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Use of IoT for Structural Health Monitoring of Bridge Prototype Using Force Sensitive Resistor

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***Abstract*: As the world is becoming more and more technologically advanced. It's time for integrating tomorrows tech into today's construction world. IoT being one of the latest and useful concept emerging in electronics and IT field is tried to integrate into construction field. In this paper the author has proposed the use of IoT based continuous feedback model in which compression sensors are placed around the structure mainly bridge to monitor the effect of loading on it. Author also has proposed a prototype which can be used to demonstrate the ways in which this modular device can monitor the structural health assessment. Author has tried to develop high performance, low power usage and efficient system to build IoT platform. This being said is done as a step to assess SHM, live in-situ loading assessment, and much more.**

***Keywords*: Force sensor, IoT, structural health monitoring.**

1. Introduction

A. What is IoT?

The Internet of Things is an integrated division of the Internet of the future, consisting of a combination of network proliferation and rapid development. The IoT is a field of information technology that creates connecting links between the "Internet" and the actual physical "things." The IoT aims to bring everything under a common infrastructure, not only to control everything, but also to define the actual state of things.

Fig. 1. Network of IoT

According to a group of European research projects, "The Internet of Things (IoT) is an integrated part of the Internet, a dynamic universal with self-anchoring potential common to common and interoperable message labels. It can be defined as a set of connections, wherever physical and implicit "things" are, "with an intelligent interface that seamlessly fits into the information network, as well as identity, material attribution, and implicit properties."

B. Why use IoT in the construction sector?

The construction industry has always been characterized by accidents and downtime. Many construction accidents are due to the carelessness of workers and can be mitigated by taking appropriate precautions, but it is much more difficult to detect and prevent catastrophic obstacles such as sudden collapse of buildings and structures. Despite strict safety rules and regulations, structural failures still occur from time to time. Prior to structural failure, there is usually a transitional period in which the structure exhibits anomalous changes.

For example, anomalous changes in the load and verticality (tilt) of a support member of a structure indicate that the structure is not stable. Abnormal changes in groundwater level can also occur. These changes will eventually amplify and exceed safety limits, eventually leading to structural damage. If we can quickly recognize and analyze noticeable changes, we can issue appropriate warning signals in a timely manner and initiate corrective actions in a timely manner. In the worst case, there is still enough time to evacuate to avoid injury or casualties. Therefore, continuous real-time monitoring is essential to prevent accidents due to structural damage.

Monitoring:

Structural health Monitoring has always been an integral part of civil engineering. Common monitoring requirements include, among other things, water table, component forces, ground movement, structure subsidence and slope, and toxic gases. Current groundwater level monitoring practices typically involve technicians inserting water level sensors into field standpipes to obtain measurements. Even during critical work stages, measurements are usually made twice a day, so fluctuations between them cannot be detected. Similarly, ground movement, subsidence, and slope monitoring operations are still carried out by field surveys and traditional survey methods. Therefore, measurements are rarely made more than once a day. Because traditional methods are labor-intensive, these methods result in disproportionately high labor costs, making continuous monitoring impossible. Moreover, their time-consuming nature also hinders the availability of real-time readings. Data loggers can reduce the number of people required, but they cannot provide real-time processing

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and analysis because they need to acquire data with a large time lag.

C. What is SHM?

SHM is a non-destructive evaluation method for monitoring the integrity of structures such as bridges and buildings. This is because these buildings and bridges can gradually deteriorate due to various reasons, including important tools used in old buildings and bridges. To ensure safety to secure people. Researchers in different disciplines have taken different approaches to SHM, but most of the work in this area is done by civil and mechanical engineers. Here job is mainly to analyze the natural frequency of the structure and make decisions.

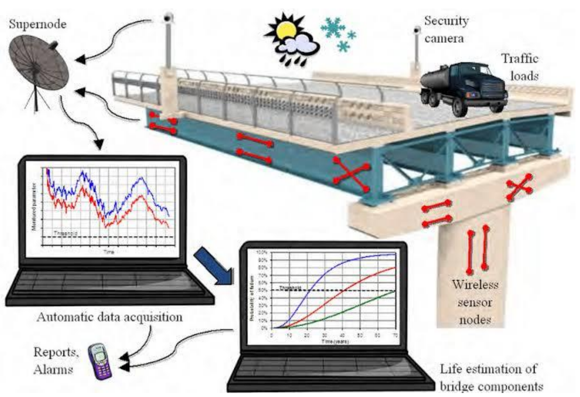

Fig. 2. Use of IoT for structural health monitoring

Importance of IoT in SHM?

