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SEQUOIA Horizon Europe project
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Newsletter #3

Aug-2024

- Single photon detection for entangled photon pairs
- Novel supercontinuum system
- Automatic retinal layer segmentation algorithms

Funded by the European Union

This project has received funding from Horizon Europe, the European Union's Framework Programme for Research and Innovation, under Grant Agreement No. 101070062 (SEQUOIA). Funded by the European Union.

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Single photon detection for entangled photon pairs

Micro Photon Devices s.r.l. (MPD) is an Italian SME based in Bolzano, well known as a reliable supplier of single photon detectors (single pixels and cameras) that are an enabling technology for many scientific research applications. MPD's products are based on single photon avalanche diodes (SPADs) that offer high sensitivity from UV, to visible, and down to the near infrared (300 to 1700 nm range).

SPADs are similar to avalanche photodiodes (APDs) but operate with a bias voltage above breakdown, where a single photon can trigger a macroscopic avalanche that allows for a very easy detection of the photon and, more importantly, of its of arrival time with sub-nanosecond resolution. Within the SEQUOIA project, MPD has been tasked with delivering SPAD arrays optimized for quantum OCT (QOCT).

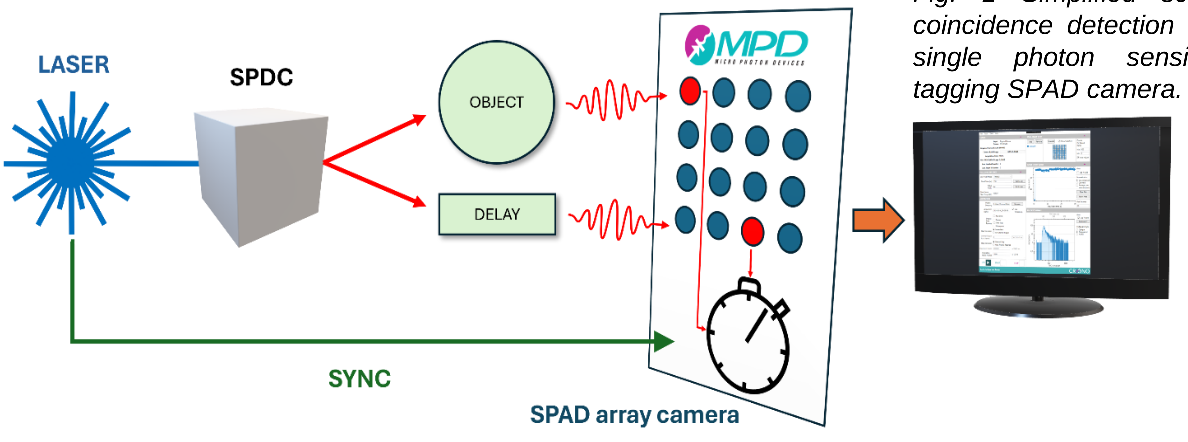

Fig. 1 Simplified schematic of coincidence detection with MPD's single photon sensitive, time-tagging SPAD camera.

SEQUOIA will need to detect entangled photon pairs that fall in the visible light range. Silicon-based detectors are a good choice, as their sensitivity range perfectly matches the project's target, and they offer the unique ability of monolithic integration with all the processing electronics in a standard CMOS process. Specifically, MPD is supporting the experimental partners (in particular DTU) with a pair of its current-generation SPAD arrays, to allow DTU to refine the OCT protocol and gather valid and useful results to prove the advantage of QOCT. The current cameras offer 2048 pixels and operate in counting mode with gates as short as a couple of nanoseconds, allowing detection of photon pairs.

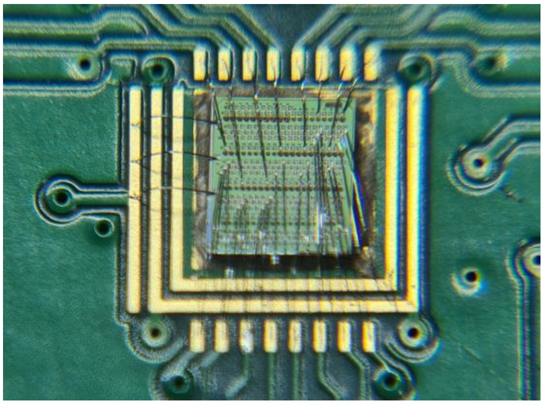

Fig. 2: Detail of a SPAD chip-on-board.

However, this is an interim solution, as MPD is now engineering a brand new SPAD camera specifically designed for the SEQUOIA project requirements. The new SPAD camera will maximise the photon pair detection rate by moving from a photon-counting to a photon-timing architecture, that significantly improves the effective measurement rate (see Figure 1 for a simplified depiction of the measurement method). Time-tagging single photons allows flexibility in optical experimental design, as photon pair detection can be deferred to a post-processing stage. MPD will also optimise the SPAD detection efficiency to further improve the signal to noise ratio.

