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THE IMPACT OF LONG SHORT-TERM MEMORY TOWARDS ACTIVE VIBRATION CONTROL OF HORIZONTAL FLEXIBLE PLATE

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BACKGROUND STUDY

Flexible structures like plates, beams, shells are rapidly developing and widely used across industries like aerospace, automotive, and manufacturing due to their significant advantages, including reduced weight, lower energy consumption, and lower cost (Pan et al., 2022). Before this, rigid plates became a common structure that applied in structural and mechanical systems in early engineering solutions. The rigid plates produce strength and stability for static and high-load application. But flexible structures become a choice because of the design that included weight consideration, dynamic interaction, complex or variable geometry that cannot be achieved by the rigid structures. A primary example is the use of thin-walled components in aircraft to minimize overall weight (Hadi et al., 2021; Zamri et al., 2022).

However, their high flexibility also makes them prone to significant vibrations from external disturbances. These vibrations lead to serious problems such as noise, fatigue, and performance decline, which compromise system reliability, precision, and lifespan (Zamri et al., 2022). Consequently, understanding their dynamic behavior has attracted substantial research attention. Due to the high vibration from the structure, vibration control systems have become an initiative to mitigate the unwanted vibration. There are two main methods that are classified as the vibration control systems which are passive vibration control (PVC) and active vibration control (AVC) (Tavakolpour et al., 2009). Passive control uses added materials like dampers and viscoelastic layers but is mainly effective at higher frequencies (Zamri et al., 2022).

In contrast, Active Vibration Control (AVC) is more suitable for flexible plates, as it generates a counteracting force to cancel vibrations, particularly effective at the low frequencies typical of these structures (Zamri et al., 2022). This approach increases damping and modifies dynamic behavior to reduce vibration amplitude, stress, and fatigue. Based on the previous studies, the ACV was introduced by Lueg in the early 1930s for noise cancellation and proposed the superposition theory where a secondary sound signal 180° out of phase to destroy the unwanted vibration source (Hadi et al., 2021). Hence, the active vibration control provides use of smart structure that can achieve the efficiency in the performance, cheaper, development in the data acquisition and the frequency value of the vibration sources can be altered the geometry or boundary conditions of the plate.

Nowadays, by connecting with modern technology, adaptive learning represents a fundamental connection between theoretical concepts with continuous improvement to meet up the practical implementation like Long Short-Term Memory (LSTM). LSTM networks are capable to provide a mechanism that allows system to remember temporal patterns, predict future states and produce more accurate results.

PROBLEM STATEMENT

The industrial applications of horizontal flexible plates have gained significant attention due to their versatile functionalities such as vibration absorption, flexibility, increasing effective stiffness without added material, and can be applied to complex dynamic analysis. The mode shapes of thin plates can be affected by the mass loading where the larger the mass of the transducers, the lower the natural frequencies (Abdullah et al., 2008). According to previous study, they found that horizontal plates produce a dynamic characteristic where gravitational forces interact with external loads and vibrations, especially the shape is thin and lightweight (Biglar & Mirdamadi, 2014). But thin plates tend to have lower stiffness which can gain problems such as bending and twisting when subjected to the vibration. For example, in robotics field, dynamic loads produce much higher stress than static loads, primarily due to resonant vibrations (Sugiantoro et al. 2025). Thus, control strategies are needed to avoid fatigue and failure in the vibration control system.

Despite the attractive attributes of horizontal flexible plates, conventional control approaches face some challenges, particularly in real-time application. This approach is applicable on linear parametric system models, which may not be suitable for the non-linear behaviors and unpredictable interactions with the complex system (Murad et al., 2024). Therefore, the non-parametric can be developed as the transfer function of the system to control the vibration because it can predict very small prediction error with suitable choice of the input data (Darus & Al-Khafaji, 2012).

Next, LSTM is one of the algorithms that are suitable for vibration control. Wahyu Ramadhani et al., (2024) analysed LSTM is as a part of integration from Recurrent Neural Network (RNN) that built up with internal memory and a multiplication gate. In this study, the LSTM is proposed because of its efficiency in recognizing and understanding pattern within the sequential data. LSTM is trained to adapt longer sequences compared to traditional RNNs especially when dealing with natural language processing (NLP), translation and speech recognition. It has a strong and reliable baseline for handling complex sequential data (Krichen & Mihoub, 2025). In this research, the absence of stability analysis for implementing the LSTM as a controller to control the vibration control at the same time, to figure out the capability of LSTM to be worked as a standalone controller by set up the experiment during the analysis process.

DEEP LEARNING

Deep learning (DL) is a powerful subset of machine learning (ML) and Artificial Intelligence (AI) represents a transformative technological paradigm within the Fourth Industrial Revolution (4IR), in altering methodologies for processing and interpreting the extensive datasets which are generated by Internet of Things (IoT) especially in the industrial field. Machine learning (ML) and deep learning (DL) have become popular in recent years. Kim & Cho (2018) claimed that deep learning is a promising solution for unpredictable situations of the real world. Providing a good initial state which helps implement and stabilize the training process for the specific tasks because of the extractor feature is embedded to the learning model. This deep learning also tends to make progress in critical areas such as computer vision (CV), natural language processing (NLP), and speech recognition (Shen et al., 2023).

