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REVIEW

of the doctoral dissertation of Mr. Hamid Shiri

entitled

„*Modelling and analysis of long-term historical data of time-varying complex systems in the presence of impulsive noise for condition monitoring*”

The basis for the development of this review is letter no. RDND08/163/2024 of 17.07.2024 from the Chairman of the Scientific Discipline Council of Environmental Engineering, Mining and Energy of the Wrocław University of Science and Technology, prof. dr hab. inż. Robert Król.
The review was developed in relation to the following legal acts:
- Ustawa z dnia 20 lipca 2018 r. Prawo o szkolnictwie wyższym i nauce (Dz.U. z 2023 r. poz. 742 z późn. zm.).

1. Assessment of the relevance of the dissertation topic and the correctness of the formulated research goals and problems

The doctoral dissertation submitted for assessment concerns research on the development of methods for monitoring the technical condition of machines based on recorded diagnostic signals, also on a long-term scale. Technical diagnostics based on vibroacoustic methods are used in many areas of knowledge in various scientific disciplines. Additionally, this knowledge is of a strongly applied nature. Hence, the subject of the doctoral dissertation will probably find a large group of interested recipients. In the work, the PhD student focuses on publicly available research results of important elements of rotating machines, such as bearings. I consider the choice of such a measurement database to be justified because it will be used in the case of mining machines, which are additionally characterized by work under high load and in

extremely difficult environmental conditions, hence diagnosing their technical condition is a major research challenge. The developed very advanced and diverse methods of processing vibration signals and estimating operational and reliability measures (health index - HI and Remaining Useful Life - RUL) can certainly be used in the design of condition-based maintenance (CBM) systems in the operation of mining machines. **All this clearly indicates the correct choice of the topic of the doctoral dissertation and the relevance of the research problems raised by the PhD student**. The issues of operation and maintenance of mining machines, and consequently monitoring their technical condition, constitute a very important area of knowledge in the scientific field of Environmental Engineering, Mining and Energy. The methods of extracting operational data in mining machines developed by the PhD student, using vibration measures, constitute a new holistic approach to the technical diagnostics of mining machines. Based on the analysis carried out, it should be stated that the dissertation is interdisciplinary in nature. **Taking into account the research object and the area of potential applications, it can be stated that the subject matter and scope of the dissertation allow it to be classified as part of the discipline of Environmental Engineering, Mining and Energy**.

In the dissertation, the PhD student presented an explicit mathematical record of the developed analytical methods and the verification of these methods on the basis of actual measurement data taken from publicly available measurement data. **In this context, the topic of the dissertation should be considered current, cognitively interesting and of great utilitarian importance**.

The primary objective of the research is **to investigate, explore, and develop approaches to the assessment and prognosis of machinery health based on long-term data**. The specific objectives include:

• Investigation of the effect of non-Gaussian noise on modeling long-term health index data.

• Development of robust framework for identifying and modeling long-term health index data in the presence of non-Gaussian noise.

• Development of segmentation approach based on long-term data for the purpose of machine health assessment while considering non-Gaussian noise.

• Development of robust probabilistic models for machine prognostics based on long-term health index data in the presence of non-Gaussian noise.

Additionally, the Author defines research questions that replace the formulation of the thesis. These questions are as follow:

- *How can a model be developed to effectively handle long-term historical degradation data in the presence of non-Gaussian noise?*
- *What methods should be employed to properly identify, characterize, and extract useful information from long-term historical degradation data for the development of robust data-driven degradation models?*
- *How can the segmentation of long-term degradation data be robustly performed, particularly in the presence of non-Gaussian noise?*
- *What approaches should be employed to robustly predict RUL based on long-term degradation data, especially in the presence of non-Gaussian noise?*

In the future, in order to maintain the full methodology of research, I suggest formulating scientific theses or hypotheses. Regardless**, I believe that the aim of the work and the research questions are correct and creative**.

2. Body and characteristics of the dissertation

The content of the reviewed doctoral dissertation of Mr. Hamid Shiri is contained on 116 pages, divided into 7 chapters. In addition, there are summaries in the language, a list of figures and tables, a list of abbreviations, a list of symbols and a bibliography consisting of 158 items (including 6 co-authored items). The entire dissertation is written in English. A short description of the chapters, highlighting the most important scientific contribution of the Doctoral Student in my opinion, is included below.

Chapter 1: Introduction

The introduction sets a solid foundation by framing the importance of long-term condition monitoring and highlights the limitations of current approaches in handling complex, impulsive noise. The author clearly defines the motivation and objectives, focusing on the need for robust methods to model health data in non-stationary, noisy environments.

Contribution:

It provides a well-contextualized overview of the problem and effectively motivates the need for advanced modeling techniques, especially in the presence of non-Gaussian noise.

