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Precision metrology for large freeform non-specular surfaces

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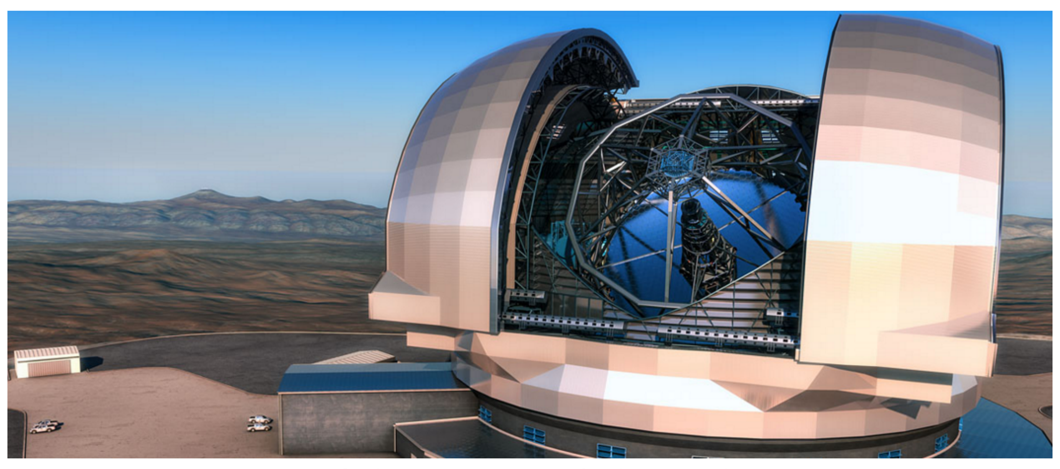
1. Introduction

Metre–scale surfaces are required for large science projects: such as telescopes for astronomy; and laser systems for fundamental physics research. At several stages during manufacture, these optics require low uncertainty measurement: despite the non-specular nature of the measurand surfaces.

Current measurement systems are not capable of measuring non-specular freeform metre-scale surfaces, in mid- to low-spatial frequencies, with uncertainty equivalent to ultra precision sub-metre-scale measurement techniques.



[1]

2. Aim & objectives

This project aims to realise a method for low uncertainty probe positioning within large measurement systems. This will enable the measurement of metre–scale non-specular freeform S-filtered surfaces to accuracy an order of magnitude smaller than current measurement capabilities. In measurement uncertainty, this means $\sigma' = \sigma/10$, where σ is the state-of-the-art for measurement uncertainty of methods for metre-scale optics.

The objectives of this project are to: build analytical models to determine error budgets for candidate probe position measurement systems; design a solution to achieve system measurement uncertainty of σ'; construct a parameter for the assessment of measurement uncertainty for systems measuring pseudo-3D/2.5D surfaces; define and develop a new artefact for testing such a system to quantify measurement uncertainty.

3. Probe stability and precision assessment

The time required to measure a metre-scale freeform surface is significant. If an optical probe based system is to be used to measure such a surface, the probe's measurement stability should be analysed.

A chromatic probe (Fig. 1) was held in a fixed position by an aluminium probe holder with a measurand surface placed within the probe's measurement range (Fig. 2). The artefact was constructed from a machinable ceramic and its surface was non-specular. The measurement of position was recorded over eight hours (Fig. 3).

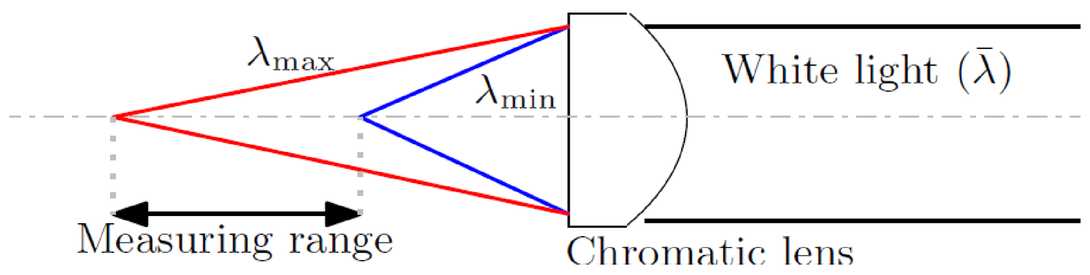


Figure 1. A white light source with wavelength range, λ, is directed into a chromatic lens and dispersed axially to generate a unique focal point for each wavelength [2].

