Review

of PhD thesis work for the acquisition of the scientific degree "Doctor"

Professional field: 4.1 Physical Sciences
Doctoral Program: "Physics of Wave Processes"
Author of the dissertation: Maryam Viqar, IOMT-BAS
Scientific supervisors:
Assoc. Prof. Dr. Violeta Madjarova (IOMT-BAS, Bulgaria)
Prof. Dr. Elena Stoykova (IOMT-BAS, Bulgaria)
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Prof. Dr. Atanas Gochev (University of Tampere, Finland)

Topic of the dissertation: "Deep learning models for reconstruction and analysis of vascular images obtained by variable wavelength optical coherence tomography (SS-OCT)"

Reviewer: Vera Marinova Gospodinova, professor, Ph.D., IOMT- BAS
scientific jury, appointed by order of the Director of IOMT-BAS No. RD-15-749 of 08.10.2025.

1. Brief biographical data about the doctoral student

Maryam Viqar was born in 1992 in Aligarh, India. In 2015, she completed her Bachelor of Technology degree at Aligarh Muslim University, India, and in 2020, she completed her Master of Information and Communication Technology at the same University. In 2021, she won a competition for a full-time doctoral study in the PLENOPTIMA project, funded by the Marie Skłodowska-Curie Actions of the European Union, part of the Horizon 2020 Framework Programme for Science and Innovation, Innovative training networks (ITN) activity. The doctoral study is joint with the University of Tampere, Finland.

During her doctoral studies, Maryam Viqar passed all the necessary exams, successfully completed 2 specialized training courses, a language course and a computer skills course.

2. Data about the dissertation

The dissertation is dedicated to optical coherence tomography as a modern, non-invasive method for imaging diagnostics (biomedical visualization). The dissertation is methodically structured on 5 research questions posed by the author, united in two main challenges:

1) developing efficient deep learning (DL) models with a reduced number of parameters that can simultaneously provide high-quality segmentation maps and high-accuracy vein wall thickness measurements by the analysis of optical coherence tomography (SS-OCT) images.

2) developing deep learning models that reconstruct images from SS-OCT data with improved computational efficiency and image quality.

The dissertation consists of 130 pages and includes 5 chapters containing: Introduction, Overview, 2 Experimental Chapters, Conclusion, Main Contributions, List of publications on the dissertation and List of presentations at international conferences, List of references.

TheIntroduction part is an introductory to the topic of the dissertation and contains a brief overview of the application of DL to improve the capabilities of optical coherence tomography (OCT). This is followed by a definition of the key challenges and a statement of the open problems to be solved. The last section of the introductory part describes the general structure of the dissertation.

Chapter 2 is a References Review, which presents the key challenges and issues that motivate the research questions. The importance of OCT images and the role of DL, such as image segmentation and reconstruction, are highlighted. The review chapter begins with an introduction to OCT systems and the extraction of depth information needed to generate images. The author addresses the challenge of using SS-OCT for vascular studies, which requires highly accurate segmentation. Chapter 2 provides the basic principles of OCT and a comparative analysis of different OCT systems in terms of signal-to-noise ratio (SNR) and the Swept-Source systems used for data acquisition. The OCT image processing processes are explained in detail. The state-of-the-art DL methods used for segmentation and reconstruction are reviewed. Finally, recent advances in medical image analysis that integrate OCT data with DL models are reviewed, based on their potential in clinical applications. The current gaps in OCT imaging are summarized and the state-of-the-art deep learning methods are reviewed.

Chapter 3 is dedicated to varicose vein segmentation solutions using a segmentation model based on an encoder-decoder architecture, with a focus on reducing model complexity (Publication I). Methods for estimating the shape and thickness of varicose veins using DL are skillfully proposed here (Publication II).

Chapter 4 reviews DL approaches for image reconstruction from OCT data, with a focus on SS-OCT systems where the raw data are inherently nonlinear in the wavenumber domain. Methods for generating high-quality OCT images directly from low-quality reconstructed images are presented (Publication III). An innovative reconstruction model with low time complexity based on an encoder-decoder architecture is proposed (Publication IV).

Chapter 5 summarizes the main contributions and conclusions. It also outlines potential directions for future research within the topic, as well as opportunities for further applications.

The dissertation is written on the basis of 4 publications and 8 presentations at international conferences, with the printouts of all articles attached at the end. It contains 33 figures, 12 tables and 150 cited sources.

From the report on the fulfillment of the minimum requirements in Appendix 1, Table 1, according to indicator Г, the doctoral student has scored 65 points out of a minimum of 30, with two of the publications being in journals with an impact factor and quartiles Q1 and Q2, and the remaining 2 publications being in SJR. Thus, from group A and group Г, the doctoral student presents a total of 115 points out of a minimum required 80 points. In addition, Mir yam Vikar has 22 points out of 11 noted independent citations (referring to group D, which according to the requirements is not mandatory for completion). The noted

citations are an excellent indicator of the relevance and significance of the research carried out in the dissertation.

2.1. Relevance of the problem developed in the dissertation

The aim of the dissertation is to investigate the application of deep learning (DL) to improve the analysis and reconstruction of SS-OCT images.

