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QUESTIONNAIRE – PH.D. THESIS REVIEW FOR THE SCIENTIFIC COUNCIL IN THE DISCIPLINE OF INFORMATION TECHNOLOGY AND TELECOMMUNICATIONS OF THE WARSAW UNIVERSITY OF TECHNOLOGY

Title of the thesis: **Deep Learning Methods for Automated Urban Monitoring System using Synthetic Aperture Radar**

Author of the thesis: **I Made Sandhi Wangiyana, M.Sc., Eng.**

1. **What scientific issue is examined in the thesis /thesis statement/ and has it been formulated with sufficient clarity by the author? What is the nature of the thesis (theoretical, experimental, other)?**

The thesis consists of an introduction (in which the aim, motivation, thesis statement and author's own contribution are presented) and six subsequent chapters with a summary, in which the following topics are described: basics of Synthetic Aperture Radar (SAR), adaptation of Artificial Neural Networks (ANN) in the research carried out by the PhD Student, analysis of the latest research on methods based on Deep Learning for the assessment of building damage using SAR technology, analysis of the impact of data segmentation on improving the quality and detection of features (data) from acquired SAR images, an autoencoder method for the analysis and detection of large changes in multitemporal SAR data, performance analysis of unsupervised clustering and supervised deep segmentation methods, and final conclusions.

The author explicitly formulated three theses (page 18 of the thesis), to which he devoted the fourth, fifth, sixth, and seventh chapters of the thesis respectively, in the following wording:

- It is possible to improve the classification of building footprints using data augmentation for a limited set of SAR images.
- It is possible to detect large event changes from multitemporal SAR images using an autoencoder that was trained in an unsupervised way.
- It is possible to do urban Land Use Land Cover (LULC) classification on a single polarization SAR image.

The formulation of the above-mentioned theses is logical and rational, especially considering the fact that effective solutions are being sought at the present time, especially for monitoring changes in radar imagery of urban areas using Deep Learning algorithms. It should be noted that the aforementioned theses of the dissertation have been supported by studies using a sufficiently large dataset and represented by a variety of SAR imagery depicting urban settings such as industrial areas, ports, metropolitan agglomerations and agricultural areas. This confirms the ability to further generalise and apply the algorithms developed by the PhD student.

The thesis under review is of a theoretical-simulative nature, as evidenced by the theoretical analysis and practical adaptation of the developed algorithmic solutions in SAR imaging analysis techniques.

2. **Did the dissertation adequately analyse the sources /including world literature, state of the art, and industrial applications/ demonstrating sufficient knowledge of the author. Have the conclusions of the source review been formulated in a clear and convincing manner?**

The bibliography contains 201 references to the literature, including articles, books, conference materials, and internet sources, which, in the reviewer's opinion, are selected appropriately, and the rich literature list and the resulting extensive analysis of the current state of science and research on a global scale testify to the PhD Student's extensive knowledge and competence. Thus, the Author of the thesis, correctly refers to the literature in the content of his thesis. In the introduction, formulating the aim and the thesis statement, and in the following two chapters, the Author, referring to the literature, presented, in a clear and comprehensible manner for the reader, the issues related to the Synthetic Aperture Radar technology and its dynamic development, taking into account deep learning techniques and Artificial Neural Networks. The author, in a clear manner, described the basic features of the SAR radar and the SAR images obtained.
In the fourth chapter that followed, the PhD student carried out an analysis of the state of the art in building damage assessment using SAR radar, which is one of the key applications of the change monitoring system, while pointing out further developments on the basis of artificial intelligence.
The next three chapters of the thesis (5, 6 and 7) deal with solving the research problem. In the first stage, a neural network called autoencoder was used to detect changes from multi-temporal SAR images (chapter 6). The autoencoder was trained in an unsupervised manner to learn so-called 'representations' from crops of SAR images. The distance between representations of pre and post-images in the latent space was used to identify areas that have encountered significant change.
In the second stage, two building-level analyses were proposed: building footprint extraction (Chapter 5) and land classification (Chapter 7). A convolutional neural network was used to segment (split) objects from the SAR image. The above-mentioned approach directly correlates with the topic of disaster mitigation, where updated geo-spatial data are needed for the analysis process after the occurrence of different types of disasters.

