Master in Photonics – "PHOTONICS BCN"
Master ERASMUS Mundus "EuroPhotonics"

MASTER THESIS PROPOSAL

Dates: April – September 2023

Laboratory: Optoelectronics group (led by Prof. Valerio Pruneri)
Institution: ICFO – The Institute of Photonic Sciences
City, Country: Castelldefels (Barcelona), Spain

Title of the master thesis: Compact particle size analyser enhanced by machine learning and quantum imaging techniques

Name of the master thesis supervisor and co-supervisor:
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Keywords: Particle scattering, machine learning image analysis, quantum imaging, single-photon detection

Summary of the subject:

Light scattering, a fundamental phenomenon responsible for many physical effects, such as the blue colour of the sky, can be exploited to create essential devices. One such example of this is particle size analysers (PSA). These devices have gained popularity in industry for counting particles and determining their size distribution, which is crucial for monitoring and controlling many production processes and for biological and environmental applications. The state-of-the-art PSA probe the radial distribution of diffracted or scattered light at a defined distance from the sample. The particle size distribution is then estimated from the scattering pattern using appropriate optical models. Commercially available PSA are expensive and large devices that limit their widespread application. In the Optoelectronics group, we have developed an ultra-compact PSA [1] that in combination with a customized machine learning algorithm can predict the median volume diameter of particles.
As light scattering is influenced by factors other than particle size, including shape, refractive index contrast and suspension concentration, the PSA can also be employed in biological applications such as detection of microorganisms in water.

Nevertheless, there is a fundamental difficulty in analysing small particles (< 5 μm) like microorganisms, particularly at low concentrations, because the light scattered off particles overlaps

with much brighter unscattered background light. Additionally, when probing large sample areas, it is difficult to resolve small scattering angles much smaller than the size of the spot.
Resolving this problem would greatly improve the usefulness of scattering analysis in critical real-world applications, such as measuring low concentrations of microorganisms in water.

The machine learning-enhanced PSA developed in our group represents a promising approach towards solving this problem. Another possible solution may be provided through quantum imaging techniques, using spontaneous parametric down conversion (SPDC). In SPDC, pairs of photons can be generated that are strongly anti-correlated in their emission angle. In other words, if we know the trajectory of one photon, we can immediately infer the trajectory of the other.
By probing a weakly scattering sample with SPDC photon pairs, looking at how these correlations change directly lets us obtain a background-free measurement of the scattering distribution despite illuminating an arbitrarily large sample area [2]. To image correlated photon pairs, in our group we use single-photon avalanche diode (SPAD) arrays – special cameras that can detect the arrival of single photons with very high precision in time.
Therefore, combining the two approaches of machine learning image processing, and detecting quantum correlations in photon pairs, may yield a PSA sensitivity that improves over the state-of-the-art.

In this project the student will design and implement a novel PSA, based on classical and quantum light detection. The student will form part of the Optoelectronics group at ICFO, led by Prof. Valerio Pruneri, working closely with members of the imaging team in order to take advantage of the group's expertise in machine learning and quantum imaging.

References
[1] Hussain, R., Alican Noyan, M., Woyessa, G. et al. "An ultra-compact particle size analyser using a CMOS image sensor and machine learning," *Light Sci. Appl.* **9**, 21 (2020).
[2] Peeters, W. H., Moerman, J. J. D., & Van Exter, M. P. "Observation of two-photon speckle patterns," *Phys. Rev. Lett.* **104**, 173601 (2010).

Objectives:

- Particle size analysis experiments with classical light
- Introduction to methods in experimental quantum optics – SPDC, SPAD array cameras, and coincidences
- Data processing and analysis with image processing and machine learning in Python
- Design and implementation of a quantum-enhanced scattering analyser
- Measurements of industrially relevant scattering sample solutions

Additional information:

Required skills:

- Familiarity with programming using Python programming language (common scientific computing libraries such as NumPy etc)
- Previous experience with optics laboratory setups would be a bonus