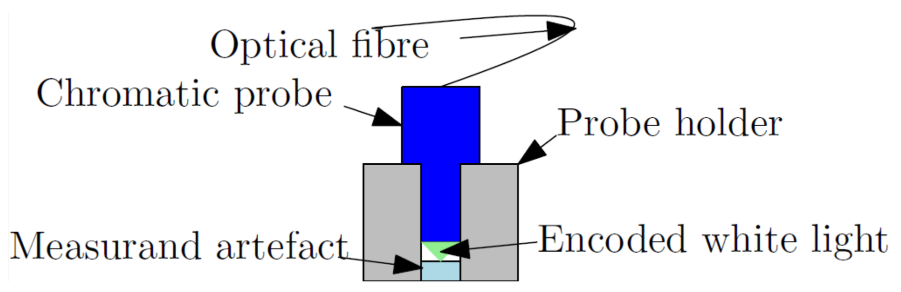


Figure 2. A chromatic probe held by a probe holder to measure a constant distance to the artefact surface.

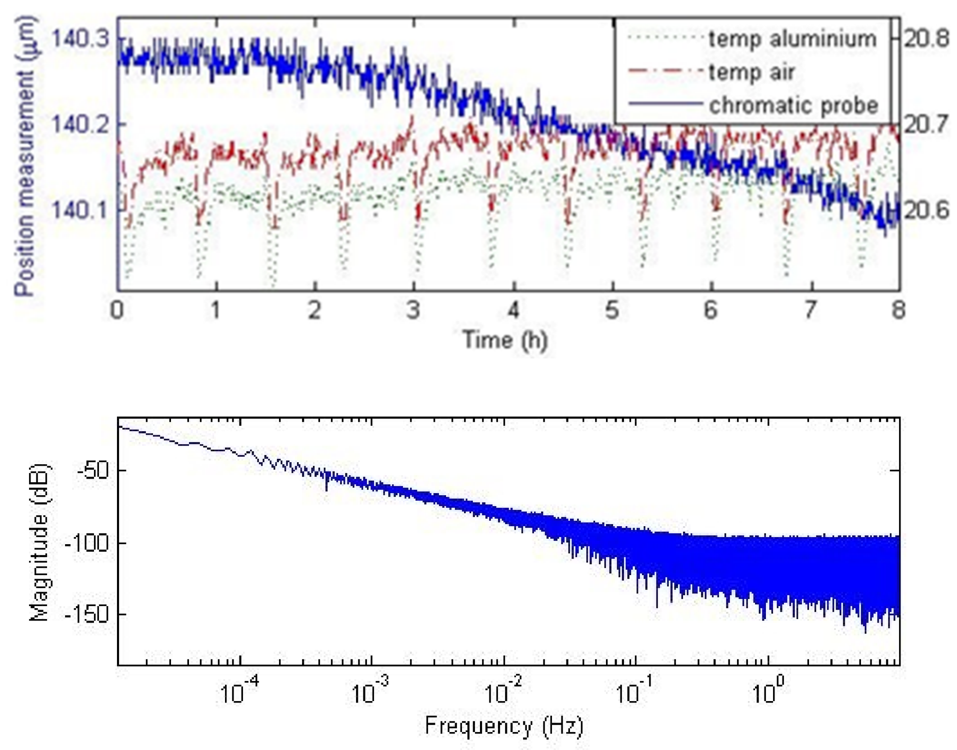


Figure 3. The position measurement of a chromatic probe over an eight hour period, the temperature of an aluminium probe holder, and air temperature (top) and fast Fourier transform of the measured position (bottom).

In order to validate whether a probe has the capability to measure a metre-scale freeform surface, assessment of the probe's measurement accuracy is required.

The probe was held with orientation control and aligned normal the measurand surface (Fig. 4). The probe was incrementally displaced along its measurement axis. Its position measurement was recorded and the deviation from the true displacement calculated (Fig. 5).

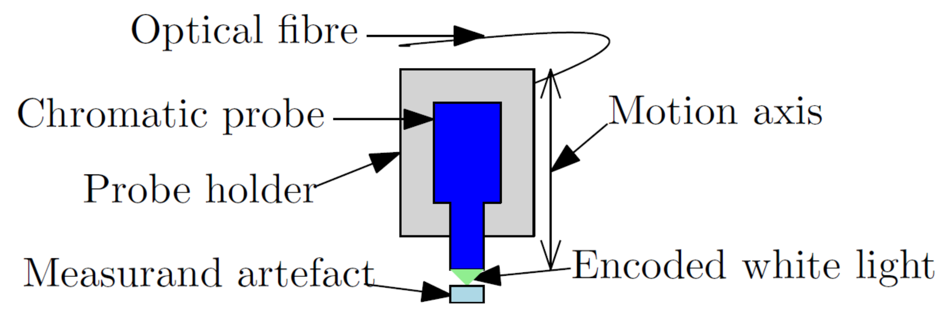


Figure 4. A chromatic probe held by a probe holder with orientation control. The holder is set-up on a precision linear axis.

