INTERNET OF THINGS (IOT) BASED AMBIENT VIBRATION MEASUREMENT OF STRUCTURE

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Abstract— Major structures like buildings, dams, bridges are subjected to serious loading and their performance is likely to alter with time. It is subsequently essential to check the performance of a structure through continuous monitoring. Structure Health Monitoring (SHM) is a process in which certain methodologies are executed for determining the presence, location and severity of damages and the remaining life of structure after the occurrence of damage. This research focuses on realization of an ambient vibration loading based SHM framework employing smart sensors and Internet of Things (IoT) to detect damage on time. In general terms, damage can be defined as changes introduced into a system that adversely affect the current or future performance of that system by smart sensor and computer programs.

Keywords— **Structure Health Monitoring, Internet of things (Arduino & Packetsender), Accelerometer sensor, Recording & analysis of ambient vibration.**

I. INTRODUCTION

Considering to quality of structures that diminishes due to persistent loading and effect of environment, early discovery of damage is extraordinary concern for civil structures. In case not recognized in time, damage may have serious results for security of inhabitants. There are a few common occasions which may influence the quality of structure. It should be ensured that the structure is secure after such characteristic events. It may conceivable that a modern developed structure may not be performing well with respect to design parameters, either due to inferior fabric or defective construction. This all could be guaranteed by appropriate health monitoring of structure. [32]

The SHM process includes the observation of a framework over time utilizing intermittently, inspected dynamic reaction estimations from an array of sensors, the extraction of damage-sensitive highlights from these estimations, and the statistical investigation of these highlights to decide the current state of framework health. Particularly so when damages to structures are concerned, it is important to note that there are stages of expanding difficulty that require the knowledge of previous stages, specifically:

1. Detecting the presence of the damage on the structure (Sensors cannot measure damage. Feature extraction through flag processing and statistical classification is essential to convert sensor information into damage information)
2. Locating the damage
3. Identifying the types of damage
4. Quantifying the severity of the damage

On the other hand, IoT could be a recent communication worldview that envisions in a near future, in which the objects of daily life will be prepared with microcontrollers, handsets for computerized communication, and reasonable convention stacks that will make them able to communicate with one another and with the users, getting to be an indispensably portion of the Internet.

The reality is that the IoT permits for all intents and purposes unending openings and associations to take place, numerous of which we can't indeed think of or completely understand the effect nowadays. It's not difficult to see how and why the IoT is such a hot subject nowadays; it certainly opens the entryway to a lot of opportunities but also to many challenges. Security could be a huge issue that's oftentimes brought up. Mechanical devices of all sorts are getting to be more common in our everyday lives: smart devices are being incorporated in buildings, houses, cars and public framework such as streets and bridges. The modern devices provide us an unordinary degree of connectivity in our normal activities, for example when we employ our tablets or smart phones to check mail or browse the open network, but moreover in more inventive shapes of network, such as getting notifications specifically from our fridge or collecting data from our dress and shoes. This innovative transformation brings unused opportunities and challenges for users, businesses, and society.

This paper investigates such a context, where we start to co-exist and connected with a network of interconnected devices that's known as the IoT. Recently IoT has given a promising choice for SHM. In recent years, SHM issues have gotten expanding interface from numerous academic and building fields. One hot subject is to identify, locate and evaluate damages of structure so as to calculate its remaining life and predict upcoming accidents. In SHM, structural highlights which are extricated from intermittently dispersed estimation utilizing sensors are subject to variable environmental conditions.

So we are proposing a modern face of IoT, which has been considered as an unused generation of systems that combine ambient vibration loading of the structure which caused due to different sources, with information transmission and processing through wireless communication techniques or wireless sensor networks, give a better option for SHM. So that the upcoming accidents or disasters caused by structural problems (e.g. building collapse, damages) may be prevented. It is a process in which certain methodologies are executed for determining the presence, area and severity of damages and the remaining life of structure after the occurrence of damage in an IoT on ambient vibration loading of the structure.

Ambient vibrations are generally caused by external force applied either directly to the floor by people, machinery or indirectly by moving floor supports after transmission through the building structure or through the ground.
The principal sources of these vibration in buildings are:

- Human activity, e.g. walking, dancing, jumping, etc.
- Vibrating machinery
- External forces, e.g. traffic at ground level or underground, or wind buffeting.

