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REVIEW

The doctoral dissertation of Abdalraheema A. Ijjeha, M.Sc.,
entitled "Feasibility Study of Artificial Intelligence Approach
for Delamination Identification in Composite Laminates."

The basis for the review is a letter from the Director of Scientific Issues of the Institute of Fluid Power Machinery, Prof. Grzegorz Żywica, dated August 29, 2022, regarding the assignment of this opinion to me. The substantive basis is the provided dissertation.

The reviewed dissertation entitled "Feasibility Study of Artificial Intelligence Approach for Delamination Identification in Composite Laminates" by Abdalraheem Ijjeh, M.Sc. (from now on referred to as the Author), deals with the interesting and topical problem of damage detection in composite structures. The dissertation mainly focuses on the issue of using modern tools from the field of Machine Learning to analyze Lambda waves propagation in a composite panel.

The Author has taken up a complicated topic that requires careful preparation in the field of Artificial Intelligence techniques. He did - I do not hesitate to use the word - a vast amount of work related to constructing Deep Neural Networks-type systems for practical applications of delamination detection and conducting experimental studies. Many of the world's leading research centers deal with the issues of using Artificial Intelligence methods for process and image recognition, so this is a topic of the utmost relevance. The importance of the topic addressed by the Author is due to the area of the potential application of the results of the work (I mean the built and tested system for detection and localization of delamination) in scientific research and the analysis of structural systems. I must clearly emphasize here that this is a challenging research task, requiring patience, repetition of

simulations of proposed new diagnostic systems, and searching for more and more new concepts of diagnostic system architectures. In his doctoral thesis, the Author undertook a very topical problem from the scientific, cognitive, and application points of view, at the same time, a problem that is difficult to practical implementation. Thus, the choice of the topic and the scope of the reviewed work should be considered timely and fully justified.

The undertaken task specifying the purpose, scope, and methodology of solving the problem presented in the dissertation is formulated clearly and correctly.

Overview of the dissertation

The dissertation by Abdalraheem Ijjeh, consisting of 126 pages, is divided into six chapters. The list of literature includes 167 items.

The scope and purpose of the dissertation are presented in the introduction. The main objective of the dissertation was formulated as: "to develop an artificial intelligence (AI) driven diagnostic system for delamination identification in composite laminates ..." as well as tool and application objectives. These objectives can be defined as the analysis of various approaches and possibilities of applying Machine Learning techniques to the construction of this system. The tasks to be solved were defined correctly by the Author.

Chapter two, "State of the art in for SHM," discusses the basics of structural diagnostics methods, particularly composite structures. Special attention was paid to techniques related to Lamb elastic wave propagation. The Author also discussed methods of wave excitation and methods of wave measurement, particularly Scanning Laser Doppler Vibrometry (SLDV). The third chapter discusses the principles and fundamentals of the application of AI methods in structural diagnostics. The primary attention was directed to modern models of systems defined through an approach called Deep Learning. Chapters 2-3 thus discuss the principles, concepts, and assumptions to build a system for elastic wave propagation analysis.

Chapter four presents a methodology for applying Deep Learning to detect and locate delamination in composite systems. The method of generating learning sets using a numerical model is presented. The generated data was written in the form obtained from SLDV measurements presented as images. Two approaches were used: i) Root Mean Square (RMS) images of velocity amplitudes summed after time, ii) frames of propagating Lamb waves. The following models were proposed: 1) Convolutional Neural Network (CNN) with one convolutional layer, 2) Fully

Convolutional Networks (FCN) with multiple convolutional layers - five models operating in the literature (Res-Unet, VGG16-AE, FCN-DenseNet, Pyramid SPN, GCN) were considered here, 3) Autoencoder ConvLSTM which takes animations of full wavefield as an input, 4) Super-Resolution image reconstruction (DLSR) – “this model was developed for super-resolution image reconstruction that can cover the high-resolution full wavefield frames with high accuracy from the low-resolution acquired full wavefield by SLDV”. Models 3 and 4 are original proposals of the Author. These models account for a very high evaluation of the dissertation and provide directions for future research into creating new solutions of the Machine Learning genre in identification and diagnostic tasks.

The next chapter (the fifth) presents and discusses the application of the built DL network models to detect and localize delamination in a composite slab. Two approaches are presented: 1) testing the possibility of detecting damage using data obtained from the numerical model, and 2) testing the possibility of detecting damage on data obtained from experimental measurements. All constructed networks were tested. The results obtained on measured data for AE-ConvLSTM and DLSR networks are excellent. It was shown that these networks - learned on the numerical model - can detect delamination at any location. They can also detect multiple delaminations. It was shown also that this two approaches outperform remaining Deep Learning models that take only the RMS Images as input. The research results obtained, in my opinion, are impressive.

The dissertation concludes with the sixth chapter, where the Author summarizes the results of the work, gives conclusions from the research, and presents possibilities for further development of the developed system.

The dissertation's main objective was designing and constructing a diagnostic system based on Lamb wave measurements and Artificial Intelligence tools.