Structural Health Monitoring (SHM) has emerged as an important research topic for improving human safety and reducing maintenance costs. However, most existing SHM systems face real-time challenges due to environmental impacts and various operational risks. In addition, remote monitoring and constant monitoring facilities are not in place. To overcome this, you can use the Internet of Things (IoT). This gives you the flexibility to monitor structures (buildings, bridges) from anywhere.

2. Literature Review

Donato Abruzzese, Davide Bracale et. Al (2021), Permanent monitoring of thin structures with low-cost devices

In this research article, the author sought to monitor stress in thin structures using a small, inexpensive device.

1) This device can record the load history. At key points, send alerts as needed to ensure security against the risk of collapse, or simply to perform maintenance/repair work.
2) Such devices are mounted using inexpensive off-the-shelf electronics and conventional strain gauges.
3) Application examples are shown as laboratory tests for reinforced concrete slabs, masonry slabs, and steel beams.

The results show that permanent monitoring of stress in new structures can be conveniently performed using low cost devices such as those we designed and implemented ourselves.

Suseela Alla, S.S. Asadi (2020), Integrated methodology of structural health monitoring for civil structures

1) The main goal of this work is to convey the SHM methodology. This is because SHM does not have a clear methodology for determining structural reliability and longevity.
2) Therefore, this paper contains the proposed methodologies of work. Structural health monitoring will be taken over for building renovations.
3) Basic abilities have usually been systematically assessed using exposure estimates.
4) Most studies performed heap score estimates over a clear, discrete, unpredictable period determined by scaffold stacking and boundary changes.

Donato Abruzzese, Andrea Micheletti et.al (2020), IoT sensors for modern structural health monitoring. A new frontier. The long-term goal of this study is to enable wireless, low-cost devices and data management software for building condition monitoring and CEI.

1) Use remote sensors embedded in or attached to structural members to measure stress as well as acceleration.
2) Equipped with such a system, any structure can become part of the Internet of Things and alert users and authorities if the structure becomes less secure or endangered.
3) An important aspect is the chaotic storage of measurement data over time. It cannot rely solely on third parties and requires the use of appropriate data protection technology.
4) This study was conducted through experimental testing and verification of developed and implemented monitoring equipment, both in the laboratory and in the field.

The results show that it is possible to implement cost-effective monitoring systems and related installation technologies for integration into all new or existing buildings and CEIs.

K. Smarsly, E. M. Mthunzi, O. Hahn and J. Planer (2019), Validation of an ultra-low-cost wireless structural health monitoring system for civil infrastructure

In this article, we have introduced a wireless structure monitoring system that is very cheap and easy to install.

1) A prototype wireless SHM system consisting of off-the-shelf components with a total cost of less than € 30 was designed and implemented.
2) The software architecture of the wireless SHM system follows a modular and extensible design, enabling real-time acquisition, onboard data analysis, low power wireless communication, and IoT connectivity.

As a result, the wireless SHM system is very cheap, easy to install, and accurate enough to act as a "fast tester" for analyzing the behavior of civil engineering infrastructure *within short-term static monitoring campaigns. It has been proven to be.*

Pritam Paul, Nixon Dutta, Shuvam Biswas (2018), An Internet of Things (IoT) Based System to Analyze Real-time Collapsing Probability of Structures.with the help of Internet of Things (IoT).

The writer of the paper has proposed an answer of SHM,

1) That's each transportable and sturdy in nature.
2) Their proposed tool may be installed on a concrete beam, steel structure, slabs, bridge joints, gusset plates, beam column joints etc.
3) This tool measures the willing angles and analyses bends in which it`s installed and ship the statistics to telephone app via Bluetooth Low Energy (BLE) for real-time viewing.
4) It also can ship raw statistics to the cloud via a Wi-Fi module for destiny studies and analysis. This tool makes use of flex sensors to reveal the slightest bending from in which it's miles installed. Whenever, deformation takes place the tool offers alert to the population with the aid of using humming an alarm and lights the LED that's the final results of consistent tracking with none human interaction. All raw statistics are processed via in-constructed processor.

