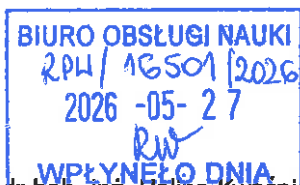




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Dissertation Review

Dissertation Title: DIGITAL SIGNAL PROCESSING AND ARTIFICIAL INTELLIGENCE
METHODS IN AGRICULTURAL PRODUCTION TECHNOLOGIES
USING INNOVATIVE BIOFERTILIZERS

Dissertation Author: Aleksandra Konopka, M.Sc. Eng
Supervisor: Ryszard Kozera, D.Sc.
Assistant Supervisor: Prof. D.Sc. Lidia Sas-Pasz

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1. Problem area of the thesis

Artificial intelligence, and especially machine learning methods, is not only a rapidly developing field of science but is also increasingly finding applications across various sectors of the economy. Modern agriculture offers significant potential for diverse applications of intelligent technologies, from fruit-picking machines to methods useful in creating and evaluating biofertilizers. Implementing intelligent systems in agriculture requires intensive research to ensure that the developed methods function as required. Developing (and implementing) AI methods for agriculture requires collaboration between AI specialists and domain experts, here – agricultural specialists relevant to the given problem.

M.Sc. Aleksandra Konopka undertook an interdisciplinary project – the application of machine learning methods to specific problems deemed important by field experts. The work was carried out by an interdisciplinary team of specialists in computer science and agriculture.

The selected topics for analysis included the classification of two types of data: (i) soil bacteria and (ii) plant ploidy, based on microscopic images of blackcurrant stomata.

The first problem is important for the precise monitoring and support of beneficial microbes, which, for example, can help reduce the use of artificial fertilizers and improve yields. The second topic could facilitate the selection of resistant varieties without the need for costly genetic testing or cytometry, or deliver biofertilizers through leaves, because the size and density of stomata depend on changes in chromosome number (ploidy).

In the summary of this part of the review, I state that the author has addressed an important and timely topic, primarily from an application perspective. It can be expected that, like any application of machine learning methods to a real-world problem, it will present the doctoral student with a computer science problem to solve.

2. Composition and Content of the Dissertation

This section addresses the dissertation's structure and content. I emphasize the definition of the research problem, the originality of the solution to the posed problem, the purpose, and the scope of the work. In accordance with the applicable law, these elements are the core of a doctoral dissertation. The statutory requirements state that the subject of a doctoral dissertation should be an original solution to a scientific problem, an original application of research results in the economic or social sphere, or an original artistic achievement. Below is a brief overview of the dissertation structure.

The PhD thesis consists of Introduction, Overview of theses and publications, Included publications, Conclusions and Future work and extensions. Next is Appendix: Research curriculum vitae and Bibliography. The Bibliography should be before the appendices.

In the Introduction, the author introduces the topic of her work as the application of computational methods in biology, specifically the automatic classification of selected genera of soil bacteria and the classification of plant ploidy based on microscopic images of blackcurrant stomata. The Candidate presents some justification for combining these two applications in a single doctoral dissertation. Many real-world problems in biology require advanced intelligent methods to solve. These two issues may have stemmed from the doctoral student's participation in the project (BIOSTRATEG, number BIOSTRATEG3/344433/16/NCBR/2018). At the beginning of Section 1.3, we find the following explanation of the two subjects considered: the dissertation "combines analysis of

biofertilizer ingredients (bacteria) and analysis of plant structures which can be influenced by biofertilizers, and which are critical for development of biofertilizer applications (stomata)."

The chapter *Introduction* explains why the biological problems raised in the paper are important. This information is essential for readers with little knowledge of biology. Regarding the introduction to machine learning models, it is likely relevant to readers who are well-versed in biological problems but unfamiliar with machine learning. Section 1.4 announces the surveys of the existing research relevant to the dissertation. It identifies established contributions, highlights current limitations and research gaps, situating the present work within the broader scholarly context.

According to the literature overview presented, research on soil bacterial classification is very limited. In the accessible literature, research on soil bacteria was performed on stained samples or with fluorescence microscopy. Public datasets of microscopic images of raw soil bacteria were unavailable. The research presented in the dissertation aimed to **fill the gap in soil bacteria classification**. The author has been inspired by methodologies used in the automatic classification of bacteria, e.g., morphology and bacteria living in other environments. Therefore, the team used various ML models, different feature sets, and image preprocessing in their research.