For moving towards to the projects of smart cities, such framework will be the part of smart structures that can sense the ambient vibrations loading by sensors. Damage in structure cannot be measure by Sensors, but flag processing and statistical classification is essential to convert sensor information into damage information. Many sensors will be attached in buildings to acquire information containing ambient vibration loading states of the structures. After information collection, transmission, processing and analysing which will be done as coding in computer program Arduino, its sending to users mobile or computer device through internet and Pocketsender. User would be able to interpret the information immediately which was not available earlier or was too late to reply, and structural issues such as building cracks and mechanical breakdown can be successfully identified or predicted, or the analysed data can be checked by the program in same structure.

The essential objective of this investigate work is to consider the method for monitoring of structure failure with help of internet of things. The particular objectives were:

- To evolve a modern integrated technique to record data of ambient vibration Loading of structure with Accelerometer sensor and Arduino program
- To develop a low cost technique of SHM with Collecting the recorded data, analysis and monitor by Pocketsender and send to anywhere.

II. Materials and Programs

Materials which we are using in this research are:

1. Accelerometer Range ±8g, Accuracy ±0.01g (REES52 GY-521 Mpu6050 Module+3 Accelerometer for Arduino) in Fig.1.
2. ESP8266 Nodemcu Board (WiFi) (OLatus Ol-Nodemcu-Cp2021 Wireless Module Nodemcu WiFi Internet of Things Development Board Based Esp8266) in Fig.2.
3. 500mAh Li-ion Battery (Invento 3.7V 500mAh Rechargeable Lo-ion battery) in Fig.3.

Fig. 1 Accelerometer Sensor

Fig. 2 Nodemcu Board

Fig. 3 Li-ion Batter

Computer Programs for coding, analysing, transferring and monitoring of data are:
1. Arduino
2. Pocketsender

III. Methodology and Experimental

Scope of this research work includes three layers which is perception layer, network layer and application layer.
- Perception layer (identify the object and sensor, and collect information through sensor, etc)
- Network layer (make accurate transmission and processing of information obtained in the perception layer through the network, etc)
- Application layer (analyze and process massive data and information through cloud computing, etc)

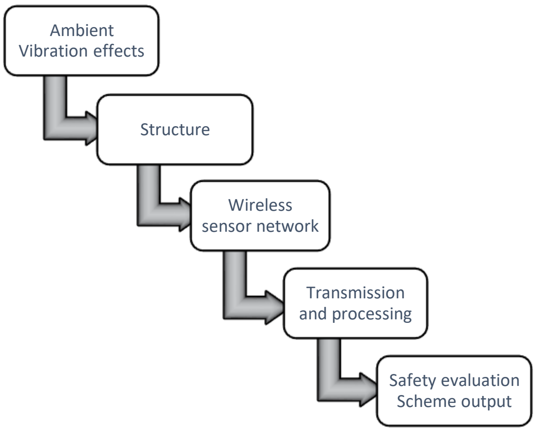


Fig. 4 The workflow of internet of things (IoT) based ambient vibration measurement of structure

In this paper, Information about the inspections carried out is collected Through sensors. so after applying sensors at critical locations of the structure, the analyses and process of the data will be done by the IoT programming application. With this information it is possible to evaluate damage and the conditions of the structures, in order to prioritize the financing for the repair and maintenance of the structure.

After sensor data collection, transmission, processing and analyzing, structural problems such as building damage, changes in structure, and mechanical breakdown can be successfully detected or predicted, so that the upcoming accidents or disasters caused by structural problems (e.g. structure collapse, mechanical accident) may be prevented. Furthermore, threshold values for alarm signals can be set to inform structure operators of critical events.

Experimental Validation Work

The main propose of this experimental is, finding deflection and calculating maximum stress in beam before failure by accelerometer sensor, Nodemcu, Arduino, and Pocketsender. The accelerometer sensor gives the angle of sloping beam and by the ARDUINO program we find the deflection and stress of beam due to ambient vibration and loads though coding program. Point to be noted (angle is in degree from sensor but Arduino program cannot accept degree value so the angle should be change to radiant R=Dπ/180).