Seongwoon Jeong and Kincho H. Law (2018), An IoT platform for civil infrastructure monitoring.

This research paper describes an IoT platform tailored for engineering applications that applies an information modeling approach to promote data interoperability and integrate engineering information with sensor data.

1) In addition, the distributed data management framework allows data belonging to different project stakeholders to be shared between authorized users and software agents.
2) The IoT platform is demonstrated using civil engineering infrastructure monitoring scenarios that include different types of sensor data and technology models.

The results show that the IoT platform can facilitate information sharing and data use, especially for civil engineering infrastructure monitoring applications.

Seung Ho Kim, Han Guk Ryu and Chang Soon Kang (2018), Development of an IoT-Based Construction Site Safety Management System.

In this paper, writer have proposed an IoT-primarily based totally production webweb page protection control machine which may be operated at low fee in each small and large-scale production sites.

1) The improvement machine includes IoT-cones, the employee protection test devices, the cell gateways, the protection control server, and the cellphone utility of the protection manager.
2) The IoT-cones set up in chance zones discover the method of employees and outsiders, generate caution indicators with inside the chance zones while drawing near the chance zones, and offer the scenario to the production.
3) The proposed machine has been evolved with a prototype the use of ultrasonic sensors, embedded structures, such wi-fi verbal exchange structures because the Zigbee, Wireless Fidelity (WiFi), and Long Term Evolution (LTE).

Brinda Chanv, Sunil Bakhru, Vijay Mehta (2017), Structural Health Monitoring System Using IOT and Wireless Technologies.

This white paper outlines the status of current research on technology and implementation methods and attempts a comparative analysis.

1) This framework is designed to effectively monitor the current state of the building. Therefore, appropriate measures can be taken to prevent accidents.
2) This system helps governments issue early warnings of unwanted critical conditions to residents based on cloud data. Therefore, they can take legal action sooner before it collapses.
3) In the future, some parameters of the building can also be monitored using IoT-enabled devices or sensors to improve security. System prototypes can be used in a variety of applications such as environmental hygiene monitoring systems and greenhouse monitoring systems.

*Ahmed Abdelgawad and Kumar Yelamarthi (2017) Internet of Things (IoT)***,** Platform for Structure Health Monitoring**.**

This paper proposes a complete real-time IoT platform for SHM.

1) The proposed platform consists of a WiFi module, Raspberry Pi, DAC, ADC, buffer, and PZT. The two PZTs are attached to the structure and connected to a high speed ADC.
2) A buffer was used for level conversion and protection of the Raspberry Pi. The Raspberry Pi produces the excitation signal and the DAC converts it to analog.
3) We also used a Raspberry Pi to detect if the structure was damaged.
4) In addition, I used raspberries to send the health status of the structure to the internet server. The data is stored on a web server and can be monitored remotely from any mobile device.
5) The system was verified in a real test bench in the laboratory.

The results show that the proposed IoT SHM platform successfully verified that the seat was healthy with 0% error. In addition, the proposed platform has an error of up to 1.03% in damage position and up to 8.43% in damage width.

Ahmed Abdelgawad, Kumar Yelamarthi (2016), Structural Health Monitoring: Internet of Things Application

In this document, the full real-time SHM platform is integrated into the IoT system.

1) The proposed platform consists of ProTrinket, NRF module, WiFi module, and Raspberry Pi 2.
2) The proposed mathematical model is implemented

in ProTrinket to detect if the structure is normal.

3) If there is damage, ProTrinket will determine the location and extent of the damage. ProTrinket uses the nRF24L01 + module to send this information to the Raspberry Pi 2.
4) The Raspberry Pi 2 acts as a hub for collecting data from different locations within the structure. The Raspberry Pi 2 uploads data to the cloud via the WiFi module.
5) Data is stored in the cloud and can be viewed remotely from any mobile device. The system was validated in a real test bench in the laboratory.

The results show that the proposed platform has 1% error in identifying damage and 9% error in detecting the width of damage.

