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Blowing hot and cold: temperature sensitivities of 3D optical scanners

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Abstract

The National Physical Laboratory (NPL) is developing a verification facility to allow UK industry greater confidence in the measurement capability of high precision 3D optical surface-form scanners that are increasingly in demand. The benefits of 3D optical scanners, which include point-cloud data capture, speed and portability, mean that they are being adopted in favour of Cartesian CMMs. The NPL verification facility is environmentally controlled to simulate the conditions where 3D scanners are deployed, such as workshop floors where thermal environments may vary and affect dimensional measurement performance. Temperature sensitivity tests were performed on two 3D optical scanners placed within NPL's 3D optical scanner verification facility. Both scanners measured the separation between the centres of two spheres mounted on a Zerodur bar while the facility's air temperature was changed within a 16 °C to 28 °C temperature range. As Zerodur has an extremely low thermal expansion coefficient the length of the bar was expected to change by 31 nm over this temperature range. Results showing ≈±6 µm/°C changes in the sphere separation are therefore caused by the instruments. Such changes highlight instrument limitations and emphasize considerations that users should be aware of when performing measurements at the highest level or when using 3D optical scanners in environments where there are likely to be sudden changes in temperature.

Keywords: 3D optical scanners, temperature, verification

1. Introduction

Temperature is of critical importance when performing accurate dimensional measurements as it not only affects the object being measured but also the instrumentation used to perform the measurement. Temperature has been shown to affect the performance of 3D optical scanners [1] and instrument manufacturers use different methods to overcome temperature effects: some 3D optical scanners are manufactured using carbon fibre, which is known for its low thermal expansion coefficient [2], but may also exhibit hysteresis making its behaviour difficult to predict [3]. Other manufacturers use aluminium as its thermal properties are well known and are therefore easier to predict than other materials. Temperature measurements from thermocouples embedded within an aluminium frame can be used to correct for expansion or contraction due to temperature change and provide a warning when the instrument's calibration is likely to be affected.

The fast operation and portability of 3D optical scanners make them particularly attractive for the use away from the temperature stabilised metrology laboratory and into places where temperature conditions will vary significantly, such as production lines, outside at excavation sites or crime scenes. At the same time, 3D optical scanner manufacturers may claim that, under ideal conditions, their instruments are capable of measurement accuracies < 10 µm. A means of independent verification is needed to support 3D optical scanner manufacturers' claims. Independent verification will also help end-users choose the 3D optical scanner most appropriate for their measurement requirements and guide their understanding into the limitations of their equipment.

NPL's National FreeForm Centre is developing a verification facility [4] to meet these needs and allow UK industry greater confidence in the measurement capability of high precision 3D optical surface-form scanners. The facility is environmentally controlled to simulate typical usage conditions where temperature and lighting may vary, and includes a range of test artefacts that have been specifically developed to identify scanner resolution and sensitivity to colour, roughness, and laser scanning articulating arm scan velocity.

This paper presents temperature sensitivity tests, from NPL's 3D optical scanner verification facility, that are designed to measure dimensional sensitivity to temperature change and presents the results of measurements performed on two fringe projecting scanners, both of which employ carbon-fibre frames.

2. The 3D optical scanner verification facility

NPL's 3D optical scanner verification facility comprises a purpose-built environmentally-controlled laboratory with approximate dimensions (3×5×2.5) m, test artefacts, test procedures and test equipment developed to examine the performance of 3D optical scanners. With adjustable lighting conditions and controllable air temperature ranging from 16 °C to 24 °C, the facility is designed to simulate the typical environments where 3D optical scanners are increasingly being used.

Fringe projectors commonly have ≈(400×400×300) mm measurement volumes with manufacturers claiming measurement accuracies < 10 µm, while laser scanning articulating arms frequently work in ≈33 m^3 spherical volumes with claimed accuracies < 100 µm. To characterise such instruments, NPL's National FreeForm Centre has designed artefacts and test procedures to assess data quality (how representative the measured data is of the object being measured) and data quantity (the amount of data that is measured). The tests include instrument environmental sensitivities, such as temperature and lighting, instrument properties, including resolution, measurement volume and the effects of scanner orientation, and artefact properties such as angle, colour, reflectance, roughness and material. Specific laser scanning articulating arms tests also identify sensitivities to scan velocity, height and joint encoder angle.