Among the bibliography items referring to the theses of the dissertation (section 1.4, p. 18) and the research conducted in the thesis, five publications by the Author can be found, including:

- 1 article entitled „Data Augmentation for Building Footprint Segmentation in SAR Images: An Empirical Study" published in the journal MDPI Remote Sensing, according to the MEiN list – 100 pts - [reference list item no. 15];
- 4 articles from international conferences, i.e.:
  - "Effects of SAR Resolution in Automatic Building Segmentation Using CNN" and "Flood Detection Using Variational Autoencoder in SAR Images" published in the Signal Processing Symposium – SPSympo materials (in 2021 and 2023) – [reference list items no. 16 and 18, respectively];
  - "Unsupervised SAR Change Detection Using Autoencoders" and "CNN Performance Analysis for SAR Object Classification" published in the materials from the International Radar Symposium – IRS (in 2022 and 2024) - [reference list items no. 17 and 18].

It should be noted that three of the papers indicated above are authored articles, where the PhD student is an independent author, while in the other two the PhD student is the first author, so I assume the leading author.

I consider the research undertaken by the Author to be legitimate and convincing and resulting from a correct assessment of the state of the art in the area in question, including the significant achievements of Polish researchers.

3. **Has the author addressed the issues raised? Has he used an appropriate method for doing so and are the assumptions made reasonable?**

The PhD student proposed an algorithmic solution focused on generalising the prediction to new events. He also validated the developed algorithmic solution on a representative dataset, which is an appropriate way to measure the performance and efficiency of deep learning algorithms. Simulations represent a real-world use case in which the model is trained on 'historical' data and makes predictions based on data from new events, which is the correct course of action.
In the reviewed thesis, the PhD student thus confirms the applicability of techniques based on deep learning for monitoring the Earth's surface using SAR radar imagery. The methods proposed in the thesis have been validated on real measurement data and are described in Chapters 5, 6 and 7 of said thesis.
In some of the experiments carried out, the classification algorithm proposed by the PhD student showed poor performance at the chosen metric scale. However, this is in line with other studies reported in the literature where similar results are presented. This indicates a general challenge with the performance of the algorithm, when using SAR data. This issue is characterised in Chapter 4, which describes methods for assessing building damage on SAR imagery.
The approach presented by the PhD student is exciting and innovative, not reflected in the literature 'reports' internationally. Thus, the issues considered by the PhD student have been considered in detail and fully resolved.

4. **What is the originality of the thesis? What constitutes the author's independent and original contribution? What is the position of the thesis in relation to the state of the art or level of technology represented by the world literature?**

The PhD student assumed that the ideal augmentation monitoring system consists of a two-stage detection, which is directly related to the two objectives of the system, i.e.: to detect changes over large areas and to analyse their impact on individual buildings. The above-mentioned assumption is due to the physical limitations of SAR imaging, where there is a trade-off between swath width (coverage area) and spatial resolution. A large scanning lane is needed to detect changes in terrain, while the highest spatial resolution available for narrower scanning lanes is needed to analyse the details of individual buildings.
Therefore, the PhD student assumed that the ideal way to monitor changes in SAR images is a two-step process. Firstly, change detection is performed over a large area and then, in a second stage, to perform a deeper analysis, one moves on to analyse smaller areas that correspond to higher resolution images.

The most important aspects, representing the original and creative contribution of the Author of the thesis, include:

- experimental verification of data set extension methods and how they can be applied to SAR radar imagery;
- experimental classification of objects in SAR imagery based on the developed neural network;
- development of a general large-event detector based on autoencoders, trained on unlabeled SAR images acquired for different time instants;
- a review of state-of-the-art research on building damage assessment based on deep learning using SAR images;
- development of cutting-edge algorithms and software for monitoring changes in SAR imagery using deep learning.

A key component of this software has been reviewed and published in the journal MDPI Remote Sensing [item no. 15 - reference list], which confirms the originality of the proposed methods included in this thesis. The author's attempt to develop a two-stage monitoring system for urban analysis using deep learning is a novel work. Similar studies use optical images as input or use only bitemporal SAR images (not including continuous monitoring).
In my opinion, the analyses made by the Author in this thesis and in the co-authored publications [15÷19] can be considered as fully original. The review of the state-of-the-art methods of building damage classification in SAR images, data augmentation and evaluation of their impact on urban SAR image scenes, as well as the use of autoencoder for detection of general events in multi-temporal SAR images - testifies to the significant own contribution of the Author of the thesis and significantly extends the knowledge in the field of selected SAR detection and recognition techniques.
Considering the technologies that accompany the acquisition, processing and recognition of objects in SAR images, the results achieved by the author can be used in practice.

