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Structural Damage Identification Using Machine Learning Techniques: A Critical Review

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Abstract: The importance of structural health monitoring has grown in response to the growing requirement for the safety and functionality of civil structures. Recent advances show that computational digital signal processing have enormous potential for developing more efficient, reliable, and robust structures damage identification systems. Artificial Neural Networks (ANNs) are computational models made up of many and highly interconnected processing elements that process information, establish complex, highly nonlinear relationships and associations from large datasets. The ability of the ANN is to train a given data set and predict missing data on that basis to makes an appealing proposition for knowledge acquisition for problems where there is currently not be acceptable theory. In the contemporary era of science and engineering, convolutional neural networks (CNN) and recurrent neural networks (RNN) are two of the most powerful tools. The present literature on the application and development of conventional neural networks (ANNs), convolutional neural networks (CNNs), and recurrent neural networks (RNNs) is important for structural health monitoring and damage detection is reviewed. Some significant issues with traditional damage identification systems can be solved, and damage detection accuracy can be enhanced, by using CNNs and RNNs.

Keywords: Structural health monitoring (SHM), Artificial Neural Networks (ANNs), Convolutional Neural Networks (CNNs)

1. Introduction

Natural and man-made risks can cause structural damage or even collapse in civil engineering structures. An unanticipated structural breakdown can be disastrous not just in terms of human lives and financial losses, but also in terms of the societal consequences. Artificial neural networks (ANNs), which replicate the human nervous system to learn in uncertain and inaccurate conditions, are highly useful for addressing inverse issues and have been utilised for structural damage detection with varying degrees of success in recent decades. Because of these features, ANN is a versatile and powerful machine learning technique for damage identification. In general, neural networks are well suited to scenarios in which a large amount of data is accessible but an explicit algorithm for processing it is

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difficult to define. Convolutional neural networks (CNNs) are notable for their pioneering results in a range of domains connected to pattern recognition throughout the last decade. The most advantageous element of CNNs is that they reduce the number of parameters in the ANN. Recurrent neural networks are good for learning sequential data or changing time series data. It's also feasible that RNN will do well in detecting catenary mooring line deterioration based on data from floating platforms

Damage to a structure is described as changes in geometric and material attributes that result in a loss of stiffness and stability, which has a detrimental impact on the structure's functionality. Damage detection can improve structure safety, lower maintenance costs, and increase serviceability. Damage identification at an early stage is critical for preventing structural system failures and collapses that are unexpected and catastrophic. Structural health monitoring (SHM) methods have been utilised in civil engineering to analyse the status of structures. a new generation of ANNs with deep structures is being studied to optimise the weights of hidden layers close to the input layer. Furthermore, CNNs differ from traditional neural networks in terms of signal transmission between neurons and layers. Signals are transmitted along the input and output channels in classic neural networks.

To review the available technical literature on the application and development of conventional artificial neural networks (ANNs), convolutional neural networks (CNNs), and recurrent neural networks (RNNs) to identify damage in civil structures. Damage identification and structural health monitoring of the structures by using artificial neural networks, deep convolutional neural networks and recurrent neural networks is presented. The neural networks model is a supervised learning model that applies sample data from a trained network model to achieve corresponding target values. Neural networks are made up of a multitude of interconnected neurons. ANNs, CNNs and RNNs can be used in structural damage detection and health monitoring. Many reasons why artificial intelligence is becoming more important, and it is better than traditional neural networks because weights of convolutional layer are used for feature extraction and the weights is full concreted layers are being use for classification and also to determine the training process.

2. Literature review on the application of ANNs for damage identification

One of the artificial intelligence methods, artificial neural networks (ANNs), has recently been introduced as an alternative technique for detecting damage in civil structures. When a neural network is properly trained, it is capable of detecting, locating, and quantifying structural damage in a short period of time, and it can also be used for real-time damage assessment. This chapter is to review the application and development of artificial neural networks to detect damage in civil engineering structures.