By using Trigonometry method shown in Fig.5 we can easily find deflection and stress with some calculations:

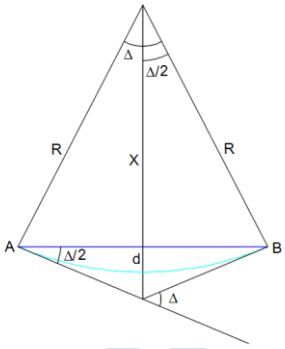


Fig. 5 Analyzing beam deflection by using Trigonometry method

Calculation of deflection (D) from combination of (a) and (b):

$$sin\left(\frac{\Delta}{2}\right) = \frac{L/2}{R} = \frac{L}{2R} \qquad cos\left(\frac{\Delta}{2}\right) = \frac{X}{R}$$

$$R = \frac{L}{2\,sin\left(\frac{\Delta}{2}\right)} \qquad \ldots (a) \qquad X = cos\left(\frac{\Delta}{2}\right)R \qquad \ldots (b)$$

$$D = R - X = R - cos\left(\frac{\Delta}{2}\right)R = R\left(1 - cos\left(\frac{\Delta}{2}\right)\right)$$

$$D = \frac{L}{2\,sin\left(\frac{\Delta}{2}\right)}\left(1 - cos\left(\frac{\Delta}{2}\right)\right) \qquad \ldots 1$$

There are different loads acting on beam as point load, UDL load, rectangular load and so on. As we are calculation ambient vibration load which is usually as UDL load, so base on this experimental, we are going for a simply supported rectangular beam with UDL load:

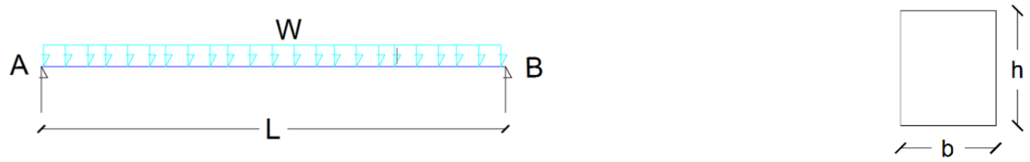


Fig. 6 Simply supported rectangular beam with UDL loading

$$Deflection\ (D) = \frac{5\,W\,L^4}{384\,E\,I} \qquad \ldots (c)$$

So based on this formula (c) (W) load which act on beam is unknown (d), (E) Elastic of modules which is different for all material of structure based on IS-456.

$$I = \frac{b\,h^3}{12}$$

$$\mathrm{W} = \frac{384\,E\,I\,D}{5L^4} = \frac{384\,E\,b\,h^3 D}{60\,L^4}$$

$$Weight\ (W) = \frac{32\,E\,b\,h^3 D}{5\,L^4} \qquad \ldots (d)$$

Stress in beam after calculation and comparing with maximum stress capacity in code IS-456. Calculation of stress (δ):

$$Y = \frac{h}{2}$$

$$Z = \frac{I}{Y} = \frac{2\,b\,h^3}{12\,h}$$

$$Z = \frac{b\,h^2}{6} \qquad \ldots (e)$$

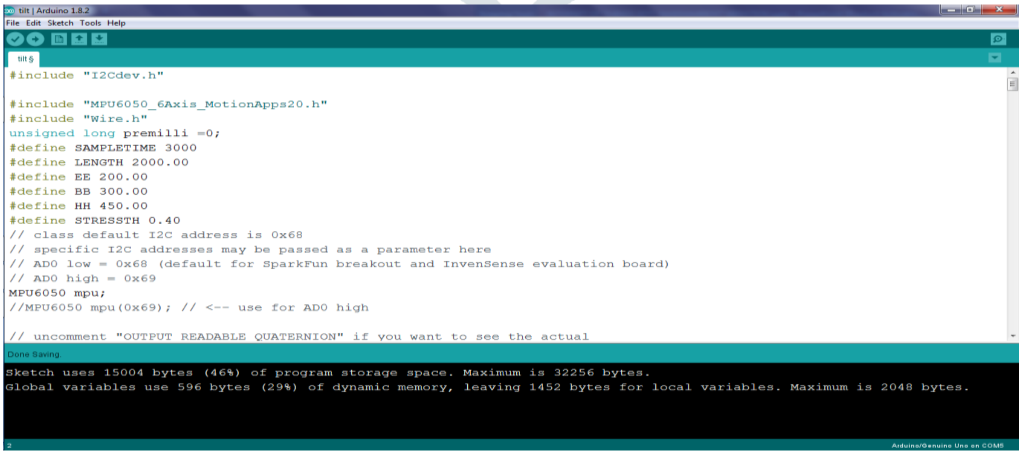
$$\mathrm{M} = \frac{W\,L^2}{8} = \frac{32\,\mathrm{E\,b\,h^3 D\,L^2}}{40\,\mathrm{L^4}}$$

