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

Project title:
Measurement methods and factors affecting the luminance of two-photon visual stimuli

1.1. Project goals

Two-photon vision is a new phenomenon that involves the visual perception of pulsed laser beams outside the visible range (850-1200 nm) [1]. It is caused by two-photon absorption occurring in the visual pigments therefore, the perceived color corresponds to half the wavelength of the stimulating beam [2]. The underlying physical process is different from that of normal vision, which opens a wide field of interdisciplinary research at the intersection of physics, optics and psychophysics of vision and, in the context of practical applications, biomedical engineering.

The luminance of "normal" one-photon light sources is based on the luminous efficiency function V(λ). Its equivalent does not exist for two-photon vision, making comparing two-photon sources and the retinal displays with normal ones challenging. For example, there is no direct method to determine the contrast of two-photon displays, which is essential for currently developed applications (e.g., two-photon microperimetry [3,4]), as well as for future ones, such as Augmented Reality (AR) glasses [5].

This project aims to test psychophysical methods of luminance measurement for two-photon stimuli of different wavelengths and determine their limitations. The effects of non-spectral factors on two-photon luminance, such as laser pulse parameters and the display method will also be analyzed.

The expected result is the determination of the luminance range achievable for two-photon vision retinal displays using sources with known spectral and temporal parameters. The project outcomes will expand the knowledge of the functioning of human vision and contribute to the development of modern diagnostic techniques in ophthalmology and AR technologies. The results will be published in high-impacted JCR journals and presented at international conferences.

1.2. Outline

The research will be performed with existing optical systems for the generation of two-photon stimuli, both at the Institute of Physics NCU and at the International Center of Translational Eye Research in Warsaw. The Ph.D. student's task will be to develop and calibrate two novel ways of displaying two-photon stimuli by constructing a miniaturized retinal display using MEMS scanners for AR glasses and equipping one in the existing system with DMD (Digital Micromirror Device). For the measurement of two-photon luminance, the established psychophysical technique will be applied for the first time - heterochromatic flicker photometry, which was used to determine of V(λ) function for one-photon vision (further referred as HFP method). The results will be compared with techniques based on subjective adjustment of the brightness of adjacent stimuli, currently used in two-photon vision research (further referred as Adjustment method) [6]. All psychophysical experiments involving human volunteers will be conducted in accordance with laser safety standards for ophthalmic devices and adhere with the declaration of Helsinki upon approval of Bioethics Committee.

1.3. Work plan

A Gantt chart outlining the work plan for the project is provided below, where year is represented by Y and consecutive semester is indicated by S:

<table>
<tr><th>Task</th><th>Y1, S1</th><th>Y1, S2</th><th>Y2, S3</th><th>Y2, S4</th><th>Y3, S5</th><th>Y3, S6</th><th>Y4, S7</th><th>Y4, S8</th></tr>
<tr><td>1-Reading background literature, developing experimental skills, learning psychophysical techniques principles used in vision sciences.</td><td bgcolor="#d3d3d3"></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2-Two-photon luminance measurements with existing NCU two-photon vision optical system for the wavelength range 850-1300 nm. The already implemented Adjustment method will be applied. Publication of the results.</td><td bgcolor="#d3d3d3"></td><td bgcolor="#d3d3d3"></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3-Implementation of HFP method for NCU system: reconstruction of optical set-up and programming software.</td><td></td><td bgcolor="#d3d3d3"></td><td bgcolor="#d3d3d3"></td><td bgcolor="#d3d3d3"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4-Two-photon luminance measurements in NCU with HFP method. Comparison of results obtained in Task 2. Publication of the results.</td><td></td><td></td><td bgcolor="#d3d3d3"></td><td bgcolor="#d3d3d3"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5-Construction of MEMS based miniaturized retinal display (MEMS-RD) and software development. Calibration of the display. Realization in NCU (Toruń) or/and ICTER (Warsaw), depending on funding. Publication/conference presentation.</td><td></td><td></td><td></td><td></td><td bgcolor="#d3d3d3"></td><td bgcolor="#d3d3d3"></td><td bgcolor="#d3d3d3"></td><td></td></tr>
<tr><td>6-Construction and calibration of novel type of two-photon display with DMD, software development and calibration. Realization in NCU (Toruń) or ICTER (Warsaw), depending on funding. Publication/conference presentation.</td><td></td><td></td><td></td><td></td><td></td><td bgcolor="#d3d3d3"></td><td bgcolor="#d3d3d3"></td><td bgcolor="#d3d3d3"></td></tr>
<tr><td>7-PhD thesis writing</td><td></td><td></td><td></td><td></td><td></td><td></td><td bgcolor="#d3d3d3"></td><td bgcolor="#d3d3d3"></td></tr>
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1.4. Literature (max. 10 listed, as a suggestion for a PhD candidate)

