An economical approach of structural strength monitoring utilizing internet of things

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ABSTRACT

In the current environment, structural health monitoring (SHM), has become increasingly important. The cost of sensors and connectivity has significantly decreased, allowing for remote data gathering for critical analysis and structure monitoring. This allows for the assessment and improvement of the structures' residual lifespan. The internet of things (IoT) is a network of intelligent sensors that combines the identification and detection followed by sending the different structural responses to remote computers for further analysis i.e., processing and monitoring. In this work, an integrated IoT platform for damage detection is proposed which includes an Arduino, Wi-Fi module, and sensors. The sensors gather responses from the host structure which follows a precise mathematical model is introduced to determine and measure the structural damage in comparison to the reactions of the structural member that is in good health. To determine the degree of damage, the responses recorded from the damaged and healthy beams are analyzed using the cross-correlation (CC) damage index. Moreover, the analysis carried out reveals the CC values are uploaded to the cloud, where, if the CC value is over the threshold limit, a mobile warning message is delivered.

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1. INTRODUCTION

The internet of things (IoT) holds a vital role to progress and advance numerous applications in all the engineering fields in the last few years [1]. Several creative solutions are put forth to improve human existence, particularly in the domains of electronics, industrial machinery, and airplanes. One process where IoT has not yet been applied in real-time is structural health monitoring (SHM). The task of determining and measuring the harm is ongoing in SHM [2], [3]. The methods employed in SHM are evolving from visual inspection, non-destructive procedures and sensors employing data gathering methods, to sensors using the IoT devices because of its important role in damage assessment [4], [5]. As these techniques progress, there is less need for human intervention during SHM procedures. SHM is the process of identifying early signs of structural deterioration. By utilizing the aid of sensors and data-gathering tools, it is certainly possible to continuously monitor a structure to identify and calculate its remaining life. Sensors are the most accurate and sensitive devices used in health monitoring [6]. They are crucial in transmitting continuous data from the host structure and recording responses. To save this immense dataflow in a Wi-Fi module or in a cloud server, the IoT in SHM enters the scene [7], [8]. Without requiring human inspection of the structures, IoT also makes it possible to remotely monitor any kind of structure. Various mathematical models and signal-processing techniques are used to examine the responses. It can be observed from literature, ultrasonic waves are formed and recorded through the emitter and receiver. An alert is then transmitted to the server through the remote control installed in the service room [9], [10]. In case of any damage detection, the location and extent of damage on steel plates if found in the structural reinforcement is analyzed through analytical and experimental research. A percentage inaccuracy is estimated and a comparison is made between the two research findings. SHM to use a wireless sensor network to locate the damage. Bridge deterioration is detected using the "curvature difference probability waveform" and "mean normalized curvature difference of waveform energy" approaches [11], [12]. There are two main methods used for damage identification i.e., cross-correlation function amplitude (CCFA) and support vector machine (SVM). This is done in two steps: first, data received from the sensors is then curated using CCFA to analyze the host structure's dynamic responses; second, the data is passed to SVM to categorize the structural damage. Three distinct piezoelectric transducers were used in the studies to measure the sensitivity utilizing the electromechanical impedance technique. Every transducer has a different sensitivity depending on the frequency range [13], [14]. In addition to having a relatively high cost, the current wired monitoring system has higher bandwidth and high sensor data proportion, extremely high sensor synchronization, and often a small number of sensors which are connected in the identical network [15]. Conversely, the wireless monitoring system is inexpensive and has a large number of sensors that are compatible with one another, constrained bandwidth, low sensor data rates followed by crucial node synchronization [16], [17].

2. MATERIALS AND METHOD

The present work uses lead zirconate titanate (PZT) transducers and Arduino to measure the degree of mutilation on a smart aluminum beam. Analog to digital (A2D) and digital to analog (D2A) converter modules are utilized to facilitate communication between Arduino and PZT transducers. On an aluminum beam, two PZT transducers surfaces are attached; one serves as actuator followed by a sensor. By applying sinusoidal stimulation to the beam via an actuator pointing in the direction of the sensor, harmonic analysis is carried out. These responses are received by the PZT sensor, and they are examined using an Arduino-written mathematical code. After analysis, the data is uploaded to a cloud platform where graphs and alerts are stored and utilized to indicate when damage is above a predetermined threshold as depicted in Figure 1.

