From Simulation to SHM: Reducing Numerical Errors for Reliable Neural-Network-Based Damage Detection

Paweł Kowalski[1,2*], **Wiktor Waszkowiak**[3,2], **Łukasz Doliński**[3,2] **and Arkadiusz Żak**[3,2]

[1]Department of Control Engineering, Gdańsk University of Technology, Gdańsk, Poland
[2]Digital Technologies Center, Gdańsk University of Technology, Gdańsk, Poland
[3]Department of Biomechatronics, Gdańsk University of Technology, Gdańsk, Poland
e-mails: pawel.kowalski@pg.edu.pl, wiktor.waszkowiak@pg.edu.pl, lukasz.dolinski@pg.edu.pl, arkadiusz.zak@pg.edu.pl

KEYWORDS: *Damage Localisation, Convolutional Neural Network, SHM.*

Artificial neural networks (ANNs) are increasingly used in structural health monitoring (SHM) for damage detection and localization [1]. In our previous work, ANNs were successfully applied to identify damage in isotropic plates using data generated with the time-domain spectral finite element method (TD-SFEM). This approach forms the basis for the development of a digital twin framework, in which numerical simulations are used to generate training data for data-driven diagnostic models.

Accurate localization of smaller defects, as well as improvement of spatial resolution, requires the use of shorter wavelengths, which in turn necessitates higher excitation frequencies. However, increasing the frequency range introduces significant challenges in numerical modelling. In particular, discretization errors become more pronounced and may manifest as numerical anisotropy, including direction-dependent wave speeds and frequency band gaps. These effects distort the simulated wavefield and degrade the quality of the data used for training neural networks.

A straightforward way to extend the usable frequency range is to refine the mesh, increasing the number of finite elements. While this approach improves accuracy, it leads to a substantial increase in computational cost. This becomes a critical limitation in the context of ANN training, where large datasets are required and simulation time directly impacts the feasibility of the approach.

To address this issue, a class of spline-based finite elements is employed, which significantly reduces numerical anisotropy and eliminates numerical band gaps without a substantial increase in computational cost. As a result, the usable frequency range of the numerical model is extended, enabling one to generate higher-quality training data within practical computational limits.

The improved numerical data are subsequently used to train artificial neural networks for damage localization. The results demonstrate that the proposed approach allows for accurate identification of damage at higher frequencies, while maintaining computational efficiency. These findings highlight the importance of controlling numerical properties in simulation-based machine learning pipelines and demonstrate the potential of spline-based finite elements in supporting data-driven SHM applications.

ACKNOWLEDGEMENT:

Financial support of these studies from Gdansk University of Technology by the 1/2023/IDUB/I3b/Ag grant under the ARGENTUM - Excellence Initiative - Research University program is gratefully acknowledged.

The author of this work would like to gratefully acknowledge the support for their research provided by the Academic Computer Centre in Gdansk. All results presented in this paper have been obtained by the use of the software available at the Academic Computer Centre in Gdansk.

[1] A. Sattarifar, T. Nestorović, Damage localization and characterization using one-dimensional convolutional neural network and a sparse network of transducers, *Eng. Appl. Artif. Intell.* **115**, 105273, 2022. https://doi.org/10.1016/j.engappai.2022.105273