INVITED

Multiplexed Hartmann Wavefront Sensors for Complex, Broadband, and Vector Wavefields

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Abstract. Optical sensors are limited to measuring intensity. For this reason, wavefront sensors need to convert phase information into intensity modulations. One method to achieve this involves using a Hartmann mask positioned near a camera sensor. This technique is compatible with low-coherence illumination and has been implemented using various encoding optical elements, such as arrays of holes or microlens arrays. For instance, high-resolution and quantitative phase imaging has been demonstrated using a diffraction grating [1], a method known as lateral shearing interferometry (LSI) [2].
In this presentation, we will illustrate how LSI can also measure broadband speckle wavefields generated through multiple scattering media [3], enabling digital fluorescence phase conjugation through tissues [4]. Additionally, we will present a generalization of LSI using a birefringent diffraction grating to perform polarimetric LSI of vector beams [5], which is relevant for optical metrology and polarization-resolved fluorescence microscopy. Finally, we will demonstrate that this generalized principle can be applied to single-shot hyperspectral wavefront sensing, leveraging the spectral dispersion of thin scattering media, with applications in the metrology of ultrashort lasers [6].

1 Introduction

Optical wavefront sensing is a critical technique in various fields, including astronomy, and biomedical imaging. Wavefront sensors typically convert phase information into intensity modulations by placing a Hartmann mask in the close vicinity of a camera sensor. Lateral Shearing Interferometry (LSI) uses a diffraction grating as a Hartmann mask to create a dense grid of foci on a camera sensor [2]. This method allows for high-resolution and quantitative phase imaging [1]. By leveraging the principles of Hartmann wavefront sensing, we illustrate the versatility and power of lateral shearing interferometry (LSI) and its multiplexed generalizations for measuring broadband or vector wavefields.

2 Digital Fluorescence Phase Conjugation

One of the key challenges in optical imaging is the ability to focus light through scattering media, such as biological tissues. Digital optical phase conjugation (DOPC) is a promising technique that can achieve in-depth focusing by measuring and correcting the wavefront

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distortions caused by scattering. However, DOPC becomes particularly challenging when using fluorescent guide stars due to the low photon budget, large spectral bandwidth, and the absence of a reference beam.

We demonstrated the possibility of focusing a laser beam through multiple-scattering samples by measuring speckle fields in a single acquisition step with a reference-free, high-resolution LSI [4]. By taking advantage of the large spectral bandwidth of forward multiply scattering samples [3], DOPC is achieved using fluorescence light from a guide-star. A laser beam is focused at the excitation wavelength while measuring the broadband fluorescence speckle field.

3 Polarimetric LSI of Vector Beams

Imaging both the polarization and the wavefront of a light beam typically demands several intensity acquisitions. Sequential acquisition is incompatible with the monitoring of ultra-fast processes. To address this challenge, we propose a vector-beam LSI. This device relies on the same principle as LSI: A patterned polarization-modulating Hartmann mask placed in close vicinity to a camera encodes both phase and polarization information in a single fringe pattern. The solution we propose for full-Stokes polarimetric wavefront imaging is compatible with partially coherent polarization states, is highly achromatic, provides high-resolution images, and could be implemented in a compact and monolithic design. This technique is of interest for optics metrology and and super-localization microscopy.

4 Single-Shot Hyperspectral Wavefront Sensing

Under broadband illumination, traditional wavefront sensors assume an achromatic wavefront, which makes them unsuitable for these applications. To overcome these limitations, we introduce a hyperspectral wavefront sensing scheme based on the Hartmann wavefront sensing principles, employing a multicore fiber as a modified Hartmann mask. Our system leverages the angular memory effect and spectral decorrelation from the multicore fiber, encoding wavefront gradients into displacements and the spectral information into uncorrelated patterns. We demonstrate the efficacy of this method for recording the hyperspectral wavefront cube from single-pulse acquisitions at the Apollon multi-PW laser facility and for optical dispersion microscopy.

References

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