**46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA**

QNDE2019-1234

A STUDY OF ENVIRONMENTAL EFFECTS ON LONG TERM GUIDED WAVE STRUCTURAL HEALTH MONITORING IN OUTDOOR CONDITIONS

Sungwon Kim[1]
Daniel O. Adams
Department of Mechanical Engineering, University of Utah
Salt Lake, UT, USA

Joel B. Harley
Department of Electrical & Computer Engineering, University of Florida
Gainesville, FL, USA

ABSTRACT

There have been many investigations into structural health monitoring system performance for industrial deployment. However, extensive studies on long-term environmental effects, their effects on accurate damage detection, and the handling of large data sets have remained representative challenges. This paper discusses results from a long-term study of a guided wave structural monitoring system in outdoor conditions in Salt Lake City, Utah. We study the effects of environmental variations, compensation strategies on these variations, and how to handle the processing of such large data sets. We study correlation coefficients with baseline guided wave data and their relationship to environmental parameters. We study a data compression method based on random projections to efficiently manage and process the large guided wave data sets. The qualitatively analyzed environmental parameters and correlation coefficients confirm that temperature compensation is a key feature for accurate damage detection. The qualitative analysis of the random projection data compression suggests a promising method for working with a large wave data set.

Keywords: Structural health monitoring, guided waves, big data set.

1. INTRODUCTION

There has been many diverse research studies on structural health monitoring systems for mechanical and civil structures, such as pipelines [1] and bridges [2]. Applications of structural health monitoring systems have also expanded to wind turbines [3], nuclear power plants [7], and aerospace structures [4]. However, industrial deployment of structural health monitoring systems faces two common challenges, which prevent wide and efficient application.

One common and chronic challenge is compensation for environmental effects. Guided waves, which are commonly used in many structural health monitoring systems, are easily subjected to environmental changes, especially temperature and precipitation [5]. Considering that many structural health monitoring systems are exposed to the outdoors without protection, the effects of natural foreign objects, such as rain or accumulated snow, are not negligible factors for accurate damage detection. Compensation for these environmental effects is one of the critical techniques for successful implementation of a damage detection algorithm from laboratory research to field application [5].

The other challenge is efficient storage and processing of large data sets. Generally, most structural health monitoring systems are designed for long term operation and produce continuous data streams. Many advanced, robust damage detection algorithms use entire data sets to increase the accuracy of damage detection [6]. Over time, these data sets can grow to large proportions. In addition, the amount of data can be exponentially increased based on the number of sensors and measurement intervals. As a result, the study of an efficient method to store and process large data set while keeping important information for damage detection is necessary for long term operation of structural health monitoring systems.

This paper studies a structural health monitoring system setup in Salt Lake City, Utah. The system measures guided waves as well as four environmental parameters (temperature, humidity, air pressure, and illumination). We specifically study a long-term experiment over a one-year period. Correlation analyses were conducted to characterize the guided wave in the given environmental condition. To study the effects of environmental parameters, representative data sets under severe weather conditions were selected and analyzed. In order to investigate an efficient way for data compression, random projection methods were applied to the collected data set with different compression ratios. The computation time, storage efficiency, and damage detection accuracy with the compressed data were calculated to evaluate the effectiveness of the suggested method. Our results show that random projections does improve our storage and computational efficiency.

[1] Contact author: Sungwon.kim@utah.edu

The rest of this paper is composed of four sections. In section 2, two theoretical backgrounds for the correlation analysis and the random projection method are introduced. Section 3 deals with the experimental setup. Section 4 contains the results of the test to address the effects of environmental parameters and the efficiency of data compression. Section 5 describes the conclusion and future work.

2. THEORETICAL BACKGROUND

2.1 Correlation-based analysis

Correlation-based analyses are one of the fundamental algorithms that are used in structural health monitoring to track signal changes over time. The algorithm requires a baseline signal as a reference. The reference signal is compared with newly measured signals to calculate the correlation coefficient. The result shows how many discrepancies exist between the two signals. A rapid or sudden change in the correlation coefficient is often considered the result of an external event, such as damage or temperature changes. The correlation-based analysis is a straight-forward concept and relatively easy for application. However, the correlation coefficient is sensitive to variations in environmental and operational conditions.