Chapter 2: Problem Formulation and State of the Art

This chapter offers a detailed literature review, identifying key gaps in current machine health prognostics and setting the stage for the thesis's contributions. The author addresses both data-driven and physics-based models, focusing on the challenge of non-Gaussian noise in long-term data.

Contribution:

The thorough examination of existing methods and the clear articulation of research questions provide a solid theoretical foundation. The focus on robust statistical models for noise handling is a key strength.

Chapter 3: Experimental Data

The author introduces synthetic and real-world datasets from wind turbines and bearings, validating the applicability of the proposed models. The data selection enhances the generalizability of the methodologies.

Contribution:

The inclusion of diverse datasets ensures the robustness of the proposed approaches and highlights their practical applicability across different industrial scenarios.

Chapter 4: Long-term Health Index Data Modeling

This chapter develops a robust framework for modeling long-term health index data, focusing on handling non-Gaussian noise using advanced statistical methods. The proposed framework successfully addresses the challenges of heavy-tailed distributions in machine degradation processes.

Contribution:

The novel use of statistical techniques for non-Gaussian noise handling is a significant contribution, leading to more accurate degradation modeling. Validation on synthetic and real-world data underscores the method's effectiveness.

Chapter 5: Segmentation of Health Index Data

This chapter proposes both offline and online probablstic segmentation methods, using techniques like piecewise regression and Hidden Markov Models, switching maximum correntropy Kalman filter. The segmentation effectively identifies different stages of machine degradation.

Contribution:

The real-time segmentation capability is particularly valuable for industrial applications, enabling proactive condition monitoring. The methods perform well under non-Gaussian conditions.

Chapter 6: Remaining Useful Life Prediction

The author introduces a probabilistic RUL prediction approach using the maximum correntropy extended Kalman filter (MCEKF), a novel contribution to handling non-Gaussian noise in predictive models.

Contribution:

The use of MCEKF offers a significant improvement over traditional methods in noisy environments, enhancing the accuracy of RUL predictions. The validation on multiple datasets demonstrates the method's robustness.

Chapter 7: Conclusion, Contributions, and Future Research

The thesis concludes by summarizing the main contributions, which include robust modeling, segmentation, and RUL prediction techniques tailored to non-Gaussian noise environments. The author provides insightful directions for future research, particularly around non-linear (non-monotonic) modeling and the use of machine learning for enhanced prognostics.

3. Evaluation of the dissertation

The substantive assessment of the reviewed doctoral dissertation by Mr. Hamid Shiri is very good. The subject matter is important and has an interdisciplinary and application character. In terms of theoretical considerations and practical applications, it contributes to the Scientific Discipline of Environmental Engineering, Mining and Energy, while its utilitarian nature may find interest in the areas of mechanical engineering, technical diagnostics and signal processing. Particularly noteworthy is the high level of formalization of analytical methods and their verification using publicly available research on real objects, which is a great value of the reviewed dissertation.

Mr. Hamid Shiri contribution to the field are:

- exploration the modeling, analysis, segmentation, and prediction of RUL using long-term HI data;
- focus on HI data with non-Gaussian (heavy-tailed) noise;
- well-established references for handling HI data with non-Gaussian noise;
- proposition of a new framework for modeling and identifying long-term HI data in the presence of non-Gaussian noise;
- robust approaches for segmenting HI data into three stages based on historical data and an online method for real-time segmentation into three stages;
- probabilistic method for predicting RUL using an exponential state degradation model and a robust filter;
- establishing statistical-based modeling approaches.

Mr. Hamid Shiri has published several articles related to long-term HI data modeling, identification, segmentation, and RUL prediction. The results obtained in this thesis were published in the following articles:

Żuławiński, W., Maraj-Zygmąt, **K., Shiri**, H., Wyłomańska, A., and Zimroz, R. (2023). Framework for stochastic modelling of long-term non-homogeneous data with non-Gaussian characteristics for machine condition prognosis. **Mechanical Systems and Signal Processing**, 184, 109677.

Shiri, H., Zimroz, P., Wodecki, J., Wyłomańska, A., Zimroz, R., and Szabat, K. (2023). Using long-term condition monitoring data with non-Gaussian noise for online diagnostics. **Mechanical Systems and Signal Processing**, 200, 110472.

Shiri, H., Zimroz, P., Wodecki, J., Wyłomańska, A., and Zimroz, R. (2023). Data-driven segmentation of long-term condition monitoring data in the presence of heavy-tailed distributed noise with finite-variance. **Mechanical Systems and Signal Processing**, 205, 110833.

Shiri, H., Zimroz, P., Wyłomańska, A., and Zimroz, R. (2024). Estimation of machinery's remaining useful life in the presence of non-Gaussian noise by using a robust extended Kalman filter. **Measurement**, 114882.