A search of the scientific literature shows that **no research has been dedicated to using ML methods for ploidy-level classification based on the analysis of microscopic images of stomata**. One can find scientific papers on applying ML methods to other tasks, e.g., object detection, species classification, or the binary presence/absence of stomata cells. The literature indicates that **no one has used Vision Transformers on stomata image analysis in any context**. In this situation, the PhD candidate identified a gap in the automatic classification of ploidy levels from stomatal microscopic images using classical ML methods, as well as a few DL methods.

The next sections present shortly the principal contributions of this dissertation. Summarizing this part, the main contribution lies in the extensive research on using ML methods for two classification tasks: soil bacterial classification and ploidy-level classification. One relatively simple modification of the ML method, namely the Extreme Learning Method, was proposed. I cannot find a significant scientific contribution in the discipline of Information and Communication Technology. I see extensive research applying known machine learning

techniques, with a relatively simple modification to one method, to new tasks in agriculture or biology. This research required significant effort and expertise to prepare real-world datasets.

Chapter 2. overviews the publications that constitute the thesis. It is worth noting that the author describes her contribution in the papers, as well as the contributions of other authors. The second part of this chapter is a synthesis of the research articles that comprise the thesis. We can find there some details about the experiments and their results.

Chapter 3 contains copies of articles included in the PhD dissertation. All of them were reviewed before publishing; I do not comment on them here.

The conclusion to the whole thesis is in Chapter 4. The Author underlines the comprehensiveness of the experiments conducted on dedicated, expertly prepared datasets of microscopic images of soil bacteria. There were five or four genera of soil bacteria. Next, a summary of the achieved classification quality is provided. The second part of this chapter underscores that AI methods were used for the first time to classify plant ploidy levels from microscopic stomata images. The Author also underlined that Vision Transformers were employed for the first time for stomata-related tasks. The results obtained with ResNet and VIT are shortly summarized.

Ms. Aleksandra Konopka proposes directions for further development of the research presented in her doctoral thesis. She envisions the following research:

- developing and applying a more diverse dataset of bacteria and microorganisms to research;
- expanding the analysis of mixed datasets consisting of various bacterial genera on single images;
- more research using Vision Transformers;
- research on ploidy level classification of species other than blackcurrant;
- applying other state-of-the-art AI methods;
- using Generative AI for data augmentation;
- expanding research on the use of Explainable AI methods.

As in her doctoral thesis, Ms. Konopka primarily envisions work that expands on existing research using known methods. There are no challenges here that would inspire new approaches. These may arise during the conduct of reliable research. I would expect to see

identified weaknesses in the approaches used, which will be challenging and require innovative solutions.

3. Originality and Significance of Achievements

The research area of the dissertation is important and current but mainly from the application perspective. The practical aspect is very clear and important. In the abstract, the author states that the PhD dissertation comprises seven publications. The first one concerns the classification of soil bacteria using classical ML methods and features related to shape and texture. The second one uses features related to distribution, shape, and color. The third uses Convolutional Neural Networks as classifiers. The fourth paper presents the author's modification of the ELM-RBF method; she proposes using k-medoids and mean shift clustering methods. This approach was studied with use of publicly available datasets.

Research in these papers was conducted on manually prepared set of soil bacteria. The fifth paper presents result of all previously used ML method but trained on an automatically created data set of soil bacteria.

The last two papers deal with another real-life problem, namely classification of plant ploidy based on microscopic images of stomata. In the sixth paper the authors segment images with YOLO method and classify by classical methods and Convolutional Neural Networks.

In the seventh paper, in addition to Convolutional Networks, for stomata classification the authors also used Vision Transformers for classification, and the Grad-CAM (Gradient weighted Class Activation Mapping) method to explain the performance of the classifiers.

Summing up, the dissertation contains original scientific research, they obey:

- A variety of experiments performed on datasets prepared by microbiology experts, which include microscopic images of five selected soil bacterial genera. Several classical and a few deep learning methods were used.

- A variety of experiments were performed on a dataset prepared automatically. Here, images were collected under different lighting conditions and with various microscopic glasses. This data obeys four selected bacterial genera.

- A new ML method was proposed, which is a modification of the Extreme Learning Machine Radial Basis Function. This modification involves using the mean shift and k-medoids algorithms. Wide experiments were performed to evaluate the quality of the proposed modification.

- The state-of-the-art research on the classification of ploidy levels in plants based on microscopic images of stomata. The dataset consisted of three classes: diploid, triploid, and tetraploid (such research was not present in the accessible literature). To verify the usefulness of ML methods for this task and their generality, the authors experimented with two separate raw datasets collected at different times of vegetation, training the model on one and testing on the other.

