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# DETERMINATION OF THE LATERAL RESOLUTION OF AN INTERFERENCE MICROSCOPE USING A MICRO-SCALE SPHERE


Rong Su[1], Matthew Thomas[1], Peter de Groot[2], Jeremy Coupland[3], Richard Leach[1]

[1]Manufacturing Metrology Team, Faculty of Engineering, University of Nottingham, UK

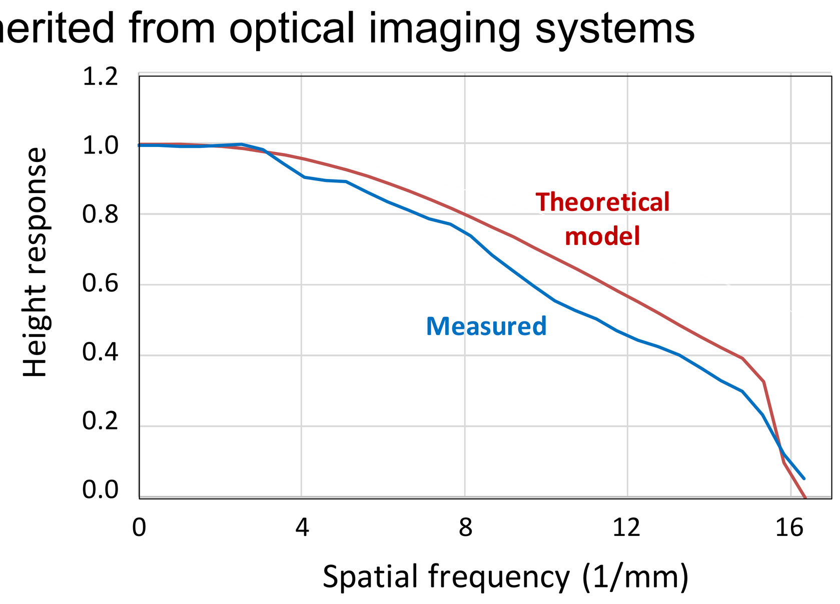
[2]Zygo Corporation, Middlefield, Connecticut, USA

[3]Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, UK


## Lateral resolution characterisation for surface topography instruments

- Lateral resolution for surface topography is the ability to clearly distinguish between the surface heights of two closely spaced points
  - Current specifications for lateral resolution often include the traditional Rayleigh and Sparrow criteria, inherited from optical imaging systems
- A more complete characterisation of lateral resolution is the linear height-response *instrument transfer function* (ITF). ITF represents the measured amplitudes relative to the true amplitudes of surface sine waves as a function of spatial frequency **k**

$$\mathrm{ITF} = \frac{\mathrm{output}(\mathbf{k})}{\mathrm{input}(\mathbf{k})}$$




*Example instrument transfer function of a laser Fizeau interferometer showing a spatial frequency limit of 16 cycles/mm over a 100 mm aperture*

- The ITF can be directly measured over a range of surface frequencies by using a number of calibration artefacts for lateral resolution, e.g. line pairs, star patterns, a series of sinusoids with a chirped pitch, or pseudo-random binary structures [1]
- Alternatively the ITF can be calculated for an optical system using a micro-scale sphere based on the so-called 'Foil model' of the surface [2-3]

