Structural health monitoring using IOT embedded system

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***Abstract* —As we are getting better and better with integrating technology in our day today life. So is the field of civil engineering. To make this more better and advance in both technical and reliable aspects, we have proposed a integration of IOT(INTERNET OF THINGS) based embedded system into construction industry for Structural health monitoring and assessment, we have built a prototype of a IOT embedded system using series of small single board computers (SBCs) Tensilica L106 32-bit RISC processor and load cell sensors, to monitor the live load on the structural elements of the bridge. In this paper we have given a detailed overview of the system and its working.**

Index Terms—Internet of things, Load cells, Single board computer, Structural health monitoring, Tensilica L106 32-bit RISC processor.

I. INTRODUCTION

IOT

According to institution of Research Projects in Europe, "Internet of Things (IoT) is an unified a part of outlook net and might be described as a colourful prevalent set of connections with self-armature potentials standard for usual plus interoperable message etiquette anyplace corporeal plus implicit "things" have identity, fabric impute, in addition to implicit disposition at the side of clever interface, which can be perfectly integrated into the records network".

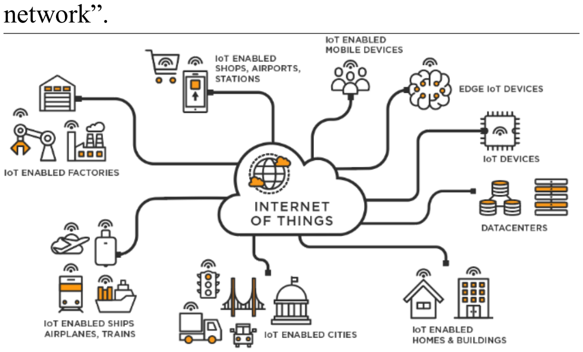

Fig. IOT and It's Widespread Network

The connection hyperlink among the Internet and bodily matters make to be had to admittance the manage over bodily matters from well-described or feasible distance below not unusual place infrastructure and to accesses the sensor data. 'Smart matters/objects' performs crucial function with inside the Internet of Things which have interaction and talk the statistics and additionally it's miles feasible to alternate database through the use of the Internet. A huge Network will broaden through Internet of Things with wide variety of wi-fi perceptible "matters" interactive with each other and taking part the developments. The Ambient Intelligence, insidious computing and omnipresent computing ideas are essentially followed withinside the IoT depicts the concurs of the population and possessions that may be related at any given time, at any place, with any person, the use of a few community plus a few broadband utility.

Technology and infrastructure

The design of internet of Things ought to be made on top of a network frame that assimilates cabled and mobile technology in an exceedingly clear yet as unified form. The vision of IoT, property between the physical world and net may be happy by the oftenness Identification (RFID), Short domain mobile technology and detector networks. currently days more analysis goes on the Wireless network technologies which has capability to deliver obscure wire-free communication. varied technology should be provided for the gathering of information concerning the physical issue (Environment) and therefore the effective object monitoring. The relevance and interaction between the Physical Things associated net ought to be complete by putting in acceptable software package to manage the network through fully its resources, devices and distributed services. within the case of failure of system, the software should manage and forecast the self configuration and auto-recovery. once shaping a correct technology and software the hardware choice becomes troublesome task in IoT. The analysis still is needed to develop hardware having radical, little energy, multi-purpose structure on a section which will have the flexibility of self-adaptiveness and self organization. The devoted formula may be employed in the chip set of hardware system with an ultra-low power very large scale integrated (VLSI) circuits