Undoubtedly, the topic is extremely relevant and interesting, due to the combination of 2 important aspects - on one hand, optical coherence tomography (OCT) is an established method in medical imaging. On the other hand, a number of challenges impose the need to develop innovative improvements in terms of automation - for example, in real-time clinical imaging, the reliability of optimization and balancing accuracy with computational complexity is extremely important.

To achieve the goal, the doctoral student has set herself to answer 5 research questions related to: (1) assessing the accuracy of segmentation of venous layers with minimal model complexity (Low-complexity segmentation); (2) developing an integrated model for reliable segmentation with accurate thickness measurements; (3) reconstructing images directly from raw SS-OCT data with reduced computational and hardware requirements, while maintaining image quality comparable to standard SS-OCT; (4) optimizing data in the spatial and Fourier domains for improved quality and reduced noise (Spatial and Fourier domain reconstruction); (5) creating a low-complexity DL model for real-time reconstruction.

2.2. Knowledge of the state of the problem and analysis of literature data

The literature review (Chapter 2) is very well presented and systematized, the key challenges and issues that motivate the research questions are described. The importance of OCT images and the role of DL, such as image segmentation and reconstruction, are emphasized. The overview chapter begins with an introduction to OCT systems, the extraction of information in depth necessary for image generation. The author examines in detail the challenge of using SS-OCT for vascular studies, which requires highly precise segmentation and physical measurement of soft tissues.

Chapter 2 provides an overview of the basic principles of OCT and a comparative analysis of different OCT systems in terms of signal-to-noise ratio (SNR) used for data acquisition. OCT image processing processes are explained in detail. State-of-the-art DL methods used for image-based segmentation and reconstruction are reviewed. Finally, recent advances in medical image analysis that integrate OCT data with DL models are reviewed, based on their potential in clinical applications. Current gaps in OCT imaging are also summarized.

The literature review is written on the basis of 150 sources, most of which are from recent years. This shows the candidate's excellent awareness and in-depth knowledge of the problems on the topic of the dissertation. Undoubtedly, the doctoral student is well aware of the state of the problem.

2.3. Research methods in response to the set goals and objectives

To achieve the goals, the doctoral student used theoretical and experimental approaches for analysis and reconstruction of OCT images of venous structures, as well as in the

development and optimization of DL models - all of them excellently combined and thought out. Initially, the author described in detail the development of new DL models for segmentation and assessment of vein thickness. Subsequently, the topic is focused on a more fundamental challenge: the high computational load and hardware dependence of the standard SS-OCT reconstruction model.

It is also worth noting here the original approach with which Maryam Viqar identifies the k-linearization step as a major obstacle and proposes a new, DL-based framework to completely bypass this process, allowing high-speed and high-quality image reconstruction directly from raw, nonlinear wavelength data.

The methods developed in the dissertation show high efficiency and significance for the development of modern OCT diagnostics.

2.4. Analysis of the results obtained

The results of the dissertation are presented in Chapters 3 and 4.

Chapter 3 examines the practical application of DL-based methods for analyzing SS-OCT images of venous structures, directly answering research questions 1 and 2. According to the author, one of the main problems in OCT systems is related to image quality, due to speckle noise or expensive hardware or software-based processing techniques . To overcome the challenge of model complexity due to a large number of parameters, she develops Opto-UNet, based on the U-Net architecture (Publication I). The model offers a highly optimized structure for accurate segmentation of venous images, surpassing other models in its capabilities.

Furthermore, in Chapter 3, an integrated TREE model capable of predicting vein thickness using transfer learning is presented (Publication II). The TREE model is developed on the simultaneous determination of segmentation maps and thickness values from SS-OCT images.

Chapter 4 reviews DL approaches for image reconstruction from OCT data, with a focus on SS-OCT systems where the raw data are inherently nonlinear in the wavenumber domain. Methods for generating high-quality OCT images directly from low-quality scans are presented, as shown in Publication III. Furthermore, the author introduces a low-time complexity reconstruction model based on an encoder-decoder architecture, which is explored in detail in Publication IV. This chapter answers research questions 3-5.

The experimental results and conclusions presented in Chapters 3 and 4 show that the goals and objectives of the dissertation have been fully achieved.

2.5. Scientific and applied scientific contributions in the dissertation work

The scientific research presented in the dissertation is in the field of wave physics. I agree with the contributions of the dissertation formulated in this way, which can be briefly summarized in two main directions:

Part 1: Deep Learning for Vascular Image Analysis (contributions are presented in Chapter 3)

Contribution 1: The author develops the so-called optimized segmentation "Opto-UNet", based on the U-Net model. It has been successfully demonstrated that the model achieves high accuracy of segmentation of venous layers, making it extremely efficient and practical for clinical applications. This contribution directly answers question 1 (RQ1).

Contribution 2: In addition, the PhD student also presents an integrated "TREE" model that simultaneously performs segmentation and thickness estimation. This is a complex two-task approach that uses transfer learning. The development of the SPD module is a significant contribution that improves the network's ability to integrate information for more accurate predictions. This contribution answers research question 2 (RQ2).

