows the geometrical and dimensional tolerances tests used to generate performance metrics that characterize the performance of a 3D imaging system. A previously-published paper by our research group [5] describes these tests in detail. Size and location metrics provide us with measurement error values that quantify the accuracy concept, while form, orientation and profile are measurement precision values that quantify the concept of measurement variability.

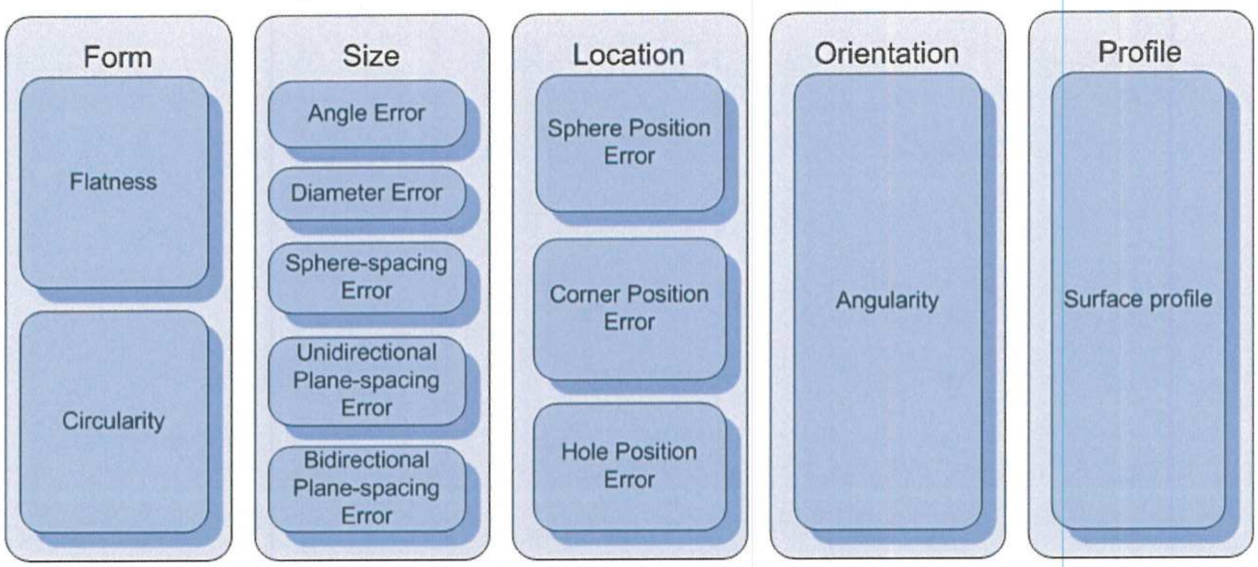

Fig. 3: GD&T-based performance metrics

3. Proposed Test Artifact and Procedures

To generate GD&T-based performance metrics, we compare measurement results obtained from a 3D imaging system in response to a certified reference value previously associated with a reference surface, or artifact. The uncertainty associated with the reference value should ideally be known to at least an order of magnitude smaller than the expected measurement uncertainty of the 3D imaging system, although some guidelines recommend a less stringent 5 times smaller [2]. A precision CMM can be used to provide these certified reference values and associated uncertainties.

We have developed a Portable Characterization Target (PCT, see Fig. 4) with associated test procedures to perform all characterization tests quickly and easily. The PCT consists of a set of low-cost commercial-off-the-shelf artifacts, each selected to correspond to a specific GD&T-related test. The PCT was designed to provide a convenient way to characterize the performance of a 3D imaging system, and has been designed specifically for short-range non-contact 3D imaging system. The PCT concept can, however, be easily adapted to other types of 3D imaging systems.

The process of obtaining performance metric values involves using the 3D imaging system to digitize the PCT three times in each of seven different positions. This approach makes it possible to evaluate the performance of the 3D imaging system within its entire scanning volume. A value is calculated at each position for each performance metric and the worst (typically maximum) value of the three replicates becomes the performance characteristic value (PCV) associated with that performance metric.