2.2 Data compression using random projections

The greatest advantage of random projections as a compression method for wave signals is that random projections do not have inherent underlying assumptions regarding the data's structure. This is an important property that can prevent or minimize the weakening of damage signatures after the compression process because the most damage signatures are weakly represented in the data. The compression process is based on the study of the Johnson-Lindenstrauss lemma [7].

3. EXPERIMENTAL METHOD

A 3 cm by 53 cm aluminum plate with circular 8 mm diameter PZT (lead zirconate titanate) transducers were used for structural health monitoring. The plate was left outdoors for over one year while being exposed to natural weather conditions, such as rain, sun, snow, and ice. Continuous data acquisition, with the exception of downtime for maintenance, was conducted with the data acquisition system. Each measurement consisted of several guided wave signals being transmitted between transmitters and receivers on the plate. New measurements were recorded approximately every 9 seconds. Six PZT sensors were used to transmit and receive guided signals. Figure 1 illustrates the approximate locations of the sensors and a map of signal transmission. As denoted in Figure 1, sensors 1-4 were configured as signal receivers and sensors 5 and 6 were configured as transmitters. In addition to collecting guided wave data, four environmental sensors were installed and measured environmental parameters: temperature, humidity, air pressure, and brightness.

Table 1 lists detailed information about the system. These parameters were measured with sensors connected to a separate data acquisition board. All environmental sensors were within 50 cm but were not in direct contact with the aluminum panel.

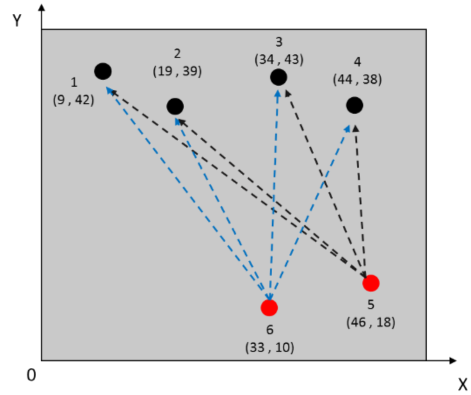

FIGURE 1: THE EXPERIMENTAL SETUP AND THE APPROXIMATE LOCATIONS OF SENSORS FROM ORIGIN (X cm, Y cm).

TABLE 1 INFORMATION OF ENVIRONMENTAL SENSORS AND DAQ SYSTEM

Component	Item number	Purchased From	Unit Needed
DAQ collecting ultrasonic data	DAQ (USB-1208HS-4AO)	Measurement Computing	1
DAQ collecting environmental condition	DAQ (USB-201)	Measurement Computing	1
Thermocouple	HEL – 776	Honeywell	1
Humidity Sensor	HM1500LF	TE Connectivity	1
Ultrasonic Transducer	SMD07T02R412WL	STEMINC	8

4. RESULTS AND DISCUSSION

4.1 Environmental variation

While temperature changes have been the most commonly studied environmental parameters, we also study the effects of accumulated rain and snow. Figure 2 show pictures were taken under such severe weather conditions. Figure 3 shows the correlation coefficients between the mild weather and severe weather conditions. The baseline signal was taken under good weather conditions. Figure 3 is divided into two periods. Period one is in clear conditions. Period two has severe weather conditions (rain and snow). Periodical fluctuations in the correlation coefficient curve, which are caused by temperature variation, can be observed in period 1. However, period two shows irregular behavior in the correlation curve. Meanwhile, low temperature and high humidity can be observed. This information represents that severe weather conditions have a large influence on the measures, as well as temperature variation.