## Foil model of a spherical cap – linear theory of imaging

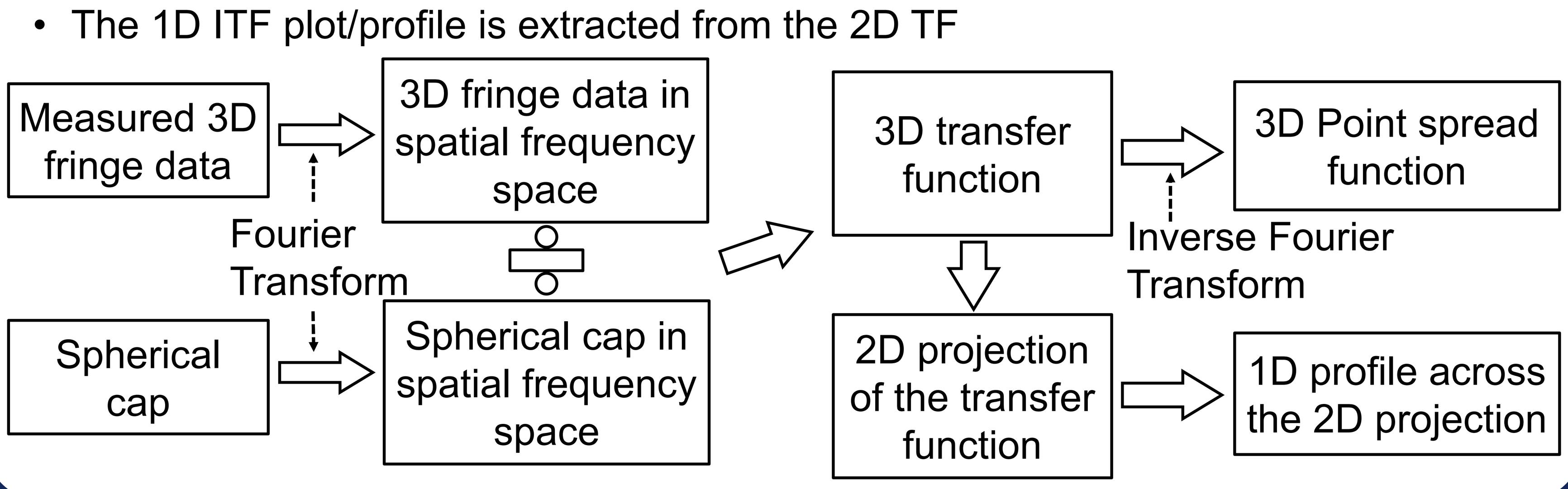
- A coherence scanning interferometry (CSI) system is modelled as a 3D linear filtering operation. There is a linear relationship between the refractive index change and the measured fringe signal
- The image $f(\mathbf{r})$ at the spatial coordinate, $\mathbf{r}$, is modelled as a convolution of the object $o(\mathbf{r})$ with a point spread function (PSF) $h(\mathbf{r})$ associated with the instrument (under certain approximations)

$$f(\mathbf{r}) = \int_{-\infty}^{+\infty} h(\mathbf{r}-\mathbf{r}')o(\mathbf{r}')\,\mathrm{d}^3\mathbf{r}' = h(\mathbf{r}) \otimes o(\mathbf{r}) \xrightarrow{\text{Fourier Transform}} F(\mathbf{k}) = H(\mathbf{k}) \times O(\mathbf{k})$$

$$H(\mathbf{k}) = F(\mathbf{k})/O(\mathbf{k})$$

## Characterisation procedure of 3D TF of CSI

- The 3D TF for the specific optical instrument at the time of calibration can be calculated by dividing the fringe data by the foil in the spatial frequency domain
- A 2D TF is calculated as the projection of the 3D TF onto the x-y plane by summing the 3D TF along the axial direction for each lateral spatial frequency
- The 1D ITF plot/profile is extracted from the 2D TF