$$Moment\ (M) = \frac{32\,\mathrm{E\,b\,h^3 D}}{40\,\mathrm{L^2}} \qquad \ldots (f)$$

$$\delta = \frac{\mathrm{M}}{\mathrm{Z}} = \frac{192\,\mathrm{E\,b\,h^3 D}}{40\,\mathrm{L^2\,b\,h^2}}$$

$$\delta = 4.8\,\frac{\mathrm{E\,h\,D}}{\mathrm{L^2}} \qquad \ldots 2$$

The final formulas (1 & 2) are set to Arduino program as coding to install in Nodemcu board, Arduino program which has two parts void setup and void loop. Setup is the preparation where it runs only once and is used to set pin mode or initialize serial communication, loop is the execution and it runs repeatedly in the program and consecutively, allowing the program to change, respond and control the Arduino boards. Both functions are required for the program to work as shown in Fig. 7:

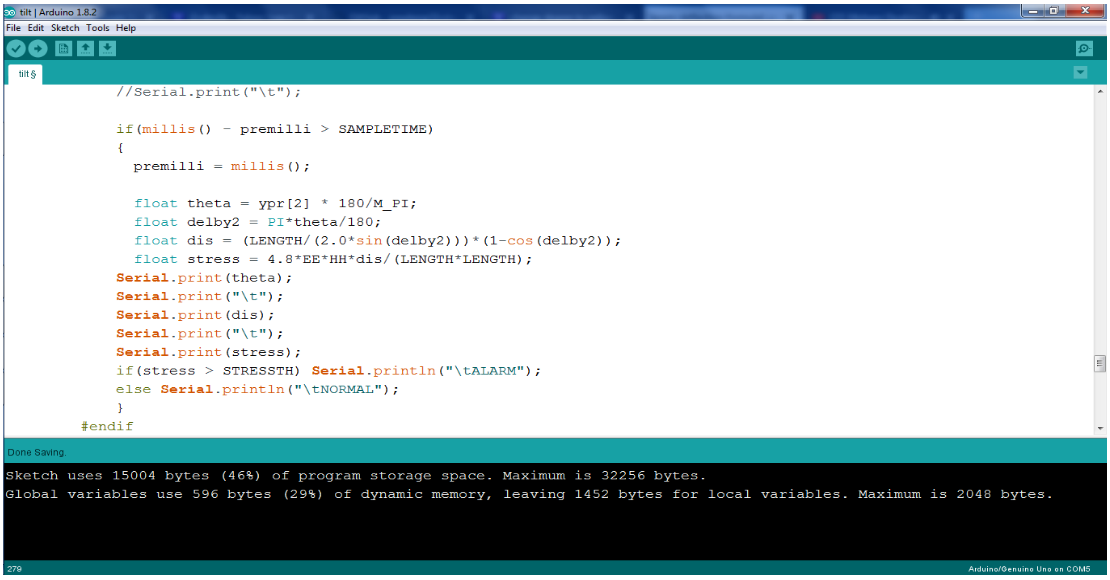


```
#include "I2Cdev.h"

#include "MPU6050_6Axis_MotionApps20.h"
#include "Wire.h"
unsigned long premilli =0;
#define SAMPLETIME 3000
#define LENGTH 2000.00
#define EE 200.00
#define BB 300.00
#define HH 450.00
#define STRESSTH 0.40
// class default I2C address is 0x68
// specific I2C addresses may be passed as a parameter here
// AD0 low = 0x68 (default for SparkFun breakout and InvenSense evaluation board)
// AD0 high = 0x69
MPU6050 mpu;
//MPU6050 mpu(0x69); // <-- use for AD0 high

// uncomment "OUTPUT READABLE QUATERNION" if you want to see the actual
```