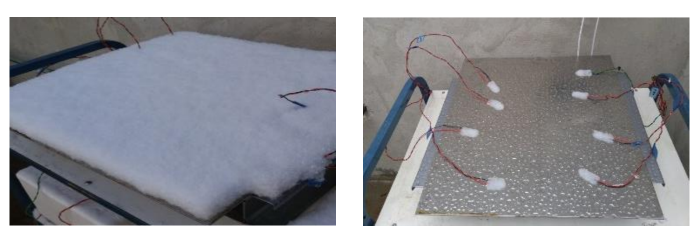

FIGURE 2: SEVERE WEATHER CONDITIONS DURING MEASUREMENT

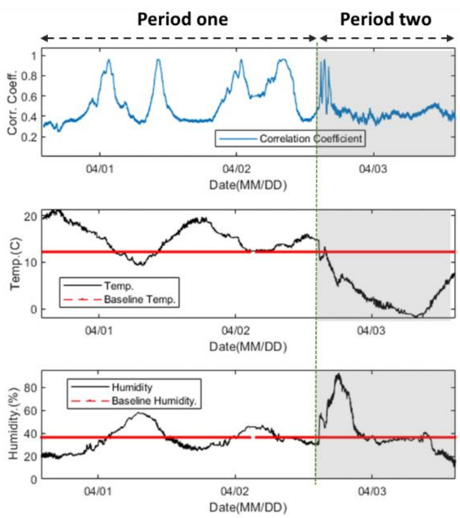

FIGURE 3: CORRELATION COEFFICIENT AND TWO ENVIRONMENTAL PARAMETERS (TEMPERATURE AND HUMIDITY).

4.2 Data compression using random projection

Data were compressed with three different compression ratios. Figure 4 shows the size of the data before and after compression. Figure 5 shows the correlation coefficient curves after compression. Generally, correlation coefficient curves are similar before and after compression. However, some noticeable differences can be observed when the correlation coefficient is below than 0.5. Thus further investigation is recommended to evaluate whether the compression process can keep damage features after compression or not.

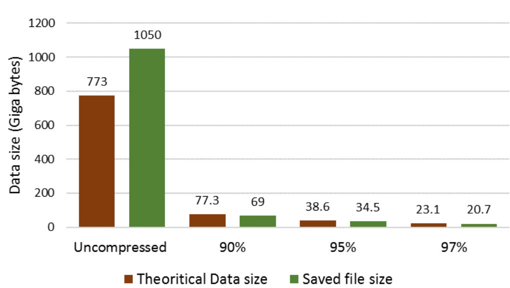

FIGURE 4: SIZE OF THE WAVE DATA OVER 120 DAYS

5. CONCLUSION

In this paper, the effects of environmental variation on guided wave and strategies for storing and processing large data sets were studied. The long-term goal is to help facilitate industrial deployment of structural health monitoring systems. A customized structural health monitoring system was used for the experiment. Through qualitative assessment of correlation coefficient curves and environmental information, practical behaviors of wave signals and potential issues for environmental effect compensation were discussed. Through random projection compression, an efficient storage management method is suggested. Two future efforts are recommended for this research. One is the development of wave signal compensation method using temperature and humidity information. The other is the application of random projections to the data set with a variety of damage conditions to validate that random projections can maintain the damage features in the data.

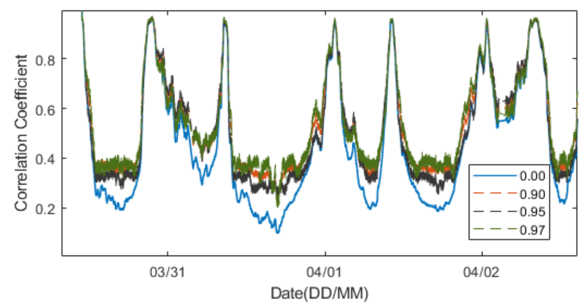

FIGURE 5: CORRELATION COEFFICIENT CURVES WITH DIFFERENT COMPRESSION RATIOS.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under grant no. CMMI-1562838.

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