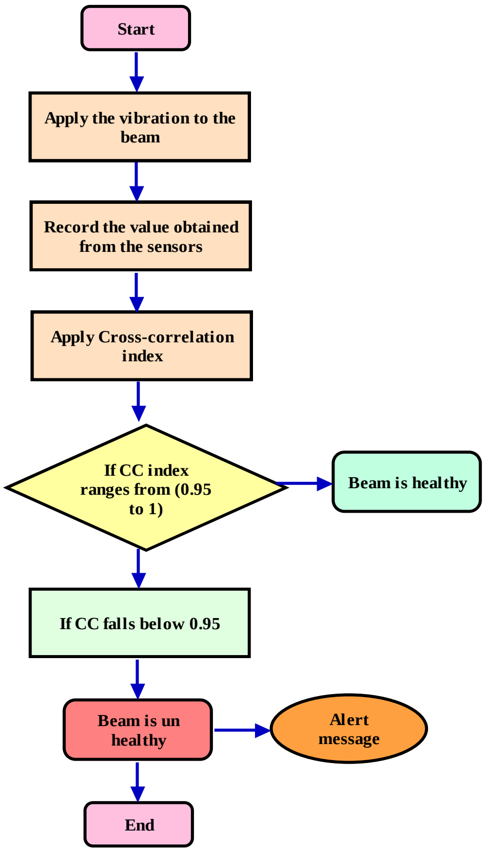

Figure 1. Flow chart of the system under study

The Arduino sends a sinusoidal wave to the actuator with the aid of the DAC. The wave is directed towards the sensor by the actuator, which also activates the host structure. The sensor records the reactions of the stimulated beam structure. To eliminate noise, a straightforward Butterworth low pass filter (LPF) is utilized to receive the signal. The cross-correlation (CC) index algorithm is used to process the filtered signals that are received and used for stimulation. An alarm note is provided to the mobile based application, so that the necessary actions will be taken to stop additional harm if the damage exceeds a threshold limit of less than 0.95. The Arduino, sensors, breadboard, jumper wires, A2D, and D2A are the apparatuses required for the experimental system. When soldering is not necessary, a breadboard is used for interim connections. Arduino and sensors are connected via jumper wires using DAC and ADC.

Analogue to digital conversion of the parameters is done by the vibration sensor. The sensors gather data for comparison and exchange data with the Arduino. There is a preset threshold value for every one of these parameters. The microprocessor periodically examines the sensor data to the threshold values. The information is given, if the comparison indicates that the sensor input values are higher than the threshold. The experimental system of the anticipated system [18] is presented in Figure 2.

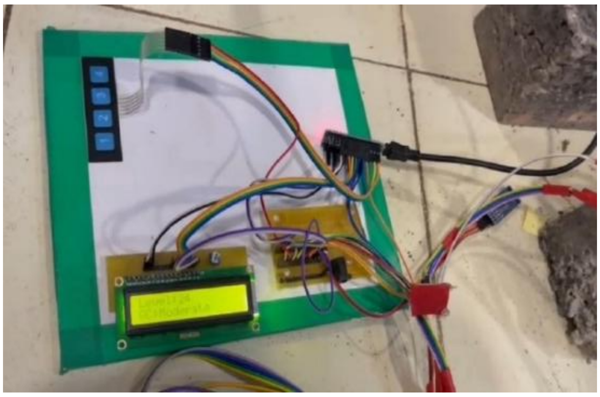

Figure 2. Experimental setup of the anticipated system [18]

In the first case, the vibration sensor input value is set to (0) and the threshold value is not reached, hence the virtual terminal displays “No Damage”. In the second case, the sensors exchange data with the Arduino and store information for further analysis. For each of these variables, there is a predefined threshold value. When the vibration sensor input value exceeds the threshold value relative to the typical value, the virtual terminal indicates damage detection and vibration has been detected. As a result, the specific outcome can be seen on the IoT platform, which gives the user precise information so they can take the appropriate step to repair the damage and prevent additional tragedy.

3. RESULTS AND DISCUSSION

The data, signs, or reactions that are gathered by the several sensors that are utilized to supervise the structures in order to identify the extent of damage. The root mean square deviation (RMSD), CC, and co-variance methods are the damage measures that are most frequently employed. CC is employed in the current work to identify and quantify the harm [19], [20]. A sinusoidal wave produced by the actuator excites the host edifice in the direction of the sensor. After the wave is detected, the sensor transmits it to Arduino. The proposed method is designed to evaluate the similarity between two signal indicators [21], [22]. The damage index that uses the CC value is defined as per (1):

$$CC = \frac{\left(\frac{1}{N}\right)\sum_{i=1}^{N}(E-\overline{E})(R_i-\overline{R})}{\sigma_E \sigma_R} \tag{1}$$

where signals are received by R and excited by E, respectively.