Zhao et al., (2019) proposed artificial neural networks arose and evolved from the concept of biological neural networks found in human brains. It is an attempt to stimulate the functioning of the human brain that has resulted in the emergence of artificial neural networks. The brain is made up of many highly connected elements known as neurons. These neurons are made up of three major parts. ANNs have received increasing attention to detect the damage in structures based on vibration modal parameters. The ability of artificial neural networks is to approximate continuous functions and pattern of classification which providing an efficient mechanism to detect the damage from modal parameters.

Shu et al., (2013) investigated the use of ANNs and vibrations in damage detection on a reduced railway bridge model. This study focuses on a damage detection system based on artificial neural networks (ANN) and statistical structural dynamics features as inputs. Sensitivity analysis is performed to determine whether changes in variances and covariances of structural dynamic responses can be used as input to artificial neural networks. A finite element model of a single span simply supported beam railway bridge was created in ABAQUS. This includes taking into account both single and multiple damage scenarios. A back propagation neural network was built and trained to detect damage, as shown in Figure below.

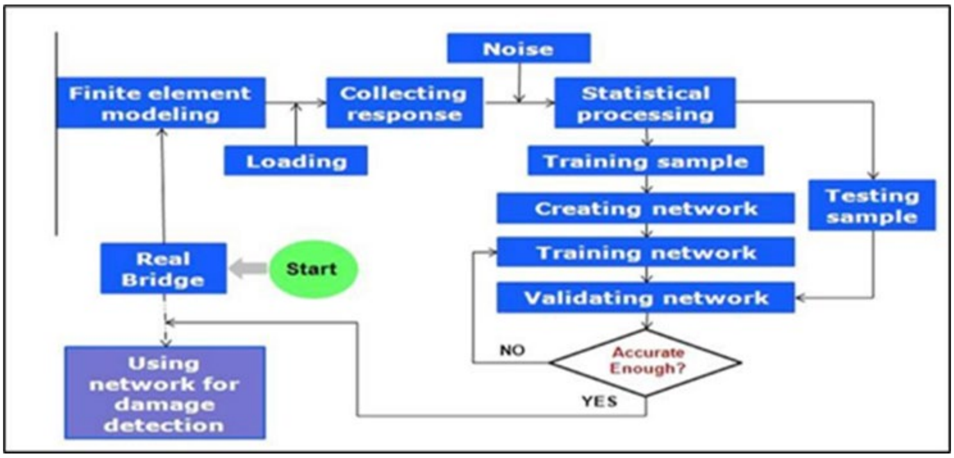

Figure 1: Flow chart of ANN for damage identification in bridge

Shu et al., (2013) reviewed damage assessment will be able to determine whether damage has occurred, where the damage is located, and provide an estimate of the degree of the damage. Artificial neural networks are one of the most common methods for handling inverse problems, and they may be used to map the inverse relationship between measured responses and structural factors of interest using data sets that have been trained and tested. Based on a review, it is clear that various studies using artificial neural networks and modal features of structures in the field of damage detection and structural monitoring have been conducted during the past decades.

3. Literature review on the application of CNNs for damage identification.

A deviation from the reference data in these parameters indicates that the structure may be damaged. Convolutional neural networks are neural networks that have one or more convolutional layers and are used for image processing, classification, segmentation, and other auto-correlated data. The application and development of convolutional neural networks to detect damage in civil structures is discussed in this chapter. During the previous few decades, it has also been used to construct damage diagnosis algorithms employing dynamic factors such as natural frequencies, mode shapes, damping ratio, and so on.

Sony et al., (2021) investigated Convolutional Neural Networks (CNNs) have lately become the most frequent type of deep learning technique due to their ability to learn directly from the raw signals in a large-scale dataset. This section shows how CNNs are utilised in civil structures to detect vibration-based structural concerns. CNNs are artificial neural networks with numerous layers that are supervised and feed forward (ANNs). CNNs integrate the feature extraction steps of classification and feature extraction into a single learning body. CNNs can learn to optimise features straight from the raw input during the training phase.

Study reviewed by Abdeljaber et al., (2018) shows that 1-D structural damage detection known as verification on a structural health monitoring benchmark data. Engineers from a range of fields are interested in structural damage detection. While existing damage detection systems use machine learning concepts, the majority of machine learning-based solutions extract "hand-crafted" characteristics that are fixed and manually picked ahead of time. Their effectiveness varies drastically among various data patterns, depending on the structure under inquiry. CNNs can combine and optimise two key sets of an assessment task into a single learning block during the training phase. Figure 2 shows that, even though 1D CNNs have recently achieved state-of-the-art performance in vibration-based structural damage detection, CNN training requires a large number of observations, especially in large structures.