3. Problem Statement

Internet of Things (IoT) technology has become increasingly popular in recent years. However, the application of IoT technology in civil engineering is relatively unexplored. IoT technology can have a significant impact on engineering by leveraging cutting-edge information and communication technology (ICT).

However, in reality, it is difficult for IoT platforms to process domain-specific technical information (geometric models, technical simulation models, etc.) with different types of sensor data. Technical information and sensor data need to be integrated, shared, and interoperable with a variety of software tools in order for the data to be used effectively.

4. Methodology

The IoT monitoring system consists of four building blocks: sensor unit, communication backbone, server, and user device. A simplified representation of the system.

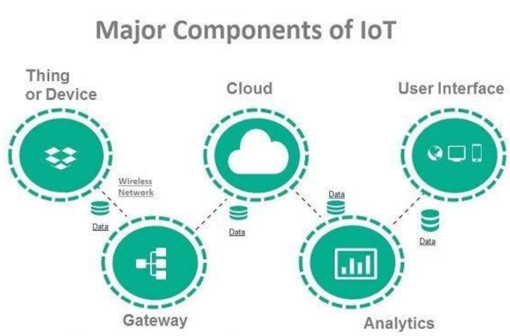

Fig. 3. Components of IoT

Design criteria:

Given that this system is intended for use in construction and civil engineering construction sites, there are four important factors to consider:

- *Robustness:* Construction and civil engineering sites are usually dusty and dirty outdoor environments from construction activities. Therefore, the sensor units and CCs placed at the site must be dustproof, waterproof, fireproof and able to withstand storms and possible impacts.
- *Security:* Typical construction sites are relatively chaotic during working hours. Wiring of equipment in the field, such as power supply and signal communication, should be kept to a minimum as it can interfere with worker activity and instead pose a potential hazard. The sensor unit and CC power supplies also require a safety mechanism to prevent overload and overheating.
- *Automation:* The surveillance system must be able to operate continuously with minimal maintenance without human intervention. Access to electricity at construction and civil engineering sites is difficult and often requires destructive wiring, so sensor units and CCs should ensure efficient energy management and low power consumption. It has to be designed to eliminate the need to charge the unit in the field. It is also compatible with energy harvesters.
- *Reliability:* A reliable connection between the sensor unit CC and the server is essential to enable continuous real-time monitoring. The system architecture ensures that the data transfer is fast enough so that the data is available immediately or with minimal time delay, the connection is interrupted at any time, and it can be automatically reestablished in a short time. is needed. In addition, the system architecture must be able to efficiently manage data traffic for system scalability and ensure data integrity across transmissions.

Necessity of IoT in Civil Engineering:

Buildings are the basis of social infrastructure and need reliable methods to monitor them. Ensuring their safety and efficiency is also very important. In general, structures include the placement of various elements such as columns, beams, and slabs.

1) People are investing heavily in civil engineering infrastructure. Appropriate structural reviews are needed for these infrastructures to analyze how old they are and whether they can withstand longer. Improving safety seems to be a strong motivation.
2) Over the last 20 years, more than 1700 people have died and more than 4000 have been injured in structural injuries. Predicting structural failures and monitoring the condition of structures can save millions of lives and save us from huge economic and economic losses. Therefore, it is important to continuously evaluate the condition of the structure. This is a great opportunity to use the latest technology to detect imminent structural damage.
3) During construction, it is difficult to ensure consistent quality and strength of different parts of the infrastructure. Therefore, it is important to measure caliper variability from section to section. If this variation is below a certain limit, the infrastructure can be considered undamaged. Exceeding this limit will cause damage. Exceeding a certain value will lead to failure.

Structural health monitoring (SHM) using IoT:

It refers to collecting important structural health parameters such as vibration, stress, moisture and cracks and analyzing this data to take precautions against potential future failures. The purpose of SHM is to provide a continuous diagnosis of the "state" of elemental materials, their various components, and the entire structure. This helps in the timely maintenance of the structure and extends the life of the building.

