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# Monitoring Structural Health using the Internet of Things

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***Abstract :*** Infrastructure development is essential for the development of any nation. Several factors are responsible for the deterioration of such infrastructures' integrity and reliability. Further, aging structures cause concerns for life and property. Advancements in sensor technologies and the Internet of Things have enabled automatic structural health monitoring for civil infrastructures. It uses a data-driven method to monitor, evaluate and report structural health on time. It helps improve structural reliability and safety management while reducing the cost of maintenance, saving life and property from structural collapses. This paper presents a structural monitoring system using the Interment of Things following a suitable architecture that is easier to implement.

***IndexTerms* - Internet of Things, Sensor, IoT Architecture, Structural Health Monitoring**

## I. INTRODUCTION

There have been rapid developments in the construction of buildings, dams, bridges, and other structures around the globe in the past several decades. Various factors such as deterioration, excessive loads, and environmental factors such as heavy rain, wind, temperature, cyclones, earthquakes, etc., cause damage to the structures and raise safety concerns. The integrity and safety of these infrastructures need to be monitored to make them sustainable. Consequently, it saves people living in and around these structures.

Generally, buildings and bridges are designed and built according to the International Building Code (IBC) or National Building Code of different countries or Bridge Construction Standards of ISO and have a reasonable in-built safety factor [1]. Despite these standards in place, there have been several reports of structural collapses worldwide, causing massive damage to life and property.

A study on Structural collapse in India has found that between 2001 and 2015, an average of 7 people died per day due to the destruction of structures, including buildings failures [2]. With 74 people who died in a building collapse in 2013 in Thane in Maharashtra, India's one of the worst building collapses ever [3]. While in the US, it has been found that, on average, nine lives were lost per day between 1989 to 2000 [4]. With 114 people dying in a structural collapse in 1981 of the US' Kansas City remains their deadliest ever in history [5].

Therefore, continuous monitoring of the structural health of buildings, dams, bridges, etc. is of paramount importance to save life and property. Of late, the Internet of Things (IoT) is known for its use cases in many areas. There have been several stand-out applications of IoT in health monitoring, traffic monitoring & control, industrial process control, defense monitoring, and safety-critical tasks. The Internet of Things, coupled with sensing technologies, has a lot of potential for identifying locations and severity of damages to a structure by regularly monitoring its characteristics and promptly providing necessary alerts. It can quantify the severity of damage and predict the remaining life of the structure.

In this paper, an IoT-based system for structural health monitoring has been reported following a suitable architecture that is feasible from the implementation point of view.

## II. RELATED WORKS

[6] proposes a system that uses the flex sensors as the main sensing element with using Arduino 101 as the development board that comes with an integrated accelerometer. The wireless module which collects the data and sends it to an application is also connected to a cloud service provider. The system alarms through a piezo buzzer and Red LED. The Blynk app was used to display the collected data that it had collected from cloud storage, giving the alerts as well. The result could also be displayed on a 'Bluetooth Serial Monitor' to check the real-time data.

[7] implemented a system using Raspberry pi 2, ProTrinket, and NRF module. Pro Trinket receives the data sent by the sensors and uses the NRF module (a transceiver) to send data to Raspberry pi, which has an NRF module and is connected to the cloud for storage and insights.

[8] proposed a system that includes Arduino Uno to collect the information from the flex sensors & the NodeMCU is used to send the fetched data to a server and send a signal of message through the GSM module of SIM. The flex sensors are used as a primary sensor to measure the crack or bending in the structure & when detected, an LED starts blinking along with the alarming

buzzer. A message also gets sent to the owner of the structure and the rescue team when the value of the sensor gets above the threshold.

[9] implemented a system composed of nodes via RS485 protocol and communicates with a master. Each node comprises of RS485 driver, which is directly in communication with Microcontroller Sam3X8E ARM Cortex - M3. The microcontroller uses the I2C bus to communicate with the Accelerometer ADXL335. The Accelerometer has an internal temperature sensor that the microcontroller can read for the data compensation.

## III. Proposed System

Figure 1 depicts the architecture of our Structural Health Monitoring System which consists of 3 parts:

- Sensing Node
- The Gateway
- Application Server

**Sensing Node:** The sensing node can be any microcontroller that can take in the sensing data from the sensors and also we can have multiple of them each having different sensors in different places. All these sensing data are separated by Topics, as each sensor's data are sent through one Topic which is uniquely identified throughout the application server.

**The Gateway:** The Gateway is in the center and integrates the sensing node and application server by acting as a bridge to convey the messages onto the application server. The gateway can also filter out the data given to the application server by choosing to give only the subscribed topic, which is a specialized feature of the MQTT protocol.

**Application Sever:** The application server is the place where the data finally reaches. After it receives the data, it can further process and cleanse the data according to the standards set. The application server can also be used to store the data in a database where it can aggregate all the data and average the data so that the data is more accurate and precise.

The usage of MQTT Broker in our implementation provides reliability and independence of parts that collect the data and the parts that need to receive the data making the whole system robust.