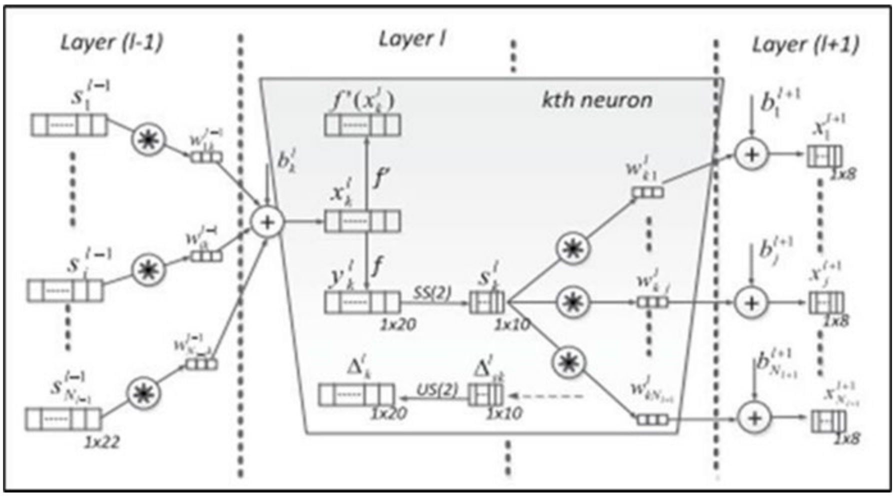

Figure 2: Layers of adaptive 1D CNN

This chapter examines how CNN-based SHM research by Abdeljaber et al., (2018) has progressed in recent years in order to address these issues using next- generation sensors such as cameras, drones, and robots, infrastructure owners may reliably and autonomously detect and localize many types of damage in various structures. This research also focuses on building real-time CNN algorithms, open-source civil structure databases, extending CNN techniques and decreasing classification imbalances that occur in large-scale infrastructure. Data from benchmark research is used to examine CNNs, which have been proved to be an effective vibration-based structural damage detection method in the authors' most recent work. This review also focuses on building real-time CNN algorithms, open- source civil structure databases, extending CNN techniques and decreasing classification imbalances that occur in large-scale infrastructure.

4. Literature review on the application of RNNs for damage identification.

The supervised learning principle is used in the Recurrent Neural Network (RNN), which is a deep learning model. Machine learning includes deep learning as a subset. It's also known as deep organized learning or hierarchical learning. RNNs usually use the output of the previous element's element-level model in the sequence. Intuitively, each element-level model should capture past contextual information from the sequence and use the current element to provide an output that may be used as context for the next element in the sequence. Recurrent networks can process examples one at a time while maintaining a recurrent element. RNNs were created expressly to suit these requirements. The overall predictive model of an RNN is made up of element-level models that are connected.

Lee et al., (2021) addressed RNNs employ the backpropagation through time (BPTT) method, which differs from regular backpropagation in that it is designed specifically for sequence data. RNNs typically run into two problems which is expanding gradients and vanishing gradients. These are defined by the size of the gradient, loss of the function along the error curve. When the gradient becomes too small, it continues to diminish. Input units, output units, and hidden units are all present in RNNs, with the hidden unit performing most of the work. The way RNNs and feed-forward neural networks channel information gives them their names. A feed-forward neural network only transmits data in one way, from the input layer to the output layer via hidden layers.

