Optical Fourier Ptychography for super-resolved imaging

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Tomographic Diffraction Microscopy (TDM) is a computational microscopy technique in which the three-dimensional map of the sample refractive index is estimated from multiple sample holograms obtained under different illumination angles. This approach was developed more than twenty years ago and is now successfully implemented in commercial systems. It's interest is that it provides the real and imaginary part of the refractive index with a better resolution than that observed with standard microscopes [1,2]. It's drawback is that it requires an interferometric system for recording the holograms. In the last ten years, it was proposed to simplify drastically the TDM implementation by reconstructing the sample from intensity measurements only. This approach led to phaseless tomographic diffraction microscopy also named Optical Fourier Ptychography (OFP) which is able to provide an estimation of the complex sample refractive index from multiple intensity images obtained under different incident angles. It uses sophisticated reconstruction algorithms that estimate iteratively the sample so as to minimize the distance between the experimental data and the synthetic images of the estimate [3,4]. In most OFP implementations, the microscope configuration is in transmission (i.e. the illumination and observation are on opposite sides of the sample). In this case, the reconstruction benefits from the phase information laying in the interference between the specular transmitted field and the diffracted field. In addition, several efficient approximate models, such as Rytov or the Beam Propagation Method, can be used in the transmission configuration for computing rapidly the synthetic images required by the inversion scheme [5]. Thus OFP in transmission has known an increasing success and was shown to be particularly efficient for increasing the field of view together with the resolution[4].
In this thesis, we propose to extend the principle of OFP to the reflection configuration [6] and to illuminations that are not necessarily collimated beams, (for example periodic light grids or speckled light). Our first objective is to develop a general reconstruction scheme which recovers the complex sample refractive index from intensity images obtained under different known illuminations. Our inversion method will be based on a conjugate gradient algorithm for minimizing the cost functional and resort to rigorous and approximate solvers able to simulate the light scattered by relatively large (tens of wavelengths) objects for simulating the images provided by the sample estimate. We will study the interest of using structured illuminations, the limits of the approximate models in the reconstruction procedure (especially in the reflection configuration) and the influence of possible aberrations in the optical train. In a second step, we will apply the reconstruction scheme to experimental data obtained on our home made OFP. Note that the student will participate to the getting of the experimental images. Last, in a third step, we will investigate the possibility to recover the sample without an accurate knowledge of the illuminations (which can be experimentally demanding) and try to recover the sample using only information on its displacement or on its statistics.
For this essentially theoretical and numerical PhD, we are looking for a motivated student who has strong basis and appetence in mathematics, signal processing and programming. Knowledge in theoretical electromagnetism would also be appreciated.

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