Bridge Health Monitoring using IoT

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Abstract – *The increase in the demand for the structural health monitoring information led to the development of the structural health monitoring. The bridges may get collapsed or tilted due to concrete problem or due to flooding or due to excess overloading on the bridge. So, there's a requirement to design a system which will monitor the condition of the bridges.*

Till date, most of the SHM systems face challenges functioning at real-time and therefore the monitoring amenities are yet not established properly. To overcome this problem, Internet of Things is often used, by which we can monitor the system from anywhere. Such a system will help in disaster management and human safety. This system is composed of: Monitoring devices installed in the bridge environment, communication devices connecting the bridge monitoring devices and also a cloud-based server with a dynamic database that stores bridge condition data. This cloud-based server calculates and analyzes data transmitted from the monitoring devices. The system can monitor and analyze in real time the condition of a bridge and its environment, including the water levels, fluctuation in vibrations. The data will be stored and can be checked remotely from any mobile device. This system is validated by employing a test bed in the lab.

Key Words: Structural Health Monitoring, Sensors, IoT, Arduino, Data Analysis

1. INTRODUCTION

SHM is a vital tool to enhance the safety and maintainability of critical structures like bridges. SHM delivers real time and accurate information about the concerned structure giving detailed information about its condition.

Now-a-days due to incidents of bridges or change in deflection of the bridge structure, or bridge piers severely damaged by moisture, or by excess variation in vibration are frequently reported annually. Different disasters and damaged sites require different professional disaster rescue knowledge and equipment so as to realize optimal rescue results. However, lack of data about the damage site can impede information management at the rescue center and operation, leading to poor rescue efficiency or maybe preventable causalities.

Generally, to perform SHM, firstly, data must be collected using sensors. The different types of sensors are often used by SHM to generate the signals traveling through solid configurations. Later, this data is collected from the sensors and must be analyzed by applying different signal processing techniques, because a minor variation within the system is triggered by various factors like noises, temperature changes, environmental effects, might cause significant changes within the response from the sensors, concealing the potential signal changes due to structural defects.

Therefore, during this study, the IoT, Sensor networks are adopted to resolve the above-mentioned problems of bridge safety information transmission and management by developing an IoT-based bridge safety monitoring system capable of monitoring the environmental data of a bridge and transmitting the data to the mobile devices of bridge safety management.

The system developed in this study can help promote the advancement of bridge safety management and control by providing breakthroughs to the above-mentioned problems of conventional systems. For developing bridge monitoring system, following technologies are going to be used. Diverse theories have been proposed and implemented to fulfill distinct requirements of structures. Integration of these various theories has helped not only to enhance the efficiency and performance of the SHM systems but also to scale back the computational time and costs. In order to share data and ensure reliability, the SHM systems use network-based services to coexist and interact with smart interconnected devices that are referred to as the IoT. The IoT brings new opportunities for our society. With the maturity of the IoT, one of the recent challenges within the structural engineering community is development of the IoT SHM systems which can provide a promising solution for rapid, accurate, and low-cost SHM systems. Moreover, the combination of SHM, and therefore the IoT enabled ubiquitous services and powerful processing of sensing data streams beyond the potential of traditional SHM system. In this paper, an entire SHM platform embedded with IoT is proposed to detect the damage in bridges.

Following are some of the advantages of SHM system:

- The continuous monitoring of the structure since sensors are a part of it.

• The possibility of real-time damage detection.

• The possibility of using sensor or actuator networks.

• Robust data analysis that can provide relevant information about the damage.

• An automated inspection process to reduce the number of unnecessary maintenance tasks, thereby improving the economic benefits.

• Operational and environmental evaluation conditions.

2. IoT Background

The Internet of Things (IOT) is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment.

This term was coined by Kevin Ashton of Procter and Gamble, later MITs Auto-ID Center in1999.

2.1 Components of IoT

The Internet of Things (IOT) is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment.

This term was coined by Kevin Ashton of Procter and Gamble, later MITs Auto-ID Center in1999.

