Detection of Failures in Civil Structures Using Artificial Neural Networks

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Abstract. This paper presents an approach to failure detection in civil structure using supervised learning of data under normal conditions. For supervised learning to work, we would typically need data of anomalous cases and normal conditions. However, in reality there is abundant of data under normal conditions, and little or none anomalous data. Anomalous data can be generated from simulation using finite element modeling (FEM). However, every structure needs a specific FEM, and simulation may not cover all damage scenarios. Thus, we propose supervised learning of normal strain data using artificial neural networks and make prediction of the strain at future time instances. Large prediction error indicates anomalies in the structure. We also explore learning of both temporal trends and relationship of nearby sensors. Most literature in anomalies detection makes use of either temporal information or relationship between sensors, and we show that it is advantageous to use both.

1 Introduction

Civil infrastructures are an important part of society and a country's economy. With the recent advances in sensing technology, the care taker of civil structures nowadays are able to obtain huge amounts of real-time data from numerous sensors, such as strain gauges installed on their structures. The structures are being monitored constantly by the sensors, at a high time-resolution of up to one reading every ten minutes. However, the abundance of data poses a problem. With the constant influx of this huge amount of real-time data, it becomes harder for humans to analyse make sense of. As the data gathered is complex, the use of simple threshold limits for triggering an alert is inaccurate. False alarms waste precious time and effort and increasingly degrade the users' confidence on the monitoring system [1].

This paper proposes the use of an artificial neural networks to detect alarm conditions in sensor data. To detect alarm condition that requires attention is equivalent to detecting anomalous behaviour of the structure. Anomalous structural behaviours manifest in anomalous sensor readings. The voluminous amount of sensor data provides much information that can be extracted. Using a machine learning approach, the problem would have been a binary classification

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problem of either anomalous or non-anomalous. However, to make the binary classification, we would need training data that belongs to each of the class. In reality, there are much lesser anomalous training data than non-anomalous. Furthermore, a lot of human effort is required to tag each training instance as either anomalous or non-anomalous. While it is possible to simulate the structure using finite element modeling to generate failure cases[2][3], a specific model has to be simulated for each civil structure and the simulation may not cover all damage cases. Having plenty of data under normal conditions, we propose an approach that predicts the normal behaviour. A reading is anomalous if it deviates significantly from the prediction.

In the next section, we will present the objective of structural health monitoring and an overview of state-of-the-art techniques in structural health monitoring. In the third section, we look at the usage of artificial neural networks for fault detection and diagnosis in various domains. In section four, we will introduce our method using artificial neural networks for structural health monitoring. Finally, we will present experimental results using our method on real world strain data with anomalous condition, to validate our system.

2 Structural Health Monitoring

Structural Health Monitoring (SHM) refers to the continuous monitoring of the structure's state properties, in order to identify anomalous structural behaviour. The monitoring at its simplest can be done by visual inspection of the structure or manual physical measurements of different parts of the structure. The current state-of-the-art includes monitoring via an array of strain or optics sensors continuously feeding data to a management system that will analyse the data and send alerts automatically to relevant personnel [4][5].

Anomalous structural behaviour may be due to construction events such as post-tensioning, concreting during construction, or random events such as heavy traffic, changes in weather, rainfall, etc. These are expected loads during the lifetime of a structure and will not affect the integrity of the structure. On the other hand, anomalies can also be caused by deterioration in the material [6] and damages resulting from ground movements due to nearby constructions. These are hazardous situations and the relevant personnel must be alerted as soon as possible.

Various techniques have been proposed to detect structural fault from sensor data. One approach is the discrete wavelet transform (DWT). DWT is applied on raw strain data to filter the signal into high and low frequency components. The coefficients in the highest frequency component of the transform are then used to identify abrupt changes in the strain values which indicate likely occurrence of anomalous events on the structure [7].

Artificial neural networks were used as pattern classifiers to detect structural damage in a few studies. In one study, the damaged patterns of a bridge were generated using simulation and the neural network was trained using the generated patterns. The neural network was able to detect the damage location