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Neural Network Regression for Structural Health Monitoring Using Smartphones

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I. Introduction

Structural health monitoring (SHM) plays a vital role in ensuring the safety and durability of aerospace, mechanical, and civil engineering structures. SHM refers to the process of acquiring, validating, and analyzing technical data to aid in life cycle management decisions for a structure. It involves the development of a system capable of detecting changes in a structure caused by damage or deterioration during normal operation, as well as unexpected environmental conditions like earthquakes. A structure's behavior, such as its vibration response, can be influenced by a variety of factors, including sudden or gradual changes in its states, loading conditions, and response mechanisms

In this paper, we have developed a smartphone-based SHM platform that provides an alternative, easier-to-implement method at a lower cost compared to other existing approaches. We propose the utilization of an algorithm based on echo state neural networks, which models the damage in buildings using data obtained from smartphones placed in different parts of the structure. To validate our methodology, we have designed an experiment that employs a dedicated test station for testing the effectiveness of structural damage detection algorithms. Furthermore, we have conducted a comparative analysis of this methodology against classical methods.

II. Smartphone-Based Structural Health Monitoring

Smartphones are ideal for Structural Health Monitoring (SHM) due to their built-in sensors (such as accelerometers), advanced operating systems (like iOS and Android), affordability, and mobility for easy data collection. Communication is carried out through the TCP/IP protocol, with the client receiving command sequences from the host smartphone via a unique IP address. The smartphones and computer connect to the network through a WiFi router. Our SHM system is wireless and works locally. We use Android and IOS as our smartphone operating system because it is partly open source and has libraries that allow direct access to internal peripheral devices, like the accelerometer and gyroscope. Data from these devices is read via a sensor management service at regular intervals. Our proposed smartphone based SHM system is shwon in Fig.1. The smartphones used in our proposed SHM system have accelerometers capable of measuring linear acceleration along the X, Y, and Z axes. We use a computer with Windows 10 operating system to manage communication between all SHM components, store and analyze building data, and run the damage detection algorithm, see Fig.2.

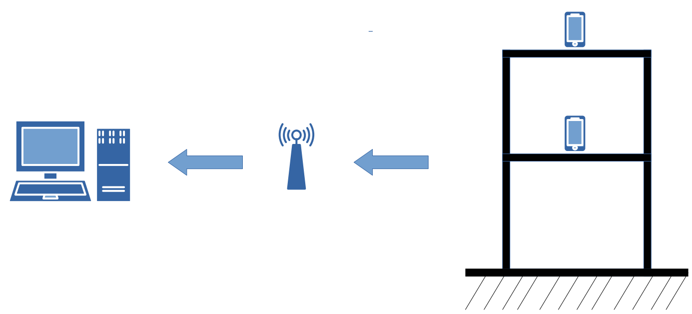


Fig. 1. Scheme of smartphone based SHM system.

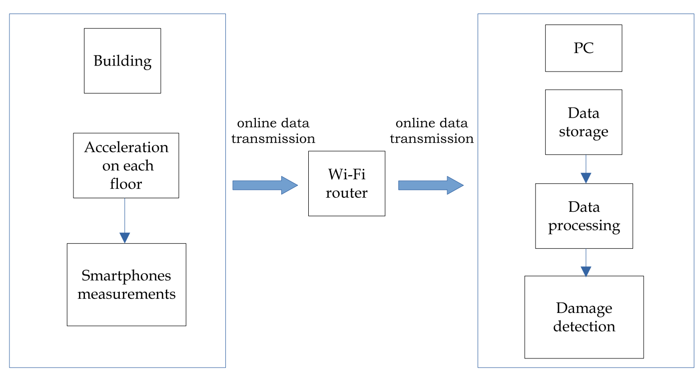


Fig. 2. The operation of the smartphone based SHM system.

III. Neural network regression for SHM

Prior to applying our approach to identify damage in the testing station, we must first process the data obtained from the smartphones by employing a signal reconstruction technique and a filter to mitigate any noise present in the measurements. Next, we will employ the ground-based data as the input to the network and utilize the damaged or undamaged data as the target for training. The output weights obtained from the training will subsequently be utilized for structural health monitoring as shown in Fig. 4.

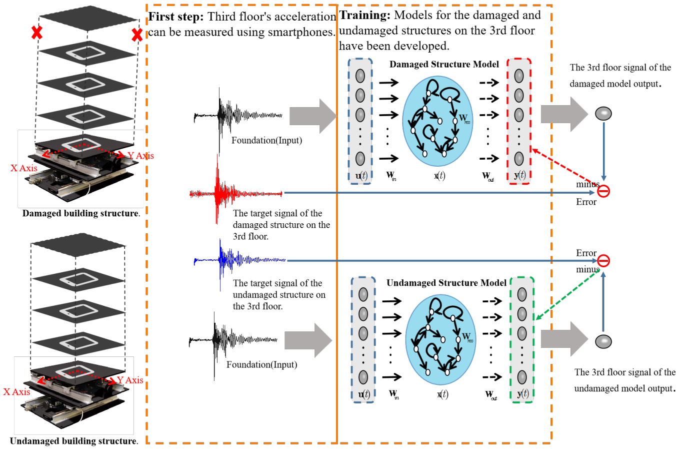


Fig. 3. Proposed smartphone based SHM simulation system.