A modal parameter identification method based on RNNs by Xu et al., (2004) presents RNN-based approach for identifying modal parameters in structure- unknown systems. There are two steps in the proposed method. The first phase is to employ off-line learning to build a RNN to map the structure-unknown system's complex nonlinear relationship between excitations and responses. The second stage is to suggest a method for employing trained neural networks to determine the system's modal parameters. The dynamic attributes of the structure are directly evaluated using the trained RNNs weighting matrices. The first stage is to build an RNN that maps the nonlinear relationship between excitations and responses using off-line training. The second stage is to suggest a method for employing trained neural networks to determine the system's modal parameters. Finally, an example is given to show how the suggested method may be used to find the modal parameters of a structure-down system. Figure 3. shows the proposed topology for RNNs

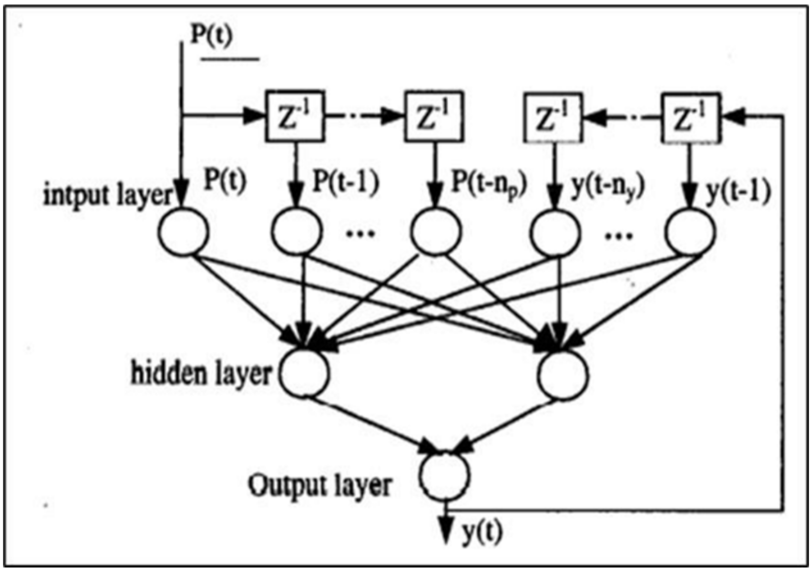

Figure 3: Topology of RNN

Xu et al., (2004) reviewed deep learning strategy for detecting damage, even small local damage, was proposed in this chapter. RNN was the platform behaviours data created through simulation that was utilized to train the deep learning models. For each scenario, the structure damage model was simulated, and response data and matching data were collected. The RNN- based damage detection model based on literature research was created using these data. Despite the absence of measurement and error in the test data, the RNN mode achieved a high level of accuracy. The RNN model had a very low measurement error level of accuracy.

5. Conclusion and recommendation

To generate the statistical ANN model and determine the structural condition, a health monitoring approach is applied. The results showed that, when compared to the ANN approach, the statistical ANN approach provides even more reliable structural damage diagnosis. CNN, one of the most significant advances in image recognition, was used to solve the problem of damage identification and localization. The CNN method can find abstract features and complex classifier boundaries that can distinguish between different problem features. The results reveal that the CNN architecture performs better in terms of accuracy training data set contains both noise-free and noisy data. A recurrent neural network-based approach for identifying modal parameters of structure damage detection systems is presented. RNN can efficiently map the damage location between the vibration system's responses and excitations. RNN technique makes it simple to diagnose damage in a structure-unknown system.

The use of ANNs to identify structural damage was examined in chapter two. The selected features were modelled using ANN based on operational parameters, and then linear regression was utilised to differentiate between the healthy and damaged states. There is no need for operational state setup because the method does not require prior data filtration. (CNN) was developed, which can discover abstract features that can discriminate between different aspects of interest. These feature maps are used to distinguish between damaged and healthy cases in analytic simulations. The structural damage was characterized using measured frequency response function data rather than modal data. RNN would be installed to monitor the structure using a neural network health monitoring technique, and a more extensive examination would be conducted to determine the severity of damage using the proposed technique.

The purpose of the literature review presented in this study is to show how ANN, CNN, and RNN can be used for structural health monitoring. The training and enhancement of deep neural networks techniques is still necessary. ANN, CNN, and RNN are important methods for identifying structural deterioration that are easily applied in real-world scenarios. CNN and RNN may be able to help solve the constraints of existing technology availability by incorporating a self-sensing actuator in the ANN. The study of these three neural networks is the first step in characterizing structural damage detection using a health monitoring technique. This method demonstrated numerous damage detection methods, including the use of sound frequencies and image categorization.

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