PHD PROJECT DESCRIPTION

(4000 characters max., including the aims and work plan to de published online)

Project title: Imaging using Quantum Optical Coherence Tomography

1.1. Project goals

- New detection scheme based on a single-photon sensitive spectrometers and incorporated in the work-flow of the existing Fourier-domain Quantum OCT (Fd-Q-OCT).
- Novel Swept Source Quantum OCT (SS-Q-OCT) where the central wavelength of the pump is changed and the diagonals of the joint spectrum are acquired one after another.
- Super-resolution imaging test on a variety of signals.
- Biological imaging will be attempted.

1.2. Outline

One of the most dynamically evolving optical imaging techniques is Optical Coherence Tomography (OCT). It is a non-invasive and non-contact method for volumetric imaging with micrometric axial and lateral resolution, providing very good quality images of the inside of semi-transparent objects, such as eyes. Quantum OCT (Q-OCT) works around the fundamental limitations of OCT by enhancing the very process of image formation and provides two advantages: twofold resolution increase and cancellation of resolution-degrading even-order dispersion. The core of Q-OCT is a source of entangled photon pairs, generated by Spontaneous Parametric Down-Conversion (SPDC), interfering within a Hong-Ou-Mandel (HOM) interferometer. In the original realization of Q-OCT, Time domain Q-OCT (Td-Q-OCT), the A-scan is obtained from HOM dips.

Q-OCT, despite a great potential, has limitations: it produces image-scrambling artefacts, additional elements in the signal which do not relate to the structure of the object, acquisition times are very long, and it is affected by odd-order dispersion. Although Q-OCT cancels out even order dispersion, with the second order generally thought to account for most of dispersion-related resolution degradation[4], the contribution of the third order dispersion cannot be neglected as it leads to resolution worsening and most of all, distortions, especially for spectrally broadband light and dispersive, bulk objects. Having noticed that slight changes in the central frequency of the pump light makes the artefacts in the depth profile transition from a peak to a dip and vice-versa, it was suggested that the artefacts can be removed by averaging depth profiles taken for multiple pump frequencies.

To address the speed and artefact issue, a Swept Source Quantum OCT (SS-Q-OCT) will be developed and analyzed, together with the existent Fourier-domain Quantum OCT (Fd-Q-OCT) setup, for successful approaches in acquisition speedup inspired by classical OCT. Also, with the access to the spectral information by means of the acquired joint spectrum in both Fd-Q-OCT and SS-Q-OCT, the effects associated with the artefacts and dispersion will be easily identified and then removed. This task will be done in collaboration with our colleagues that will develop machine learning tools exactly for that purpose within the same project this is research is part of, Opus-29 “Advancing light-based imaging using Quantum Optical Coherence Tomography and Machine Learning”. The research will be carried out at the Single Photon Applications

Laboratory, at the Physics faculty-Nicolaus Copernicus University in Torun.

1.3. Work plan

-A Swept Source Quantum OCT will be developed, allowing comfortable switching with the existing a Fd-Q-OCT.

-Optimization of experimental parameters for maximum speed and sensitivity.

- Biological imaging will be attempted.

1.4. Literature (max. 7 listed as a suggestion for a PhD candidate preliminary study)

Tomlins, P. H., & Wang, R. K. (2005). Theory, developments and applications of optical coherence tomography. Journal of Physics D: Applied Physics, 38(15), 2519.

Nasr, M. B., Saleh, B. E., Sergienko, A. V., & Teich, M. C. (2003). Demonstration of Dispersion-Canceled Quantum-Optical Coherence Tomography. Physical review letters, 91(8), 083601.

Kolenderska, S. M., Vanholsbeeck, F., & Kolenderski, P. (2020). Fourier domain quantum optical coherence tomography. *Optics Express*, *28*(20), 29576-29589.

Kolenderska, S. M., de Brito, F. C. V., & Kolenderski, P. (2025). Demonstration of Fourier-domain Quantum Optical Coherence Tomography for a fast tomographic quantum imaging. *arXiv preprint arXiv:2502.08372*.

Yepiz-Graciano, P. D., Salamanca-Roldán, D., Cruz-Ramírez, H., U'Ren, A. B., & Ramírez-Alarcón, R. (2025). Sub-second A-scan Acquisition Using Marginal Spectral-Domain Quantum Optical Coherence Tomography. *arXiv preprint arXiv:2512.01110*.

1.5. Required initial knowledge and skills of the PhD candidate

- Master's Degree in Physics or a relevant discipline.
- Background in theoretical and experimental physics.
- Knowledge of Optical Coherence Tomography or Quantum Optical Coherence Tomography preferred but not mandatory.

1.6. Expected development of the PhD candidate's knowledge and skills

Experience, knowledge and skills attractive in the high-tech industry and academia: Design, construction, and optimization of optical setups, in-depth knowledge of how OCT/Quantum OCT operate, critical thinking and problem-solving skills.