Recenzje spełnia wymogi formalne Przewodniczący Rady Dyscypliny Inżynieria Lądowa, geodezja i Transport

Phong Ba Dao, DSc, PhD
AGH University of Krakow
Faculty of Mechanical Engineering and Robotics
Department of Robotics and Mechatronics
Al. Mickiewicza 30
30-059 Kraków, Poland
e-mail: phongdao@agh.edu.pl

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Review of the doctoral dissertation by Mr. NGUYEN CONG DUC entitled "Bridge health monitoring using automated FE model updating, signal processing, and machine learning"

This doctoral dissertation focuses on bridge health monitoring (BHM), which is essential for ensuring the safety, reliability, and longevity of road and railway bridges. The research proposes the use of automated Finite Element (FE) model updating, signal processing, and machine learning techniques to improve BHM.

Outline of the dissertation

The dissertation is divided into seven chapters, which provide an overview of the techniques commonly used for bridge health monitoring (BHM), detail the measurement setups, and describe the methods developed for processing the measurement data. Additionally, real-world examples are presented in detail to illustrate the effectiveness of the developed methods. The chapters are organized as follows:

Chapter 1 provides an introduction, explaining the motivations behind conducting research on bridge health monitoring approaches. It outlines the aim and scope of the research work and offers an overview of the dissertation's structure.

Chapter 2 reviews the current developments and emerging trends in BHM. The chapter discusses the latest advancements and the increasing demand for BHM systems. Specific market needs in Vietnam and Poland are highlighted, along with advanced signal processing techniques in BHM. Furthermore, the chapter introduces a digital twin framework for data-driven bridge health monitoring.

Chapter 3 outlines the data acquisition instruments and advanced signal processing techniques. It covers the diagnostic load testing apparatus used for bridges and emphasizes advanced processing methods, such as wavelet transforms, FFT-based integration and differentiation techniques, and machine learning algorithms.

Chapter 4 focuses on railway bridge health monitoring using machine learning, specifically examining the Dębica railway steel arch bridge. The structural health monitoring (SHM) system employed for this bridge is described in detail, and optimized Artificial Neural Networks (ANN) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) regression models are developed for vibration-based SHM.

Chapter 5 presents railway bridge health diagnostics using wavelet analysis and deep learning. It utilizes data collected from the vibration-based SHM system of the Dębica railway bridge to

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Chapter 5 presents [illegible] bridge health [illegible] data collected from [illegible] develop deep learning classification models. Convolutional Neural Networks (CNN) models (GoogLeNet) are employed to predict the structural health conditions using wavelet scalograms generated from vibration signals, and orbit-shaped CNN models are used for hanger health diagnostics.

Chapter 6 explores bridge diagnostic load ratings through automated FE model updating. This approach is applied to two road bridges in Vietnam. The chapter discusses the calibration of FE models for two case studies involving reinforced concrete and steel-concrete composite bridges.

Chapter 7 concludes the dissertation, summarizing the findings and offering recommendations for further research.

Coherence, scope and impact of the dissertation

The structure of the chapters follows a coherent flow. The doctoral dissertation is entirely application-oriented, focusing on the use of machine learning and signal processing algorithms to address BHM challenges in bridges. No new theoretical contributions are developed in the thesis. The dissertation ultimately proposes that combining advanced data processing techniques and model calibration can make bridge health monitoring more reliable and cost-effective, enabling engineers to monitor and assess bridge safety more efficiently.

Major contributions

The primary contributions of the dissertation can be summarized as the following key points:

1. Railway bridge health monitoring using intelligent data processing: ANN and ANFIS regression models are employed to predict the dynamic behavior of a railway steel arch bridge in Dębica, Poland. Field data, collected from a nine-month period, is used as input to train ANN and ANFIS models. ANN models optimized using a genetic algorithm are found to outperform ANFIS models.

2. Railway bridge health diagnosis using wavelet analysis and deep learning: Wavelet transforms and GoogLeNet CNN classification models are applied for bridge health monitoring using vibration data. Scalogram images, generated from wavelet transforms, are used as inputs for CNN models to classify the health states of the bridge based on tension forces in hangers. Additionally, vibration-based orbit-shaped image patterns are used for automated hanger health diagnostics.

3. Bridge load testing using automated FE model updating: The thesis emphasizes the importance of FE model calibration for accurately predicting bridge behavior. Optimization of FE models is performed using genetic algorithms and particle swarm optimization, interfacing with the MATLAB software and FE modeling tools like SOFISTIK TEDDY and ANSYS APDL. These calibrated models allow for more accurate predictions of load limits and overloads, aiding in the evaluation of bridges.

4. Practical applications: The developed methods can be applied to various types of bridges, including RC bridges, steel-concrete composite bridges, and railway steel arch bridges. The integration of machine learning with vibration-based SHM systems helps analyze data and predict structural behavior, improving the effectiveness of monitoring and decision-making.

Other comments for possible improvements of the dissertation

- The concept of the digital twin in the context of bridge health monitoring is introduced in the thesis (Chapter 2) without a proper technical definition, which may lead to confusion for readers. To address this, the reviewer suggests adding a short paragraph to clarify the term. The author has used the Taiji model (or Yin-Yang symbol) to describe the integration of SHM digital twins for bridges. However, this model or symbol cannot substitute for a proper technical definition.

- The Yin-Yang symbol is commonly used across various fields to represent two opposing aspects of a single entity, such as good vs. bad, hard vs. soft, or day vs. night. However, in my opinion, the Yin-Yang symbol may not be suitable for representing the digital twin concept. In a digital twin framework, the real structure and its simulated model are not two opposing sides but should be identical to each other.

- Figure 3.2 contains photos that prominently feature human faces, which cover a significant portion of each image. I suggest replacing these photos with ones that focus solely on the bridge. This will ensure that the emphasis remains on the subject matter of the study, allowing the visuals to better complement the technical content.

- The reviewer suggests that the author include a block diagram to illustrate the method developed in Chapter 4. Each computational step should be represented by a block, making the method easier to understand and follow. Currently, the method is described solely through text, which is insufficient. It is worth noting that the methods in Chapters 5 and 6 are accompanied by block diagrams, which clearly present the processes developed. Adding a similar diagram to Chapter 4 would enhance clarity and consistency.

- Section 4.3: The author should review the sentence "The sampling frequency of the SHM system was 1024 resampled to 128 for storage" and ensure that the appropriate units are included where necessary.

- Figures 4.5, 4.6, 4.8, 4.9: what is the meaning of the three stars behind each correlation coefficient? It is suggested that these stars should either be clarified or removed to avoid confusion.

- In Chapter 4, the author presented only the training and testing results of the models. However, no validation results using these models were provided. It would be more complete if the author validated the best-performing model using a case study with a different dataset (not included in the training and testing data). This would better demonstrate the model's generalizability and effectiveness in real-world applications.

- In Chapter 5, how can the author ensure that the observed unhealthy shapes (such as eight, heart, line, etc.) are not due to varying environmental and operational conditions (e.g. temperature, humidity, traffic load), but rather indicative of bridge condition degradation?

Summary

Considering the assessment of the doctoral dissertation, I believe that it is an original solution to a scientific problem and demonstrates the general theoretical knowledge of the PhD student in the scientific discipline of civil engineering, geodesy and transport. It also confirms the ability to conduct scientific work. It thus meets the requirements of the Act of July 20,

2018, Law on Higher Education and Science (Journal of Laws of 2018, item 1668, as amended). I request that it be accepted and allowed for public defense.

With best regards,

Associate Prof. Phong Ba Dao, DSc, PhD