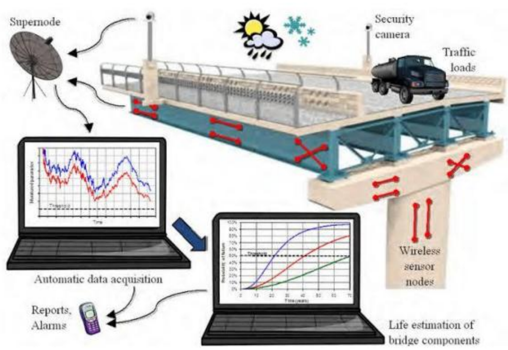

Fig. 1. IOT in Construction Sector

Construction Sector

The construction business has perpetually been encumbered by accidents and failures. whereas variety of construction accidents are thanks to workers' carelessness and might be eased by properly following preventative measures, ruinous failures resembling explosive collapse of buildings and structures are a lot of more durable to observe and prevent. albeit tight safety codes of practice and rules are put in place, structural failures still occur from time to time. The collapse of an industrial building throughout demolition works in urban center killed half dozen workers and contused ten others in 2001; downfall and unseaworthy underground water pipes led to the collapse of a wall in Hong Kong, triggering a landslide that killed five and harmed three pedestrians in 1994; and an house in Shanghai primepled over and killed a employee in 2009 thanks to excavation work with depleted observance of ground movement. On top of injuries and casualties, such failures additionally incur large economic losses. this means that current codes of follow and regulations, that are supported existing technologies, still ought to be improved to higher forestall structural failures.

Pre Requisite of Failure

Prior to a structural failure, there'll generally be a transition amount throughout that structures exhibit abnormal changes. For example, abnormal changes of the load on, and verticalness (inclination) of, supporting members of a structure are signs that the structure is losing stability. Similarly, abnormal changes will occur in underground formation level. These changes eventually intensify to exceed safety limits and at last lead to structural failures. If abnormal changes are often detected and analyzed quick enough, acceptable warning signals can be issued timely and remedial measures can be administered in time. in an exceedingly worse scenario, there will still be enough time for evacuation to stop injuries and casualties. Thus, continuous period observation is important in preventing accidents because of structural failure.

Monitoring

Monitoring works have forever been AN integral a part of construction and civil engineering. Common observation necessities embrace however don't seem to be restricted to underground groundwater level level, support force, ground movement, settlement and tilt of structures, and harmful gases. this monitoring apply for underground water table level usually involves a technician inserting a water level sensing element into a stand pipe at the development site to require readings. Measurements are typically taken at the most doubly on a daily basis even throughout important work amounts and so fluctutations during the interim period can't be detected. Similarly, monitoring works for ground movement, settlement, and tilt are still conducted by site surveys and ancient mensuration methods. As such, measurements are seldom taken over once per day. As traditional practices are labor-intensive, conducting observation ceaselessly with these practices isn't possible as labor prices would be disproportionately high. In addition, their long nature additionally prevents readings to be accessible in real time. whereas knowledge loggers are able to cut back the specified manpower, they're withal still unable to supply realtime process and analyses as there's a substantial wait for data to be retrieved.

Srucutural health monitoring (SHM)

SHM could be a nondestructive analysis technique to watch the integrity of civil structures corresponding to bridges, aircraft, and so on Since the gradual deterioration of structures will happen for various reasons, such as continuous exposure to the inclement weather, overloading, etc., SHM is a very important tool to be enforced in previous buildings, bridges, etc., to confirm the protection of human beings. though researchers from different discipline took different approaches for SHM, most of the works during this field were done using civil and mechanical engineers' approach. Their works concerned largely to research natural frequencies of structures to form decisions. However, in this paper, the chosen approach was to develop a way to {analyze |to research| to investigate} signals (electrical) and implement the projected technique on an embedded platform.

Structural Health monitoring (SHM) is turning into an important analysis topic to boost the human safety and to scale back maintenance costs. However, most of the prevailing SHM systems face challenges working at time period because of environmental effects and totally different operational hazards. Furthermore, the remote and constant monitoring amenities aren't established yet, properly. to beat this, net of Things (IoT) may be used, which might offer flexibility to watch structures (building, bridge) from anyplace.

