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Assessing fringe projector volumetric error sources using the NPL tetrahedral artefact

Martin Dury[1], Sean Woodward[1], Stephen Brown[1], Michael McCarthy[1]

[1]*National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, United Kingdom*

martin.dury@npl.co.uk

Abstract
The National FreeForm Centre, within the National Physical Laboratory (NPL), launched a 3D optical scanner characterisation facility in 2015 with the aim of supporting UK industry's use of high precision 3D optical surface-form scanners through greater confidence in their measurement capability. In comparison with Cartesian CMMs, fringe projectors are a relatively new and fast developing technology, as such their sources of measurement error are yet to be fully understood. NPL's new facility is a major step towards developing methods to understand the uncertainties associated with 3D optical scanner measurements that are required for traceable metrology
Fringe projectors operate over a moderate three-dimensional volume and, being lens-based instruments, may be susceptible to aberrations, particularly at extreme positions within the system's measurement volume. This paper presents a tetrahedral artefact that NPL has developed to assess fringe projector volumetric error sources. The artefact comprises spheres held in a fixed, tetrahedral formation using a variety of precision steel rods that allow assessment across volumes from 300 mm × 300 mm × 300 mm to 1000 mm × 1000 mm × 1000 mm. By performing a series of measurements of the tetrahedral artefact with the scanner under test, volumetric error sources are characterised through variations in the sphere diameters and sphere separation distances, while chromatic error sources are identified using combinations of different coloured spheres.

3D optical scanners, measurement volume, characterisation, fringe projectors

1. Introduction

The National FreeForm Centre, within the National Physical Laboratory, has recently launched the 3D optical scanner characterisation facility [1] with the aim of supporting UK industry's growing use of high precision 3D optical surface-form scanners through greater confidence in their measurement capability. This facility comprises a purpose-built environmentally-controlled laboratory (approximate dimensions: 3 m × 5 m × 2.5 m), tests, test artefacts and equipment to examine the performance of 3D optical surface-form scanners and understand their sources of measurement error. The facility's tests include assessment of environmental effects, such as changes in temperature and lighting, instrument properties, such as resolution, measurement volume and the effects of scanner orientation, and artefact properties such as angle, colour, reflectance, roughness and material.

This paper reports preliminary results from one of the facility's tests, which uses a tetrahedral artefact to understand how colour, position and distance can affect the measurements of objects placed within the scanner's measurement volume. The tetrahedral artefact test procedure has been developed to provide quick performance verification and support the development of methods to understand 3D optical scanner measurement uncertainties required for traceable measurements.

2. The NPL tetrahedral artefact

Tetrahedron artefacts were first developed with the aim of achieving quick 3D optical scanners performance verification in accordance with VDI/VDE 2634 using single spheres placed at the tetrahedron's corners [2].
The NPL tetrahedral artefact (figure 1) builds on these tetrahedron design aims by combining VDI/VDE 2634 style performance verification with assessment of chromatic sensitivity using coloured spheres.

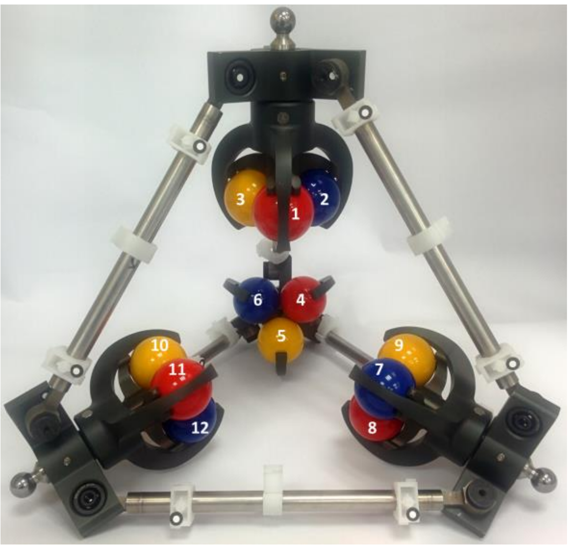

Figure 1. The NPL tetrahedral artefact. Numbered labels have been added to the above photograph to aid analysis.

The NPL artefact forms a regular tetrahedron geometric shape using three sets of precision steel connecting rods. This allows the tetrahedron to be constructed to fit within 300 mm × 300 mm × 300 mm, 600 mm × 600 mm × 600 mm and 1000 mm × 1000 mm × 1000 mm measurement volumes, which are typical to industry. Three coloured (one blue, one red and one yellow) spheres, each with a 50.8 mm diameter, are mounted at each of the tetrahedron's four corners using specially designed claws to ensure that all three spheres are in contact.