3. Measuring Temperature Effects of 3D Optical Scanner

Temperature sensitivity tests were performed on two carbon-fibre framed fringe projecting 3D optical scanners with similar measurement volumes: a Breuckmann stereoSCAN 3D-HE and a GOM ATOS IIe. For the purposes of impartiality, the systems are referred to as "system A", and "system B", in no particular order.

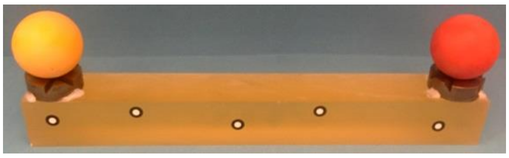

Figure 1. The measurement artefact used for 3D optical scanner temperature sensitivity tests.

The tests began by setting the facility to a particular air temperature, such as 16 °C or 24 °C, and one of the scanners was placed inside it to stabilise. Once the scanner was at a stable temperature, it was calibrated according to the manufacturer's procedure and set to measure repeatedly, at 15 minute intervals, the ≈300 mm separation between the centres of two spheres attached to a Zerodur bar (which has a thermal expansion of coefficient of 0.01 ppm/°C), measured as shown in figure 1. The facility set point was then changed to the other temperature extreme (24 °C or 16 °C) and the measurements were continued until the scanner had stabilised to the new temperature. To simulate typical usage, the scanner was recalibrated following the manufacturer's procedure and the measurements were repeated while the facility's temperature was returned to its original setting. Automated analysis was performed on the measurement's point clouds using a Polyworks macro to identify changes in the measured separation distance between the sphere centres.

4. Results

Figure 2 presents the measurement results from systems A and B. System A measured a 60 µm increase and then a 50 µm decrease in the sphere centres separation after increasing and then decreasing the facility's set point temperature.
Measurements on system B resulted in a 50 µm increase and then a 30 µm decrease in the sphere centres separation after increasing and then decreasing the facility's set point temperature.

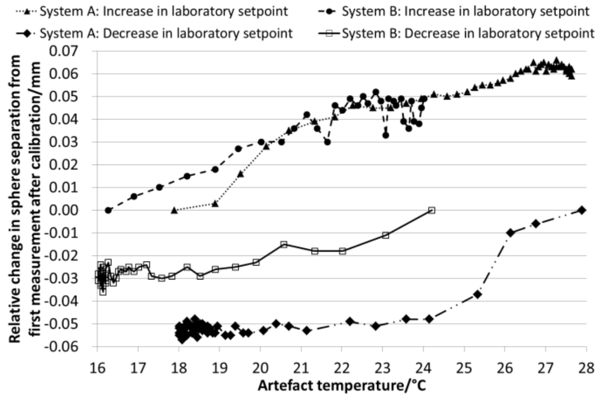

Figure 2. The effect of temperature on dimensional measurements from systems A and B.

System A was measured over a 18 °C to 28 °C temperature range due to additional instrumentation in operation that prevented the facility from going below 18 °C, but allowed the upper set point temperature to be extended to 28 °C
As the length of the Zerodur bar would change by 31 nm across this temperature range the results strongly suggest that the instruments are the cause of these dimensional changes. Differences between the measurements for the upward and downward temperatures changes may have been caused by hysteresis in each system's carbon fibre frame, their optical component dimensions or positions, or projector and camera angles.

5. Conclusions

NPL's National FreeForm Centre is developing a verification facility to allow UK industry greater confidence in the measurement capability of high precision 3D optical surface-form scanners. The facility is designed to simulate typical 3D optical scanner usage environments and as such includes tests to measure dimensional sensitivities with changing temperature.

This paper reports temperature sensitivity measurements of two carbon-fibre framed fringe projecting scanners and reports changes as great as 60 µm, for a 10 °C temperature change, in the separation between two spheres mounted on a Zerodur bar. The temperature ranges tested are similar to those experienced on a summer's day in the UK and highlight 3D optical scanner temperature limitations and sensitivities, particularly for those end-users tempted to take their instruments out of the temperature stabilised laboratory and onto the production line or outside.

NPL's 3D optical scanner verification facility will help end-users identify suitable instruments for their measurement needs and support scanner manufacturers by providing independent verification of their instruments.

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