Optical Interface for Phase Retrieval

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Phase Retrieval is advantageous for the observation of weak phase modulated objects. Its phase topology can be revealed by capturing a stack of defocused images and applying the computational Phase Retrieval algorithm. In general this method is limited in lateral size and axial distance. An optical interface expands this range and enables a previous signal processing step within the lab setup.

1 Introduction

Phase Retrieval is a method for determining the complex-valued wavefront from its intensity distributions in different defocused plane positions. The propagation between these intensity distributions follows a well-defined mathematical description, i.e., the convolution with the impulse response of free space, which we use to iteratively determine the respective complex-valued distributions that satisfy the captured intensity distributions. These intensity distributions must be coincident to each other, i.e., the wave field emanating from the object must be completely captured in all diffraction planes, including the latest diffraction plane, see Fig. 1.

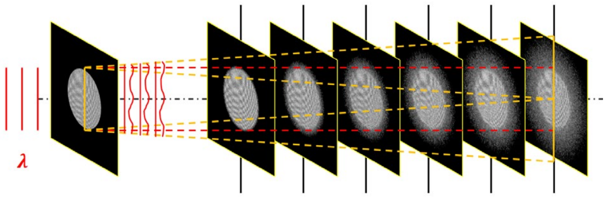

Fig. 1 *Conventional setup for Phase Retrieval.*

2 Optical interface

We consider our illuminated object as a composition of various gratings with different grating period. Each grating diffracts the incoming light into an angle Θ following the grating equation:

$$\sin\theta = \lambda / g \qquad (1)$$

Due to propagation, the maximum diffraction angle Θ_{max} scales the lateral extent of the wavefield depending on distance z, wavelength λ and minimal grating period g_{min}. The limited lateral size of the camera sensor strongly restricts the conventional Phase Retrieval method. We overcome these restrictions by applying an optical interface between the object and the camera which allows us to control the aperture (perceptible diffraction angle, finest structure detail) and the field size (magnification). Additionally we replace the axial movement of the camera (defocusing) using a tunable lens in our optical system. Since the optics should directly transmit the plane wave illumination from the object into the image space, telecentricity on both sides is necessary. Only a telescopic system meets this requirement.

The facilities of aperture control and axial shift of image plane are realized in the pupil plane, i.e., the common focal plane of first (objective) and last (ocular) lens. The aperture is adjusted by installing an iris diaphragm and the defocus by a tunable lens. Both components cannot be implemented at the same position due to their mechanical size. The separation of the unique pupil plane into two optically conjugated pupil planes creates access to the required positions at which the aperture diaphragm and the tunable lens can be inserted. Thus, both functionalities can be implemented and adjusted independently. We realized two setups: i) one telescope with an internal pupil imaging at one stage (one lens), ii) two succeeding telescopes in relay with optically conjugated pupil planes to each other.

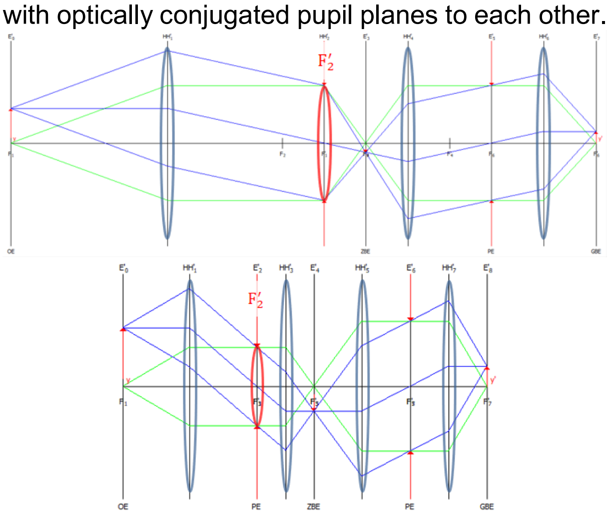

Fig. 2 *Paraxial schemes of realized optical setups with tunable lens (red). Top: Telescope with internal pupil imaging. Bottom: Telescopes in relay.*

3 Hardware based signal processing

An additional feature of the aperture stop is the hardware based signal processing before retrieving