The author of the dissertation proved the achievement of the assumed goal and verified the research questions posed. He proposed methods for processing measurement signals and estimating operating parameters, which have the potential of predicting the phases of machine operation. The doctoral student correctly selected the measurement data, based on which he verified the developed analytical methods. Thus, it should be considered that the goal of the dissertation was achieved.

The author did not avoid minor errors and generalizations. However, these errors do not affect my high assessment of the reviewed doctoral dissertation.

Therefore, my assessment of the entire doctoral dissertation is unequivocally positive.

4. Comments and inquiries

A careful reading of the dissertation leads to the following comments and questions:

1. Can the type of measurement systems and the location of sensors affect the results of the machine condition estimation?
2. What criterion was used to select measurement data to develop and verify signal processing methods?
3. Can the developed methods be used for other diagnostic signals (sound pressure, temperature, recorded images, etc.)?
4. In this thesis, the effect of health index construction and the methodology for extracting this health index are not investigated. Please confirm that health index is the best indicator for describing the degradation process.
5. More attention could be given to the health index construction process and the preprocessing of raw data, which may present challenges in real-world industrial implementations.
6. What could be potential effect of non-linear behavior of the health index?
7. In the methods developed parameters were identified and tuned using historical data. What if we don’t have such data?
8. To estimate the RUL, the results provided in this thesis are based on known end-of-life (EOL) thresholds. The estimation of EOL can be difficult. Therefore what is opinion of Author to find any solution?
9. The discussion of hybrid models could have been expanded, particularly in the context of integrating physical knowledge with the data-driven approaches.
10. How can we use the AI based methods for signal processing and condition-based maintenance?
11. Why estimation of CP1 and CP2, determined by HMMR, HLP, and DPS... gives such different results?
12. Why is MSE (page 56, Figure 5.4) used in the presentation and analysis of final results sometimes and "Percentage error" (page 62, Figure 5.12) used in another case?

13. The Author (on page 62) states "Furthermore, the Bayesian technique offers the benefit of yielding probabilistic outcomes, which can help reduce uncertainty." Are there any studies known by Author that confirm that the Bayesian technique reduces uncertainty?

These comments have no significant impact on the substantive value of the work.

5. Conclusion

The reviewed doctoral dissertation by Mr. Hamid Shiri stands out in terms of the quality of the analytical considerations and the holistic approach to scientific issues. The entire dissertation shows a logical and correct course of action, characteristic of conducting scientific research. This allows us to conclude about the skills and maturity of Mr. Hamid Shiri in planning and implementing research experiments. **It should be clearly stated that the reviewed dissertation is an original solution to a scientific problem by the PhD student and demonstrates his extensive general theoretical knowledge and ability to independently conduct scientific work in the Scientific Discipline of Environmental Engineering, Mining and Energy**. Additionally, it should be emphasized that the utilitarian nature of the dissertation, which allows for the extraction of its results to many engineering areas.

Due to the topics discussed in the dissertation, I also analysed the scientific achievements of the Author, which are outstanding for a young scientist. This indicates that the issues of Mr. Hamid Shiri's research work are current, and its results are recognized by reviewers of renowned international journals with a very high IF.

The most important achievements of Mr. Hamid Shiri presented in the reviewed doctoral dissertation should be considered the development of a set of methods for estimating machine operational measures taking into account accompanying phenomena generating signal noise.

The comments presented do not have a major impact on the fact that the Author independently completed the scientific and research task. To solve the problem, the PhD student demonstrated knowledge of signal analysis, used correctly selected

research methods, demonstrating the ability to conduct an experiment, and effectively verified the developed methods.

I believe that the reviewed doctoral dissertation by Mr. Hamid Shiri entitled "*Modelling and analysis of long-term historical data of time-varying complex systems in the presence of impulsive noise for condition monitoring*" meets the requirements specified in the Act of July 20, 2018 - the Law on Higher Education and Science (Journal of Laws of 2023, item 742, as amended) (Ustawa z dnia 20 lipca 2018 r. Prawo o szkolnictwie wyższym i nauce - Dz.U. z 2023 r. poz. 742 z późn. zm.). It can therefore serve as a basis for considering the application to award the Candidate the degree of doctor of technical sciences. In connection with the above, I apply an application to admit Mr. Hamid Shiri to publicly defend the reviewed dissertation as a work within the scope of the Scientific Discipline of Environmental Engineering, Mining and Energy.

At the same time, due to my very good assessment of the dissertation, the highly innovative nature and international level of the achieved results, and the utilitarian significance and outstanding scientific achievements (significantly exceeding 300 points), I apply to the High Council of the Scientific Discipline of Environmental Engineering, Mining and Energy of the Wrocław University of Science and Technology to distinguish the subject doctoral dissertation.

Signed by /
Podpisano przez:

Rafał Andrzej
Burdzik
Politechnika Śląska

Date / Data: 2024-
09-25 23:51