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

Project title:

Adaptive optics and optical phase modulation techniques for OCT imaging of the retina and choroid of the human eye.

1.1. Project goals

A. To develop computational adaptive optics methods for OCT imaging of the retina and choroid of the human eye.

B. To research the methods for cellular-level imaging through highly scattering layers of the eye fundus: the retinal pigment epithelium and choriocapillaris.

C. To design, construct and test an OCT setup for cellular-level imaging of the human retina and choroid.

1.2. Outline

Adaptive optics (AO) is a set of techniques and methods used for modification of optical fields in imaging systems in order to improve resolution of the images by correcting aberrations. In Optical Coherence Tomography (OCT), adaptive optics has been used to achieve cellular-level imaging resolution in imaging of the retina of the human eye in vivo [1] and to detect dynamic processes occurring within certain types of cells [2, 3]. There are a few groups of adaptive optics techniques suitable for the application in OCT [4]. The all-hardware approach uses Shack-Hartman wavefront sensors and deformable mirrors to detect and correct optical aberrations in the imaged object in real-time [1]. In a sensor-less AO approach only deformable mirrors are used to modulate the optical field while the images are analyzed numerically in real-time. The goal is not to detect aberrations but to improve the imaging resolution by searching for the best correcting shape of the deformable mirror [5,6]. The third possibility are fully computational methods which correct the OCT images in the post-processing, that is, in the acquired OCT data [7].

The goal of this PhD project is to study and research the methods for the cellular-level resolution in the OCT imaging of the human retina and choroid. While methods for imaging of the retina are a subject of intensive research in many research groups around the world, adaptive optics methods for imaging of the choroid remain an unexplored area. There are two reasons for this. First, up to recently [8, 9], there were no methods which would enable *in vivo* imaging of the choroid down to capillary vessels. Secondly, which is more interesting from the scientific point of view, high-resolution imaging of the choroid will require researching the topic of imaging through a layer of photoreceptor cells with wave-guiding properties, a layer of highly scattering retinal pigment epithelium, and a layer of choriocapillaris which not only scatters light but also light scattering changes dynamically as the blood circulates in this vascular network. The techniques of adaptive optics will therefore have to be combined with the methods of imaging through turbid media.

With the development of OCT techniques enabling imaging of the choroid, search for techniques of cellular-level imaging resolution for not only retina but also the choroid became possible. The PhD candidate will have an opportunity to participate in the development of the project from the initial stages and gradually gain expertise starting with the study of basics in AO imaging and moving towards imaging through scattering media.

1.3. Work plan

- In the introductory phase of the project, the PhD candidate will learn, under the tutorage of the supervisors, the theoretical and experimental basics of and adaptive optics techniques. The goal is to identify and understand advantages and limitations of the existing AO OCT methods and search for solutions which can be implemented for imaging of patients in the ophthalmology clinics.
- In the intermediate phase, the candidate will study the topics of tissue optics, with the focus on light scattering by tissues and cells, and will research the existing techniques of imaging through turbid media. The goal is to understand the challenges of imaging through scattering media and search for methods possible for implementation in OCT systems.
- The advanced phase of the project realization will include design, construction and tests of the OCT imaging systems with the capability of cellular-level imaging resolution of the retina and the choroid.

1.4. Literature

1. R. Zawadzki, et al., “Adaptive-optics optical coherence tomography for high-resolution and high-speed 3D retinal in vivo imaging”, Opt Express ;13:8532–8546, (2005).
2. O. P. Kocaoglu, et al., "Photoreceptor disc shedding in the living human eye," Biomed. Opt. Express 7, 4554-4568 (2016).
3. Liu Z, at al., “Characterizing motility dynamics in human RPE cells”, Opthalmic Technologies XXVII, 10045:1004515 (2017).
4. Marcos S, et al., “Vision science and adaptive optics, the state of the field”, Vision Research, 132, 3-33, (2017).
5. Y. Jian, et al., “Lens-based wavefront sensorless adaptive optics swept source OCT”, Scientific Reports volume 6, Article number: 27620 (2016),
6. F. A. South, et al., "Combined hardware and computational optical wavefront correction," Biomed. Opt. Express 9, 2562-2574 (2018).
7. L. Ginner, et al., "Noniterative digital aberration correction for cellular resolution retinal optical coherence tomography in vivo," Optica 4, 924-931 (2017).
8. K. Kurokawa, et al., "Adaptive optics optical coherence tomography angiography for morphometric analysis of choriocapillaris [Invited]," Biomed. Opt. Express 8, 1803-1822 (2017).
9. J. V. Migacz, et al., "Megahertz-rate optical coherence tomography angiography improves the contrast of the choriocapillaris and choroid in human retinal imaging," Biomed. Opt. Express 10, 50-65 (2019).

1.5. Required initial knowledge and skills of the PhD candidate

The candidate will develop all necessary skills during the work on the project. However, basic knowledge in the following areas are expected:
- imaging optics and physical optics,
- basic skills in computer programming (familiarity with at least one of the programming enviroments: C/C++, Matlab, Python, LabView),
- familiarity with computer control of electronic devices.

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

The PhD candidate will have an opportunity to learn, study and research various scientific and engineering topics, adjustable to his or her interests:
- selected problems in tissue optics: influence of scattering in biological tissues on light properties and light propagation,
- modeling of light propagation in turbid media (Monte Carlo, FDTD),
- image formation with partially coherent light,
- methods for controlling light properties and propagation,
- optical techniques in medical imaging and diagnostics,
- design (ZEMAX, OSLO) and construction of optical systems for biomedical imaging,
- biomedical data and image analysis methods,
- advanced programming (GPU, FPGA),
- development of data acquisition software,
- computer control of imaging devices.