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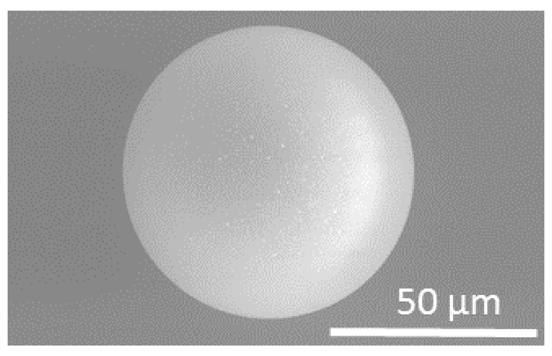
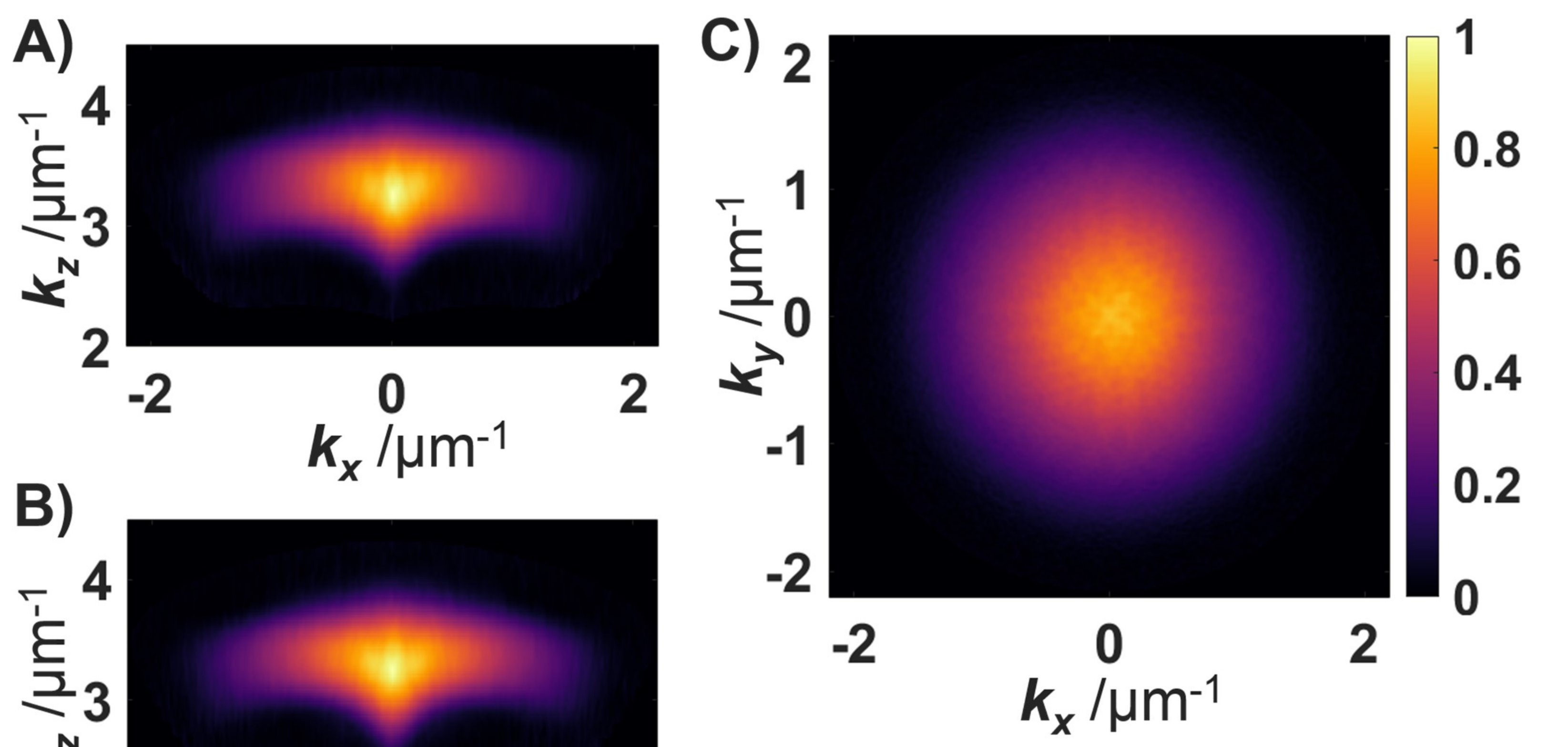
## Results

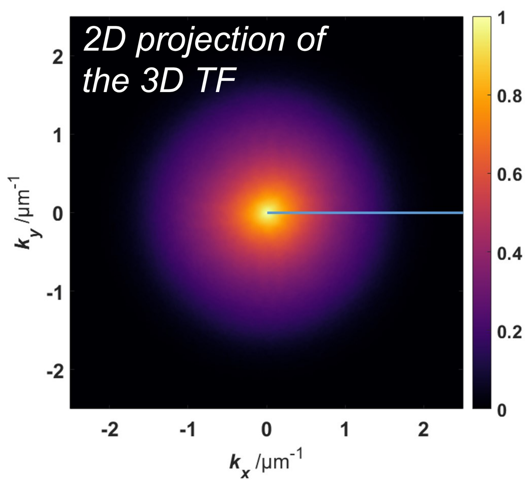
- Three silica microspheres of diameters 44 µm, 57 µm and 59 µm were measured with CSI, each at four different orientations to reduce the effect of any directional bias
- The 3D TF from each sphere is projected to obtain a 2D projection, and a 1D profile extracted