Components of IOT: Sensors: according to (IEEE) sensors are often defined as a device that produces electrical, optical, or digital data derived from an event. Data produced from sensors is then electronically transformed, into resultant output information that is useful in decision making done by intelligent devices or individuals.

The term IoT is semantically associated with two words "Internet" and "Things," where Internet is understood as the global system that use TCP/IP protocol suite to interconnect different computer networks, while 'Things' refer to any object/device in the surrounding environment that has the potential to sense and collect data. Therefore, IoT is often defined as a global system which supports IP suite, which has objects equipped with sensors, radio frequency identification (RFID) tags or barcodes have a unique identity, operate in a smart environment and are harmoniously integrated into the information network by using intelligent interfaces. IoT relies on a wide range of materials, network infrastructure, communication protocols, Internet services, and computing technologies. Among the range of various technologies involve within the IoT concept, WSN is one among the most important technologies that enable the integration of sensing devices into IoT ecosystems. Sensing devices are deployed in network to seamlessly collect and send real-time data through the web to gather at a data center. End users can remotely control the devices using Internet services. They will also access the data center via Internet anytime from anyplace - to retrieve, process, and analyze data. IoT architecture is an open architecture based on multilayers. Services-oriented architecture is one among the approaches that are adopted by researchers in recent years to implement IoT system. Different services like sensing, transmission, collection, storage, and information processing are offered due to the interaction between multiple layers. IoT devices and sensors suffer from computational and energy constraints. Therefore, to attain coaction across the heterogeneous networks and also allow coherent data exchange through the IoT system, various protocols and standards are established.

3. Related Work

Existing System of bridge safety management have the problems like: Failure to collect data or monitor on-site conditions in real time. The data collection through the large size electronic equipment have higher cost or higher power consumption, often resulting in inaccurate data. In proposed system, we are going to use sensor network technology with IoT platform. Here the detected data is transmitted to the server for users to have real time monitoring of the bridge conditions via mobile telecommunication devices. Bridge Structural Health Monitoring (SHM) has been an intense research area for some time. Traditional, direct approaches are to collect acceleration signals by installing sensors on a bridge. The drawback of such direct approaches is that it requires a polished and expensive electronic framework which includes the installation, maintenance and power support. Moreover, although it is easy to get a large number of data samples, it is expensive to label them (which involves physically inspecting the bridge and determining its health); thus, very few data samples are actually.

SHM processing incorporates various sensors, the signal processing, and hardware implementation of the framework. Many sensors, for example, accelerometer, vibration, and piezoelectric have been used. Accelerometer sensor is used to get the three-dimensional coordinates of the target structure and monitor its health. Vibrational sensors are used in Sensor Networks send distributed data interpretation to detect the local data trends like normal vibrations, abnormal vibrations, and structural tilts. SHM systems established under vibration parameters have become an area of focus in recent studies, as they detect damage that cannot be visually detected or the damage hidden within internal areas of the structure. For the Vibration based systems, vibrations along the structure changes according to the stiffness of the body when it is damaged and this can be detected. The usage of Sensor Network in SHM systems has increased in recent times due to its low installation and maintenance costs. Compared to other data acquisition systems, sensor network technology has various benefits such as low maintenance cost, flexibility, and ease of deployment.

Signal processing is the key component of any SHM. The data obtained through these data acquisition systems are not very accurate as the vibrational and environmental effects influence the output data. The errors in the output data can be removed by using Principal component analysis (PCA) and Hilbert-Huang Transform (HHT) with EMD for data processing and analyzing data to detect structural health problems. The guided wave SHM system along with digital signal processing module which executes stimulation of signal sensing and data processing to process all the data. The instantaneous baseline damage detection based on Wavelet Transformation (WT) and cross correlation (CC) analysis is carried out by the DSP module of low-power piezoelectric guided waves system.