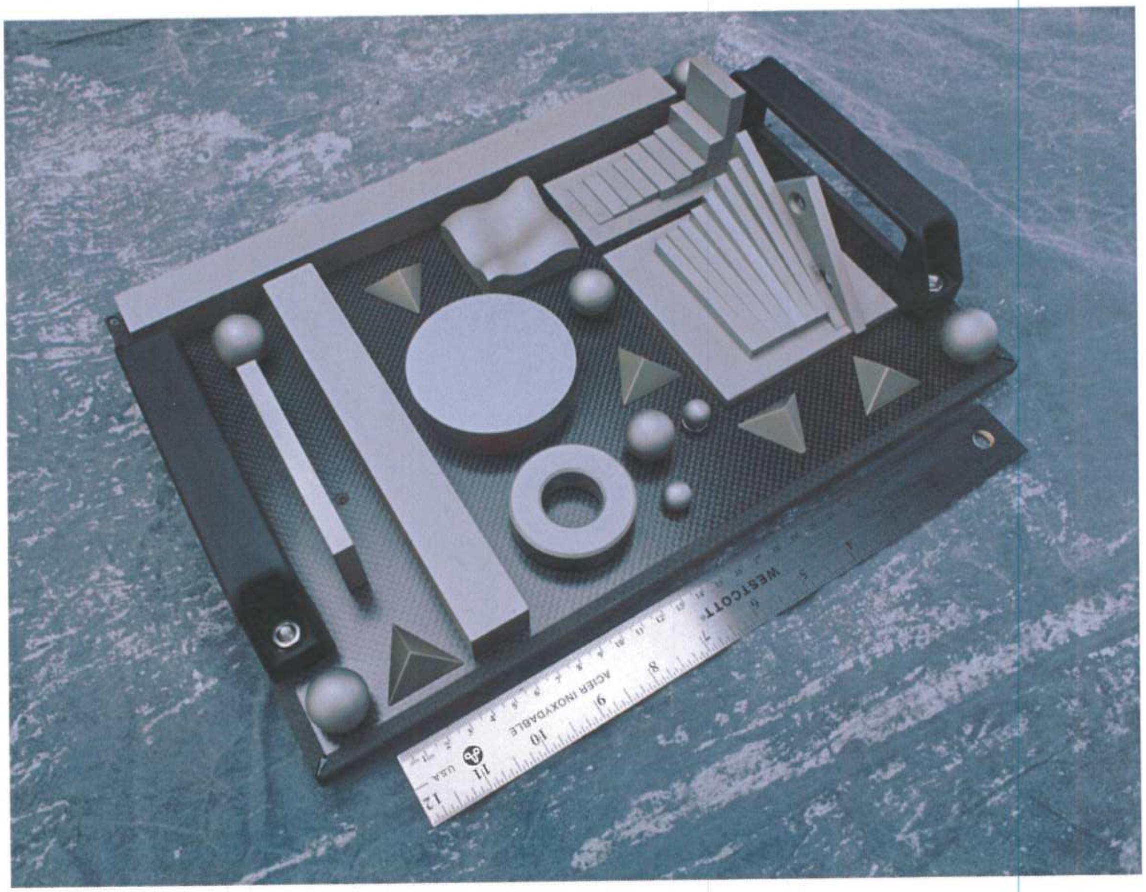

Fig. 4: Portable Characterization Target (PCT) for the characterization of 3D imaging systems

For the manufacturer, the PCV can be used to establish a performance specification such as the Maximum Permissible Error (MPE) associated with a given performance metric for that system, as defined in the ISO 14253-1 standard [14]. For the user, the PCV can be used to verify whether the system is operating in conformance with the MPE specified by the manufacturer.

4. Conclusion

In the absence of internationally-recognized standards for the characterization and verification of 3D imaging system's performance, it is difficult to rely solely on the performance specifications provided by different manufacturers to perform a fair comparison or to predict whether a given 3D imaging system is suitable for a particular application. The user often doesn't know how these values were obtained. Moreover, these performance specifications are typically not specifically linked to the type of measurements that will be performed by the 3D imaging system. This makes it difficult to compare different systems to select one for a specific application without performing a benchmark test on potentially many different systems.

We propose an approach based on how a 3D imaging system is typically used rather than being driven by the type of instrument being used. The proposed GD&T-based approach makes it possible to obtain performance metrics that are understandable to, and usable by people in industry who typically use these systems. To facilitate our proposed GD&T-based assessment, we have developed a Portable Characterization Target (PCT) that can be used by either manufacturers or users of 3D imaging systems to easily perform characterization and verification of short-range non-contact (triangulation-based) 3D imaging systems.

This work is the first step in developing an international standard for the characterization and verification of short-range non-contact 3D imaging systems.

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