Part 2: Deep Machine Learning for OCT Image Reconstruction (contributions are presented in Chapter 4)

This is the most significant contribution of the dissertation, addressing the fundamental processing of SS-OCT data and addressing research questions 3, 4, and 5.

Contribution 3: An innovative model "WAVE-UNET" has been developed, trained to reconstruct high-quality OCT images directly from raw data in the wavelength domain, which are nonlinear in k-space. Thus, by bypassing the expensive (from a computational point of view) and hardware-intensive k-linearization, with this development the doctoral student has made a significant contribution to the paradigm in SS-OCT image processing. This contribution answers question 3. (RQ3).

Contribution 4: An innovative dual-domain system is developed using a spatial domain (SD-CNN) and a Fourier domain (FD-CNN) network. This approach optimizes data in both domains while achieving excellent speckle noise suppression and is shown to be highly effective for morphological structure recovery. This contribution answers question 4. (RQ4).

Contribution 5: The culmination of the contributions in the thesis is the development of a validated, low-complexity, high-speed DL framework that serves as an alternative to the standard reconstruction model. The author has provided evidence of reduced processing time (Table 4.5), demonstrating the application of this approach to real-time imaging, which is critical in clinical and research systems. This contribution answers question 5. (RQ5)

The methods developed in this dissertation show high efficiency, and the results presented are original and reliable.

3. Assessment of the personal contribution of the doctoral student

I have known Maryam Viqar since the very beginning, when she joined IOMT as a full-time PhD student on the PLENOPTIMA project, funded by the Marie Skłodowska-Curie program of the European Union. Even then, she impressed with her professional training, intelligence, and responsibility.

From my personal impressions of the doctoral student and the reports she presented at the IOMT seminars, as well as from several international meetings and conferences we have attended together, I believe that the work carried out on the dissertation is her personal

work. Moreover, at the beginning of the dissertation, after the indicated author's articles, the contribution of each of the co-authors in the articles is described in detail.

Here I would like to note that Maryam Viqar is extremely active in various scientific events. It is an excellent impression that the author works in good cooperation with doctors from Sofia Med University Hospital, which makes the work interdisciplinary.

In addition to the 4 articles for the dissertation, Maryam is a co-author of 7 more articles published in journals during the period when she was a full-time doctoral student at IOMT.

4. Publications on the dissertation

The dissertation is based on 4 journal publications, 2 of which have an impact factor and 2 have an impact rank. It should be noted that Maryam Viqar is the first author in all four publications.

The dissertation has received 11 citations on its topic. The results of the dissertation have also been presented in the form of reports or poster presentations at 8 conferences and scientific forums.

The doctoral student's publication activity, as well as the number of citations noted, are an excellent indicator of the relevance of the scientific problem and the significance of the achieved results.

5. Evaluation of the autoref

The abstract is very well-structured and meets the requirements for volume and content. The main activities, results obtained and contributions of the dissertation are reflected.

6. Critical notes and questions

I have no critical comments on the dissertation.

I have the following questions and comments:

- Which features of venous layers are most difficult to segment and how does the segmentation model respond to uncertain pixels when venous boundaries are highly blurred?
- By what criteria were the specific areas (orange background and yellow background) used in Figure 4.8 selected to calculate the CNR results presented in Table 4.2?
- Which is the most challenging direction in improving deep learning methods for next-generation swept-source OCT (SS-OCT)?

7. Reasoned and clearly formulated conclusion

The contributions in the dissertation are substantial and of a scientific-applied nature. A very large amount of data has been processed and the corresponding experiments have been performed. Important results have been achieved, published in journals with an impact factor (quartiles Q1 and Q2) and an impact rank. In all articles on the dissertation, Maryam Viqar is the first author. Part of the results of the dissertation have been presented at international scientific forums. So far, 11 citations have been noted, which proves the relevance of the topic being developed. Undoubtedly, the contribution of

the doctoral student is significant, as this is described in detail on page Xvi in the dissertation.

Viqar has made significant contributions to the field of biomedical engineering in conjunction with deep learning methods. The dissertation not only provides new approaches for vascular analysis, but also makes a significant contribution to foundation of image reconstruction from SS-OCT data. The study successfully answers all the questions posed, demonstrating a thorough mastery of both the basic principles and advanced deep learning techniques. This work will undoubtedly be of great interest to both clinical researchers and manufacturers of OCT systems. The presented dissertation work is original and of high scientific value.

The dissertation submitted to me for review and the scientometric data of Maryam Viqar meet and even exceed the national requirements for awarding the ONS "doctor" in the Act on the Development of the Scientific Staff in the Republic of Bulgaria, as well as the requirements for defending a dissertation in the Regulations on the Terms and Procedure for Acquiring Scientific Degrees and for Holding Academic Positions at the IOMT-BAS.

In conclusion, I declare my agreement and recommend to the esteemed Scientific Jury to award the educational and scientific degree "Doctor" in the professional field 4.1 Physical Sciences, specialty "Physics of Wave Processes".

02.12.2025

Reviewer:

/Prof. DSc. Vera Marinova/