- SHM processes typically use appropriate sensors to monitor the entire structure for a period of time, extract damage-sensitive features from the measurements provided by the sensors, and analyze these features to analyze the current state of the structure.
- The structural health monitoring system involves the process of using sensors to measure various important parameters, collect these detections, perform analysis, and give correct response. This will prevent imminent accidents due to structural problems.
- The Internet of Things (IoT) represents a general concept of the ability of network devices to collect data with various sensors and share the collected data over the Internet. The IoT can be seen in three components: Internet-oriented (middleware), mono-oriented (sensors), and semantic-oriented (knowledge). The Internet of Things or IoT basically refers to the process of connecting an embedded system to the Internet.

The main objective of the proposed system is to know the integrity of the operational structure on a continuous real-time basis, providing the ability to maintain real-time building safety and increase durability. We detect and identify weaknesses and damage to infrastructure due to aging in a timely manner, and carry out preventive maintenance before collapse.

A. Proposed System

1) IoT

The proposed IoT platform architecture is designed to manage data collected from a variety of engineering data sources, including information models and sensor networks. The information model contains comprehensive information about the target system, including geometry, physical characteristics, functional characteristics, and sensor information. The sensor network, on the other hand, produces heterogeneous sensor data, from high frequency time series data to video and camera images.

The IoT platform consists of three basic layers: communication layer, mapping layer, and storage layer to support data storage and retrieval. In the data storage process, the communication layer handles communication with the data source.

Specifically, web servers and message brokers provide a standardized interface to the communication layer for receiving data from various data sources over the Internet. The mapping layer contains a data mapper that maps the received semi-structured information model to the database schema. The mapped data is passed to the storage tier. The storage tier contains a distributed database system that divides, replicates, and stores data.

Data stored in the distributed database of the IoT platform can be accessed and queried from a variety of applications such as data analysis tools, engineering analysis software, and 3D modeling tools through the user interface. For the data acquisition process, the web server provides a standardized web interface for the communication layer, which applications can use to retrieve data. When the application receives the request, the web server retrieves the data from the distributed database. If necessary, call the data mapper to remap the retrieved data to the standardized data schema of the information model. This schema can be parsed and used in a variety of applications. Finally, the retrieved data is delivered to the application.

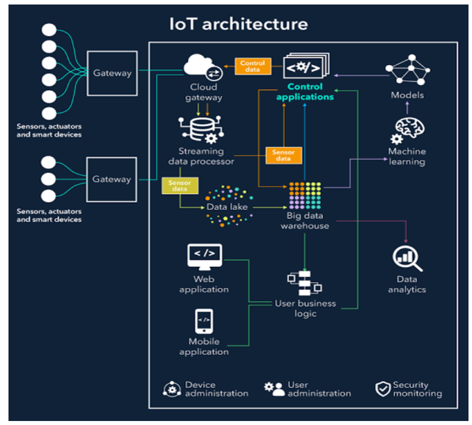

Fig. 4. IoT architecture

The proposed IoT platform will be deployed in cloud computing environments for scalability, accessibility, and reliability reasons. In particular, IoT platforms can be deployed with cloud-level Infrastructure as a Service (IaaS) (that is, virtual machines provided by the cloud). This makes platforms more portable between different cloud providers or between public, private, and hybrid clouds.

Necessary parts:

1. Arduino kit
2. Jumper wire
3. 1-10 ohm resistance
4. Force Sensitive Resistance (FSR)
5. 4-480 ohm resistor
6. 3 LEDs
7. Breadboard

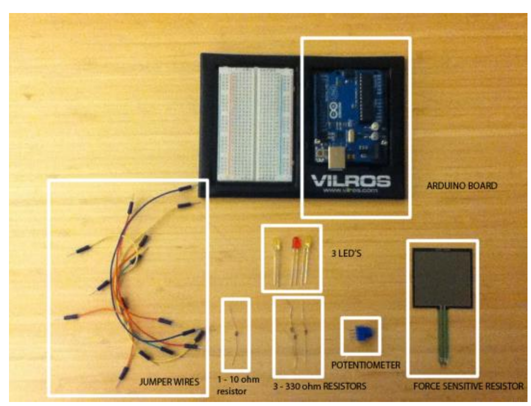

Fig. 5. Parts required

Apply a force sensitive resistor (fsr) to the breadboard. From there, place a 10-ohm resistor as shown, insert one end of the resistor in the same row as the black wire on the breadboard, and connect it to ground. Insert the jumper wire in the same row as the resistor and connect the other end of the jumper wire to pin A0 on the Arduino board. The "A0" pin is an analog pin that allows the sensor to communicate with the Arduino chip. Connect the second jumper wire from the sensor to the breadboard pins that connect to the 5V power supply in the Arduino kit (red wire).

