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

**Project title:**

Development of an eye movement model based on information from the anterior and posterior chambers of the eye.

### 1.1. Project goals

Project goal is to develop a comprehensive model of the eyeball in motion using the information simultaneously provided by two eye tracking devices: (1) the pupil and Purkinje reflection based eye-tracker that uses images of the anterior segment of the eye and (2) the retinal eye-tracker that uses images of the back of the eye. This model will serve to reach a number of specific research aims:

- to better understand what are the properties of each of the trackers in terms of key parameters including precision, accuracy, angular and temporal resolution and others
- to understand the relations between the signals registered by the anterior and posterior eye-trackers,
- to answer the questions about tasks in which each of the eye-trackers is good in, and which research fields may benefit most from their usage.

### 1.2. Outline

The eye is the organ of vision in the human body and plays a central role in human interaction with the environment and has captured researchers' attention for centuries. This interest had accelerated in the last century when it became clear that the eyes may offer a much deeper insight into the state of the human organism as they allow for direct observation of not only photoreceptors but also blood vessels and neural tissue.

One of the most prominent features of the eye is its constant motion. It is a physiological process that occurs in both a voluntary and an involuntary manner. The voluntary and large amplitude jumps in gaze position, or continuous smooth pursuit, are performed during scanning or exploring the visual world and are often synchronized with head or body motion. The involuntary and constantly performed movements include various components such as slow velocity drift and micro-saccades. Both are required to refresh the image on the photoreceptors and are thought to play an important role in enabling high-acuity vision. Also, many cortical and subcortical brain areas, as well as the brainstem and cerebellum, are involved in visual perception and processing as well as in the control and execution of eye movements. Consequently, many disorders in the eye or brain manifest in changes in eye movement patterns.

Due to the above reasons, understanding the motion of the eye is of utmost importance to the scientific community in the scientific fields such as neurology, psychology, ophthalmology, cognitive and brain sciences, as well as medicine: it not only provides a window to the cognitive processes of the mind but also gives hope to diagnose vision or neurodegenerative diseases and monitor their progress.

The existing, noninvasive eye-tracking methods allow for approximating eye motion from images of either anterior parts of the eye or posterior parts of the eye. None of these methods provides

comprehensive information on the motion of the entire eyeball with high precision, accuracy, and in the whole range of possible gaze directions. As a result, the quality of the information provided by the state-of-the-art eye-tracking methods is far inferior to what is required by the scientific community to make further progress in eye-movement-related research.
The general problem that this project attempts to solve is to close these gaps between existing eye-tracking technologies and provide important new fundamental knowledge on eye movements.

### 1.3. Work plan

- Literature review and introduction to eye-tracking theory and applications as well as hands-on training with eye-tracking devices constructed in the Department of Biophotonics and Optical Engineering.
- Design and implementation of optimal image acquisition procedures for simultaneous acquisition of anterior segment and retina of the moving human eye.
- Design and implementation of image processing techniques to extract and quantify the movement of eye structures imaged in the anterior and posterior parts of the eye. Extension of the methods to follow the evolution of these structures in time.
- Validation of the motion detection methodology in experiments with artificial eyes as well as with healthy human subjects in laboratory.
- Development of comprehensive model of the moving eye ball that combined information of the motion of the anterior and posterior parts of the eye.
- Verification of the model in psychophysics experiments with human subjects.

### *1.4.* Literature *(max. 10 listed, as a suggestion for a PhD candidate)*


1) Otero-Millan, J., et al., Saccades and microsaccades during visual fixation, exploration, and search. Journal of Vision, 2008. 8, 21-21
2) Martinez-Conde, S., et al., The role of fixational eye movements in visual perception. Nature Reviews Neuroscience, 2004. 5, 229-240
3) Klein, C., et al., Eye movement research: An introduction to its scientific foundations and applications. 2019: Springer Nature
4) Singh, H., et al., Human eye tracking and related issues: A review. International Journal of Scientific and Research Publications, 2012. 2, 1-9
5) Hooge, I.T.C., et al., The pupil-size artefact (psa) across time, viewing direction, and different eye trackers. Beh Res Meth, 2021. 53, 1986-2006
6) Bartuzel, M.M., et al., High-resolution, ultrafast, wide-field retinal eye-tracking for enhanced quantification of fixational and saccadic motion. Biomedical Optics Express, 2020. 11, 3164-3180.
7) Sheehy, C.K., et al., High-speed, image-based eye tracking with a scanning laser ophthalmoscope. Biomedical Optics Express, 2012. 3, 2611-22.
8) Niehorster, D.C., et al., Is apparent fixational drift in eye-tracking data due to filters or eyeball rotation? Beh Res Meth, 2021. 53, 311-324.
9) Nyström, M., et al., The influence of crystalline lens accommodation on post-saccadic oscillations in pupil-based eye trackers. Vision Research, 2015. 107, 1-14
10) Nyström, M., et al., An adaptive algorithm for fixation, saccade, and glissade detection in eyetracking data. Beh Res Meth, 2010. 42, 188-204

### 1.5. Required initial knowledge and skills of the PhD candidate

- Background in physics, mathematics, informatics or similar. Knowledge in optical physics and optical imaging will be an advantage.
- Basics in computer programming (preferably Python, Labview, Matlab, C/C++/C#), knowlegde of GPU programming will be an advantage.
- Knowledge of English is mandatory.

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

It is expected that the PhD candidate will develop the following main skills during the PhD:

- The capacity to plan, implement and critically analyse novel experimental methodology related to eye imaging.
- The capacity to create, implement and modify algorithms required in the implementation of quantification of eye motion.
- The capacity to independently carry out clinical studies using eye-tracking devices, with guidance from the supervisory team.
- The capacity to clearly communicate research ideas and results in English, both in written and oral formats. Particular emphasis will be placed on writing journal papers and delivering conference presentations.