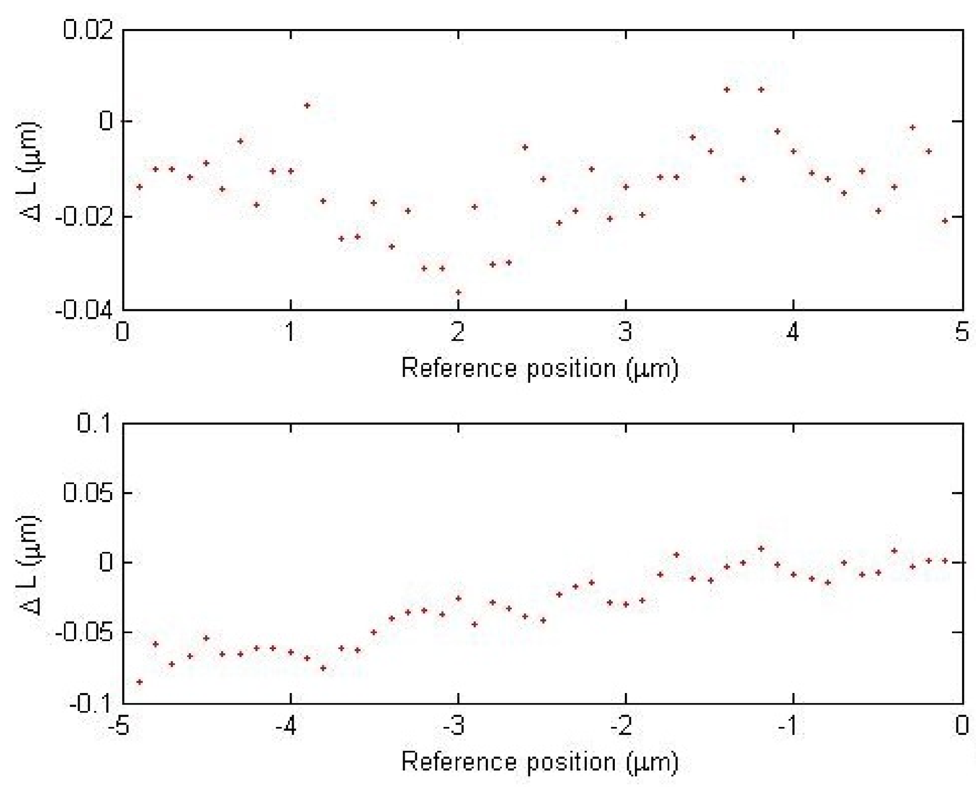
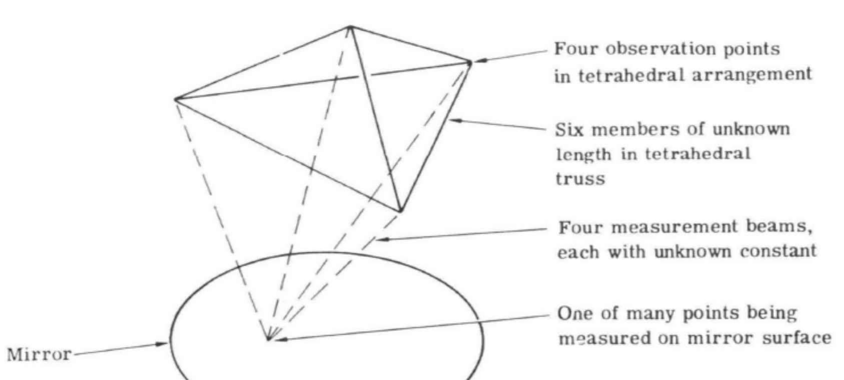


Figure 5. The difference between the displacement measured by the chromatic probe and the true displacement measured by a precision motion system (ΔL), moving from 10 μm to 15 μm (top) and 290 μm to 285 μm (bottom) as measured by the probe.

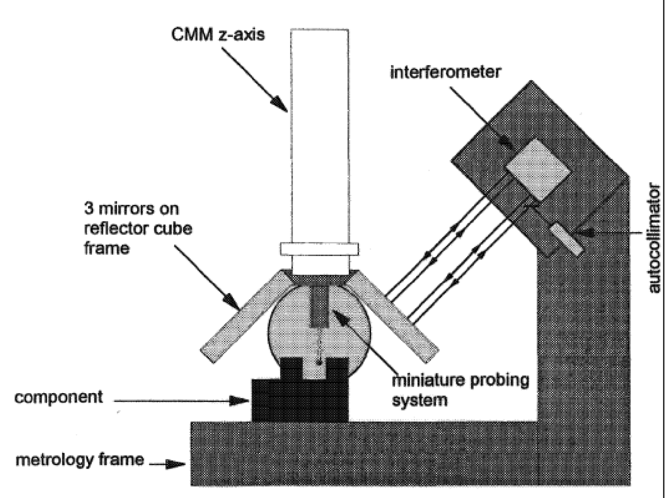
4. Probe position measurement

4.1 Multilateration [3]
- self-calibrating position measurement



Using 4-6 interferometers at each observation point + retroreflector
Coordinate measurement uncertainty = range uncertainty