4. System Design

From a general point of view, the implementation of an SHM system requires four steps: (i) the definition of the sensor/actuator system to attach to the structure; (ii) the data acquisition system; (iii) the pre-processing step; and (iv) the development of statistical models. These four steps are represented in a pyramid in Figure below. The following steps generate solution to the challenges in the different levels of damage-identification process. An additional level can even be included to consider smart solutions in which the previous levels are evaluated to determine the best combination of multiple configurations to produce an optimal solution to the damage-identification task.

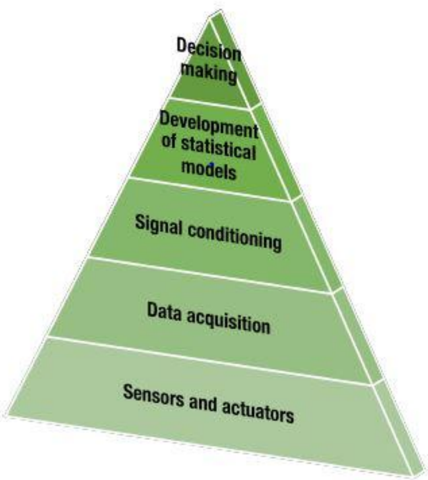

Fig -1: System Activities

The sensors used in the system are- ADXL 345, Piezoelectric, Moisture and Flex sensor. These four sensors meet the needs of the civil engineer in charge of development of a bridge.

Arduino Uno is used here to connect all the sensors and a 16*2 LCD display shows the values collected by the sensors in real time with a refresh rate of 1s. A Node MCU is used for the serial communication between the arduino and the user. The data collected by Arduino is sent to the Node MCU from the TX pin and the Node MCU receives it bia the RX pin. The Node MCU is connected to a WiFi with an active internet connection. The data collected in the Node MCU is sent to a IoT platform thinger.io on which a dashboard shows all the different values that are collected. More information on Node MCU and thinge.io is given below in the report. First the connections, codes and algorithms are explained. All the codes for the Arduino and the Node MCU are written in embeded C language in the ARDUINO IDE which is a development environment.

5. Connections

5.1 ADXL to Arduino

The adxl 345 accelerometer is connected to the arduino to collect realtime data and send it to the desired user. The VCC pin of the adxl is connected to 5V pin of the Arduino. The GND pin is connected to the GND pin of Arduino. The SCL (Serial Clock) pin of adxl is connected to the I2C SDC of the Arduino. The SDA (Serial Data) pin of adxl is connected to the I2C SDA of the Arduino. These are the four pins which connect the Arduino and the ADXL 345.

The image of the connections is given below:

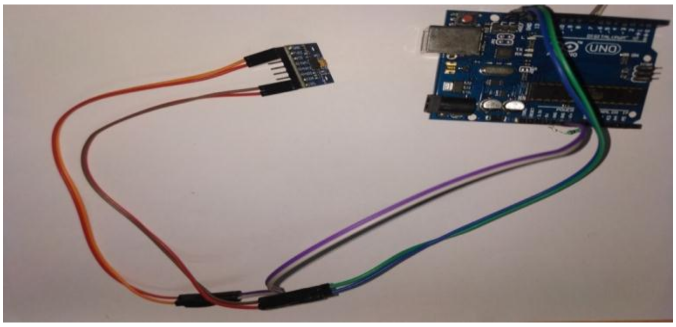

Fig -2: Connection 1: ADXL to Arduino

5.2 Flex Sensor

The connection of the Flex sensor is very simple as it only has 2 probes which are to be connected to a power supply that is 5V pin of Arduino and the other probe is to be connected to the analog pin A2 of the Arduino Uno board.

