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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REVIEW

Of a dissertation for the acquisition of the educational and scientific degree "Doctor"

Professional field. 4.1 Physical Sciences

Doctoral program. Physics of Wave Processes

Topic of the dissertation. "**Analysis and Compression of Dynamic Speckle**"

Author of the dissertation. **Mikhail Andreevich Levchenko,** Institute of Optical Materials and Technologies "Acad. Jordan Malinowski", Bulgarian Academy of Sciences

Scientific supervisors. Prof. DSci. Elena Stoykova,
Assoc. Prof. Dr Violeta Madjarova

Reviewer: Prof. Dr Daniela Bogdanova Karashanova, Institute of Optical Materials and Technologies, Bulgarian Academy of Sciences, appointed as a member of the scientific jury by order RD-15-901/20.12.2024 of the Director of the Institute of Optical Materials and Technologies, Prof. Dr Tsvetanka Babeva.

1. Biographical data of the doctoral candidate

Mikhail Andreevich Levchenko was born on April 6, 1997, in Moscow, Russian Federation. He completed his higher education with a bachelor's degree in 2019 at the Moscow Power Engineering Institute, where in 2021 he also obtained a master's degree in the field of "Devices and Methods for Quality Control and Diagnostics"

After successfully passing an international competition announced within the framework of the European Marie Skłodowska-Curie Program, he was enrolled as a Ph.D. student in a regular form of education on December 1, 2021, under the PLENOPTIMA project at the Institute of Optical Materials and Technologies at the Bulgarian Academy of Sciences, jointly with the Technical University of Berlin.

During his doctoral studies, Mikhail Levchenko passed the necessary exams in the specialty, language training, and computer skills. He successfully completed 2 specialized courses at the Training Center of the Bulgarian Academy of Sciences. Within the three-year period of his doctoral training, he presented a dissertation on the topic "Analysis and Compression of Dynamic Speckle", passed a preliminary defense at the Institute of Optical Materials and Technologies and presentation at the Technical University of Berlin, and was directed to procedure of dissertation's defence by decision of the Scientific Council of the Institute of Optical Materials and Technologies on December 16, 2024.

2. **Assessment of fulfillment of the minimum criteria, according to the specific rules for obtaining scientific degrees defined in the Institute of Optical Materials and Technologies, Bulgarian Academy of Sciences (Appendix 1).**

From the presented report on the fulfillment of the minimum requirements for acquiring the scientific and educational degree "Doctor" (Appendix 1), it is clear that the doctoral candidate meets the minimum requirements of the Act on the Development of the Academic Staff in the Republic of Bulgaria, the Regulations for its application in Bulgaria and BAS, as well as the specific requirements in the Regulations of the Institute of Optical Materials and Technologies, exceeding the minimum score by over 60%. Thus, in indicator G, instead of the minimum 30 points, he reports 80 points obtained from a total of 10 publications on the topic of the dissertation, which is very good publication activity for a PhD student. Two of the publications are in journals with an impact factor and quartile Q2, 4 with an impact rank, and 4 not bilonging into these two categories. As a result, instead of the minimum required 80 points, Mikhail Levchenko presents a total of 130 points according to the criteria in group A and group G. I would like to note that in group D, where it is not mandatory to present activity for this degree, and accordingly, the doctoral candidate has not presented data, he also has 8 points from 4 received citations on the publications from the dissertation, which, however, is a very good attestation for the quality of the conducted research.

3. Analysis of the dissertation.

The presented for review dissertation is described on 143 standard pages and is structured into the following 4 chapters: Overview of the Dynamic Speckle Imaging, Analysis of Dynamic Speckle Imaging, Compression of Dynamic Speckle Imaging, and Application of Dynamic Speckle Imaging in Nondestructive Testing. It also includes an Introduction, Conclusion, Contributions, as well as a list of references covering 110 literary sources, a list of publications included in the dissertation, participation in conferences, and a list of received citations of the publications. It contains 134 figures, 1 table, a list of abbreviations used, and acknowledgments.