The Candidate reports, as a novelty, the use of Vision Transformers for the analysis of microscopic stomata images, as they were not previously reported in the accessible literature.

Aleksandra Konopka applied the Grad-CAM method to verify how ResNets and ViTs make decisions about the class of input data. The results indicate that ViTs reveal biologically interpretable behavior.

4. Comments and Issues for Discussion

The thesis is organized into logically interconnected thematic groups, providing a coherent synthesis of the work's contribution to the field. To my surprise, the work does not define the scientific problem to be solved, the aim and scope of the research, or a research hypothesis, as is common in doctoral dissertations. Incidentally, the lack of a research hypothesis does not bother me, as I oppose the formulation of research hypotheses in doctoral dissertations in technical disciplines. However, I expect a clear statement of the scientific problem to be solved, the aim and scope of the work, and the research questions. I found nothing of the sort in the dissertation under review. In section 1.3, titled "Research Problem", I did not find the research problem defined. It says: "The research presented in this dissertation combines analysis of biofertilizer ingredients (bacteria) and analysis of plant structures that can be influenced by biofertilizers, and which are critical for the development of biofertilizer applications (stomata)."

Regarding the work's objective, I found the following sentence: "Microbiologists are aware of the differences in morphology between specific bacterial genera, and due to this, they can distinguish them manually. This process is costly, time-consuming, and requires qualified biological specialists. Therefore, this dissertation aims to automate this process." What scientific problem from the Information and Communication Technology discipline must be solved to achieve this goal? It is a shame that Ms. Aleksandra Konopka did not attempt to formulate the true goal of her work, considering the appropriate discipline. The lack of a scientific statement of the problem/objective of the work is an obvious weakness. It results in a lack of innovative solutions from the perspective of the discipline in which the thesis is

defended. The author's contribution to the discipline is the modification of the ELM method, presented and researched in one of the publications, also on some benchmark datasets.

The research is experimental, very broad, and conducted with care in data selection and in the construction of features. The task of constructing features was very well done; it required a tremendous amount of work and combined knowledge from machine learning and biology.

I appreciate the scale and quality of the experiments conducted. However, I am also lacking certain information here, and I could not find it in the included publications. I was pleased to read a sentence in one publication: "The tables in this section display the mean accuracy resulting from 50 iterations of 10% cross-validation." However, why aren't there even standard deviations? Why do we compare methods by writing, for example, "with MSE = 0.62, which is 0.07 better than the best result applying mean shift." Is this difference significant? My question is whether, and if so, which differences are statistically significant? I have not found any significance tests anywhere in the extensive research presented.

5. Conclusion

In accordance with applicable law, [LEX Legal Information System: <https://sip.lex.pl/akty-prawne/dzu-dziennik-ustaw/prawo-o-szkolnictwie-wyzszym-i-nauce-18750400/art-187>], Art. 187. [Doctoral Dissertation]:

1. A doctoral dissertation presents the candidate's general theoretical knowledge in a given discipline or disciplines and the ability to conduct scientific or artistic work independently.
2. The subject of a doctoral dissertation is an original solution to a scientific problem, an original solution in the application of the results of one's own scientific research in the economic or social sphere, or an original artistic achievement.

I must answer the above questions. For the first point, my answer is yes. The doctoral dissertation and other publications co-authored by Ms. Aleksandra Konopka, her familiarity with the world literature in her area of interest, and the data analysis methods employed demonstrate a sound theoretical understanding of the field. The method of planning and conducting experimental research, the analysis of feature sets, and collaboration with experts from outside the discipline demonstrate the candidate's good preparation for scientific work.

The answer to the second question is not so obvious – an original solution to a scientific problem. This is mainly because the thesis lacks a clearly defined scientific problem. The

author's original solution is a modification of the Extreme Learning Machine (ELM). Deep models require substantial computing power and often require enormous amounts of data. Therefore, finding a way to improve the performance of a relatively fast and undemanding method, such as ELM, compared to DL is the right approach. The dissertation presents an original approach to solving two practical problems in agriculture. Extensive research provides insights into how different ML models and feature sets behave across the considered classification tasks.

In summary, **I declare that the doctoral dissertation submitted to me for review, authored by M.Sc. Eng., Aleksandre Konopka, meets the statutory requirements for doctoral dissertations** and I request that **Ms. Aleksandra Konopka be allowed to present her public PhD defense.**



Halina Kwaśnicka