For the selection of each sensor, a thorough study was made and while analyzing how structural damage can occur, we came up with two cases:

- Bulging Walls -Weight/Humid
- Sagging Floors -Pressure

The Bulging Walls due to humid conditions could be sensed by Humidity sensors (DHT-11) and Sagging Floors analyzed by Accelerometer ADXL335.

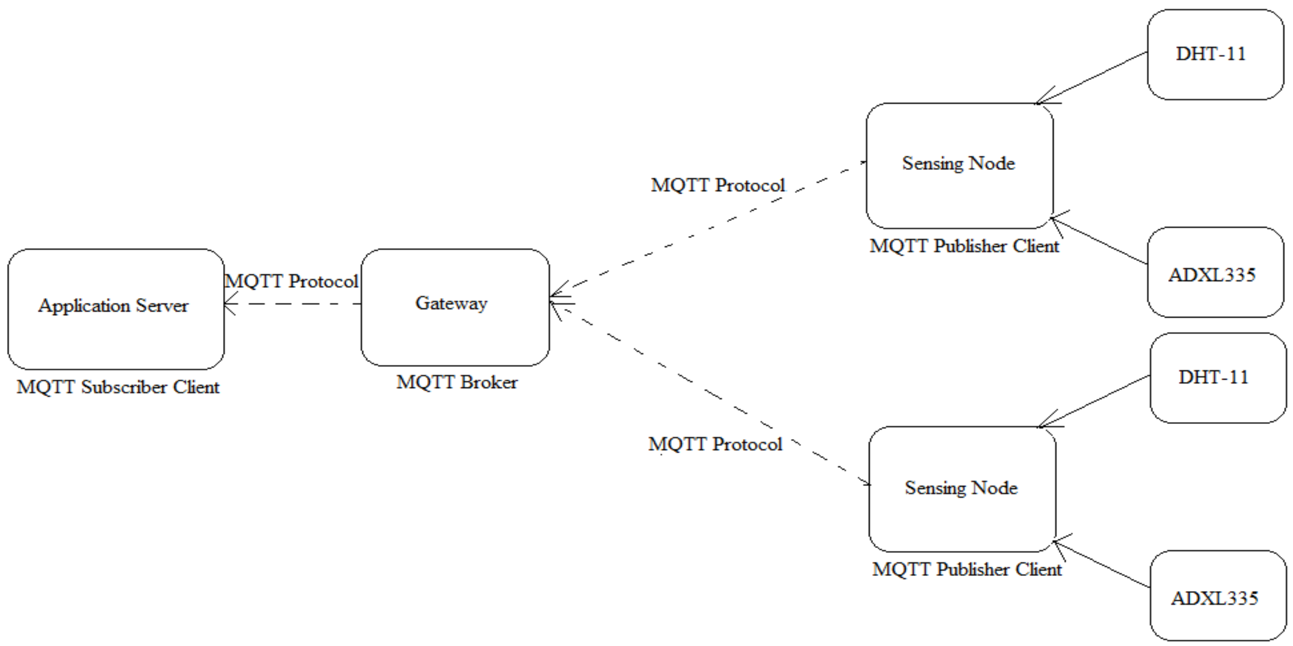


**Fig. 1. Architectural Diagram**

## IV. Implementation

Our proposed system is implemented using NodeMCU acts as a sensing node or field device that collects the data from the two sensors which are the humidity sensor (DHT11) and Accelerometer (ADXL335).

The NodeMCU incorporates firmware which Wi-Fi keeps running on ESP8266 SoC from Espressif Systems. It has a flash memory in which the program logic is dumped. A humidity sensor and an accelerometer are connected to the digital and analog pin of this module which returns its readings in respective units. Before collecting the data, the NodeMCU needs to be connected to the wi-fi so firstly, we need to check with NodeMCU if it is connected to wi-fi. After it has access to the wi-fi, it later needs to be connected with the MQTT Broker.

Here, Raspberry Pi 4 with 1 GB of RAM and 1.5 GHz of CPU speed was used as an MQTT Broker. It has a dual-band 2.4 GHz and 5 GHz wireless LAN, a faster (over 300mbps) Ethernet speed. As Raspberry Pi 4 is preconfigured with MQTT Broker Software, it allows MQTT Clients to connect with it provided it has credentials of the MQTT Broker.

For collecting the humidity readings from the surroundings, we have used DHT 11 sensor. A DHT 11 is a basic and very low-cost sensor. The sensor has a delay of 2 seconds. This means that the sensor reading can be up to 2 seconds old. The humidity sensor outputs a value that is read by NodeMCU which creates a Topic unique to this sensor and publishes the values to this topic.

For measuring the change in axis we have used accelerometer ADXL335. The ADXL335 sensor works on power between 1.8V to 3.6VDC (3.3V optimal) which is optimal for working with NodeMCU as it has a 3.3V power supply. The Accelerometer outputs a value that is placed into a separate topic and the values are sent through the Node MCU to the Raspberry Pi.