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the phase from the captured image stack. The relationship of Fourier transform between the object and the pupil planes enables us to manipulate the spectral distribution of the object: In this contribution we examined the influence of a low-pass, high-pass as well as a zeroth order filtering on the object reconstruction. Here, we demonstrate the suppression of a middle-frequency grating structure using an iris diaphragm of 2 millimeter diameter instead of 5 millimeters of full open aperture, the emphasis on edges by a central aperture stop of 2 millimeters and the elimination of DC bias applying a metallic filter (diameter: 5 microns) on glass substrate. The latter filter structure suppresses the resulting strong background illumination of an object with a weak phase modulation for dark field evaluation. The influence of filtering on reconstructed phase distributions is shown in Figs. 3-5.

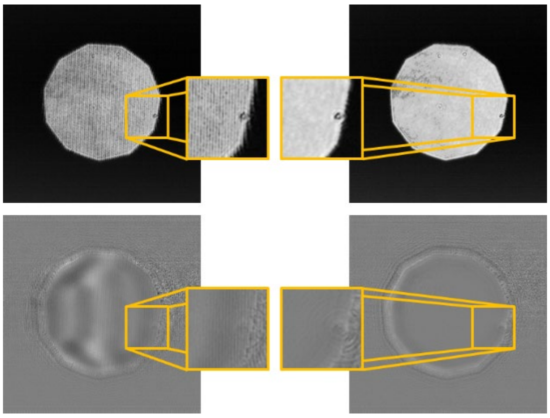

Fig. 3 *Phase grating: Influence of low-pass filter. Top: image without (left) and low-pass filtering (right). Bottom: corresponding retrieved phase distributions.*

Low-pass filter. The diffraction orders of the phase grating are blocked and the grid structure gets missing.

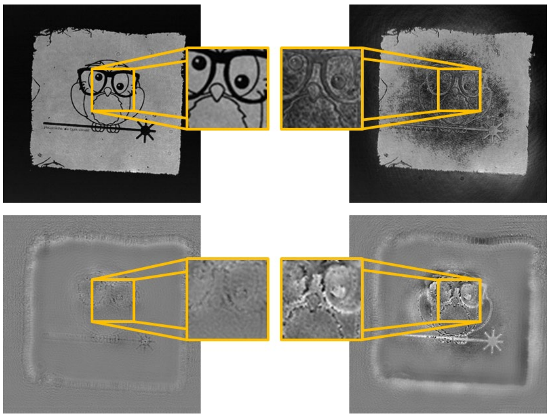

Fig. 4 *Metallic structure on glass: Influence of dot filter. Top: image without (left) and dot filtering (right). Bottom: corresponding retrieved phase distributions.*

Dot filter. We were unable to darken the entire image field, but only the structure. Nevertheless, an increased degree of phase modulation is visible.

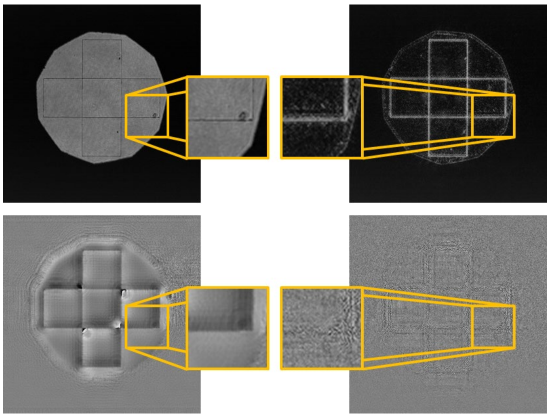

Fig. 5 *Phase tile pattern: Influence of high-pass filter. Top: image without (left) and high-pass filtering (right). Bottom: corresponding retrieved phase distributions.*

High-pass filter. The emphasis on edges is clearly visible in image plane but too much signal content is blocked. This results in a noisy phase distribution.

4 Summary and Outlook

We have designed and realized an optical interface for Phase Retrieval which frees us from the restrictions of the conventional setup. We are able to adapt the object to the camera size, to replace the axial camera shift and to implement a signal processing (hardware filter) prior the computational evaluation. We see as the next step the quantitative verification of the Phase Retrieval method for practical measurements.

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