1. G. Palczewska, F. Vinberg, P. Stremplewski, M. P. Bircher, D. Salom, K. Komar, J. Zhang, M. Cascella, M. Wojtkowski, V. J. Kefalov, and K. Palczewski, "Human infrared vision is triggered by two-photon chromophore isomerization," Proc. Natl. Acad. Sci. U. S. A. 111(50), E5445-54 (2014).

2. K. Komar, "Two-photon vision–Seeing colors in infrared," Vision Res. 220, 108404 (2024).

3. D. Ruminski, G. Palczewska, M. Nowakowski, V. J. Kefalov, K. Komar, K. Palczewski, and M. Wojtkowski, "Two-photon microperimetry: sensitivity of human photoreceptors to infrared light," Biomed. Opt. Express 10(9), 4551–4567 (2019).

4. G. Łabuz, A. Rayamajhi, K. Komar, R. Khoramnia, and G. U. Auffarth, "Infrared- and white-light retinal sensitivity in glaucomatous neuropathy," Sci. Rep. 12(1), 1961 (2022).

5. K. Komar, M. Wojtkowski, M. Marzejon; Augmented reality glasses based on two-photon vision; EU patent application EP4339663A1 (2023).

6. A. Zielińska, P. Ciąćka, M. Szkulmowski, and K. Komar, "Pupillary Light Reflex induced by two-photon vision," Invest. Ophthalmol. Vis. Sci. 62(15), 23 (2019).

7. M. J. Marzejon, Ł. Kornaszewski, M. Wojtkowski, K. Komar; Laser pulse train parameters determine the brightness of a two-photon stimulus; Biomed. Opt. Express 14 (6), 2857-2872 (2023).

8. P. Artal, S. Manzanera, K. Komar, A. Gambin-Regadera, M. Wojtkowski, Visual acuity in two-photon infrared vision, Optica 4 (12), 1488-1491 (2017).

9. P. Gil, J. Tabernero, S. Manzanera, C. Schwarz, and P. Artal, "Color characterization of infrared two-photon vision," Optica 10, 1737-1744 (2023).

10. H. K. Doyle, S. R. Herbeck, A. E. Boehm, J. E. Vanston, R. Ng, W. S. Tuten, A. Roorda; Boosting 2-photon vision with adaptive optics. Journal of Vision 23(12):4 (2023).

a. Required initial knowledge and skills of the PhD candidate

- Background in physics, informatics, bioengineering or similar.
- An experience in designing or using optical systems for eye imaging or testing vision will be appreciated.
- Basics in computer programming (preferably Labview, but also Python, Matlab, C/C++/C#), is required.
- Knowledge of English is mandatory.
- Scientific curiosity and a high level of motivation to work.
- Good communication and teamwork skills.

b. 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 and vision diagnostics and imaging.

- The capacity to create, implement and modify optical systems for vision and create algorithms and software to perform scientifically valid psychophysical measurements.
- The capacity to independently carry out measurements using optical systems for eye imaging/stimulating, 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.