

New procedure for qualification of structured light 3D scanners using an optical feature-based gauge

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ABSTRACT

This work evaluates the performance and operative limits to the dimensional accuracy of 3D optical scanning based on blue-light fringe projection technology. This technology, also known as structured light 3D scanning, is widely used in many reverse engineering applications. It allows the user to quickly capture and create point-clouds, by using images taken at different orientations of white-or blue-light fringe projected patterns on the part. For the survey, a large and feature-based gauge has been used with specific optical properties. The gauge is endowed with canonical geometrical features made of matt white ceramic material. The gauge was calibrated using a coordinate measuring machine (CMM) by contact. Therefore, it is possible to compare the measurements obtained by the structured blue-light sensor with those obtained by the CMM, which are used as reference. In the experimentation, the influence of the scanner software in the measurement results was also analysed. Besides, different tests were carried out for the different fields of view (FOV) of the sensor. The survey offers some practical values and limits to the accuracy obtained in each configuration.

1. Introduction

This work presents a practical procedure for qualifying a scanner based on structured blue light for geometrical and dimensional tolerances (GD&T) verification. The idea of evaluating non-contact digitizing systems for metrological applications was addressed in past research [1,2]. The main research works use the methodology based on GD&T and CAD comparison, using prismatic parts composed of basic elements such as planes, cylinders, spheres and cones [3–5] or complex geometries like turbine blades [2]. The focus of the present paper is similar to this research, but with the focus on guaranteeing the traceability of the experiments using a calibrated feature-based gauge. This gauge materializes a set of GD&T specifications using several canonical features and it is made of a specific and very suitable material for optical measurement.

The scanner used in this paper is based on the fringe projection technique [6,7]. It uses a structured blue-light pattern projected onto the part to capture dense point-clouds over different surfaces in very short times. This feature makes this equipment suitable for a diversity of tasks in industry. Moreover, modern software tools for transforming point-clouds into surfaces have also aided in their industrial deployment. There are several devices based on different principles that employ different algorithms for point acquisition and later for surface reconstruction. However, even when referring to the same working principle (structured light with a fringe pattern or reference target image

analysis), these systems can be equipped with one or two cameras, with different ranges and resolutions (from 2 Mpx to 12 Mpx), with or without turntables, with white or blue light, etc., which leads to a diverse range of 3D scanners.

For these reasons, among others, the attainable accuracy for non-contact 3D scanners still remains hard to quantify, due to several error sources and the number of factors involved [6,7]. In fact, there are “intrinsic” factors derived from the equipment itself, such as camera resolution, the mathematical model and the intrinsic calibration procedure [8–11], the angles between the part, camera and projector [12,13], etc. Another set of errors are those due to external sources, like the ambient light at the time of measurement [14,15] or the surface roughness and colours [14–16]. A good approximation to evaluate these errors is to establish certain types of reference artefacts (tetrahedra, freeform surfaces, etc.) to evaluate and quantify the global error [17,18].

Nevertheless, this methodology has not been followed by the development of universally accepted standards, nor by standard procedures and artefacts that permit the evaluation of conformity, or even the assignment of measurement error values to the reconstructed geometrical features, as is commonly done within any metrological instrument.

Therefore, and in spite of the dissemination of the VDI/VDE 2634 [19] German guideline (for optical 3D measuring systems), the accuracy of these measurement instruments is not clearly quantifiable and depends on many factors that need to be constrained. All these factors

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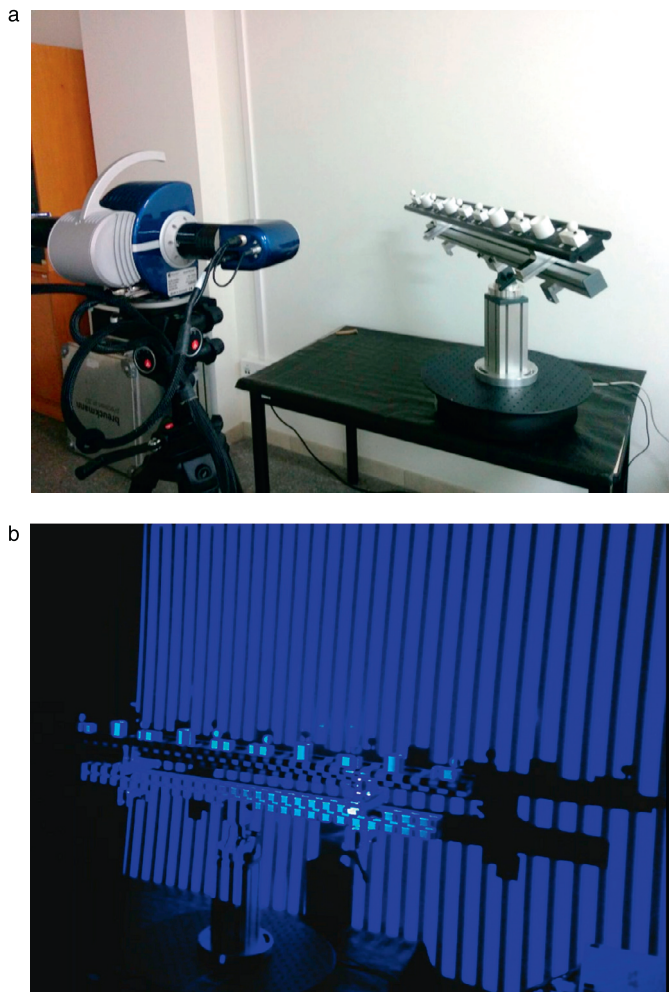