The image of the connections is given below:

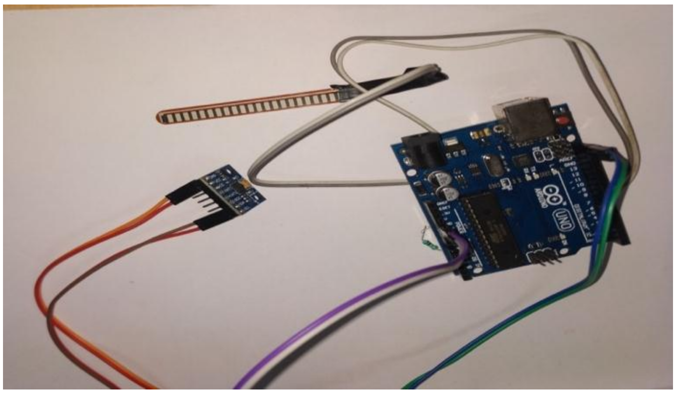

Fig -3: Connection 2: Flex Sensor to Arduino

5.3 Moisture Sensor

The moisture sensor also has only two probes which are to be connected as follows. The Right probe is connected to the analog pin A2 of Arduino and the Left probe is connected to the AREF GND (0) pin of the Arduino.

The image of the connections is shown below:

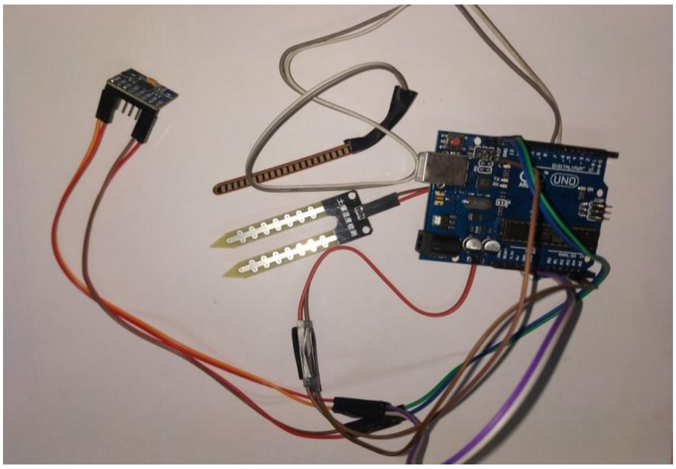

Fig -4: Connection 3 Moisture Sensor to Arduino

5.4 Piezoelectric Sensor

In the piezoelectric sensor, the white part or the sticker part is the transmitter which is connected to the analog pin A0 of Arduino and the ceramic part or the golden part is the transducer which is connected to the GND pin of Arduino.

The image of the connections is shown below:

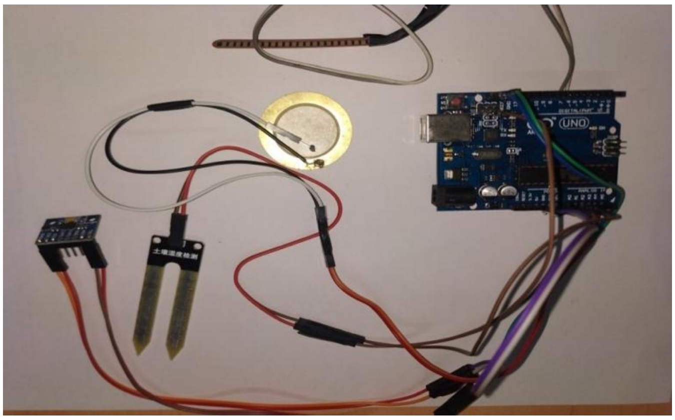

Fig -5: Connection 4: Piezoelectric Sensor to Arduino

5.5 LCD Display

The LCD display is used along with the I2C communication module which is used for smoother data transmission and receiving process in the real time. The LCD display module has 4 pins. The VCC pin of LCD is connected to the ICSP VCC pin of the Arduino. The GND pin of the LCD is connected to the ICSP GND pin of Arduino. Then the SCL pin is connected to the A5 analog pin of Arduino and the SDA is connected to the A4 analog pin of Arduino. The pins A4 and A5 of Arduino are also used as SCL and SDA when required.