Deep learning can utilize machine learning techniques based on artificial neural networks with many hidden layers for enhanced performance. It draws inspiration from the human nervous system and brain, employing multiple layers to process data hierarchically. It can organize processing units into input, hidden, output layers similar to how the brain processes information in the stages (Perumal et al., 2024). Therefore, the capacity of ML and DL to streamline complex mechanical analysis manages to reduce operational costs and improve maintenance strategies in the industrial settings. For example, the method for predicting the remaining useful life (RUL) of mechanical equipment according to a combination of convolutional neural networks and bidirectional LSTM networks (Liu et al. 2024). Thus, there are many benefits when this approach has been trained in order to improve the robustness and uncertainty of models, allowing them to generalize well even when facing huge datasets.

Furthermore, compared to the machine learning technique, it starts the process in sequential that involves pre-processing, feature extraction, meticulous feature selection, trained and classified. The effectiveness of machine learning is important to gain accurate results. Meanwhile, deep learning techniques to enable the training process can be taken from the raw data, combining feature extraction and classification into a single workflow (Perumal et al., 2024). Hence, the application of deep learning model to predict potential vibration of horizontal flexible plate to reduce the unwanted vibration effects.

NON-PARAMETRIC APPROACH

Machine learning (ML) can be classified into two types parametric or non-parametric. Parametric models operate based on a predefined mathematical structure with a fixed set of parameters that must be estimated from data before making a prediction. Meanwhile, non-parametric models are not relying by a fixed number of parameters which they can adapt the complexity directly from the data itself. The non-parametric approaches are capable to capture more complex patterns and relationships within the data, potentially leading to higher predictive accuracy.

Then, it also does not assume any specific model for the signal which makes them more flexible and less dependent on knowledge about signal's statistical properties like machine vibration analysis (Najafi & Hakim, 1992). Usually, this method effectively is implemented when dealing with data that is non-stationary, non-Gaussian or when measurements are scattered (Gautam & Singh, 2020). They can adapt to predict the data even though there are uncertainty, imprecision and partial truth within the data. According to Darus & Al-Khafaji (2012), they analysed that by using the non-parametric modeling the controller stops shaking within a minute. In this study, it is important to know beforehand which type is well-suited for particular vibration control. Due to unclear numerical interpretation or complexity of distribution in the active vibration, the non-parametric models become a conservative choice compared to the parametric models and the high capability to learn the system behavior directly from input to output data.

LONG SHORT-TERM MEMORY MODEL

Long Short -Term Memory (LSTM) networks are a specialized category of Recurrent Neural Networks (RNNs) designed to model sequential data by effectively capturing long-range dependencies. Usually, data collected across extended time periods can undergo filtering and dimensionality reduction through convolution operations integrated either into LSTM networks or directly within the LSTM cell architecture. The LSTM unit features a memory cell with three key gates which are input, forget and output gates, which control information flow using sigmoid and tanh activations. Having a gating mechanism enables the selection vital for modeling equipment degradation over time. Then, LSTM relates to Remaining Useful Life (RUL) prediction by leveraging its strength in modeling temporal degradation pattern from sensor data, as demonstrated in the previous study. (Kizito et al., 2021). The LSTMs were built up to overcome the vanishing gradient problem that exists in traditional RNNs which were created by Hochreiter and Schmidhuber in 1997. It is important because LSTM can produce a long sequence of data as gradients diminish exponentially over time which makes it difficult for standard networks to run (Krichen & Mihoub,2025). The LSTM's role in handling time series data and capturing long-term dependencies becomes perfect for the dynamic system like a vibrating plate.

In this study, the LSTM will be built up as a controller to mitigate the active vibration on the model like the horizontal plate. The pre-emptive action to produce more accurate results especially when managing complex, non-linear relationships with the data can be done by this model. It manages to predict vibrations induced by various forces and eliminating the remaining useful life (RUL) of the structure. The signals from the flexible plate will be analysed to facilitate proactive maintenance and control intervention. Thus, the integration of ML as the controller with the LSTM as the prediction model represents the active vibration control to enable safety, efficiency and adaptive operation of the horizontal flexible plate in the industrial application. The implementation system needs to prove that Long Short-Term Memory (LSTM) networks can effectively serve as self-learning controllers to reduce vibration in horizontal flexible plates. Instead of relying on complex physics-based models, the LSTM learns directly from vibration data over time. This allows it to handle real-world challenges like gravity effects and changing support conditions to control the vibration. At the same time, it can improve the safety, extends of life structures, and increase efficiency by vibration accurately and remove the unwanted motion successfully.

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