Towards a sub-attometer fibre wavemeter based on Speckle interference patterns

C. Perrella[a], E. Schartner[a], S. Scholten[a], M. Facchin[c], G. D. Bruce[c], A. Luiten[a] and K. Dholakia[a,b,c]

[a]*Institute for Photonics and Advanced Sensing, School of Physical Sciences, The University of Adelaide, Adelaide, South Australia 5005, Australia.*

[b]*School of Biological Sciences, The University of Adelaide, Adelaide, South Australia 5005, Australia.*

[c]*SUPA, School of Physics and Astronomy, University of St Andrews, North Haugh, St Andrews KY16 9SS, UK.*

A highly multi-mode medium converts a coherent input field's spatial profile into a granular speckle pattern. Typically, efforts are made to minimize or remove this effect. However, the speckle pattern produced is heavily dependent upon properties of the multi-mode medium and the input light field. By examining the speckle pattern information, parameters such as: polarization [1], wavelength [2], modal character [3], and even simultaneous measurement of two input lasers' wavelengths [4] can be extracted. Precision measurement of optical wavelength is crucial in many applications including laser spectroscopy, optical sensing, and telecommunications. The most common spectrometers utilize one-to-one spectral to spatial mapping using diffractive elements to spatially separate the wavelength components of light. Wavelength measurements utilizing speckle patterns translates this measurement into a higher-dimensional problem, allowing for both high resolution and large bandwidth in an intrinsically compact design.

Here we explore the limits of a speckle pattern-based wavemeter, aiming to achieve a measurement precision better than an attometer. This is demonstrated using a multi-mode optical fiber to produce speckle patterns (Fig. 1). Principal component analysis is used to correlate laser wavelength changes to changes in the speckle pattern allowing extraction of laser wavelength. Preliminary results show a 100am precision, with a clear pathway towards a precision of better than 1am, through the use of a highly frequency stable input laser.

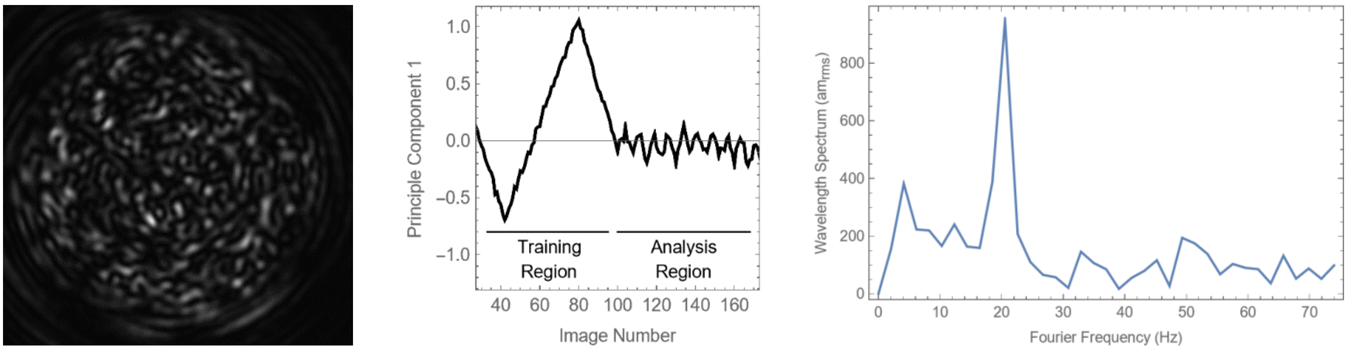

Figure 1: Left – A speckle image used for laser wavelength analysis. Middle – PC1 showing training data, then an analysis region with a 20Hz wavelength modulation applied. Right – Fourier spectrum of laser wavelength extracted from the analysis region showing the 20Hz modulation.

[1] M. Facchin, G. D. Bruce, & K. Dholakia, *OSA Contin.* **3**, 1302 (2020).

[2] G. D. Bruce, L. O'Donnell, M. Chen, & K. Dholakia, *Opt. Lett.* **44**, 1367 (2019).

[3] A. Mourka, M. Mazilu, E. Wright, and K. Dholakia, *Sci. Rep*. **3**, 1422 (2013).

[4] G. D. Bruce, L. O'Donnell, M. Chen, M. Facchin, & K. Dholakia, *Opt. Lett*. **45**, 1926 (2020).