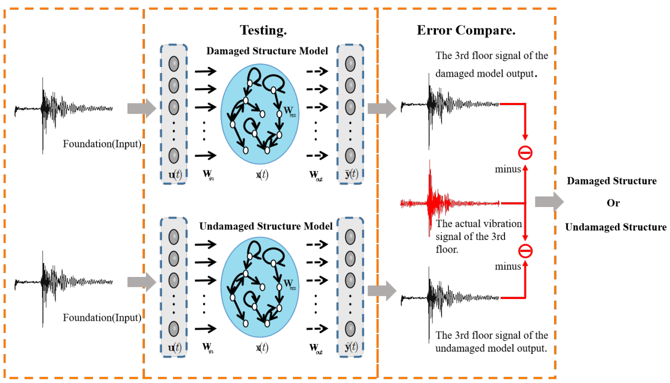


Fig. 4. Detection Phase of SHM System.

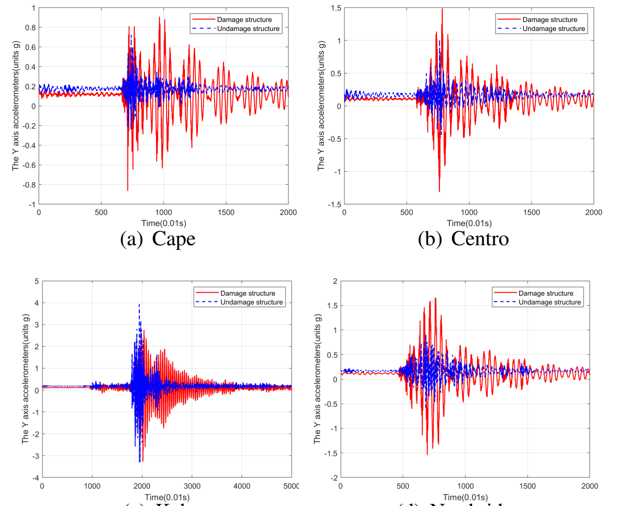
$$y(t) = Wx(t) \tag{1}$$

$$W = Y^{target} X^T (XX^T + \beta I)^{-1} \tag{2}$$

IV. Experimental Results

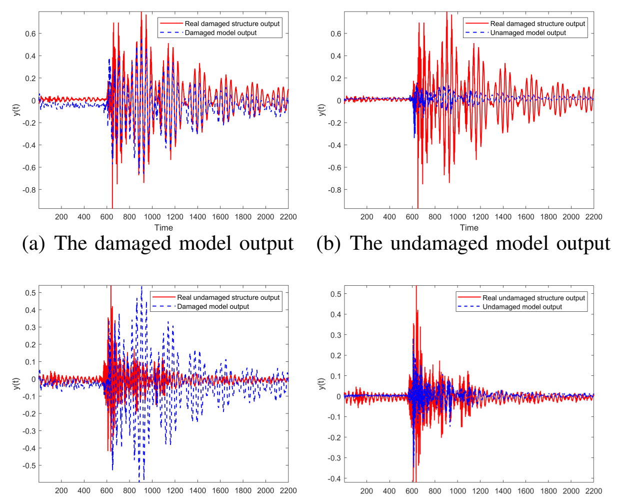
V. Conclusion

An SHM system based on smartphones was proposed in this paper, taking advantage of their mobility and ability to communicate through WiFi networks. The system utilized sensors within the phones to measure linear acceleration on each floor of a building, which was then analyzed and processed using a neural network for damage detection. The use of smartphones and NN allows this methodology to be applied to larger structures with multiple floors and other physical structures, due to their communication processes and data processing capabilities.



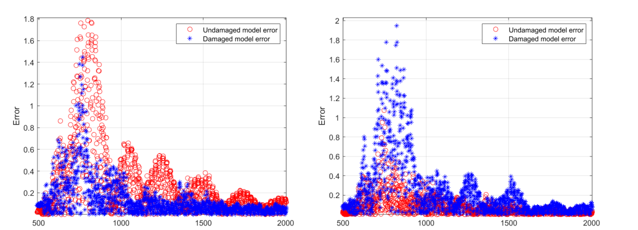
(a) Cape (b) Centro (c) Kobe (d) Northridge

Fig. 5. Comparison of acceleration data along the Y-axis for both undamaged and damaged structures during four types of earthquake simulations.



(a) The damaged model output (b) The undamaged model output (c) The damaged model output (d) The undamaged model output

Fig. 6. Detecting Structural Damage in Building Sensor Data with Robust Echo State Networks: Output Results for the Cape Earthquake.



(a) Damaged Structure (b) Undamaged Structure

Fig. 7. The errors corresponding to the damaged and undamaged structure models in the Northridge earthquake.