The connections are shown in the below image:

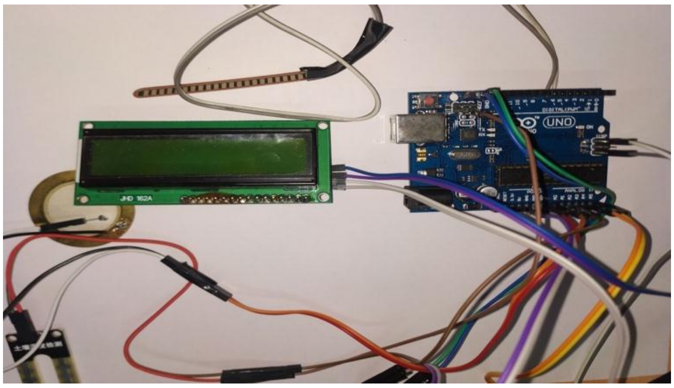

Fig -6: Connection 5: LCD Display to Arduino

5.6 Node MCU

The Node MCU is used here for the serial communication between the Arduino and the user. The TX pin of the Arduino is connected to the RX pin of the Node MCU.

The connection is shown in the below image:

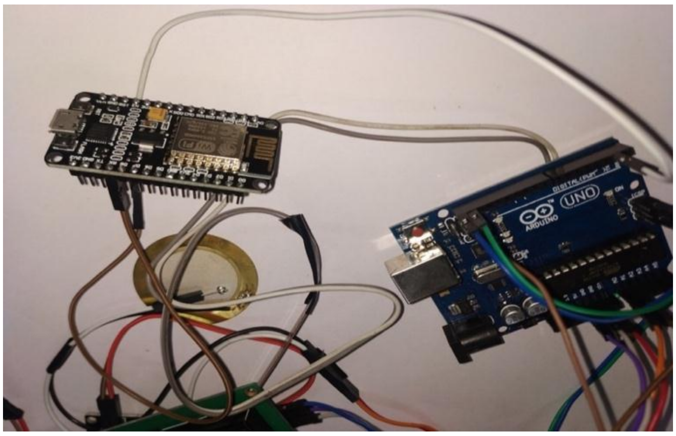

Fig -7: Connection 6: Node MCU to Arduino

Hence all the connections are made and at last the Arduino and the Node MCU both are to be connected 5V power supply. And when they are connected to the power supply.

The entire connections are shown in the figure below:

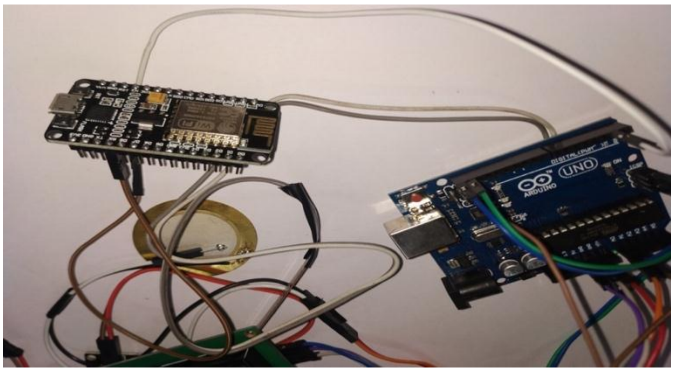

Fig -8: Overall Hardware design

6. Implementation & Result

The Arduino collects the data values from the different sensors that are connected to various analog and digital pins of Arduino. The ADXL 345 sends the values in terms of X and Y axis. The flex sensor sends the value of resistance caused in the sensor. The moisture sensor sends the percentage of moisture content in the material. And the piezoelectric sensor sends the vibrations in the surface.

All the sensors will be attached to the surface of a bridge. The system is turned on and the sensors start collecting and sending the data simultaneously. The piezoelectric sensor will return the vibrations caused in the bridge. The moisture sensor will return the moisture content in the bridge. The ADXL 345 sensor will help in observing the orientation of the bridge. And the flex sensor is installed at the joints to recognize cracks or dislocations in the joints or columns of the bridge.

