

PHD PROJECT DESCRIPTION

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

Project title: Computational Methods in Quantum Optical Coherence Tomography

1.1. Project goals

- **Investigation of new Quantum OCT configurations -**
 - New detection scheme based on a single-photon sensitive spectrometers and incorporated in the workflow 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.
- **Removal of artefacts and dispersion effects using Machine Learning -**
 - Improved processing of Quantum OCT signals, coming from both the Fd-Q-OCT and SS-Q-OCT version of the setup in terms of resilience to image-scrambling artefacts and resolution-degrading dispersion effects.
 - Development of universal training data generation for improved time-efficiency and robustness of neural network development.
- **Resolution-improving method -**
 - Model of Q-OCT-enabled superresolution imaging.
 - Neural network development for its application.

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 formation³ 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.

Despite a great potential, Q-OCT 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 degradation⁴, 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.

To address the speed and artefact issue, two new Quantum OCT modalities will be developed and analysed: Fourier-domain Quantum OCT (Fd-Q-OCT) and Swept Source Quantum OCT (SS-Q-OCT) – both building on successful approaches in acquisition speedup inspired by classical OCT. Unlike the standard Time-domain Quantum OCT, the measurement will not involve any data-acquisition-prolonging mechanical scanning. 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 without any need for complicated, measurement-prolonging hardware modifications, as is the case in Time-domain Q-OCT.

1.3. Work plan

Research related to work package 2 and 3 (WP2 and WP3):

(WP 2) Removal of artefacts and dispersion effects using Machine Learning -

- The existing Machine Learning algorithm will be developed further to allow better processing of Quantum OCT signals, first coming from the Fd-Q-OCT version of the setup. To obtain better prediction fidelity, different network architectures will be optimised and tested and more optimal loss functions will be created and applied.
- The training datasets will be modified to better reflect the optical parameters of the Quantum OCT experimental system. The found network candidates will be trained and then tested on experimental signals.
- Universal training data generation will be developed: the training signals will be automatically generated based on the given exemplary joint spectrum which came from the experiment. In this way, potential errors originating from a mismatch between simulated parameters and experimental parameters will be removed.
- Training dataset will be generated for signals coming from SS-Q-OCT version of the setup and used to obtain a neural network able to remove artefacts and dispersion effects.

(WP 3) Resolution-improving method -

- Based on the theoretical formulation and analysis of the problem by a team member, training datasets for a neural network will be created. The neural network will be trained to output a resolution-improved Q-OCT images.

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

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

Kolenderska, S. M., & Szkulmowski, M. (2021). Artefact-removal algorithms for Fourier domain quantum optical coherence tomography. *Scientific reports*, 11(1), 18585.

Maliszewski, K. A., & Kolenderska, S. M. (2021, March). Artefact removal for quantum optical coherence tomography using machine learning. In *Optical Coherence Tomography and Coherence Domain Optical Methods in Biomedicine XXV* (Vol. 11630, pp. 19-27). SPIE.

Maliszewski, K. A. (2022). *Machine learning and quantum optics: an approach to improve OCT capabilities* (Doctoral dissertation, University of Canterbury).

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 Computer Science or Mathematics or Physics or a relevant discipline.
- Background in machine learning or programming.

- 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: building of neural networks, analysis of the results provided by the networks, ability to interpret the results for the further optimisation of the outputs, in-depth knowledge of how OCT/Quantum OCT operate