When the CC value of a structure is (1), the excitation and receiving signs are identical, the structure is considered healthy. The range of CC is 0 to 1. A 30-centimeter-long, 2.7 cm wide, and 0.1 cm thick smart aluminum plate with simple support is taken into consideration. Also, the actuator and sensor are mounted on a surface typically at 15 and 20 cm, respectively, from the left support, making the beam's effective length

30 cm. Henceforth, ADC and DAC are needed to alter signals from A2D and vice versa because the sensors can only send and collect the analog data. ADC is connected to the sensor, and DAC is connected to the actuator [23], [24]. An Arduino-driven application generates a 16 kHz sinusoidal wave that is delivered via DAC to the actuator and then to the sensor. The host structure is excited by this actuator, and the signal is detected by the sensor. To apply the filter and eliminate noise from the incoming signal, an algorithm is constructed [25]. A LPF with an order of five and a normalized cutoff frequency of 0.5 is employed. The received filtered signal and the excitation signal are subjected to a CC index. After applying the Butterworth filter, a healthy beam's CC value is 0.9813. Now, as the proportion between the actuator and the sensor increases, cracks are created. Due to the fact that certain signatures that encounter damage bounce back towards the actuator, while the mounted sensor detects the remaining signatures [26]. It is evident that the damage percentages rise sequentially, the number derived from CC are decreasing as shown in Figure 3.

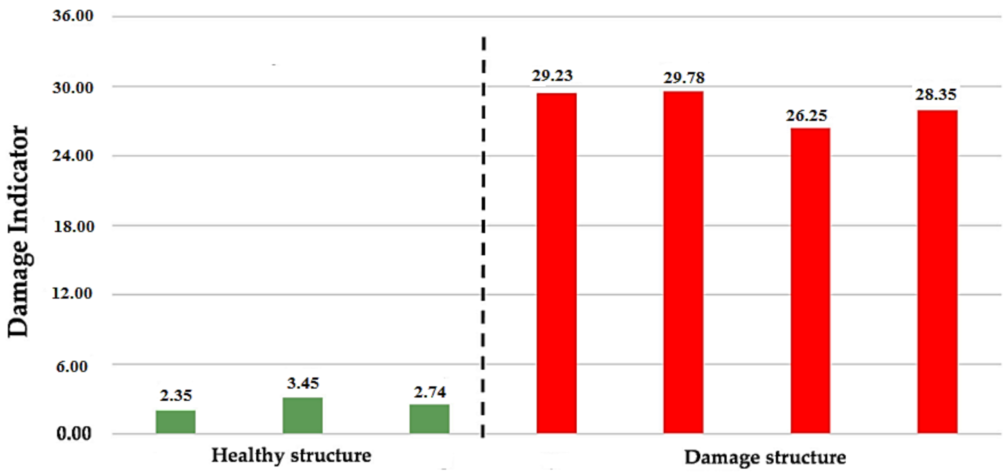

Figure 3. Damage indicator of two beams

4. CONCLUSION

SHM is the process of identifying early signs of structural deterioration. By utilizing the aid of sensors and data-gathering tools, it is certainly possible to continuously monitor a structure to identify and calculate its remaining life. Sensors are the most accurate and sensitive devices used in health monitoring. They are crucial in transmitting continuous data from the host structure and recording responses. IoT also makes it possible to remotely monitor any kind of structure without requiring any manual inspection or human intervention. This research work is carried out for structural based health monitoring scheme based on IoT device to find cracks or other deterioration in the beams. In addition, an Arduino-based system is suggested to determine the extent of damage. Following the application of filters, the incoming signal from the ADC is processed by the Arduino program to extract the CC index values. It is noted that the CC index, which ranges from (0 to +1), decreases as the proportion of damage breadth increases. A threshold limit is established and a mobile application is used to view the CC values. Moreover, every time the CC value drops below 0.5, the mobile application sounds an alarm which makes it a robust and economical tool to detect any abnormalities in the structure. The addressed problem in this work can be extended by adding few more complexities in the evaluation of the structural damage i.e., preliminary checks thorough technological advancements. Also, the monitoring part can be more accurate by conducting periodical checks at regular intervals to determine any potential threat to the structures.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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