I believe that the purpose of the study set by the Author has been achieved, and the scientific methods used in the work are correct and demonstrate the preparation of the Author for independent scientific work in the discipline of mechanics and computational methods. In addition, I believe that the presented work clearly and lucidly discusses the analyzed issue, where the Author has demonstrated research maturity and adequate preparation for scientific research.

The most significant result of the work, in my opinion, is the demonstration of the effectiveness and suitability of the applied methods of image analysis for solving the tasks of diagnostics of composite structures (strictly speaking, laminated plates). Having also conducted research in similar areas, I know how difficult and labor-intensive it is to create a suitable computational tool. I also know how valuable

it is to choose the right simulation tools and measurement methodology. This knowledge allows me to conclude that the Lamb wave propagation analysis system presented in this dissertation represents an original solution for a diagnostic system.

Formal remarks on the dissertation

The work was carefully and insightfully done, written clearly and readable. Particularly noteworthy is the literature analysis and the synthesis of the current state of knowledge in a manner consistent with the proper conduct of scientific research. The Author presented the steps to achieve the stated goal, successively solving the various research tasks. He presented the research results clearly and illustrated them with a large number of figures and charts, taking care of the quality of the illustrations. The order of the chapters is also positive, as each previous chapter is a base for the next. Literature items were properly used in the dissertation (although there was a repetition of the same literature item: [113] and [122]). The style and technical language of the dissertation present a good level, making the work readable and understandable.

Concerning the reviewed dissertation, I can say that the doctoral thesis meets the requirements of the Law formulated in Art. 13., i.e.:

1. provides an original solution to a scientific problem based on the development of DNN diagnostic system models and
2. the Author demonstrates general theoretical knowledge in the scientific discipline of mechanics in the area of computational methods, as well as
3. it demonstrates the Author's ability to conduct independent scientific research.

Comments, thesis notes, and questions

Selected comments and some questions.

1. At the beginning of the thesis, it would be good to include a list of the designations (abbreviations) used. The list would make it easier to read the thesis.
2. Note regarding the sentence on page 46; "Accordingly, to obtain satisfactory results, I used the trial and error approach to tune the hyperparameters of

the developed models." Since the selection of hyperparameters is sometimes critical to the results' quality, it would be good to expand on this information.

3. Note regarding the sentence on page 46, 6th line from the bottom; "These properties ... ". How were the CFRP parameters selected? By solving the inverse problem? By the mean-square minimization method? By trial and error method?
4. Page 47, please explain why it was decided to assume that delamination occurs only between the third and fourth layers and is not distributed randomly between them.
5. Page 49 – error in formula 4.1.
6. Note to 4.2.1, regarding the division of data into teaching and testing sets. As I am guessing, the division into 80% and 20% was done randomly from the 121600 dataset, that is, the pattern was a patch (32x32 pixels). According to my experience, it is better to divide into learning and testing sets, dividing the set not by parts of the image but by whole images (dividing the set of 475 patterns).
7. Discussion note regarding paragraph 4.3.1 - concerns the K-folds technique. I present the view that this method does not reduce overfitting and only allows a better estimation of learning error. It is most often used when we have small data sets. However, large data sets are considered in the dissertation. Did the method produce results in the cases analyzed? When discussing the results, there is no mention of this.
8. Question relating to the numerical model dataset. Has the Author considered introducing noise (random noise) into the numerical model? The noise introduction is a frequently used technique to simulate measurements.
9. Question regarding paragraph 4.5.1 Please explain how frame f1 is determined

Final conclusions

I would like to conclude this opinion with some general conclusions.

1. The dissertation is written correctly, and the thesis's logical development and the work's purpose continues.

2. The Author has demonstrated extensive knowledge of Artificial Intelligence methods and applied them to create diagnostic systems based on "Deep Learning" techniques.

3. The dissertation is an original solution to a scientific problem, especially true of the proposed DNN models: AE-ConvLSTM and DLSR.
4. The suitability and effectiveness of the proposed Machine Learning systems for solving complex wave diagnostic problems of composite plates are demonstrated.
5. The objectives of the dissertation and the tasks arising from the thesis have been fulfilled. Areas for further research have also been indicated.

Based on the above conclusions, I conclude that the work of Abdalraheem Ijjeh, M.Sc., M.Sc., submitted for review, entitled "Feasibility Study of Artificial Intelligence Approach for Delamination Identification in Composite Laminates", presents an original solution to a scientific problem, makes a creative contribution to science in the discipline of mechanics in the area of computational methods, and meets all the conditions imposed on doctoral dissertations by the current legislation - (Ustawa o stopniach naukowych i tytule naukowym oraz o stopniach i tytule w zakresie sztuki z dnia 14 marca 2003 roku – Dz. U. Z 2017 r., poz. 1789, Rozporządzenie Ministra Nauki I Szkolnictwa Wyższego z dnia 19 stycznia 2018 r. w sprawie szczegółowego trybu i warunków przeprowadzania czynności w przewodzie doktorskim, w postępowaniu habilitacyjnym oraz w postępowaniu o nadanie tytułu profesora) and I apply for admission to further stages of the doctoral dissertation, including public discussion.