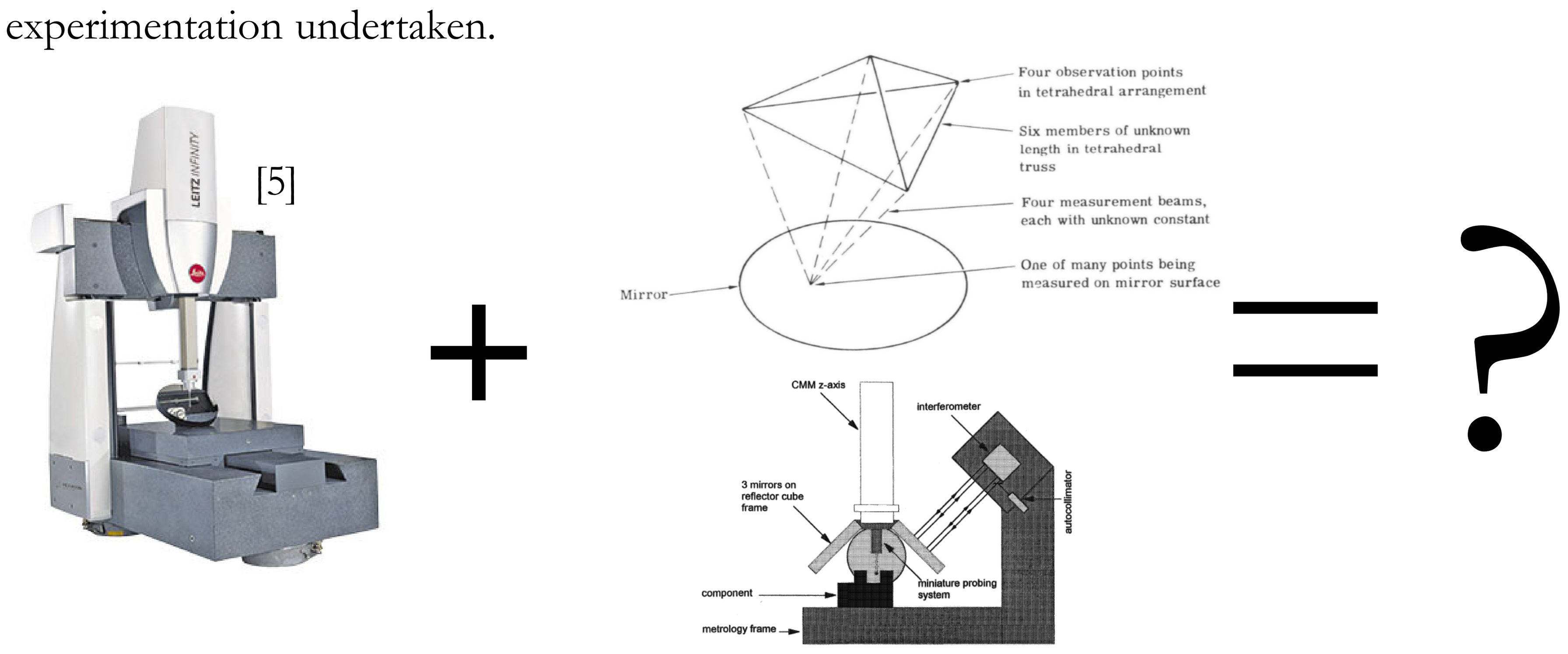
4.2 Metrology frame [4]



Cubic measurement vol. = 50 mm^3
CMM uncertainty = 50 nm

5. Further work

The next task for this project is to determine the method of probe position measurement that will produce the lowest uncertainty on the metre-scale. Analytical models of techniques will be built and initial experimentation undertaken.



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References

[1] ESO. Green Light for E-ELT Construction. http://www.eso.org/public/news/eso1440/, 2014. Accessed: 2016- 2-17.
[2] R. Leach. *Optical measurement of surface topography*, pages 71-106. Springer, 2011.
[3] A. H. Greenleaf. Self-Calibrating Surface Measuring Machine. *Optical Engineering*, 22(2):222276–222276–, 1983.
[4] G. N. Peggs, A. J. Lewis, and S. Oldfield. Design for a Compact High-Accuracy CMM. *CIRP Annals - Manufacturing Technology*, 48(1):417 – 420, 1999.
[5] HEXAGON METROLOGY. Leitz Infinity – Most accurate CMM within its class. http://hexagonmetrology.co.uk/ Leitz-Infinity126.htm#.VpaEzUqLRpg, 2015. Accessed:2016-1-13.

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