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Structural Health Monitoring Of RCC Structures By Using Various Sensors

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Structural Health Monitoring (SHM) is a crucial aspect of maintaining the integrity and safety of civil infrastructure, such as buildings, bridges, and highways. In recent years, the Internet of Things (IoT) has emerged as a powerful technology for enhancing SHM by enabling real-time, remote monitoring of infrastructure health. The integration of Internet of Things (IoT) technologies in SHM has provided new opportunities forreal-time and continuous monitoring of structures. This paper presents a comprehensive review of the state-of-the-art in IoT-based SHM, including the underlying technologies, the various IoT sensors and systems used for monitoring, and the challenges and opportunities associated with this approach. The paper also discusses several case studies that highlight the benefits of IoT-based SHM and the potential for future research in this field.

Keywords—SHM, Acclerometer, Sensor, IoT

I. Introduction

Structural health monitoring (SHM) refers to the process of continuously monitoring the structural integrity and safety of civil infrastructure such as buildings, bridges, and highways. The main goal of SHM is to detect, diagnose, and predict the behavior of the infrastructure under various loading conditions, and to identify any potential defects or damage that may compromise its structural integrity and safety. The Internet of Things (IoT) is a technology that has the potential to significantly enhance SHM by providing real-time, remote monitoring of infrastructure health. IoT refers to a network of interconnected devices that can collect, transmit, and analyze data in real-time. IoT-enabled SHM systems use a variety of sensors to collect data on the structural health of infrastructure, and transmit that data to a central server for analysis and decision-making. IoT-based SHM systems offer several advantages over traditional SHM approaches, including real-time monitoring, remote accessibility, and the ability to collect and analyze large amounts of data. This paper provides a comprehensive review of the state-of-the-art in IoT-based SHM, including the underlying technologies, the various IoT sensors and systems used for monitoring, and the challenges and opportunities associated with this approach..

IoT-based SHM Technologies

IoT-based SHM systems typically consist of three main components: sensors, communication networks, and data analysis tools. The sensors used in IoT-based SHM systems are typically designed to measure specific parameters such as strain, displacement, temperature, and vibration. Wireless communication networks such as Wi-Fi, cellular, or satellite are used to transmit the data from the sensors to a central serverfor analysis. Finally, data analysis tools such as machine learning algorithms and data visualization software are used toprocess and interpret the data collected by the sensors.

A. *IoT Sensors for SHM*

A variety of sensors are used in IoT-based SHM systems, depending on the specific application and the parameters to be monitored. Some of the commonly used sensors for SHM include strain gauges, accelerometers, temperature sensors, displacement sensors, and pressure sensors. These sensors are typically embedded in the structure or attached to the surface of the structure using adhesives or mechanical fasteners.

B. *Challenges and Opportunities*

Despite the potential benefits of IoT-based SHM, there are several challenges associated with this approach. One of the main challenges is the need for reliable and secure communication networks to transmit the data from the sensors to the central server. Another challenge is the need for accurate and reliable sensors that can withstand harsh environmental conditions and provide accurate measurements over long periods of time. On the other hand, there are several opportunities associated with IoT-based SHM, including the ability to collect and analyze large amounts of data in real-time, the potential for predictive maintenance, and the ability to remotely monitor infrastructure health from anywhere in the world

C. Literature Review

Define abbreviations and acronyms the first time they are Several studies have been conducted to investigate the use of IoT technologies in SHM. These studies have focused on

various aspects of SHM, including data collection, communication, analysis, and visualization. For instance, researchers have developed wireless sensor networks that are capable of collecting data on structural behavior and transmitting it to a central server for analysis. Other studies have focused on the development of machine learningalgorithms that can analyze the collected data and predict the health of the structure.