Fig. 1. (a) An overview of the Structured Blue-Light Scanning and the feature-based gauge on an automated turntable. (b) Fringe projection pattern of Blue-Light during a test.

explain why industrial deployment has taken place without the development of accompanying evaluation – more than conformity - standards. The fact is that metrological scanners are being sold without giving an “accredited” calibration value (traceability), without checking the quality of the point-clouds or without weighting the influence of the different fields of view (FOV) required for capturing a part [5]. This area is where this work is focused, aimed at evaluating the accuracy that a fringe pattern projection equipment is capable of attaining.

2. Material and methods

2.1. The 3D optical scanner: a structured blue-light scanner

The available equipment is a structured blue-light mobile scanner (Fig. 1). In particular, the 3D Breuckmann smartSCAN^{3D}-HE model (now known as the AICON SmartScan®) is tripod-mounted. This equipment has a projection unit and an acquisition system with two cameras on each side. It is intended for high accuracy captures at short and medium distances. It works on the basis of the miniaturized projection technique (MPT). This procedure is known as active triangulation. The projection unit provides an appropriate sequence of blue-light fringe patterns onto the part, depending on the measuring object, and with a resolution of 28 Mpx and 550 ANSI lumen. The camera system has a resolution of 4 Mpx (per camera) and captures the projected fringe pattern at a given viewing angle predefined for the distance between the cameras. The

Table 1
Field of view specifications (<http://aicon3d.com>).

FOV	125	400	850
FOV size (mm)	95 × 95	285 × 285	600 × 600
Measuring depth (mm)	60	220	400
X,Y resolution (μm)	50	140	295
Z resolution (μm)	5	16	34
Triangulation angle	32.5°	27°	27°
Working distance (mm)	370	1000	1000

scanner software determines the 3D coordinates by calculating the returned pattern. This equipment can work with different fields of view (FOVs). The available FOV values are from 30 mm to 1500 mm. The FOV is the length along the diagonal of the scannable area or the size of the image diagonal. In general, the smaller the FOV used, the higher data resolution is achieved. In this work, taking into account the size of the reference artefact (about 1 m), two different FOVs have been evaluated: 400 and 850 mm. The smallest available FOV (125 mm) limits scanning to capture a single geometry (only one feature or even a partial feature), therefore preventing the dimensional relations between different features being obtained with enough accuracy. In this research, the 125 mm FOV was reserved to determine only form errors, using a single scan for each geometry to be measured.

Table 1 summarizes the main specifications of these FOVs for a single capture.

2.2. The reference part: an optical feature-based gauge

The reference part chosen for studying the measurement accuracy of the scanner is an experimental gauge artefact. Its design is based on previous research oriented to evaluate articulated arm coordinate measuring machines (AACMM or CMA) [20,21]. In fact, the artefact satisfies to a great extent the indications of a patent regarding the design and use of a feature-based gauge aimed for CMA calibration purposes [22]. Now the actual version of the artefact has been specifically developed for the evaluation of optical and reverse engineering metrological equipment. The main innovation consists in using several ceramic features mounted on top of a supporting base (Fig. 2) made of carbon fibre reinforced polymer (CFRP) of high elastic modulus (external solid bars: $E = 150$ GPa; central supporting plate: $E = 450$ GPa). The different geometrical features available are planar surfaces, outer and inner cylinders, cones and spheres.

The gauge is shown in detail in Fig. 2. The artefact consists of six prismatic volumes ($50 \times 25 \times 25$ mm) as well as four cylindrical volumes ($\varnothing 40$ mm x 40 mm height). All of them are made of machinable glass ceramic of the commercial material MACOR® [23], manufactured with high dimensional precision. The surfaces of the prismatic volumes constitute planar-type features, while the four cylinders are used to materialize the cylindrical surface features, namely the outer cylinders (noted as cyl1 to cyl4), the inner cylinders and the inner cones. The two furthest cylinders enclose inner cylinders machined by straight turning, whereas the two inner cones have been machined inside the other two cylinders. The nominal diameter of the inner cylinders is 30 mm, the nominal angle of the inner cones is 24° and the nominal diameter of their bases is 32 mm.

At the top of each of the six prismatic volumes, a precision sphere of 20 mm nominal diameter, made of a ceramic mixture of aluminium oxide (Al_2O_3) and zirconium oxide (ZrO_2), has been mounted. The spheres have been elevated relative to the prismatic volumes by means of carbon fibre-reinforced cylindrical stems. They are designated as Sph1 to Sph6.

A fixture designed for locating and orientating the gauge supports the gauge at the Bessel points (very close to the Airy points) in order to minimize the deflection of the neutral axis of the bi-supported gauge. In

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