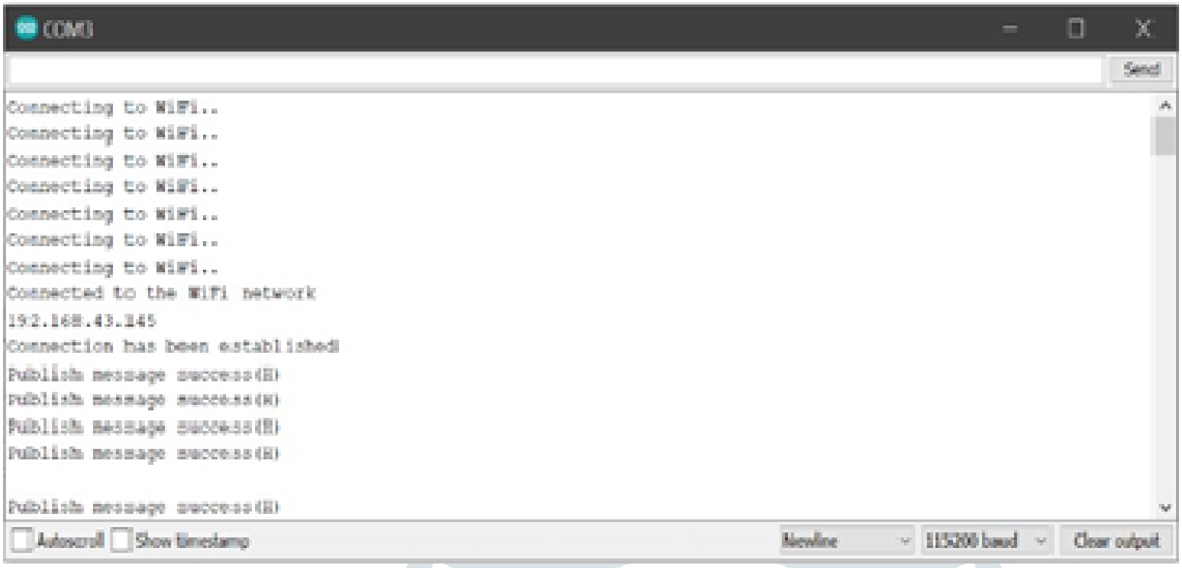


**Fig. 2. NodeMCU publishing data to Raspberry pi**

Figure 2 shows the output screen after sending in the data, a success message is printed to acknowledge that readings have been sent from the NodeMCU.

```
Humidity is : 47.00
Adxl Readings are: 430.00
Humidity is : 47.00
Adxl Readings are: 436.00
Humidity is : nan
Adxl Readings are: 436.00
Humidity is : nan
Adxl Readings are: 436.00
Humidity is : 47.00
Adxl Readings are: 436.00
Humidity is : 47.00
Adxl Readings are: 435.00
Humidity is : 47.00
Adxl Readings are: 436.00
Humidity is : 47.00
Adxl Readings are: 436.00
Humidity is : 47.00
Adxl Readings are: 437.00
Humidity is : 47.00
Adxl Readings are: 433.00
Humidity is : 47.00
Adxl Readings are: 435.00
Humidity is : 47.00
Adxl Readings are: 436.00
```

**Fig. 3. Readings from Application Server**

Figure 3 shows the output screen which displays the readings from the Application Server. For this to be successful, the Application Server has subscribed to both the Topics in the Raspberry Pi Broker which the NodeMCU has published separately for each sensor.

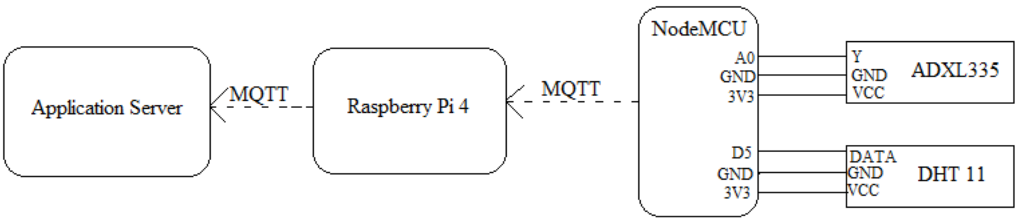


**Fig. 4. Block Diagram**

Figure 4 depicts the block diagram showing the circuit connections of DHT 11 and ADXL335 sensors with NodeMCU. Once the aggregated sensing data reaches the Application Server it is further processed for generating alert for the users.

## V. Conclusion

The structures and monuments which are the parts of civil engineering concepts are proving to be more and more important in our daily life as their vulnerability puts everyone's life at risk and also their intrinsic value to the society.

By use of this Structural Health Monitoring System architecture, we can get to know the status of the structures and take a decision accordingly.

The MQTT protocol is a very integral part of an IoT System and by its implementation, we can conclude that it has made the IoT system simpler and easier.

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