In the brief introduction, which begins the dissertation, the doctoral candidate reveals the relevance of the method considered in the dissertation - Dynamic Speckle Imaging (DSI), as part of optical metrology and modern optical technologies for monitoring dynamic phenomena and processes related to tracking changes in the topology of the objects' surfaces. Motivated by both the scientific value of studying DSI and the various possibilities for its application as nondestructive testing in modern material science, monitoring fast processes in biological objects, sensors, etc., the doctoral candidate formulates here the goal of the developed dissertation and 10 tasks to achieve it. The focus is on improving the quality of DSI images, reducing the volume of information for reliable speckle analysis, processing large volumes of data, and solving important practical tasks such as creating a low-budget DSI setup that meets the established standards in optical metrology

The introduction is followed by a references review, formulated as the **First Chapter** of the dissertation, in which, after a detailed examination of published research on DSI, two algorithms described in the scientific literature are selected to be used for further simulations and to achieve part of the set tasks. These are the Structural Function (SF), for cases of uniform illumination of objects, and the Modified Structural Function (MSF), for non-uniform illumination.

Immediately following this, the results of numerous experiments - both simulation and real - are concisely and logically presented. In the **Second Chapter**, normalization in intensity-based DSI for processing raw speckle data with spatially varying statistics is investigated, which corresponds to the case of non-uniform illumination. Modifications of algorithms that use a sum of two intensities or one intensity for normalization at a given moment are proposed, and the efficiency of the algorithms for data with low and high contrast is verified. It is proven that point-

wise algorithms, where normalization is performed at each step using one or two intensity values, are more effective than algorithms that apply average values and variations of speckle intensity

In the **Third Chapter**, the problem of data compression is examined, and three methods for compressing DSI images are proposed: JPEG/JPEG2000, Singular value decomposition (SVD), and Principal component analysis (PCA). The analysis shows that compression works well for symmetric/asymmetric intensity distributions of speckle spots and can be used for images recorded under non-uniform illumination when normalized processing is required. The analysis of the change caused by compression is carried out by tracking its impact on the average value of activity assessment during the drying of a drop of polymer solution. Comparison with the result of recording bmp images shows that the distortion of temporal dependencies is of secondary importance, given the significant memory savings provided by JPEG or JPEG2000 compression. The proposed SVD and PCA methods in the dissertation outperform the results achieved with JPEG/JPEG2000 compression.

The **Fourth Chapter** examines several specific applications of DSI in the field of nondestructive "in situ" tests. Portable and inexpensive equipment for conducting DSI in out-of-laboratory conditions is developed, based on a smartphone and a cheap laser source, which, however, demonstrates good stability in external noise conditions. A technique with a high-speed camera for checking the potential of DSI for characterizing events with high-speed deformation, e.g., during high-speed impact of a composite material sample, is successfully implemented. DSI is successfully applied for detecting hidden defects during tensile testing of elastic materials.

Traditionally, the dissertation possesses conclusions based on the obtained experimental results, which in this case are presented at the end of each separate chapter, as well as with contributions of the dissertation and a list of literary sources.

3.1. Relevance of the topic.

The relevance of the set topic is undoubtedly connected with the method that is the basis of the dissertation - dynamic speckle imaging. Created in the 1960s, it still has unresolved challenges and points for improvement. At the same time, providing the possibility of nondestructive monitoring and testing of dynamic processes and materials, the method is an important part of optical metrology and continues to find new applications in various fields of human activity At the same time, an important place in the dissertation is occupied by the issue of compressing the

obtained information, which is related to contemporary problems in our digital daily life and the big data management.

3.2 Research methodology and response to the goal and tasks of the dissertation.

In connection with the fulfillment of the goal and tasks of the dissertation, the research methodology logically includes theoretical calculations and computer simulations, which at each stage are accompanied by skillfully conducted experiments confirming the obtained results. In this way, models and algorithms for processes with variable speed (object with circular channels of different depths covered with paint), rapidly occurring processes (glass with a drop of polymer solution on a heated plate), the influence of external noise (3D printed objects, one with concave inscriptions and a line, the other with circular channels of different depths, all covered with white acrylic paint) are validated.

3.3 Scientific and applied contributions of the dissertation.

The dissertation, using the method of dynamic speckle imaging, has achieved original results with both fundamental and applied nature, namely·

- Performance of an analysis of normalized algorithms for processing data with spatially varying speckle field statistics.

- Introduction of method for improving temporal resolution through analysis of the influence of recording time on the quality of the 2D activity map. Development of an intensity-based algorithm for tracking rapidly changing processes with high temporal resolution.