D. Case Studies

- Several case studies have demonstrated the benefits of IoT-based SHM in various applications. For example, a study conducted by Wang et al. (2020) used an IoT-based SHM system to monitor the structural health of a bridge in China. The system consisted of fiber optic sensors and wireless communication networks to monitor the strain and temperature of the bridge in real-time. The system was able to detect and locate the occurrence of a large deformation in the bridge, which was caused by a truck accident, and allowed for timely repairs to be made to prevent further damage
- Another study by Li et al. (2020) used an IoT-based SHM system to monitor the structural health of a high-speed railway bridge in China. The system consisted of wireless sensors to monitor the vibration and strain of the bridge in real-time. The system was able to detect the occurrence of a crack in the bridge, which was caused by a lightning strike, and allowed for timely repairs to be made to prevent further damage..

E. Experimental Setup

The research station cannot lay out the model to the same scale as prototype but they have to adopt dimensional quantitative and dimensional scale. Large model are more expensive and take longer time to build. The research engineer has to use his judgment and decide on the size of model in consultation with the investigating engineer after considering all pros and cons and importance of bridge. Depth scale cannot be as linear scale, depth variation will be comparatively so small that can be easily measured and represented in the model same scale adopted. Hence smaller scale chosen. Here wetaking small scale of bridge structure. For that horizontal and vertical dimensions are taken differently according to convenience.

Figure-1 Setup for analysis

Figure-2 Bridge scaled model

F. Results of pilot experiment on 1:10 wooden model

To determine the value of time vs. acceleration and check the behavior of prepared mechanism, model is placed on vibration table. With fixity of model check the behavior of model at different frequency. With different frequency and different displacement with time vs acceleration graph is plotted. Setup on vibration table is showing in figure.

Figure-3 Model fixed on vibration table

Figure-4 Vibration table screen to set data

For study the bridge at 150 ft. Vanthli road, Junagadh named as Vanthli Over Bridge. It having 4 lane 1.3 km long with multiple spans of 25m prestressed concrete Box and I girder resting on 24 pillars. The bridge has two ends one is at west zone office and another is at raiya telephone exchange. Main aim of this bridge structure is to reduce the traffic at two main point of city Junagadh and Vanthli during peak hours. The size of each span that is column to column is 25m. In each span there is two pier having three I- beams with rubber bearings. On I-beams provided deck having proper drainage system. Even provision of anti-skid treatment is provided on the road of bridge.

Figure-5 Bridge at Vanthli

Figure-6 Layout of Bridge

This loading is to be normally adopted on all roads on which permanent bridges and culverts are constructed. Bridges designed for Class 70R Loading should be checked for Class A Loading also as under certain conditions, heavier stresses may occur under Class A Loading. This loading is to be normally adopted on all roads on which permanent bridges and culverts are constructed.

G. Designing Of Bridge In Software (SAP 2000)

SAP 200 is general civil engineering based software, it is useful for designing and analyzing any type of structural system. Two and three dimensions designing as well as complex or simple geometry can be solved in this. It simplify the engineering process. It allows Finite element process. It gives advance analysis option, all code provisions are provides so code based designs are easily implemented and give output reports so it is useful for any civil structure design and analysis. Bridge structure is designing in Finite element based software SAP 200 for analysis. To calculate the fundamental frequencies mode shapes are defined.

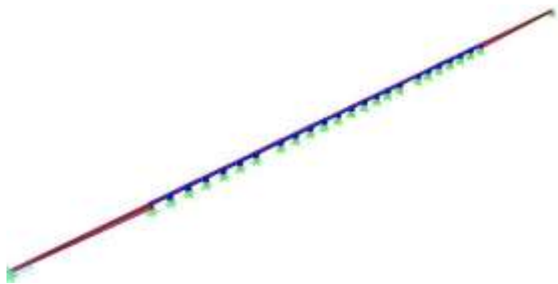


Figure-7 Bridge modelling in SAP 2000

H. Experimental Setup On Real Bridge Structure

To check the reliability of accelerometer and for vibration analysis sensor is fixed on Vanthli Bridge. When vehicles passed how sensor reacts and from acceleration data frequency of the bridge is analyzed. For that frequency vs. amplitude graph is plotted. During data collection vehicles are passing on bridge. Trucks, four wheelers, two wheelers and autos are continously passing. When vehicles are passing very small vibrations are observed. Three different spans are selected for data collection. One is mid span and another two spans selected when bridge started.