Fig. 7 (a) ARDUINO programing data



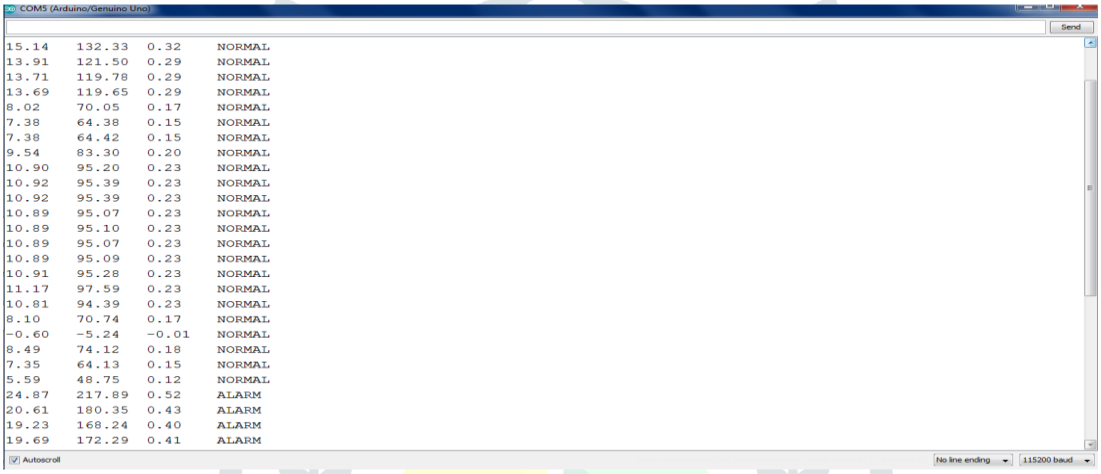
```
//Serial.print("\t");

if(millis() - premilli > SAMPLETIME)
{
  premilli = millis();

  float theta = ypr[2] * 180/M_PI;
  float delby2 = PI*theta/180;
  float dis = (LENGTH/(2.0*sin(delby2)))*(1-cos(delby2));
  float stress = 4.8*EE*HH*dis/(LENGTH*LENGTH);
Serial.print(theta);
Serial.print("\t");
Serial.print(dis);
Serial.print("\t");
Serial.print(stress);
if(stress > STRESSTH) Serial.println("\tALARM");
else Serial.println("\tNORMAL");
}
#endif
```

```
Done Saving.
Sketch uses 15004 bytes (46%) of program storage space. Maximum is 32256 bytes.
Global variables use 596 bytes (29%) of dynamic memory, leaving 1452 bytes for local variables. Maximum is 2048 bytes.
```

Fig. 7 (b) Final formulas in ARDUINO



15.14	132.33	0.32	NORMAL
13.91	121.50	0.29	NORMAL
13.71	119.78	0.29	NORMAL
13.69	119.65	0.29	NORMAL
8.02	70.05	0.17	NORMAL
7.38	64.38	0.15	NORMAL
7.38	64.42	0.15	NORMAL
9.54	83.30	0.20	NORMAL
10.90	95.20	0.23	NORMAL
10.92	95.39	0.23	NORMAL
10.92	95.39	0.23	NORMAL
10.89	95.07	0.23	NORMAL
10.89	95.10	0.23	NORMAL
10.89	95.07	0.23	NORMAL
10.89	95.09	0.23	NORMAL
10.91	95.28	0.23	NORMAL
11.17	97.59	0.23	NORMAL
10.81	94.39	0.23	NORMAL
8.10	70.74	0.17	NORMAL
-0.60	-5.24	-0.01	NORMAL
8.49	74.12	0.18	NORMAL
7.35	64.13	0.15	NORMAL
5.59	48.75	0.12	NORMAL
24.87	217.89	0.52	ALARM
20.61	180.35	0.43	ALARM
19.23	168.24	0.40	ALARM
19.69	172.29	0.41	ALARM

