PHD THESIS EVALUATION BY THE SUPERVISOR

Thesis title: Hybrid Modelling of Mechanical Digital Twin by Finite Element Method and Graph Neural Networks

Ph.D. candidate: Marek Ciklamini

The PhD thesis deals with the problem of a hybrid modelling towards designing a digital twin of a mechanical system. The hybrid model of the twin is based on interconnecting the finite element method and the graph neural network. The general objective of the thesis is to answer the question whether regressors based on graph neural networks can effectively build a digital twin capturing the results obtained by computationally demanding model obtained by finite element method. To answer the question, considering the results of the state-of-the-art analysis, four objectives are defined: The first objective aims at determining the hybrid methodology for predicting an authentic and accurate operation of a mechanical system. The second objective focuses on the key information extraction from the physical model to train the regressor. The third objective deals with optimizing the regressor training and the fourth deals with diagnosis to avoid false predictions. Subsequently, all these objectives have been fulfilled, leading to the positive answer to the stated question.

The work on the thesis topic began in 2016, **within the combined study**, under supervision of doc. Ing. Josef Kokeš, CSc. After fulfilling all the study duties, the Ph.D. candidate defended the state exam in 2021, at which the final scope of the thesis was formulated and systematic work on its compilation began. After doc. Kokeš passed away in 2022, the supervision of the Ph.D. candidate was taken over by prof. Ing. Jiří Bíla, Dr.Sc. who helped with structuring the thesis and strengthening the results. After prof. Bíla passed away in Spring 2023, I took over the supervision, jointly with the supervisor specialist Ing. Matouš Cejnek, Ph.D. Next to finalizing the thesis, we focused on strengthening the publication activities of the Ph.D. candidate. A notable aspect of the work of the Ph.D. candidate is the practical motivation of his work and professional insight gained during his rich and successful career in industry.

Jointly with supervisor specialist, Ing. Matouš Cejnek, Ph.D., we came to the following evaluation of the thesis:

Feasibility and Novelty: The proposed hybrid modelling approach, which integrates the finite element method and the graph neural network, brings significant innovation within the digital twin field. It is essential to recognize that this area remains relatively unexplored, thereby presenting potential challenges in establishing common methodologies and standards for evaluation and comparison. We consider the thesis as a valuable exploration and refinement of these methodologies to ensure robustness and reliability in future applications.

Literature Review: The state-of-the-art section is commendably well-structured and informative, catering to both seasoned researchers and readers unfamiliar with the field. The inclusion of literature spanning from pioneering publications to contemporary research provides a comprehensive overview and adds significant depth to the review. The review presented in the thesis provides further exploration and analysis of emerging trends and developments.

Research Objectives: While the research objectives are clearly articulated, some may appear overly ambitious for a single thesis. However, it is worth noting that a narrower definition of objectives could inadvertently limit the broader applicability and impact of the research. Therefore, while acknowledging the challenges posed by ambitious objectives, the comprehensive scope of the research is commendable and aligns well with advancing knowledge in the field.

Methodology: This section emerges as a focal point for potential improvement within the thesis. While the proposed work presents practical experiments yielding promising results, at some points there is a notable absence of deeper explanations and discussions regarding the underlying mechanisms. A more comprehensive exploration of the theoretical underpinnings and methodological approaches employed could provide valuable insights and enhance the overall rigour and credibility of the research findings.

To conclude, despite light criticism to the methodological part, the resented results can be considered as original, with clear contribution to the subject of hybrid modelling of mechanical systems. As all the objective stated in the thesis were fulfilled, I fully recommend the thesis for defence.

In Prague, August 8, 2023

prof. Ing. Tomáš Vyhlídal, Ph.D.

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