Figure-8 Sensor fixed on flyover

I. Results And Discussion

The results of ambient vibration of Vanthli Over Bridge which is multispan R.C.C Girder Bridge located on National Highvway Junagadh is presented. For this IOT based sensor system with wireless Wi-Fi module as described in ch.4 is used.
First of all the pilot experiment for IOT system connected with wireless sensors is tested on the 1:10 wooden model of Vanthli Over Bridge and ambient vibration of the real structure is presented as below,

Results of pilot experiment on 1:10 wooden model

The Wooden model is fixed on shaking table, Shown in figure-3. To collect data in X, Y and Z direction and fro that graphical representation is shown in this section. From different data comparisons of data is shown here.

Figure-9 Directions related to reading

Vibration based analysis with help of accelerometer mpu 6050 and Arduino 1.8.2 programming.Node mcu ESP 8266 Wi-Fi module is used to check response of accelerometer fixed on bridgestructure. Figure 3 shows that three collected data directions. Data collected in x, y and z directions as vertical, transverse and longitudinal directions. Accelerometer mpu 6050 and Wi-Fi module ESP 8266 is fixed to collect four different vibration. Acceleration data graph shows that at different frequencies variations in graph which shows that sensor reliability.

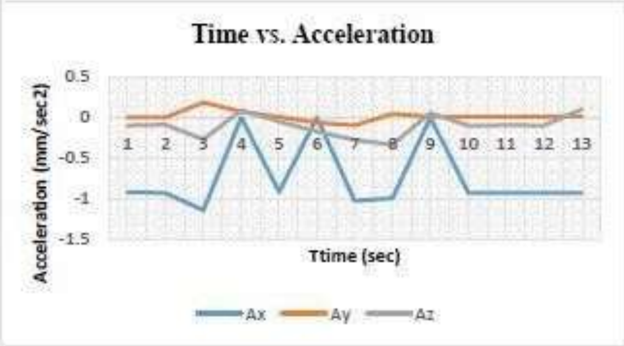


Figure-10 Time vs. acceleration

Dispalcement (mm)	Frequency (Hz)
10	10
-10	10
10	10
-10	10
10	10
-10	10
10	10
-10	10

Table-1 Vibration table first displacement mode

From Figure 4 first result taken with 10 mm displacement and 10 Hz frequency. As shown in table-1 continuous cycles generated with that data graph is plotted as shown in figure-10. Frequency and displacement is set to see the vibration effect due to vibrating table.

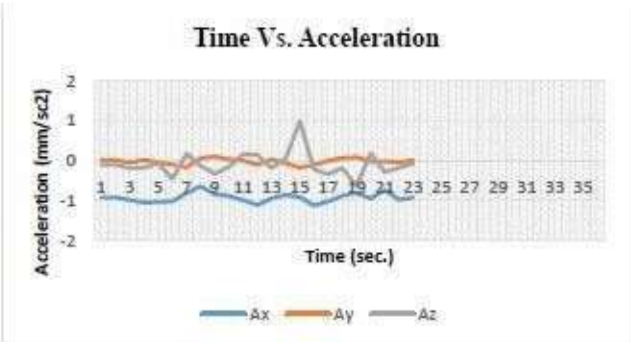


Figure-11 Time vs. acceleration

Dispalcement (mm)	Frequency (Hz)
25	25
-25	25
25	25
-25	25
25	25
-25	25
25	25
-25	25

