1. PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan)

Project title:

Acoustically-shaped light for improved ablative and imaging processes in tissues

1.1. Project goals:

- To improve the efficiency, penetration depth and spatial resolution of light-based methods for biomedical applications using combination of optics and acoustics (ultrasonics) technologies,
- To improve the delivery of light into tissues by using acoustically-shaped light, namely light which intensity distribution and propagation characteristics have been modified using ultrasound,
- To develop methodology for precise control of the focus position in tissues.

1.2. Outline

The use of optical techniques for biomedical applications is continuously expanding thanks to the unique features they offer, such as unsurpassed penetration depth, diffraction-limited resolution and possibility to operate with no physical contact. Depending on the nature of interaction of light with matter, the optical modalities can be used to either modify the structure / geometry of tissues or to perform visualization of tissues. Key examples of those technologies include **optical coherence tomography** (OCT) or **laser surgical procedures**, commonly used for the diagnostics and treatment of skin and eye conditions as relevant as skin cancer, macular degeneration or glaucoma.

Optical coherence tomography (OCT) is an imaging technique that detects back-reflected and back-scattered photons and enables non-contact and non-invasive three-dimensional (volumetric) visualization of tissue microstructure in vivo at high spatial and temporal resolution. Recent developments in light sources and wide-band electronics allowed for imaging beyond standard depth range values, which facilitated new clinical and non-biomedical applications of OCT technology. On the other hand, the advent of laser techniques offered an entirely new way of performing **ablation and treatment of tissue**. Indeed, the use of pulsed sources such as excimer or femtosecond lasers allowed the development of **novel types of surgeries that offer minimal invasiveness and unprecedented precision**. In all these methods, controlled light delivery into targeted areas is fundamental for optimal results. Failing to achieve so can cause a loss of contrast in the acquired images or even induce damage into the surrounding areas when performing laser surgery. However, existing approaches can lack the efficiency, ease of implementation or speed to provide the desired spatiotemporal control of light.

This collaborative project aims at addressing those issues by using novel acousto-optofluidic devices to shape the light. In particular, the main goal of this collaborative project is to improve the efficiency, penetration depth and spatial resolution of light-based methods for biomedical applications. Specifically, we aim to improve the delivery of light into tissues by using acoustically-shaped light, namely light which intensity distribution and propagation characteristics have been modified using ultrasound. As recently demonstrated by both Spanish and Polish partners, the unique interactions between light and sound leads to an unsurpassed control of light. In this project, **we will use this phenomenon to efficiently guide light deep into tissue, enabling two key features:**

(1) Acquisition of OCT images with enhanced signal-to-noise ratio and spatial resolution at depths not currently accessible with commercial systems;

(2) Local removal of tissue via laser ablation with improved efficiency, spatial resolution, and minimal heat dissipation effects.

The project will be implemented at the cooperating research groups at the Nicolaus Copernicus University (Bio-Optics & Optical Engineering Lab, BOEL) and the University of Barcelona.

1.3. Work plan

The specific aims given by both work packages will be achieved using the following methodology:

(1) Optimization of imaging/ablative processes using acoustically-shaped light with phantom tissue samples

The core technology of the project is the use of an optofluidic system that uses sound to shape the light. In this system, acoustic waves are generated in a fluid-filled cavity by means of piezoelectric actuators. The integration of such a system into traditional optical architectures results in an unsurpassed control of light. However, the application of acoustically-shaped light in biomedicine and for ablation/monitoring of soft tissue remains in its infancy. To fill this void and mature the use of beam shaping technologies for biomedical applications, the first part of the project will seek the optimization of acoustically-shaped light in OCT and laser ablative processes. In particular, we will perform a systematic study of the main technological parameters that influence light delivery-depth into soft materials for imaging and laser processing applications, respectively. This will be carried out using phantom samples consisting of an elastomer doped with different concentrations of high refractive index (reflective / scattering) particles. Underlying these experimental tasks, basic diffraction modeling of acoustically-shaped light propagation in scattering media will be conducted by both partners to help inform the experimental development and verification.

(2) Development of imaging and laser surgical systems based on shaped light for the monitoring and processing of ex-vivo tissue samples

The second part of the project will focus on the monitoring and processing of biological tissue samples. In particular, porcine corneal and epidermal samples will be used for the realization of parametric studies aimed at the quantification of the ablation efficiency and the imaging depth possibilities offered by acoustically-shaped light. Based on these results, empirical relations between the driving conditions of the optofluidic system and the gain in efficiency/penetration depth will be reported to find the optimal light delivery conditions in real-world samples. OCT images of tissue before and after laser treatment will be performed. This will be used to assess the potential benefits of integrating, in a single platform, laser surgery with in-situ, high-resolution monitoring.

1.4. Literature

[1] I. Grulkowski, S. Manzanera, L. Cwikliński, F. Sobczuk, K. Karnowski, P. Artal, Swept source OCT and tunable lens technology for comprehensive imaging and biometry of the whole eye, Optica 5 (2018), 52-59.
[2] S. Kang, M. Duocastella, C.B. Arnold, Variable optical elements for fast focus control, Nature Photon. 14(9), 533-542 (2020).
[3] A. Zunino, S. Surdo, M. Duocastella, Dynamic Multifocus Laser Writing with Acousto-Optofluidics, Adv. Mat. Technol. 4(12), 1900623 (2019).

1.5. Required initial knowledge and skills of the PhD candidate

- MSc in one from the following disciplines: physics, engineering, informatics or related field,
- Basic computer skills, programing skills (e.g. Labview, C/C++, Matlab or Python),
- Good communications skills,
- Ability to communicate in English,
- Not required but welcome: Experience in optics confirmed with co-authored scientific articles, conference presentations, internships on related subjects.

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

Core skills:

- Integrated training in biomedical photonics, data acquisition and data processing,
- Optical engineering methods and tools for design and optimization of advanced optical systems,
- Experience in development of advanced optical imaging modalities (microscopy, tomography etc.),
- Knowledge on laser physics,

Transferrable (soft) skills:

- Analytical thinking,
- Good laboratory practices,
- Project management,
- Science communication for different audiences (incl. oral and poster presentations),
- Scientific writing,
- Team work & international cooperation.