5. Has the author demonstrated the ability to present his results correctly and convincingly /conciseness, clarity, editorial correctness of the thesis/?

The thesis, including a bibliography and a list of acronyms used, is 129 pages long and has been written in a tight and concise manner. I consider the layout of the thesis, the order and the completeness of the individual chapters to be adapted to the subject matter and the scope of the research undertaken by the Author.
The author has correctly presented the research results that were obtained. Chapter 2 describes the techniques for interpreting SAR radar images. In Chapter 3, the author characterised the main components of deep learning techniques, and in Chapter 4, he analysed the state-of-the-art research on deep learning-based methods for assessing building damage using SAR radar. Chapter 5 was devoted to the results of building footprint extraction using SAR imagery.
Chapter 6 presents the results obtained by the PhD student using an autoencoder algorithm trained on unlabelled multi-temporal SAR images. Chapter 7 presents the obtained results for the classification of different terrain areas using a C-band single-polarisation SAR radar. The results obtained are compared by the PhD student to the results of imaging with a polarimetric radar operating in the X-band. The thesis concludes with a summary, highlighting the Author's main contribution and presenting potential future research directions that can be pursued in this field.
In conclusion, the thesis has been written in English and does not raise any objections, while the author's discussion of the research is clear and comprehensive enough to be fully evaluated in the review process.

6. What are the weaknesses of the thesis and its main drawbacks?

The scalability process of the developed algorithm can be considered too inefficient. Datasets of sufficient size were used to train and evaluate the developed algorithms. 'Sufficient' in this case means that the dataset used is comparable to a typical dataset size used in similar studies. However, the variability of urban scenes captured in the collected SAR data used in this work is still insufficient to represent 'global' detection. Several limitations are discussed in detail at the end of each of the experimental chapters, i.e.: 5, 6 and 7. For instance, in Chapter 6, despite the general ability of the autoencoder to detect changes resulting from many types of events (flood, fire, landslide), manual setting of the optimal threshold value is still required to obtain the best detection for each type of event. It was mentioned in Chapter 7 that the Urban Atlas dataset (page 94 of the thesis) used as reference labels is less reliable given the ambiguous appearance of land use classes in the SAR (e.g. industrial class).
Overall, the thesis has no fundamental flaws that would significantly reduce its value. Nevertheless, I would like to draw attention to a rather important fact that came to mind during

its review. Namely, in the aspect of the developed algorithmic techniques, it would be necessary to specify their computational complexity (e.g. in terms of time or memory) and, at the same time, to define the class of this complexity, e.g. logarithmic Θ(log n), linear Θ(n), quadratic Θ(n2), cubic Θ(n3) or polynomial Θ(nk+nk-1 + … + n).

In algorithmics in the broadest sense, problems of computational complexity have a direct bearing on the ability to validate an algorithm on modern computing machines, and they also significantly affect computation time. The computation time, and thus the response time of the system from detection to the generation of feedback about the type of detection (its features, etc.) is a key parameter.
Considering the potential use of the developed solutions for optimising data analysis in SAR imagery in modern recognition and change detection devices, the aforementioned issue becomes relevant.

7. What is the relevance of the thesis to technical sciences?

As already mentioned in earlier sections of the review, the thesis makes an important contribution in the field of methods and techniques for the analysis of SAR-derived imagery and in the field of active remote sensing methods. The second area of application is directly related to the broader security of a region, area or country. The PhD student has proposed useful algorithms using deep learning methods to estimate the impact of disasters using SAR imagery. This was made clear in the motivation for the research.

8. In which of the following categories does the Reviewer place the thesis:

a. not fulfilling the requirements for PhD dissertations by the applicable regulations,
b. requiring revision and re-review,
c. meeting the requirements,
d. meeting the requirements with a clear excess,
e. outstandingly good, deserving of distinction.

Having reviewed the thesis submitted for review by M.Sc. I Made Sandhi Wangiyan, I conclude that the thesis meets the requirements with a clear excess, and thus meets the requirements of Article 13, paragraph 1 of the Act on Scientific Degrees and Academic Title and Degrees and Title in Arts of 14 March 2003, as amended, where it refers to the original solution of a scientific problem, the candidate's general theoretical knowledge in a given scientific discipline and the ability to conduct scientific work independently.
Accordingly, I submit a motion to accept this study as a PhD thesis and admit M.Sc. I Made Sandhi Wangiyan to its public defence.

Warsaw, 2. February 2025

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