Table-2 Vibration table second displacement mode

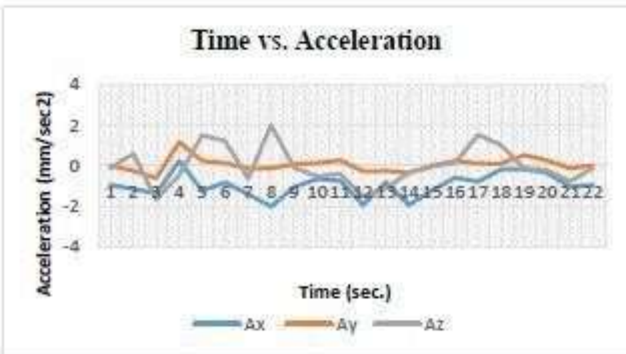
From Figure-11 first result taken with 25 mm displacement and 25 Hz frequency. As shown in table-2 continuous cycles generated with that data graph is plotted as shown in Figure-10.

Figure-12 Time vs. acceleration

Dispalcement (mm)	Frequency (Hz)
50	50
-50	50
50	50
-50	50
50	50
-50	50
50	50
-50	50

Table-3 Vibration table third displacement mode

From Figure-12 third result taken with 50 mm displacement and 50 Hz frequency. As shown in table-2 continuous cycles generated with that data graph is plotted as shown in figure-6.



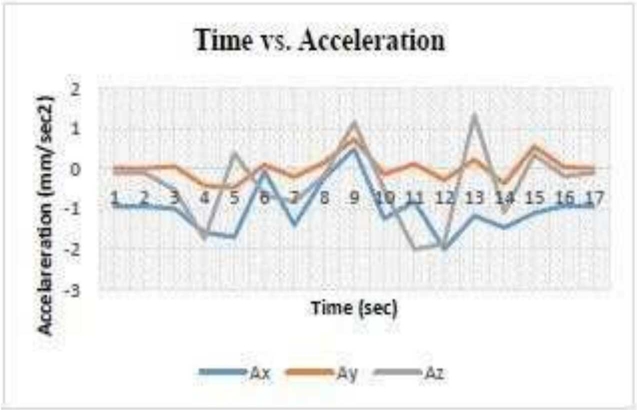


Figure-13 Time vs. acceleration

Dispalcement (mm)	Frequency (Hz)
10	50
-15	50
25	50
-25	50
10	50
-20	50
30	50
-25	50

Table 4 Vibration table fourth displacement mode

From Figure-13 forth result taken with different displacements with 50 Hz frequency. As shown in table-4 continuous cycles generated with that data graph is plotted as shown in figure-12.

From vibration table data Figure-8 is comparison of acceleration data at 10 Hz, 25 Hz and 50 Hz frequency in X direction and Y direction data is compared with each other. In X direction graph shows variation and in Y direction graph showing that there is not variation.