In the initial stage that is for 5 to 8 days, all the readings will be recorded and those will be the normal readings for the bridge. Then those values will be set as the threshold values for the proper orientation and health of the bridge. This is the analysis part.

Then comes the IoT part. The data of every second will be sent to the thinger.io dashboard which will be created manually. All the data of the sensors will appear on the thinger.io dashboard and the data can be accessed by the user of the civil engineer from any part of the world. Also, all the data of the sensors can be converted into a excel sheet automatically and then it can be further analysed.

If any of the values of any sensor is disturbed, or the values go beyond the threshold values which were set earlier, the Node MCU will immediately send an email and a text message to the authorities in charge of the bridge and also to the civil engineer in charge. The email addresses and the phone numbers of the authorities in charge are set during the analysis part. In this way if there is any harm to the bridge, the authorities can come and examine the bridge and take all the necessary actions to avoid casualties.

A few screenshots are provided of the actual implementation.

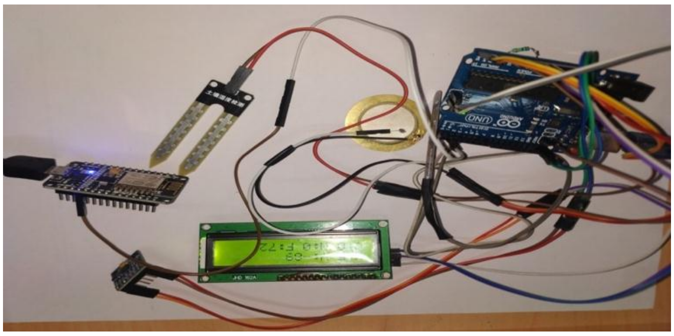

Fig -9: Hardware Interface

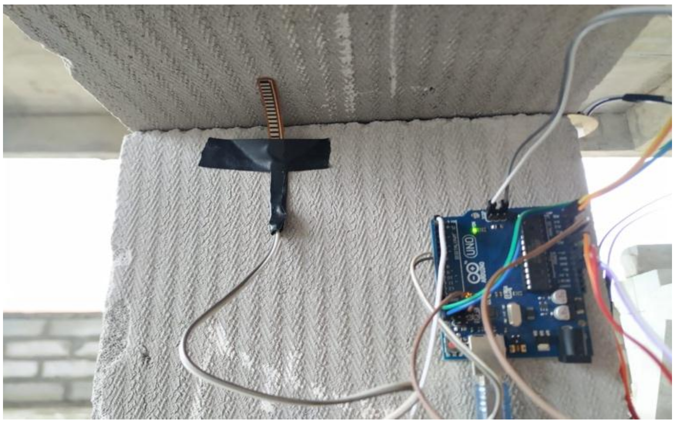

Fig -10: Implementation of Flex Sensor

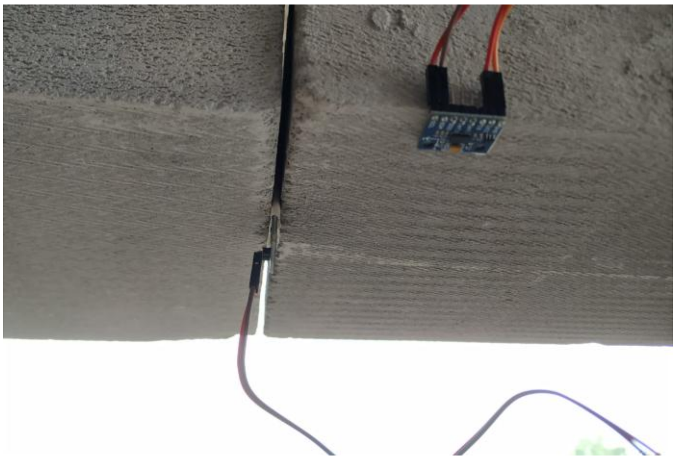

Fig -11: Implementation of ADXL and Moisture Sensor

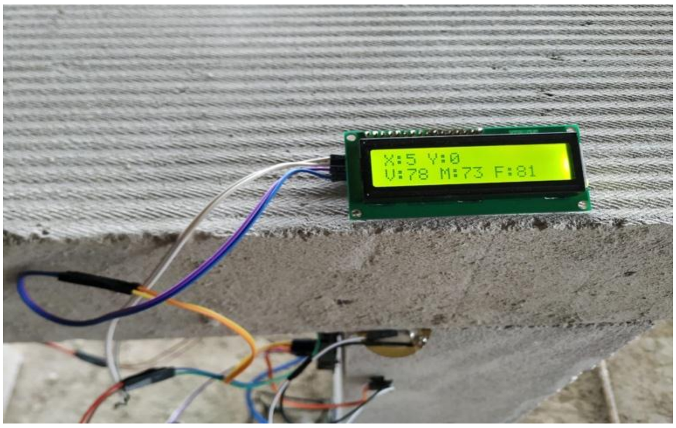

Fig -12: Implementation of 16*2 LCD and Piezoelectric Sensor

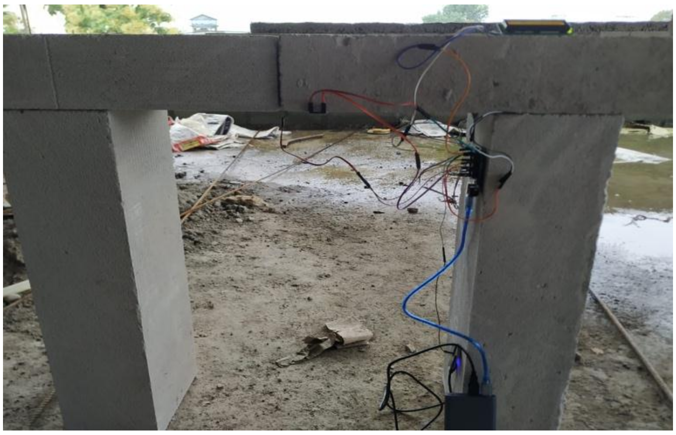

Fig -13: Overall Hardware Interface

7. Applications

[1] Using this project, we can keep eye on the various bridge in which our proposed model in embedded.

[2] The project can be further expanded and the various same structured models can be installed over the bridges for the maintenance of the bridges.