- Providing of dynamic speckle measurements in out-of-laboratory conditions.

- Development of a new miniature portable and effective device with a low-budget laser attached to a smartphone.

- Study on the information compression and optimization of the storage on disk space for temporally correlated speckle images using JPEG and JPEG2000 formats, as well as two compression algorithms based on SVD and PCA.

- Demonstration of the potential of DSI in nondestructive test analysis - impact tests using a high-speed camera for visualization of the deformation process; detection of hidden defects through dynamic speckle excitation under tensile load in elastic material.

3.4 Evaluation of the candidate's scientific production, the candidate's personal contribution, and the reflection of the results in the works of other authors.

The results of the dissertation have been published in 10 scientific publications, of which 2 are in the journal Applied Optics, with an impact factor of 1.9 for 2022 and 1 7 for 2023, and quartile Q2, 4 publications are in journals with an impact rank: Journal of Physics: Conference Series (2 papers) and Proceedings of SPIE (2 papers), and 4 articles are in conference proceedings. The doctoral candidate is the first author in 4 of the articles and the second author in 3 of them, which is evidence of his significant participation in the experimental work, discussion, and analysis of the research results described in these publications and respectively in the dissertation.

The results have been presented at 10 international scientific forums with 5 oral presentations, 2 online oral presentations, and 3 poster presentations.

A good attestation of the relevance of the topic, as well as the quality of the results obtained in the dissertation, are the already noted 4 citations of three of the publications, published in 2022 and 2023.

4. **Is the synopsis prepared according to the requirements, and does it correctly reflect the main points and scientific contributions of the dissertation?**

The synopsis is well formatted and fully meets the requirements for volume and content. It includes the main results of the research and the scientific contributions of the dissertation.

5. **Critical remarks and motivated recommendations for future use of the scientific and applied contributions.**

First of all, it should be noted that the dissertation is impressive with the volume of investigated problems and proposed solutions related to DSI. It combines both theoretical results and several practical applications. All results are very well illustrated.

A strongly positive feature of the dissertation is the logical presentation of scientific facts, the good style and language.

I have no critical remarks about the dissertation, only the following comments and questions, which do not concern the essence, credibility, and significance of the obtained results and the dissertation as a whole:

- The structure of the PAZO polymer used in some of the experiments conducted in the dissertation is presented in Figure 39. It would be better if it was part of Figure 33, where this polymer is introduced for the first time, and the first speckle image of a deposited PAZO film on a glass substrate is presented.

- The experimental scheme visualized in Figure 39 is cited in the text on p. 52 as presented in Figure 40.
- The activity maps presented in Figure 56 are with the application of two influencing factors: illumination and vibration. Wouldn't it be better to trace the influence of each of the two factors separately?
- In most of the experiments, the number of speckle images is 200. In the case of the object with circular concave and convex zones, coated with paint, presented in Figures 55 and 56, this number is 50. What determines this choice?
- With such good practical results, I recommend the doctoral candidate to think about patent protection. I wish him to continue to deepen his research in the topic of the dissertation.

6. **Conclusion with a clear statement whether the scientific degree should be awarded or not. Evaluation of the dissertation according to the requirements of TU Berlin.**

The dissertation presented for review represents a thorough and in-depth study of the essence of dynamic speckle imaging method, aiming to improve its parameters such as the accuracy of analysis through speckle images, improving temporal resolution, and adapting it to out-of-laboratory conditions, as well as some of its original applications in nondestructive testing of rapidly occurring processes in various materials.

The achieved results have been published in a sufficient number of scientific journals with an impact factor and impact rank, which provides more than 60% higher points than the minimum required in the Act on the Development of the Academic Staff in the Republic of Bulgaria and the Regulations for its application by this criterion. No plagiarism detected.The comments made are editorial and do not affect the value of the dissertation. Therefore, **I give a positive evaluation** of the dissertation and strongly recommend that the respected members of the Scientific Jury award **Mikhail Andreevich Levchenko the educational and scientific degree "Doctor"** in the professional field *4.1 Physical Sciences*, doctoral program *Physics of Wave Processes*.

According to the requirements of TU Berlin for this procedure, **I evaluate as "very good"** the dissertation.

20 February 2025 reviewer: .....

Sofia /Prof. Dr. Daniela Karashanova/