II. LITERATURE REVIEW

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

In this analysis article, the author wanted to observe stress in skinny structures employing a small, cheap device.

1) This device will record the load history. At key points, send alerts as required to confirm security against the chance of collapse, or just to perform maintenance / repair work.

2) Such devices are mounted victimisation inexpensive ready-to-wear natural philosophy and standard strain gauges.

3) Application examples are shown as laboratory tests for concrete slabs, masonry slabs, and steel beams.

The results show that permanent observation of stress in new structures will be handily performed victimisation low price devices adore those we tend to designed and enforced ourselves.

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

the most goal of this work is to convey the SHM methodology. this can be as a result of SHM doesn't have a transparent methodology for deciding structural dependability and longevity.

1) Therefore, this paper contains the projected methodologies of work. Structural health monitoring are condemned for building renovations.

2) Basic talents have typically been consistently assessed victimisation exposure estimates.

3) Most studies performed heap score estimates over a clear, discrete, unpredictable amount determined by scaffold stacking and boundary changes.

3) Donato Abruzzese, Andrea Micheletti et.al (2020) IoT sensors for contemporary structural health observation. a replacement frontier. The long-run goal of this study is to alter wireless, inexpensive devices and knowledge management code for building condition monitoring and CEI.

1) Use remote sensors embedded in or hooked up to structural members to live stress yet as acceleration.

2) Equipped with such a system, any structure will become a part of the web of Things and alert users and authorities if the structure becomes less secure or endangered.

3) a crucial side is that the chaotic storage of measure data over time. It cannot believe entirely on third parties and needs the utilization of acceptable knowledge protection technology.

4) This study was conducted through experimental testing and verification of developed and enforced observation equipment, each within the laboratory and in the field. The *results show that it's doable to implement efficient monitoring systems and connected installation technologies for integration into all new or existing buildings and CEIs.*

4) 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've got introduced a wireless structure watching system that's the lowest and straightforward to install.

1) A model wireless SHM system consisting of ready-to-wear parts with a complete price of under € thirty was designed and implemented.

2) The code design of the wireless SHM system follows a standard and extensile design, enabling period acquisition, aboard knowledge analysis, low power wireless communication, and IoT connectivity. *As a result, the wireless SHM system is incredibly cheap, easy to install, and correct enough to act as a "fast tester" for analyzing the behavior of engineering science infrastructure among short-run static watching campaigns.*

5) Pritam Paul, Nixon Dutta, Shuvam Biswas (2018) An internet of Things (IoT) primarily based System to research period of time Collapsing chance of Structures.with the assistance of Internet of Things (IoT).

the author of the paper have planned a solution of SHM

1) that' every moveable and durable in nature.

2) their proposed tool is also put in on a concrete beam, steel structure, slabs, bridge joints, gusset plates, beam column joints etcetera

3) This tool measures the willing angles and analyses bends within which it`s installed and ship the statistics to phonephone app via Bluetooth Low Energy (BLE) for real-time viewing.

4) It can also 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 within which it' miles installed. Whenever, deformation takes place the tool offers conscious of the population with the help of mistreatment buzzing an alarm and lights the diode that' the ultimate results of consistent trailing with none human interaction. All raw statistics are processed via in-constructed processor.

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

This analysis paper describes associate IoT platform tailored for engineering applications that applies an info modeling approach to market information ability and integrate engineering information with sensing element data.

1) In addition, the distributed data management framework permits data happiness to totally different project stakeholders to be shared between approved users and software system agents.

2) The IoT platform is incontestible mistreatment technology infrastructure monitoring situations that embody differing kinds of sensor data and technology models. The

results show that the IoT platform will facilitate info sharing and information use, particularly for technology infrastructure observation applications.

7) Seung Ho Kim, Han Guk Ryu and Chang Soon Kang (2018), Development of associate IoT-Based Construction website Safety Management System. during this paper, author have planned an IoT-primarily primarily based altogether production webweb page protection management machine which can be operated at low fee in every tiny and large-scale production sites.