Fig. 8 final Result of stress and deflection of beam in Arduino

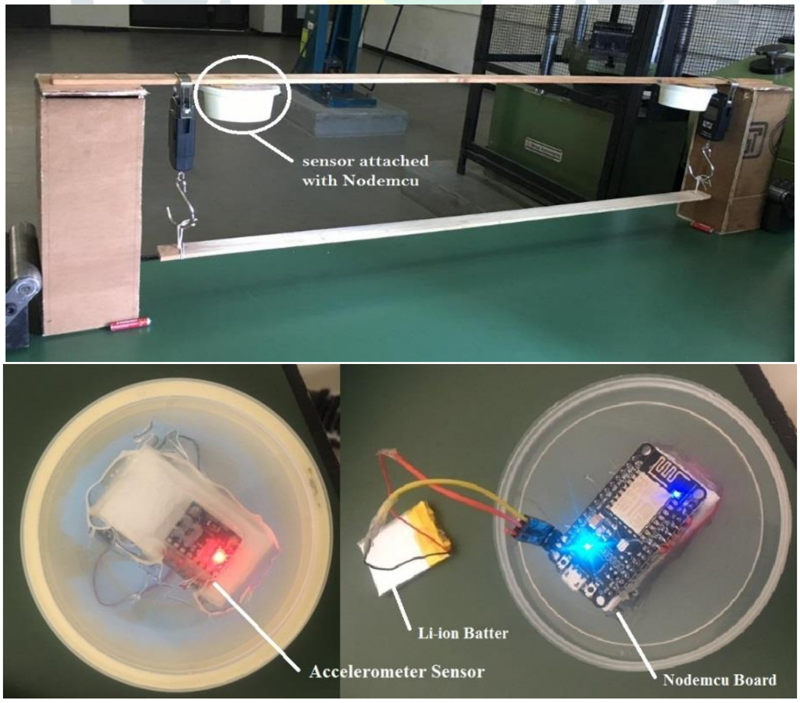


Fig. 9 wood frame sample attached with sensor and Nodemcu

After installing coding from Arduino program to Nodemcu (wireless), sensor and Nodemcu will be attached with model or real structure at place where beam is bending (sloping area) and Wi-Fi connection to sensor and board, we will receive result data in Pocketsender and from this program we can save and send data to anywhere at any time. Point to be noted that if Arduino programing data should be same as structure that sensor will be attached like wide, length, height of beam and other necessary elements.

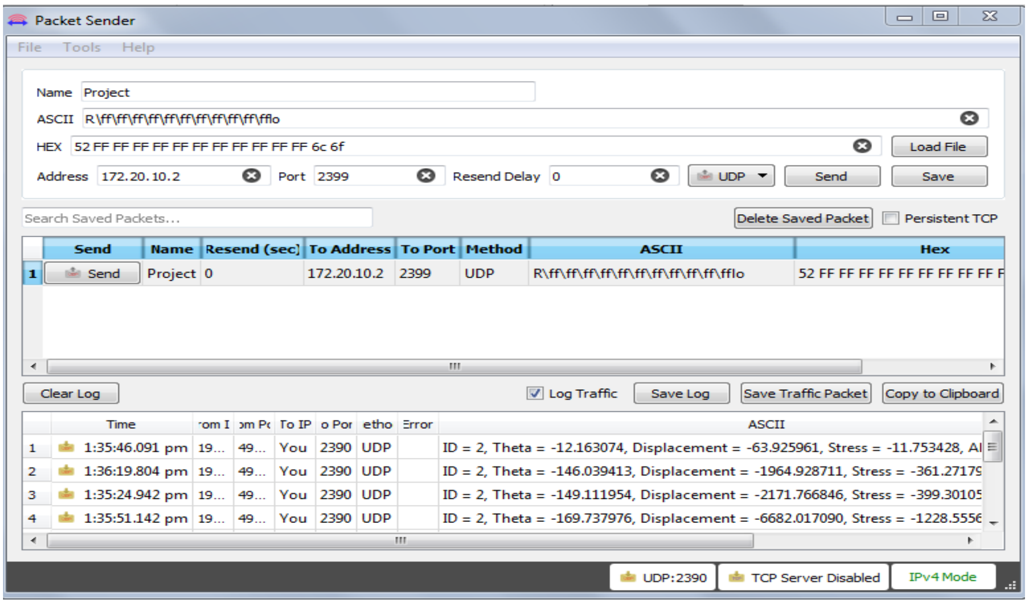


Fig. 10 Final result in Pocketsender

IV. Conclusions

SHM has been selected as a relevant subject of study in manufacturing, civil engineering and aerospace industries since it successfully allows monitoring, performance evaluation, prediction and report of structure integrity. Also IoT has received a great attention due to its potential and capacity to be integrated into any complex system. As a result of rapid development of sensing technologies such as radio-frequency identification, sensors and the convergence of information technologies such as wireless communication and Internet.

As looking to the need of the continuous monitoring of the ambient vibrations, this research is emerging as an important technology for monitoring systems. Hence IoT helps in real-time data monitoring and take immediate action if any problem arises. So IoT based on structural health monitoring can prevent catastrophic failure, Higher operational loads and environmental impact, Complexity of design and longer life time periods for structure. It can be applied to new structures as well as to existing structures.

V. Acknowledgement

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