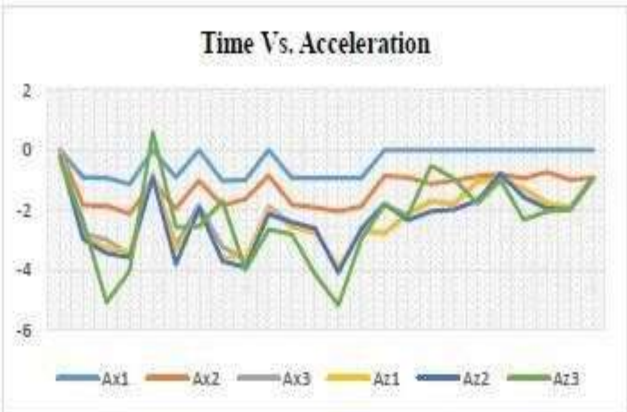


Figure 14 Time vs. acceleration Graph comparison with twodifferent frequency

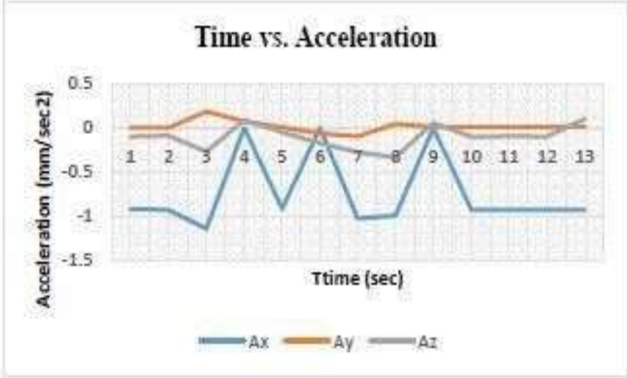


Figure 15 Time vs. acceleration Graph comparison with twodifferent frequency

From vibration table data Figure-9 is comparison of acceleration data at 10 Hz, 25 Hz and 50 Hz frequency in X direction and Z direction data is compared with each other. In X direction graph shows variation and in Z direction graph showing that there is no more variation. So from both comparison it shown that sensor is collected data in X direction only because shaking table moves in X directiononly. It not shows any variation in Y and Z direction, because there is no any variation in that two direction.

WIRELESS SYSTEM APPLIED ON REAL STRUCTURE

Vehicles passing continuously from bridge during data collection time. Due to different type of vehicles passed like two wheelers, four wheelers, heavily loaded truck and buses, measured data with accelerometer and Wi-Fi module ESP 8266 is shown in the above section and from that data FFT analysis is done graph plotted for the same.

