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

MASTER THESIS PROPOSAL

Starting full time from April 2024
Presentation at the end of July or beginning of September 2024

Laboratory: Dynamic Optical System Lab (Department of Applied Physics)
Institution: Universitat de Barcelona
City, Country: Barcelona, Spain

Title of the master thesis: Light guiding with ultrasonic sculpted waves

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Keywords: acousto-optics, optical microscopy, ultrasound

Summary of the subject (maximum 1 page):
A key frontier in optics is to rapidly and non-invasively control light inside complex media such as biological tissue. The inherent local inhomogeneities in these types of media produce the scattering of photons, with the consequent inability to focus or guide light. This has dramatic implications for biomedicine: light-based methods are typically restricted to operate at depths of only some hundreds of microns inside tissue or tissue-like constructs such as organoids. Deeper penetrations are needed to extract sound biological conclusions or for efficient diagnosis. Several techniques have been developed to address this issue, including wavefront shaping or endoscopy, but they typically result in a loss of spatial or temporal resolution, or increased invasiveness. Recently, we have demonstrated that refractive index gradients induced by ultrasound can be successfully used to compensate for scattering. In this case, ultrasound acts as an embedded waveguide or lens, helping to redirect light toward a deeper focus. However, only acoustic resonant cavities with a cylindrical geometry have been used so far. In this case, the complex media needs to be physically inserted inside the cavity, making it difficult to implement in most realistic scenarios. The challenge remains to obtain the same effect without a resonant cavity.

Objectives: The goal of this master thesis is to fill this void and generate tailored ultrasound fields for focusing and guiding light without a resonant cavity. The approach involves leveraging piezoelectric elements with different geometries to induce ultrasonic waves within scattering media. These piezo elements will be positioned externally to the medium, and a needle hydrophone will be employed to measure the three-dimensional ultrasound fields they generate. To quantify the impact of ultrasound modulation on light control, a straightforward setup utilizing either a basic camera or a photodiode with virtual lock-in detection will be employed.

The thesis is divided into six distinct parts, which will occur sequentially through a 4-month period, as detailed next. 1) Time-domain simulation of the ultrasonic fields generated by the piezoelectric elements using k-Wave. 2) Computation of the light-guiding effect induced by ultrasound using the beam propagation method and Monte Carlo simulations. 3) Implementation of the experimental setup – piezoelectric element, laser, detectors. 4) Measurement of the ultrasound field and characterization of the optical performance of the system using the modulation transfer function for media with different scattering coefficients. 4) Quantification of the improvement in focusing performance with and without ultrasound. 6) Writing of the thesis.

Additional information (if needed):

* Required skills: the candidate is expected to show an interest in multidisciplinary subjects, and basic programming in Python and MATLAB.