IOMT INSTITUTE OF OPTICAL MATERIALS AND TECHNOLOGIES "ACAD. J. MALINOWSKI"

BULGARIAN ACADEMY OF SCIENCES

ИНСТИТУТ ПО ОПТИЧЕСКИ МАТЕРИАЛИ И ТЕХНОЛОГИИ "АКАД. Й. МАЛИНОВСКИ"

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OPINION

Regarding the dissertation for awarding the educational and scientific degree "Doctor of Philosophy" in higher education area 4. Natural Sciences, Mathematics and Computing, professional field 4.1. Physical sciences, doctoral program "Physics of wave processes"

PhD candidate: Maryam Viqar, Institute of Optical Materials and Technologies "Acad. J. Malinovski", Bulgarian Academy of Sciences

Supervisors: Assoc. Prof. Violeta Madjarova, PhD, and Prof. Elena Stoykova, DSc; Erdem Sahin, Ph.D. (Tampere University, Finland) and Prof. Atanas Gotchev, Ph.D. (Tampere University, Finland)

Dissertation title: „Deep Learning Models for Vascular Image Reconstruction and Analysis in Swept-Source Optical Coherence Tomography (SS-OCT)"

Member of the scientific jury appointed by Order No. RD-15749/08.10.2025 of the Director of IOMT-BAS: Prof. Silvia Emilova Angelova, PhD, Institute of Optical Materials and Technologies "Acad. J. Malinovski", Bulgarian Academy of Sciences

I. Biographical information

Maryam Viqar obtained her Bachelor's and Master's degrees from Aligarh Muslim University in 2015 and 2020, respectively. According to the certificate issued by the National Centre for Information and Documentation (NACID), she holds a Master's degree in Electronic Engineering. She was enrolled as a doctoral student at the Institute of Optical Materials and Technologies (IOMT) in 2021 within the framework of the "Plenoptima" project, with her training conducted jointly with Tampere University, Finland.

II. General Description of the Dissertation

The dissertation submitted for evaluation, titled *"Deep Learning Models for Vascular Image Reconstruction and Analysis in Swept-Source Optical Coherence Tomography (SS-OCT)"*, addresses a current and significant scientific problem situated at the intersection of biomedical engineering, optical imaging methods, and modern machine-learning and deep-learning techniques. The topic is important from both theoretical and applied perspectives, as improved analysis of vascular structures is essential for early diagnosis and monitoring of numerous medical conditions.

The dissertation is approximately 130 pages long, and together with the full-text publications included, the total volume reaches 180 pages. The work contains all mandatory structural elements—introduction, literature review, results and discussion, main contributions, and bibliography. In addition, the four published articles presenting the core results of the dissertation are included in full. The dissertation is illustrated with 33 figures and 12 tables, which support the understanding of the presented results. The extensive visual material contributes to a convincing presentation of the experimental data and the achieved findings. The dissertation is also accompanied by a 47-page abstract.

The exposition is clear, precise, and logically structured. The literature review is thorough and encompasses 150 up-to-date and relevant sources, demonstrating the doctoral candidate's excellent awareness of the current state of the research field. The foundations of the methods and techniques used are explained in detail and with high accuracy, including the necessary mathematical formulations, which ensures transparency and reproducibility of the study. The review outlines the historical development and fundamental principles of Optical Coherence Tomography (OCT), tracing its evolution from the early TD-OCT systems to modern SS-OCT technologies. It discusses the physical principles of the method, including the formation of the interference signal, axial reconstruction, and the influence of tissue optical properties on the resulting images. The different types of OCT systems are compared in detail, with emphasis on the advantages of SS-OCT and the specifics of raw-data processing, including k-linearization, dispersion compensation, and the application of Fourier transforms. Attention is given to the limitations of traditional interpolation techniques and hardware-based solutions, which may introduce artefacts, increase noise, or complicate real-time operation. The review concludes by presenting the latest developments in deep learning (DL), highlighting the potential of modern DL architectures to enhance OCT image reconstruction and analysis, despite the existing challenges associated with adapting these models to the specific characteristics of OCT data.