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Novel supercontinuum for SEQUOIA application

In the SEQUOIA project the laser system is required to have low noise and a broadband spectrum in the ultraviolet. The laser system pumps a nonlinear down conversion crystal generating bi-photon states used to probe the sample in the quantum OCT system. Low noise and large bandwidth ensures high contrast and high resolution respectively.

To achieve this, a novel supercontinuum system based on a femtosecond pumped normal dispersion photonic crystal fibre is used to generate a highly temporally coherent supercontinuum. As seen in Figure 3, the spectrum spans a full octave from 700 nm to 1400 nm with 755 mW of pump power with a high spectral flatness. The nonlinear broadening mechanisms inside the fibre retain the temporal coherence of the pulse, such that efficient second harmonic generation is possible.

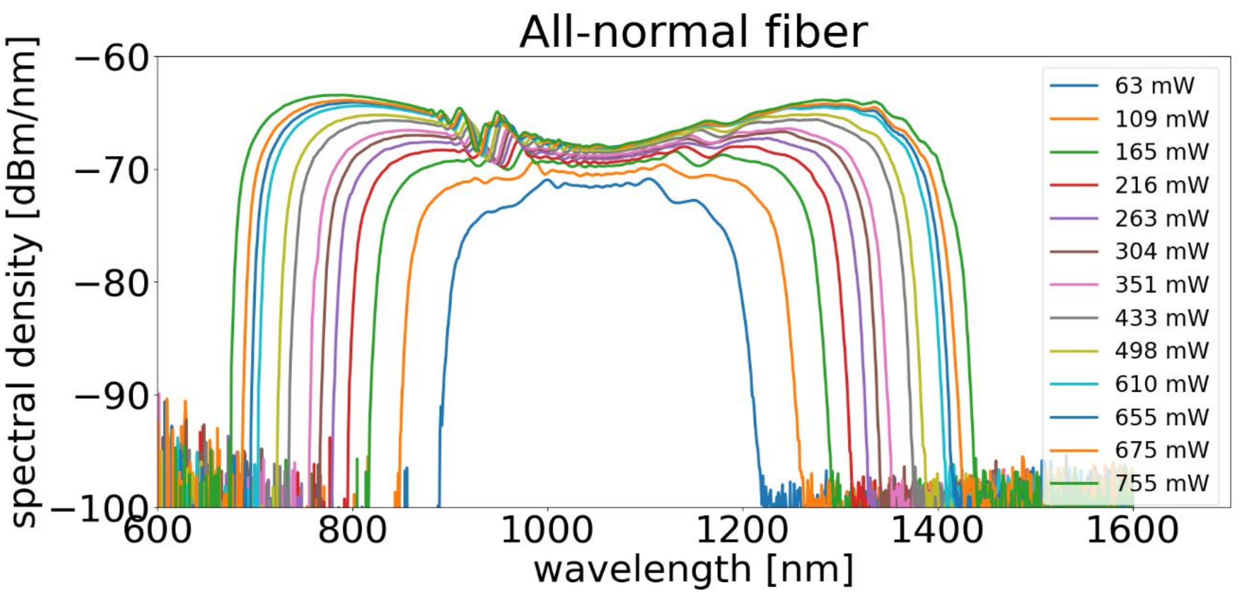

Fig. 3: Supercontinuum spectra at several pump powers.

In Figure 4, a schematic of the envisioned system is shown, with a nonlinear broadening fibre, followed by a second harmonic stage to generate the UV wavelengths. Current efforts are aimed at increasing the second harmonic generation efficiency to increase spectral density levels making the output suitable for pumping the spontaneous parametric down conversion crystal used for generating the bi-photon states.

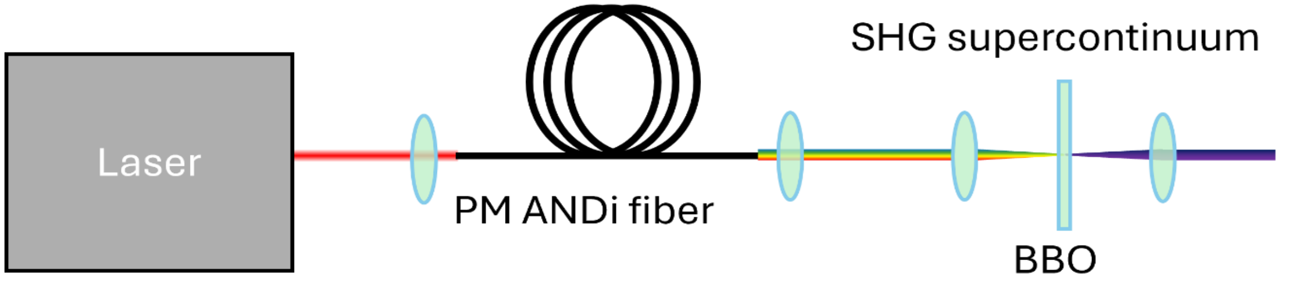

Fig. 4: Schematic of the system generating UV supercontinuum.