[3] With the help of this model, the presence of the moisture can also be detected and the future disasters can be snuffed.

[4] We can get the information regarding the health or lifetime of the bridge over our phone via email.

[5] Additionally, we can maintain any structure for the purpose like moisture detection, change in deflection, etc.

[6] This system can also be used to make contributions in the field of aerospace, civil engineering, transport, etc.

8. Advantages

[1] It is a robust and easy to use system.

[2] There is no need for extra training of that person who is using it.

[3] Proposed system will avoid death of people due to bridge collapse.

[4] We can determine which bridge requires repairing before it gets break.

[5] Traffic can be routed prior of Bridge collapse as alert of extreme levels are continuously monitored on IOT server.

[6] It generates the alert if flow, water level, and the load are increased.

[7] Early damage detection, Quick action and responses.

9. Disadvantages

Following are some of the limitations of the project:

[1] Constant maintenance of the system

[2] Replacement of sensors

[3] Sudden power cutoff

10. Expected Results

[1] By how much position bridge gets tilted.
[2] Detection of water level under the bridge.
[3] Detection of change in variation of the bridge.

11. CONCLUSION

With the relentless aging of the civil infrastructure, bridge structure's health monitoring is becoming of greater importance each day. The IoT integrated with the sensors presents the solution for the damage detection in bridges. The proposed system can give information about the change in angle of the bridge. A bridge monitoring system is needed for public safety. Such system can be designed using TCP/IP protocol for connection between sensor and Arduino, Wi-Fi module. The principal objective is to detect the damages in bridges by the use of sensor network. The Internet of things integrated with the sensors presents a solution for damage in bridge of health monitoring.

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