1) the development machine includes IoT-cones, the worker protection take a look at devices, the cell gateways, the protection control server, and therefore the wireless telephone utility of the protection manager.

2) The IoT-cones established in chance zones discover the tactic of workers and outsiders, generate caution indicators withinside the prospect zones whereas forthcoming the chance zones, and provide the situation to the production.

3) The planned machine has been evolved with a image the utilization of inaudible sensors, embedded structures, such wi-fi communication structures as a result of the Zigbee, LAN (WiFi), and long run Evolution (LTE).

8) Brinda Chanv Prof. Sunil Bakhru Prof. Vijay Mehta (2017) Structural Health observance System exploitation IOT and Wireless Technologies.

This written report outlines the standing of current analysis on technology and implementation strategies and makes an attempt a comparative analysis.

1) This framework is meant to effectively monitor the present state of the building. Therefore, acceptable measures are often taken to stop accidents.

2) this technique helps governments issue early warnings of unwanted crucial conditions to residents supported cloud data. Therefore, they'll take proceedings sooner before it collapses.

3) within the future, some parameters of the building can also be monitored exploitation IoT-enabled devices or sensors to enhance security. System prototypes are often employed in a range of applications reminiscent of environmental hygiene observance systems and greenhouse monitoring systems.

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

This paper proposes an entire time period IoT platform for SHM.

1) The projected platform consists of a WiFi module, Raspberry Pi, DAC, ADC, buffer, and PZT. the 2 PZTs are hooked up 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 {also the} DAC converts it to analog.

3) we have a tendency to also used a Raspberry Pi to sight if the structure was damaged.

4) In addition, I used raspberries to send the health standing of the structure to the net server. the information is hold on on an online server and may be monitored remotely from any mobile device.

5) The system was verified during a real check bench within the laboratory.

The results show that the projected IoT SHM platform with success verified that the seat was healthy with 0% error. In addition, the proposed platform has a slip-up of up to 1.03% in harm position and up to 8.43% in damage breadth.

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

during this document, the total period of time SHM platform is integrated into the IoT system.

1) The projected platform consists of ProTrinket, NRF module, WLAN module, and Raspberry Pi a pair of.

2) The proposed mathematical model is enforced in ProTrinket to notice if the structure is normal.

3) If there's damage, ProTrinket can verify the location and extent of the damage. ProTrinket uses the nRF24L01 + module to send this info to the Raspberry Pi 2.

4) The Raspberry Pi 2 acts as a hub for grouping knowledge from totally different locations within the structure. The Raspberry Pi a pair of uploads data to the cloud via the WLAN module.

5) knowledge is keep within the cloud and may be viewed remotely from any mobile device. The system was valid in a very real check bench in the laboratory.

The results show that the projected platform has 1% error in distinctive damage and 9% error in detection the breadth of damage.

III. PROBLEM STATEMENT

Internet of Things (IoT) technology has become more and more common in recent years. However, the applying of IoT technology in applied science is comparatively unexplored. IoT technology will have a big impact on engineering by leverage newest information and communication technology (ICT).

However, in reality, it's tough for IoT platforms to method domain-specific technical information (geometric models, technical simulation models, etc.) with differing types of sensing element data. Technical information and sensor data got to be integrated, shared, and practical with a sort of package tools so as for the info to be used effectively.

IV. METHODOLOGY

Design concerns Bearing in mind that the system is to be employed in construction and applied science sites, there are four key factors that require to be taken into thought:

• Robustness

Construction and technology sites are generally out of doors environments with countless mud and dirt thanks to construction activities. The sensing units and CCs placed at sites can so ought to be dust-proof, waterproof, hearth resistant, and be ready to stand up to storms and potential impacts.

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• Automation.