3. Measurements of the artefact

Measurement of the NPL tetrahedral artefact is based upon a procedure developed by the Metrology Institute Republic of Slovenia (MIRS) [3]. The NPL tetrahedron is built to fill the measurement volume of the 3D optical scanner being assessed, by selecting appropriate length connecting rods. The claws are attached to the corners of the tetrahedron such that all spheres are held within the interior of the artefact, thus ensuring no sphere is hidden from the scanner's view. Once constructed, the tetrahedron is placed centrally onto an automated rotation stage. The instrument undergoing assessment is optimised in accordance with the manufacturer's instructions. It is then oriented at a vertical angle of approximately 15° and placed in front of the tetrahedral artefact such that it is able to view and measure data from all of the spheres in one measurement; this is recorded as the 0° position on the rotation stage. Test measurements are performed and the scanner settings are adjusted to ensure measurements with the best data quality and the maximum data quantity. Once the scanner has been optimised, the tetrahedral artefact is measured at 0°, 120° and 240° positions on the rotation stage. Six measurements are taken at each position to assess the scanner's measurement repeatability.

4. Preliminary Results

The point clouds from the 3D optical scanner measurements of the NPL tetrahedral artefact are analysed using specially written Polyworks [4] macros, which determine the sphere diameters, distances between their centres and the measurement repeatability.

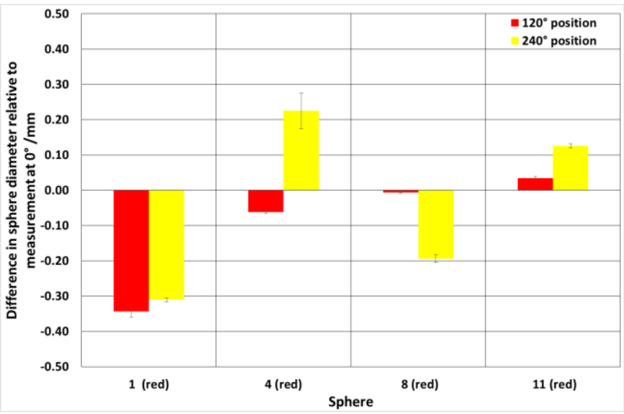

Figure 2. Differences in the measured diameters of the tetrahedral's red spheres. Error bars denote measurement repeatability.

Figures 2 and 3 show preliminary results of the diameters and centre distance results of the tetrahedron's red spheres when measured using a white light fringe projector with an approximate 400 mm × 400 mm × 300 mm measurement volume. Figure 2 shows that, relative to measurements with the tetrahedron in the 0° rotation position, the diameter of sphere 1 (labelled in figure 1) is measured to decrease by > 300 µm when at the 120° and 240° positions. Figure 3 shows respective differences in the distance between the centres of spheres 1 and 4 measured at 0° increasing to > 100 µm and > 250 µm when in the 120° and 240° positions. These results suggest that the *XYZ* positions of the measured sphere centres vary significantly between the tetrahedron's rotation positions. Investigations into variations in the *XYZ* positions of the tetrahedron's sphere centres will be the subject of a future paper.

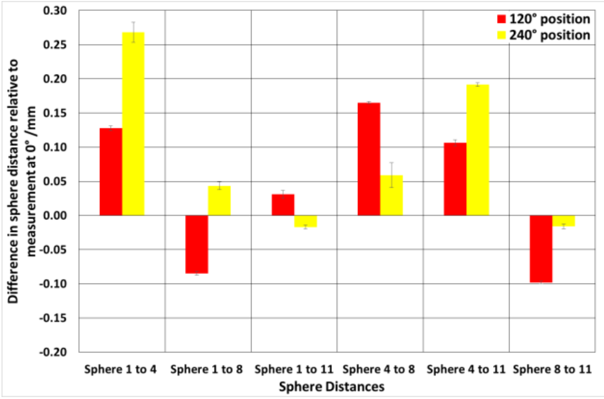

Figure 3. Differences in the measured sphere centre distances for the tetrahedral's red spheres. Error bars denote measurement repeatability.

It would be reasonable to expect the measured sphere diameters and centre distances to change between the three rotation positions due to sensitivities within the measurement volume, which the VDI/VDE 2634 is used to assess. Such sensitivities could be caused by aberrations in the scanner's optics. In addition, as the spheres are rotated within the measurement volume they will become partially occluded by neighbouring spheres reducing the amount of data that a scanner is able to measure, which may affect the measured diameters [5] and, therefore, distances. Finally, the use of monochromatic light or optical filters may cause scanners to be susceptible to chromatic sensitivity. For example, blue light scanners may measure less data from red objects, which may result in differences in the dimensional measurements of red spheres.

4. Conclusions

NPL has developed a tetrahedral artefact as part of its recently launched 3D optical scanner characterisation facility. This artefact builds on previous work using tetrahedral artefacts for quick 3D optical scanners performance verification. By using multiple coloured spheres, NPL's tetrahedral artefact has the potential of being a useful tool when quickly comparing different 3D optical scanners and identifying performance differences due to chromatic sensitivity. Preliminary results show measured variations in the 50.8 mm sphere diameters and centre distances of > 300 µm and > 250 µm respectively. Variations in the centre distances suggest an effect on the *XYZ* positions of the sphere centres, which will be the subject of an investigation described in a future paper.

References

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