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Automatic retinal layer segmentation algorithms

Universitat Politècnica de València

In the SEQUOIA project, UPV is working on developing automatic retinal layer segmentation algorithms for QOCT images. The samples used are mice retinas embedded in resin which allows comparison of images from the same samples using both conventional OCT measurements and the QOCT developed in the project. The objective of the segmentation is to detect the retinal nerve fibre layer (RNFL) which is crucial for the diagnosis of glaucoma.

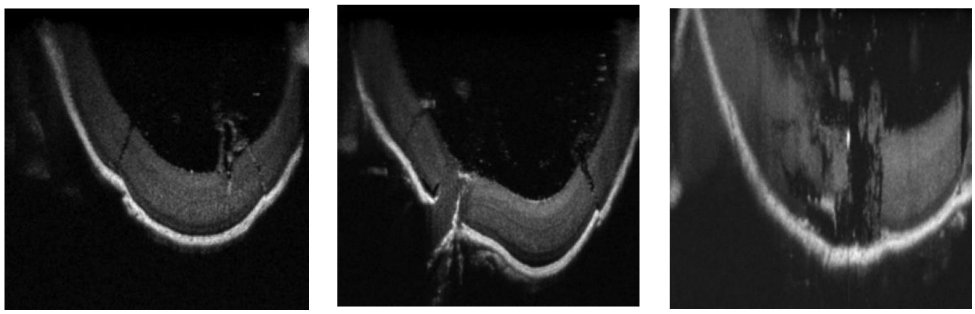
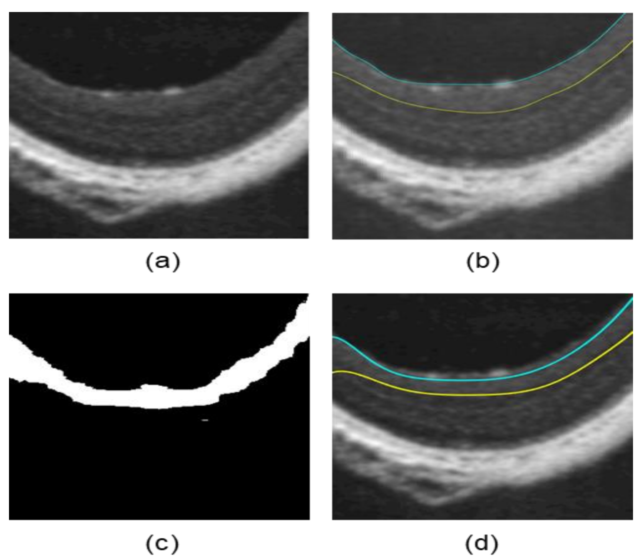


Fig. 5: Examples of defective frames. From left to right: optical artefact, optical nerve, out-of-focus image.

To meet this challenge, UPV is developing several frameworks for intervention. Firstly, a machine learning classification method is being developed to discriminate between defective frames and those valid for segmentation frames in each sample, where a defective frame is one in which the RNFL cannot be perceived due to various different artefacts (*e.g.* the optic nerve, imaging artefacts, out-of-focus image *etc.*). Secondly, a segmentation model based on convolutional neural networks is being built to detect the region of interest of the retina. This requires manual segmentation of the layer of interest (ground truth), which is a laborious and time-consuming task. To overcome this drawback, UPV is working on the generation of synthetic images and masks using generative adversarial networks. Good preliminary results have been achieved, with realistic replication of the shape and typical retinal defects as well as the noise inherent in an OCT image, and good definition of the RNFL layer, although still insufficient for the required segmentation task.

Fig. 6: Segmentation data and preliminary results: (a) image, (b) ground truth, (c) mask and (d) prediction.



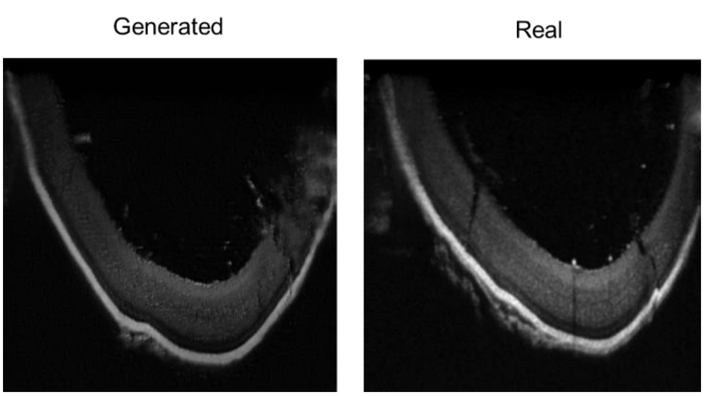


Fig. 7: Generated and real OCT retinal image.

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