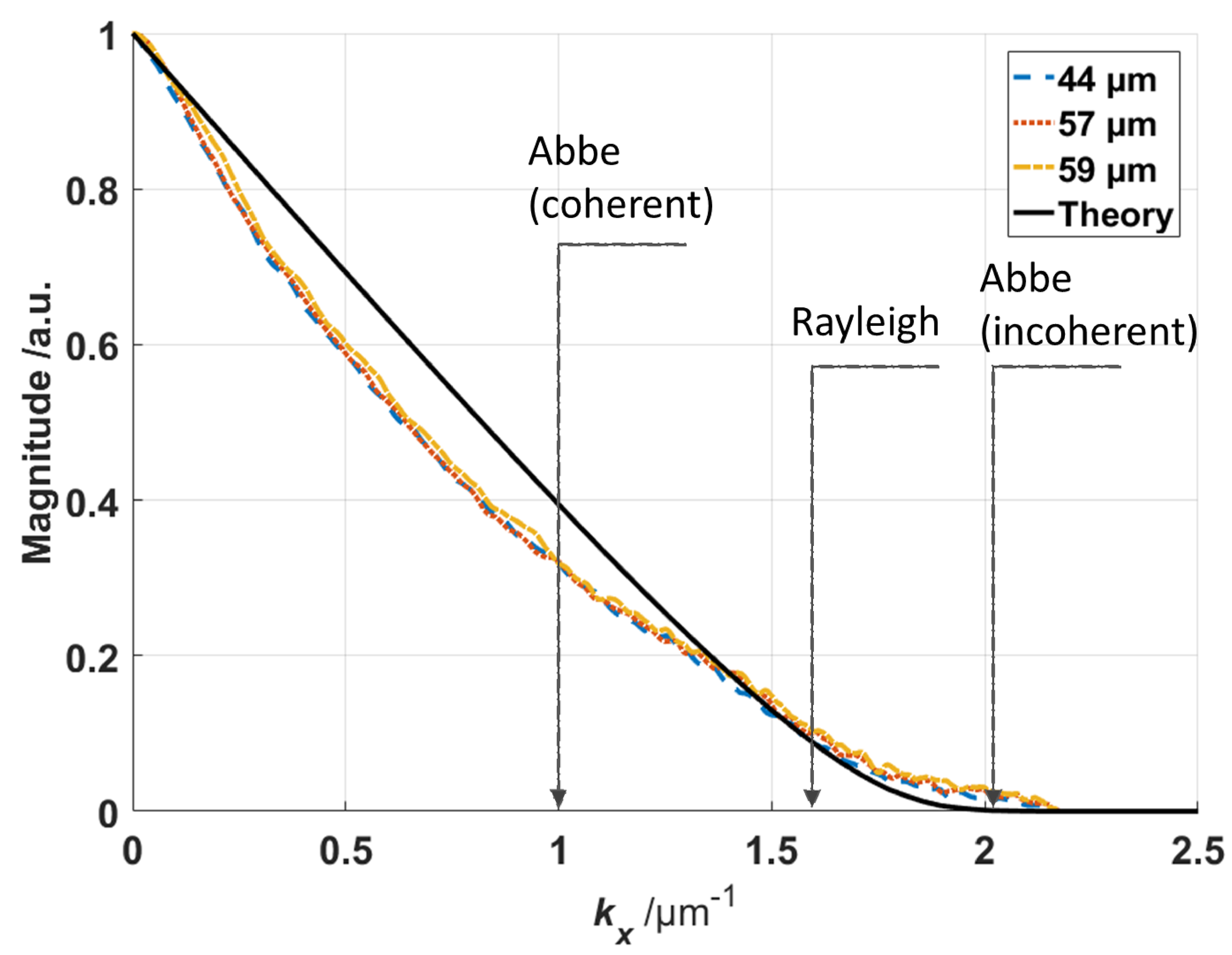




*Magnitude of the 3D TF associated with the 44 µm sphere after averaging and normalisation to one. Slices are shown at spatial frequencies A) ky = 0, B) kx = 0, and C) kz = 2/λ = 3.45 µm⁻¹ (λ = 0.58 µm). The colour bar and colour map used are shared between the three slices.*

- The 3D TFs and the corresponding 2D projections obtained from the measurements of the three spheres are almost completely identical, providing evidence that the transfer function of a CSI instrument can be obtained solely via measurement of a microsphere




*Profiles are taken along the blue line in the 2D projection of the 3D TF for each sphere measurement. The theoretical model is given by the black solid line. Cut-off frequencies corresponding to the Rayleigh and Abbe criteria of resolution limit are shown.*




## Conclusion

- ITF offers a more complete characterisation of optical instruments, and can be estimated by measuring a microsphere by utilising the linear theory of 3D imaging, here using the Foil model for CSI
- Approach provides alternative to calibration by traditional standards
- Sphere calibration enables a more complete system calibration than traditional ITF specification, potentially leading to software correction methods to extend the linear range of the instrument
- Future work will have authors provide a rigorous experimental verification of foil model, investigate validity regimes of ITF and 3D TF and their relationship

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