Computational imaging in complex media

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Due to its non-invasive nature and micrometric resolution, optical microscopy is a key tool for observing living samples at the cellular level. However, scattering and distortion caused by the inhomogeneities of biological tissues limit the depth at which an image can be obtained. This major problem has stimulated a great deal of research over the last twenty years, with numerical processing playing an increasingly important role in the image formation.
Our team is specialised in computational imaging. The latter requires an accurate modeling of the link between the recorded data and the sample and sophisticated inversion techniques for recovering an estimation of the sample from the data. In this context, we have shown that multiple scattering, which is usually detrimental to the image formation could be used to improve the spatial resolution of the imager[1].

In this project, we aim at imaging complex samples in a reflection microscope, meaning that the sample is illuminated and observed from the same side. This configuration is encountered in applications where the samples are so thick and diffusive that light cannot go through them. Our objective is to improve the image significance in this specific configuration.

The first task of the student will be to develop a numerical tool able to simulate the light-matter interactions for thick (hundreds of wavelengths) inhomogeneous samples. To this aim, we will adapt the promising Multiple Born Series technique proposed by Vellekoop's group[2].

The second task will be a study of a two-photon imaging set-up in which the sample is probed by a focused beam and the fluorescence is collected on a bucket detector. We will study the penetration depth of focused beams inside a thick inhomogeneous medium. Different beams will be optimized to increase the light penetration. This theoretical and numerical analysis will be confronted to experiments conducted by another student.

The third task will consist in a study on reflection tomography (close to Optical Coherence Microscopy). In this case, the sample is illuminated by a focused beam and the backscattered field is collected on a camera. This technique is well known to provide only information on the high spatial frequencies of the sample [3]. However, we believe that multiple scattering within the sample can provide information on the low spatial requencies of the object. We will develop an inversion tool, accounting for multiple scattering, able to extract this information.

We are looking for a student who appreciates theory and programming and has knowledge on wave propagation and, if possible, on inverse problems. The grant is already available.

References :

[1] Girard, Jules, et al. "Nanometric resolution using far-field optical tomographic microscopy in the multiple scattering regime." *Physical Review A* 82.6 (2010): 061801.

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[3] Zhang, T., Unger, K., Maire, G., Chaumet, P. C., Talneau, A., Godhavarti, C., ... & Sentenac, A. (2018). Multi-wavelength multi-angle reflection tomography. *Optics express*, *26*(20), 26093-26105.