Neural Network Dynamic Metamodels for a Highly Detailed Cable-Stayed Bridge Finite Element Model

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Abstract

Despite Finite Element Analysis (FEA) having a strong theoretical foundation with high accuracy, its significant limitation in computational time is highlighted when a large number of FEAs is required. This study thus desires to address the issue by investigating the capabilities of Neural Networks (NNs) in being surrogate models of highly detailed FE models. The generalized processes of the NN model development and the exemplar architectures of the NN models for predicting the frequencies and mode shapes are first proposed before being applied to the task of high dimensional Finite Element Model Updating (FEMU) of a complex cable-stayed bridge. Then, the aspects of the computational time, accuracy, and challenges of the NNs in future works are discussed. Results from the FEMU that utilizes the multi-restart Genetic Algorithm (GA) emphasize the efficiency of the NNs in leading the GA toward an updated FE model that better replicates the actual dynamic responses.

Keywords: structural health monitoring; bridges; cable-stayed bridges; finite element model; finite element model updating; surrogate models; machine learning; neural networks; genetic algorithm

1 Introduction

Due to the strong theoretical foundation and high accuracy in describing the actual structural behaviour of Finite Element Analysis (FEA), it is utilized in various tasks such as structural design and health monitoring (SHM). When it comes to the tasks that require a large number of FEAs such as design optimization and Finite Element Model Updating (FEMU), however, FEAs' limitations are emphasized.

One of the significant limitations is that FEA requires more computational power if more details of the structures with the finer meshes are utilized. Traditionally, to overcome this issue, structural details are simplified to reduce the inherent complexities. This undeniably magnifies the mismatching between the actual structural behaviour and the simulations if the simplification has not been done carefully or is oversimplified.

To address this issue, many studies have utilized mathematical functions, known as surrogate models or metamodels, to approximate the results of FEA. For instance, Kriging models were employed in [1] to approximate underlining links between six model parameters and dynamic responses, i.e., natural frequencies and mode shapes, for the FEMU of a bridge. Ren and Chen [2] estimated implicit relationships between three model parameters and modal frequencies using the Response Surface Methodology. The numerous metamodel utilizations were reviewed in [3].

To broaden the frontier of solutions paying particular attention to the vibration-based FEMU, the implementation of Neural Networks (NNs) as metamodels is investigated in this study. The intention is to explore the capabilities of NNs in estimating the implicit relationships between model parameters and FE-simulated dynamic responses using the Multi-Layer Perceptron (MLP)

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