The aim of the dissertation is to investigate the potential of deep learning for improving the analysis and reconstruction of SS-OCT images. The five research questions address the evaluation of segmentation accuracy of venous layers with minimal model complexity; the development of an integrated model for reliable segmentation and precise thickness measurements; the reconstruction of images directly from wavelength-linear data with reduced computational and hardware requirements; the optimization of data in the spatial and Fourier domains for enhanced quality and reduced noise; and the creation of a low-complexity DL-based solution enabling real-time visualization.

III. Main scientific results

The results presented in the dissertation demonstrate significant advances in the application of deep learning (DL) for the analysis and reconstruction of SS-OCT images of venous structures. The research shows that the integration of DL models substantially enhances automation in OCT, enabling the extraction of robust and highly reliable features that are unattainable through traditional methods. OCT systems, due to their high spatial resolution, provide rich volumetric data for the study of varicose veins, and the models developed in the dissertation further improve accuracy in assessing the shape and thickness of venous layers.

In Chapter 3 of the dissertation, two DL models aimed at automated segmentation and thickness measurement are presented. The first one, Opto-UNet, offers an optimized and parametrically lightweight architecture that demonstrates superior accuracy compared to state-of-the-art segmentation models. The second model, TREE, successfully integrates transfer learning and a specialized SPD module. It is shown that TREE surpasses existing methods in both accuracy and precision for venous layer segmentation and thickness estimation.

Chapter 4 extends the application of DL to OCT reconstruction. The WAVE-UNET model enables the direct generation of high-quality B-scan images from raw wavelength-linear data, eliminating the need for traditional steps such as k-linearization. The developed reconstruction framework in both spatial and Fourier domains effectively suppresses speckle noise and reproduces detailed morphological structures, while being optimized for low computational complexity and fast inference. Experiments conducted on various samples consistently confirm the superiority of the proposed methods over standard approaches.

IV. Contributions and significance of research

The scientific research presented in the dissertation lies in the field of wave physics and, more specifically, optical coherence tomography (OCT). The work includes scientific results of a fundamental nature that contribute to a deeper understanding of the properties of matter and specific physical phenomena. The theoretical contributions involve the development and optimization of DL models for the study of biological objects (venous structures), as well as for the reconstruction and analysis of OCT images. As a result of systematic theoretical and experimental investigations, new solutions for data processing have been proposed, and new implementations of DL-based methods have been developed. The practical applicability of the proposed solutions has been demonstrated. The achieved results have the potential for implementation in both clinical and research settings. The dissertation demonstrates a successful balance between theory and experiment and reflects a high level of knowledge acquired by the doctoral candidate. The stated main contributions accurately represent the scientific results obtained.

V. Assessment of publications and personal contribution of the candidate

The research conducted for the dissertation has been fully or partially published in four scientific works presented in full text. Among the publications included in the dissertation, one is in a Q1 journal and another in a Q2 journal. Seven citations have been identified for one of the articles. Maryam Viqar is the first author of all four publications, which is a clear indication of her primary contribution to the research performed.

VI. Critical remarks and recommendations

Maryam Viqar demonstrates excellent knowledge of the subject matter within the scope of the dissertation, as well as a thorough understanding of its theoretical foundations. I do not identify any significant weaknesses in the presented work and have no critical remarks or recommendations.

VII. Conclusion

Maryam Viqar's dissertation represents a purposeful, well-planned, and high-quality study in the field of optical coherence tomography. A substantial amount of material has been synthesized into a coherent, well-structured, and convincingly argued dissertation. The achieved results demonstrate significant scientific contributions, which justify a high evaluation of the conducted work.

The dissertation fully meets the requirements for the award of the educational and scientific degree "Doctor of Philosophy". Based on the scientific contributions and the significance of the research carried out, I express my positive opinion and propose to the members of the esteemed scientific jury to award the educational and scientific degree "Doctor of Philosophy" in the professional field 4.1. Physical Sciences to Maryam Viqar.

Sofia
29.11.2025 г.

/ Prof. Silvia Angelova, PhD/