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

Project title:

Mapping of Biomechanical Properties of Tissues using Ultrasensitive Optical Sensing Technology

1.1. Project goals

- To develop microscopic three-dimensional imaging modality that allows for both: structural end elastic properties investigation at cellular level,
- To design and optimize study protocols for microscopic sample examination,
- To provide high sensitivity additional source of contrast in structural imaging using developed technique,
- To develop theoretical model for elastic properties extraction among variety of biomedical samples.

1.2. Outline

Biomechanics is the research field that aims at explaining the mutual relation between forces and functions in living organisms at different levels of biological organization (e.g. organelles, cells, tissues, organs etc.). **Elastography** is an imaging modality that enables mapping the visco-elastic properties and stiffness of soft tissues due to mechanical loading (stress). This method investigates tissue reaction to mechanical (micro- or macro-) deformation that allows extracting basic parameters such as Young's modulus, stiffness, damping coefficient etc. **In spite of the recent technology advances, new-generation elastography systems that utilize non-contact mechanical excitation methods still exhibit challenges arising from the inability of a correct interpretation.**

Most prominent non-optical techniques that enable to obtain both elastic properties and cross-sectional (anatomical) imaging are ultrasonography (USG) or magnetic resonance imaging (MRI). The optical method that enables to perform cross-sectional imaging is Optical Coherence Tomography (OCT). Apart from standard structural images that represent depth-dependent light scattering, OCT images can provide additional contrast such as elasticity. This enabled an extension of OCT method known as **optical coherence elastography (OCE)** [1]. Mechanical stress in OCE could be delivered by different mechanical excitation mechanisms having contact or non-contact nature (e.g. mechanical indentation, pulsed laser, sound waves, airborne ultrasound, and the air puff from the tube or needle) [2]. This allows for studying influence of viscoelasticity properties of cornea in porcine eye model [3] or could be extended for in vivo human investigation [4].

This PhD project aims at developing an optical sensing methodology using OCT for ultrasensitive structure vibration detection due to mechanical excitation and further, to extract viscoelastic properties of microscopic specimen. The next task will be to provide additional contrast for structural imaging that enables to differentiate sample structure based on elastic properties. In order to do that, a phantom model for testing needs to be developed. Phasesensitive analysis of OCT data will enable to improve method resolution down to nanometer scale of deformation.

1.3. Work plan

The project includes five related and complementary specific aims:

- Mastering OCT technique; Broadband light source implementation into optical system for high resolution, three-dimensional imaging,
- Developing data analysis tool that provides elastography contrast to OCT data,
- Phantom model development for elastography testing,
- Developing, testing and evaluation of measurement protocols,
- Work on physical model development that separates viscous and elastic properties of the sample.

1.4. Literature

1. K. V. Larin and D. D. Sampson, "Optical coherence elastography - OCT at network in tissue biomechanics invited," Biomed. Opt. Express 8, 1172-1202 (2017).
2. B. F. Kennedy, P. Wijesinghe, and D. D. Sampson, "The emergence of optical elastography in biomedicine," Nat. Phot. 11, 215-221 (2017).
3. E. Maczynska, K. Karnowski, K. Szulzycki, M. Malinowska, H. Dolezyczek, A. Cichanski, M.Wojtkowski, B. Kaluzny, and I. Grulkowski, "Assessment of the influence of viscoelasticity of cornea in animal ex vivo model using air-puff optical coherence tomography and corneal hysteresis," J. Biophotonics, e201800154 (2018).
4. A. Jimenez-Villar, E. Maczynska, J. Rzeszewska, M. Wojtkowski, B. J. Kaluzny, and I. Grulkowski. "Air-puff induced eye retraction and crystalline lens wobbling measured with long depth range swept source optical coherence tomography," Invest. Ophthalmol. Vis. Sci., 60, 6822-6822 (2019).

1.5. Required initial knowledge and skills of the PhD candidate

- MSc in one from the following disciplines: physics, 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 quantum optics or atomic physics confirmed with co-authored scientific articles, conference presentations, internships on related subjects

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

<u>*Core skills:*</u>

- 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 biomechanics,

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.