Place the LEDs on the panboard. Once that is done, place a 330-ohm resistor from the negative end of the LED (short leg) to ground and a jumper wire from the positive end of the LED (long leg) to digital pin 9. Powered by information digitally provided by the sensor to the Arduino kit.

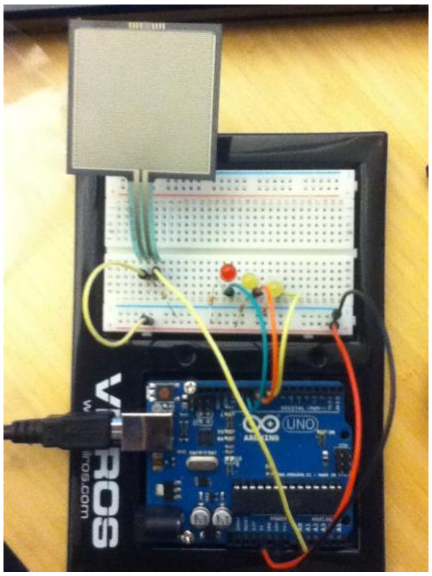

Fig. 6. Connected circuit

Arduino code:

```
//The following code was written with the reference of the online links mentioned below.
//https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr
//http://www.instructables.com/id/Force-sensitive-resistor-activated-led/
// Lets "declare" variables so that the computer knows
//about them when executing the code. We'll also need them so
//we can refer to them later.
//Variable names are case sensitive so type each name correctly
//whenever you refer to it.
int sensorPin = 0;      // force sensitive resistor connected to analog pin 0
int ledPin1 = 9;    //LED pin connected to digital pin 9
int ledPin2 = 10;    //LED pin connected to digital pin 10
int ledPin3 = 11;    //LED pin connected to digital pin 11
int sensorValue = 0;
void setup() // This funtion runs once the sketch starts up.
// We'll be using pin 9, 10 and 11 to light the LED so it's important
//to refer to it as an output. We've named it ledPin.
{
  Serial.begin(9600); // starting up your serial monitor to view varying values
  pinMode(ledPin1, OUTPUT);
  pinMode(ledPin2, OUTPUT);
  pinMode(ledPin3, OUTPUT);
}
void loop()   // This funtion runs repeatedly after setup()is completed
{
  sensorValue = analogRead(sensorPin); //reading the values from the analog pin of the sensor
  // and throwing it out as a value
  Serial.print("Force value = ");  //Display value "Force value"
  Serial.println(sensorValue);
    if(sensorValue &gt; 0 &amp;&amp; sensorValue &lt;= 500)
// an "if" statement giving a condition
//for the values that will allow you to switch between LED's.
{
digitalWrite(ledPin1, HIGH); // this is to say if the above statement is    // the LED should light up
}
else digitalWrite(ledPin1, LOW); // this is to say that if the above statement   //is not true the LED should turn or remain off.
 if(sensorValue &gt; 500 &amp;&amp; sensorValue &lt;= 800)
{
digitalWrite(ledPin2, HIGH);
}
else digitalWrite(ledPin2, LOW);
if(sensorValue &gt; 800)
  {
    digitalWrite(ledPin3, HIGH);
  }
  else digitalWrite(ledPin3, LOW);
}
```

After writing the code, connect the Arduino port to your computer and click the Upload icon (in the shape of an arrow) in the upper left corner of the interface (just below the edit menu). The Arduino circuit was fully functional and I could see the color of the LED lights change as the strength of the force changed.

This circuit is then applied to a prototype where the force sensor is connected to the pier and provides a signal that the LED display can interpret on the remote device as the load on the bridge starts increasing.

5. Limitations

Traditional civil engineering experiments developed in the laboratory include measurements of pressure, water level, acceleration, material properties, compression, beam deflection, etc.

In laboratories, these quantities are often measured very accurately using specialized equipment. Sophisticated user interfaces, typically developed by hardware vendors, allow you to collect information and visualize it in a meaningful way.

