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

MASTER THESIS PROPOSAL

Dates: April – September 2023

Laboratory: Optoelectronics group
Institution: ICFO – Institut de Ciències Fotòniques
City, Country: Castelldefels, Spain

Title of the master thesis: Quantum imaging in the SWIR region using a single pixel camera

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Keywords: Entanglement distribution, single pixel camera, SWIR imaging, machine learning

Summary of the subject (maximum 1 page):

With the arrival of commercially available quantum computers will come the need to connect them through quantum channels, i.e. the quantum Internet. There is an obvious limitation in the capacity and security that these quantum channels can provide if only qubits are considered. Polarization entangled photon-pair sources are the most widely used resource to generate these two-dimensional states for quantum communications and cryptography applications. However, other degrees of freedom have been studied to increase the number of dimensions that can be used to encode and securely transmit quantum information, such as path, spatial modes or time–frequency bins (see [1] for a review in high-dimensional quantum entanglement). The spatial degree of freedom, a discrete series of transverse spatial modes forming an orthogonal basis (such as the pixel basis), has the potential to exponentially increase the capacity of the quantum communication links, especially in free-space propagation interconnecting urban buildings, for example.

The proposed master thesis aims at characterizing the high-dimensional spatial correlations in the pixel basis generated in an entanglement photon source (EPS) working in the shortwave infrared (SWIR) region, between 0.9 - 1.7 µm, using a novel quantum imaging system based on single-pixel imaging technology and machine learning data processing.

Single-pixel cameras, based on the single-pixel imaging principle [2], are a promising paradigm to reconstruct images by employing different spatially resolved patterns that mask the object to be captured, while measuring the transmitted signal with a high-efficiency single-

point detector. The main advantage of using this imaging technique is that the detected intensity is independent of the resolution of the resulting image, being able to significantly increase the detection dynamic range and provide pixel resolution on demand. Furthermore, this technology can be broadband, offering technological advances beyond the current state of the art, and has the potential to be disruptive in spectral ranges where current solutions have limited performance, making it attractive to both academia and industry. This is because it can easily capture radiation in any under-utilized region of the electromagnetic spectrum, i.e. from gamma rays to THz radiation [3], where no other high-sensitivity 2D sensor array devices are available.

In this project, the student will learn how to capture high pixel resolution images making use of a single photon detector, e.g. an avalanche photodiode (APD) acting as a bucket detector, commonly available in any quantum optics laboratory.

Objectives:

- Look for related seminal work and commercial devices to discuss the expected performance of the proposed imaging system.
- Design and implement optical systems for high-performance image reconstruction, and participate in the experimental measurements.
- Synthesis and characterization of novel projection patterns for imaging optimization.
- Train and test the already developed algorithms (neural network) for the reconstruction of high definition images with large pixel density, minimizing the amount of measurements that are required.

Additional information:

It is desirable that the student has basic knowledge of experimental optics, Python programming, and machine/deep learning background.

References

[1] M. Erhard, M. Krenn, and A. Zeilinger, "Advances in high-dimensional quantum entanglement," *Nature Reviews Physics* **2**, 365-381 (2020).
[2] M. P. Edgar, G. M. Gibson, and M. J. Padgett, "Principles and prospects for single-pixel imaging," *Nat. Photonics* **13**, 13–20 (2019).
[3] A. Vallés, J. He, S. Ohno, T. Omatsu, and K. Miyamoto, "Broadband high-resolution terahertz single-pixel imaging", *Opt. Express* **28**, 28868 (2020).