Coherence-gated phase-shifting wavefront measurements

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Abstract

Adaptive optics is widely used in astronomy to obtain diffraction-limited images through the turbulent atmosphere of the Earth. Over the last years, adaptive optics has gained the attention of a wider audience including microscopy.

Two-photon excitation microscopy (TPEM) illuminates one point inside a sample with a strongly converging, near-infrared laser beam, where fluorescent light is created when two NIR photons are simultaneously absorbed, and a single photon is emitted at shorter, visible wavelengths. The fluorescent light is then collected, and by scanning the illumination point through the sample, an image is created.

The inhomogeneities in index of refraction of the sample aberrate the laser beam. This significantly decreases the intensity squared at the focus and thus reduces the fluorescent light while increasing the size of the fluorescing volume. This degrades the image quality and limits the depth penetration.

Due to the large intensity difference between the illumination beam and the backreflected NIR light, it is not trivial to collect only light scattered back from the laser focus. Common wavefront sensing approaches such as Shack-Hartmann wavefront sensors are therefore difficult to use. Instead, simple intensity-optimization schemes have been used, which are less robust and slower. We are working to improve this method by using smart predictive algorithms, but in the meantime we are looking into different wavefront sensing techniques.

This problem can be mitigated by using coherence gating where a reference beam and the back-reflected NIR light from the sample interfere. Since we are using a 100fs-pulsed laser, the interference occurs only over a 30-micron length. This can thus be used to select a narrow depth range of interest, and filter out any unwanted scattered light, as has been shown by [1].

We take this approach one step further and directly measure the wavefront with the interference pattern, without using a microlens array. Using a piezo stage on the reference beam, we alter the phase difference and reconstruct the wavefront in an interferometric fashion. This method provides full wavefront information while being insensitive to light reflected and/or scattered from volumes and surfaces outside of the range of interest.

References

1. S. Tuohy, and A. G. Podoleanu, "Depth-resolved wavefront aberrations using a coherence-gated Shack- Hartmann wavefront sensor" Optics Express, **18**, 3458–3476 (2010).