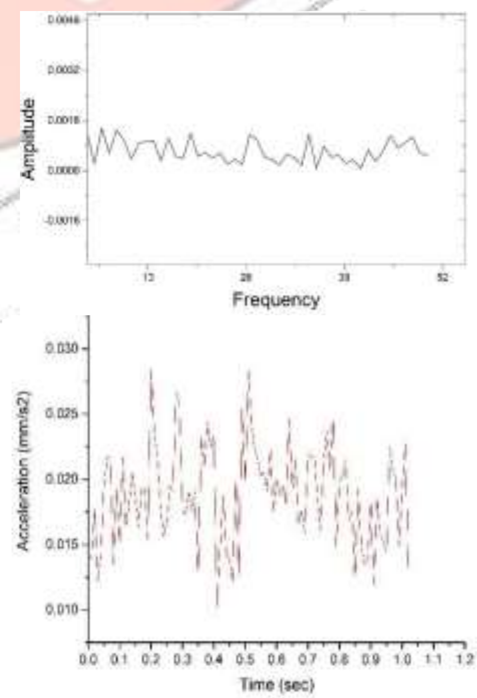


Figure 16

a) Time vs. acceleration b) Frequency vs. amplitude

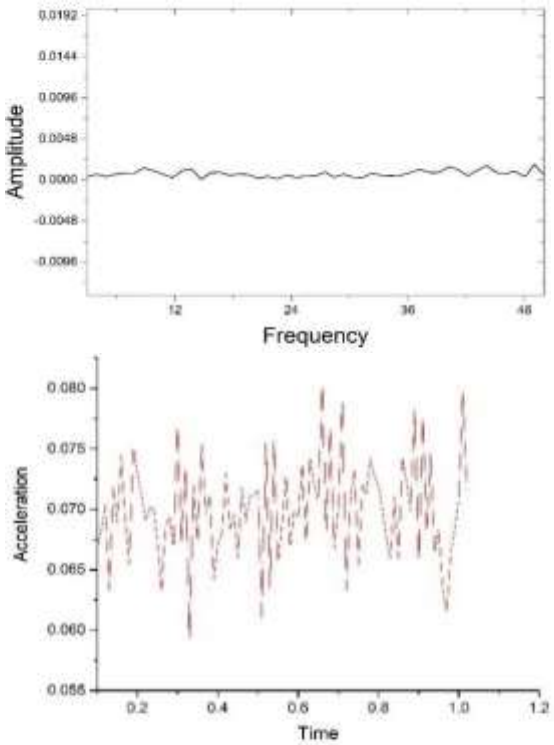


Figure 17
a) Time vs. acceleration b) Frequency vs. amplitude

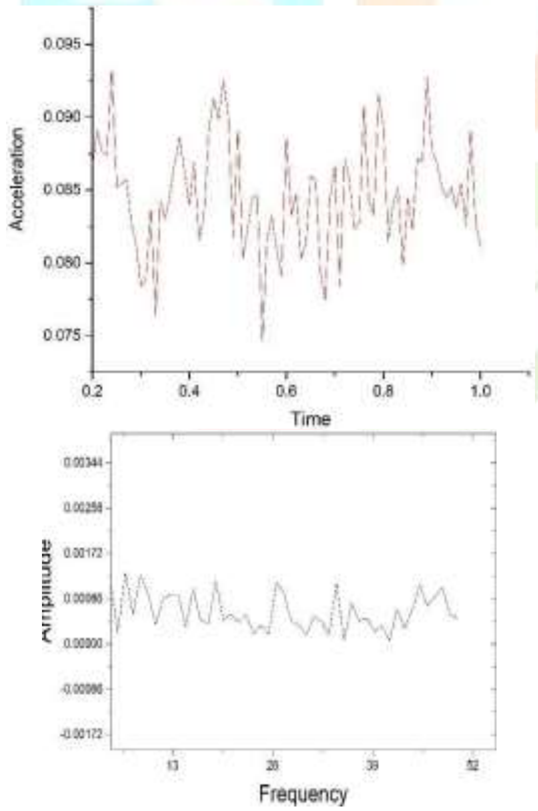


Figure 18
a) Time vs. acceleration b) Frequency vs. amplitude

After getting response on scaled model wireless system applied on real bridge structure. Three different spans are selected to check the variation as well as response of passed vehicles. After getting data FFT analysis is done and find the natural frequency for selected bridge structure. Compare experimental frequency with Finite element model frequency which shows that the finite element based frequency is 2.83886, 3.3111, 3.5208, and 3.64669 respectively with their mode shapes while it comparing with FFT analyzed data the highest frequency is up to 1.735. Which shows that with passing vehicles continuously it not give adverse effect to bridge structure. So heavy vehicular vibrations not affect bridge.

J. Conclusion

The integration of IoT technologies in SHM has provided several benefits, including real-time monitoring, reduced maintenance costs, and improved safety. However, there are still some challenges that need to be addressed. One of the main challenges is the development of reliable and accurate sensors that can collect data on various types of structures. Another challenge is the development of machine learningalgorithms that can accurately analyze the collected data and predict the health of the structure.

Physical laboratory model developed from actual structure data to check the response of accelerometer with cable system and wireless system. After validate response on vibration tabledata collected from actual bridge. Time vs. acceleration graph plotted and FFT analysis done to find frequency of bridge structure. That frequency is compared with mode shape frequencies which get from model analysis in SAP 2000.

From this study it concluded that with the help of IOT application and wireless sensing technology it is easy to monitoring the health of structure. There is wide range ofsensor available and many Wi-Fi modules are available

- It is demonstrated through pilot study of 1:10 wooden model tested on shake table that if the bridge is subjected to resonance than IOT based system designed here gives early warning alarm.
- For ambient vibration as well as vibration induced due to high frequency earthquake or wind load can be detected by accelerometer mpu 6050.
- Arduino 1.8.2 is convenient to operate because of very simple system based on computer languages. Programming in Arduino 1.8.2 is easy and any program can be set and run.
- Wireless monitoring of bridge structure is demonstrated and validated through software and pilot study in the laboratory.

In conclusion, the use of IoT technologies in SHM is a promising area of research that has the potential to revolutionize the way we monitor and maintain structures.However, further research is needed to overcome the current challenges and develop reliable and accurate systems for SHM.

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