However, due to hardware and software costs and equipment limitations, the majority of students do not have access to the laboratory in the experimental form.

Reinforcement learning mechanisms, including learning automata models and cellular learning automata, are powerful tools in unfamiliar environments, so BSHM has some promising topics and important unsolved topics that need further attention and investigation in the coming years. I have a solution question. When using these compact, low-power, low-cost devices in the IoT streamline, some issues still need to be resolved. Robust communication must be ensured between peripheral sensors and the central facility responsible for data acquisition (database) and further processing of results. It is believed that it is possible to use batteries to power the system, so this aspect should also be taken into account for reliability in order to avoid interruptions in handling. This means that the hardware and software systems for communication and data management must be long-term reliable, given the need for permanent monitoring.

6. Result

The led indicator can be seen changing with increase in the load on the force sensors. This prototype can be used to demonstrate the use of IoT in civil engineering for site information in remote areas.

7. Conclusion

This project provides an exploratory approach to the many possibilities that civil engineering raises in terms of Internet of Things, automation, monitoring, and control of civil engineering situations.

The tools used represent accessible and affordable options for use in classrooms and educational laboratories for beginners.

i. The first exploratory approach means the integration of the three domains.
ii. Systematic use of digital manufacturing technology and electronic prototyping platforms.
iii. A creative and visual way to develop the code provided by the block-based development platform. This integration of perspectives is an attempt to introduce a rigorous scientific approach to civil engineering mathematics into technology and art.

References

[1] Donato Abruzzese, Davide Bracale et. Al (2021), Permanent Monitoring of thin structures with low-cost devices.
[2] S. Jeong, K. Law, "An IoT Platform for Civil Infrastructure Monitoring," 2018 IEEE 42nd COMPSAC, Tokyo, 2018.
[3] S. Hou, G. Wu, “A low-cost IoT-based wireless sensor system for bridge displacement monitoring”, Smart Mat. Struct., 2019.
[4] M. Cosentino, “Il Controllo strutturale permanente attraverso sensori nativi”, MS Thesis (in Italian), Univ. of Rome Tor Vergata, 2017.
[5] D. Forconi, “Sistema di monitoraggio strutturale per l’edilizia storica in muratura tramite reti wireless a controllo remoto”, MS Thesis (in Italian), Univ. of Rome Tor Vergata, 2018.
[6] Suseela Alla, S. S. Asadi (2020), Integrated methodology of Structural health monitoring for civil structures.
[7] Donato Abruzzese, Andrea Micheletti et.al (2020), IoT sensors for Modern structural health monitoring. A new frontier.
[8] K. Smarsly, E. M. Mthunzi, O. Hahn and J. Planer (2019), Validation of an ultra-low-cost wireless structural health Monitoring system for civil iinfrastructure
[9] I. F. C. Smith, C. Alberto, “Cyber civil infrastructures”, chapter in Future Cities Laboratory: Indicia 02, Lars Müller Publishers, 2019.
[10] Pritam Paul, Nixon Dutta, Shuvam Biswas (2018), An internet of things (IoT) based system to analyze real-time collapsing probability of Structures.
[11] Seongwoon Jeong and Kincho H. Law, (2018), An IoT platform for civil Infrastructure monitoring
[12] M. A. Mahmud, K. Bates, T. Wood, A. Abdelgawad and K. Yelamarthi, "A complete Internet of Things (IoT) platform for Structural, Health.
[13] Seung Ho Kim, Han Guk Ryu and Chang Soon Kang (2018), Development of an IoT-based construction site safety management system.
[14] Brinda Chanv, Sunil Bakhru, Vijay Mehta (2017), Structural Health monitoring system using iot and wireless technologies.
[15] Ahmed Abdelgawad and Kumar Yelamarthi (2017), Internet of Things (IoT) platform for structure health monitoring.
[16] Ahmed Abdelgawad, Kumar Yelamarthi (2016), Structural health Monitoring: Internet of Things application.
[17] Y. Lu, H. Ma, Z. Li, “Civil Infrastructures Connected Internet of Things”, Current Adv. Civ. Eng., 2(1), 2014. Monitoring (SHM)," 2018 IEEE 4th WF-IoT, Singapore, 2018.