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

MASTER THESIS PROPOSAL

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Laboratory: Quantum Engineering of Light
Institution: ICFO
City, Country: Barcelona, Spain

Title of the master thesis: Frequency-entangled paired photons for imaging based on the use of the Transport of Intensity equation

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Summary of the subject (maximum 1 page):
The transport of intensity equation (TIE) is a non-interferometric technique that allows to retrieve the unknown phase profile of a light beam through intensity only measurements. If the light beam has been transmitted or reflected from an object, the retrieved phase allows to reconstruct the shape (optical path length) of the object (see [1] for a tutorial concerning TIE). TIE is applicable under partially coherent illumination, permitting good spatial resolution, high signal-to-noise ratio and excellent image quality.

If $I(x,y)$ designates the intensity profile of the light beam, TIE involves measuring the derivative of the intensity ($\partial I(x,y)/\partial z$), where z is the direction of propagation of the light. This implies the measurement of the intensity at different planes ($z-\Delta z/2$ and $z+\Delta z/2$). However, in 2010 Waller et al. [2] showed that one can measure instead the intensity in the plane of interest z at different wavelengths. This requires the use of frequency filters. How narrowband should be the filters to provide a high-quality measurement of the phase? While at optical communication wavelengths (~1550 nm) good frequency filters exist, at the mid and far infrared this might not be true, so TIE based on multiple wavelengths can not be used at these frequency bands. This is an important drawback since imaging using longer wavelengths can provide important information and deeper penetration depth into samples.

Frequency entangled photons generated in spontaneous parametric down-conversion (SPDC) can provide a solution. If the light beam that pumps the nonlinear crystal in a SPDC scheme is

CW, the signal and idler beams generated, that can be at very different frequencies, show a strong frequency correlation. Therefore, strong filtering of the signal will induce strong filtering of the idler beam.

In this project we aim at investigating the frequency filtering required for obtaining high quality imaging using TIE. We will investigate how the accuracy of phase retrieval with TIE depends on how strong is the frequency filtering, and will search for how much filtering can be achieved using standard, commercially-available frequency filters in the mid and infrared. We will study how frequency entangled photons generated in SPDC can provide the required filtering at mid and far infrared frequency bands. We can even explore the possibilities that this technique offers for exploring in the terahertz frequency domain.

Recently, the use of quantum correlations in TIE-based imaging has been considered.

References

[1] Chao Zuo, Jiaji Li, Jiasong Sun, Yao Fan, Jialin Zhang, Linpeng Lu, Runnan Zhang, Bowen Wang, Lei Huang, Qian Chen, *Transport of intensity equation: a tutorial*, Optics and Lasers in Engineering **135,** 106187 (2020).

[2] Laura Waller, Shan Shan Kou, Colin J. R. Sheppard, and George Barbastathis, *Phase from chromatic aberrations*, Optics Express **18**, 22817 (2010).

[3] Giuseppe Ortolano, Pauline Boucher, Ivano Ruo Berchera, Silvania F. Pereira, and Marco Genovese, *Phase retrieval enhanced by quantum correlation*, arXiv:2109.10095v1 [quant-ph] 21 Sep 2021.