PhD Position Optical nanoscopy

Super-resolution imaging using unknown illuminations

The Institut Fresnel and ICFO-the Institute of Photonic Sciences are two research laboratories based in Marseille (France) and Barcelona (Spain), devoted to research and higher education in all areas of optical and photonic sciences.

Institut Fresnel and ICFO are seeking to recruit talented, enthusiastic young scientists who are highly motivated to boost their research career in the areas of nano-optics and/or biophotonics and join the prestigious European Erasmus Mundus Doctorate program Europhotonics.

Context

In active imaging, the target is usually probed by different illuminations. The probing wave can be a scanning focused laser beam in confocal optical microscopy or a radar electromagnetic wave radiated from a moving antenna as in remote-sensing application, or a sound wave stemming from a circular array of transducers as in acoustical tomography. These multiple illuminations permit to ameliorate significantly the imager resolution. Yet, a reconstruction procedure must be used to restore the high-resolution sample image from the data obtained under different illuminations. The recorded data are usually expressed as the convolution by a point spread function of the product of the sample by the illumination. The point-spread function (PSF) of the imaging system corresponds to the data recorded for a point-like target. The PSF is a low-pass filter with a bounded frequency support that produces blurry (ie. low-resolution) images. However, *if non-uniform illuminations are used*, the illumination modulates the sample function before the PSF is applied and information beyond the frequency support of the PSF can be retrieved.

Many data processing techniques in various application domains such as Synthetic Aperture Radar (SAR) remote-sensing or Structured Illumination Microscopy have been proposed to produce high-resolution reconstruction from a set of *low-resolution* recorded data. However, all these reconstruction algorithms require the knowledge of the illumination. Now, this information may be quite difficult to obtain. Hence, in Structured Illumination Optical Microscopy, the control of the illumination is achieved at the expense of very strong instrumental constraints. In other applications, the knowledge of the illumination is not even a realistic hypothesis since the surrounding medium interacts with the incoming wave.

The goal of this thesis is to develop reconstruction methods that require very little prior knowledge on the illuminations and to apply them to data obtained in fluorescence and marker-free optical microscopy in order to get super-resolved three-dimensional sample images. In case of success, this work will be a breakthrough in optical imaging that will find numerous applications in nano-optics, biophotonics, nanotechnology…

Research subject, work plan

In the field of fluorescence microscopy, our groups showed that an appropriate algorithm (blind-SIM) could retrieve the super-resolved image of a thin biological sample from a set of low resolution fluorescence images obtained with uncontrolled speckle illuminations (obtained by laser shining a grained transparent plastic cover) or by a distorted periodic light pattern (obtained with the interference of two coherent beams). The reconstruction algorithm developed for this purpose jointly estimated both the sample fluorescence (the target) and the unknown illuminations through the minimization of a merit function. This technique, which has been developed only for two-dimensional data is very promising and requires further investigations.

The first work of the PhD student will be to extend the technique to three-dimensional fluorescence imaging. Indeed, structuring light in the transverse and axial plane (as in light sheet microscopy) should permit to improve the resolution of the microscope in all directions.

A second task will be to apply this technique to marker-free imaging. In this case, the image is given by the field diffracted by the sample under spatially coherent illumination. In the single scattering regime, the image formation model of marker-free microscopy is close to that of fluorescence microscopy. Thus we expect that an adapted blind-SIM approach should work for marker-free microscopy.

A third task will be to analyse the performance of the blind-SIM method (depending on the illumination properties, the number of images, noise) and to develop a possibly more robust and more accurate technique which do not require to reconstruct the unknown illumination patterns. A possible approach would be to develop a merit function that depends on the statistics of the

illuminations parameters, but not on their specific values.
All these algorithmic development will be applied to synthetic and experimental data coming from existing microscopes in both laboratories. The student will participate to the improvements of the experimental setups and will participate to the getting of the data.
We are looking for a highly motivated student that appreciates theory, who has some knowledge in electromagnetism, imaging and possibly signal processing. However in this project, theory and experiment are strongly connected. For this reason the candidate must also be interested in experimental issues.

Terms of employment – PhD fellowship

The position is intended as full-time (38 hrs / week, 12 months / year) appointment. Fellowships are offered for periods up to three years conditional on satisfactory performance in research activities.

PhD candidates will work under a co-tutelle supervision (joint supervision of doctoral studies by at least two universities within the consortium) between Fresnel Institute (Marseille, France) and ICFO (Barcelona, Spain). At least one semester will be spent in each of the co-supervising institutions.

The selected PhD student will work under close supervision of a senior researcher and benefit from direct mentorship. PhD students will also benefit from several courses specially developed within the European Erasmus Mundus Doctorate program Europhotonics.

A PhD degree will be granted after successful completion of the PhD research.

Application procedure

Suitable candidates are requested to follow the procedure described via the Europhotonics doctorate website http://www.europhotonics.org/emundusdoctorate/

Selection is based on merit and potential, measured in terms of the academic record and personal achievements. Proactivity, participation in community activities, and capacity for team-work are also taken into account.

Supervisors and Contacts

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For general information, visit http://www.fresnel.fr/spip/spip.php?rubrique29&lang=en and http://www.icfo.eu/research/sln.php

Selected references

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