The observation system has to be ready to operate incessantly while not human intervention and with minimum maintenance. Since access to wattage in construction and technology sites is troublesome and sometimes needs obtrusive wiring, sensing units and CCs can then ought to be designed to realize economical power management and low power consumption such the requirement to charge units on site are minimum, and might conjointly accommodate energy harvesters.

• Reliability.

Reliable property between the sensing unit, CC, additionally the server is crucial to modify continuous and time period monitoring.

The system design has to make sure that information transmission is quick enough such data is on the market outright or with token postponement which connection, if interrupted at any point, will be mechanically reestablished at intervals a brief time. Furthermore, the system architecture needs to be ready to with efficiency manage data traffic for the system's measurability and also guarantee data integrity throughout transmissions.

Structural health monitoring (SHM) using IOT

It refers to grouping vital structural health parameters like vibration, stress, wet and cracks and analyzing this knowledge to require precautions against potential future failures. the aim of SHM is to supply endless identification of the "state" of elemental materials, their varied components, and therefore the entire structure. This helps within the timely maintenance of the structure and extends the life of the building.

• SHM processes usually use applicable sensors to watch the whole structure for a amount of time, extract damage-sensitive options from the measurements provided by the sensors, and analyze these features to investigate the present state of the structure.

• The structural health observance system involves the method of victimisation sensors to live varied vital parameters, collect these detections, perform analysis, and provides correct response. this can stop impending accidents thanks to structural problems.

• the web of Things (IOT) represents a general conception of the flexibility of network devices to gather knowledge with various sensors and share the collected data over the Internet. The IOT are often seen in 3 components: Internet-oriented (middleware), mono-oriented (sensors), and semantic-oriented (knowledge). the web of Things or IoT primarily refers to the method of connecting AN embedded system to the Internet.

the most objective of the planned system is to understand the integrity of the operational structure on endless period of time basis, providing the flexibility to take care of real-time building safety and increase durability. we have a tendency to observe and establish weaknesses and injury to infrastructure thanks to aging in a timely manner, and perform preventive maintenance before collapse..

The planned IoT platform is deployed on a cloud computing atmosphere for scalability, accessibility and reliability. Specifically, the IoT platform are often deployed on the Infrastructure as a Service (IaaS) layer of cloud (i.e., virtual machines offered by cloud) , that assures platform movability across totally different cloud vendors or among public cloud, non-public cloud and hybrid cloud. The system is developed using device unit which consists of Load sensor

➢ (Accelerometer-ADXL345),

➢ Strain sensor (BF350 3AA),

➢ Moisture sensor;

➢ Data acquisition and processing unit which includes Arduino Uno and Wi-Fi module(ESP8266) that process and transfer sensed data on cloud.

➢ Data collected by Arduino Uno is also given to the visual studio for locally storing data and visualizing data on the bar chart form.

➢ This stored data is accessed by users. This enables user to check current state of the building and take necessary steps toward it.

➢ Alert will be given for initiating preventive maintenance service if emissions caused by structures are beyond reasonable limits.

Outputs of all the three transducers (accelerometer, strain sensor, moisture sensor) are given to the Arduino Uno microcontroller. This microcontroller takes continuously 128 readings and takes average of 128 readings. This output is further given to the ESP8266 Wifi module for sending it to the cloud over the internet for doing analysis on it. The output of Arduino Uno is also given to the Vb.net desktop application for real-time analysis on data.

V. PROTOTYPE

A. IOT Embedded System

The projected IoT platform design is meant to manage information collected from a spread of engineering data sources, as well as information models and sensing element networks. the data model contains comprehensive information regarding the target system, including geometry, physical characteristics, practical characteristics, and sensor information.

- Necessary parts
1. Arduino kit
2. Jumper wire
3. The HX711 amplifier module with the 50kg load cells

Fig. 2 load cells

4. An Arduino Uno or Uno compatible board
   Or an Arduino Nano or Nano compatible board
5. Two 1k resistors if you want to create the single-cell circuit
6. Tensilica L106 32-bit RISC processor

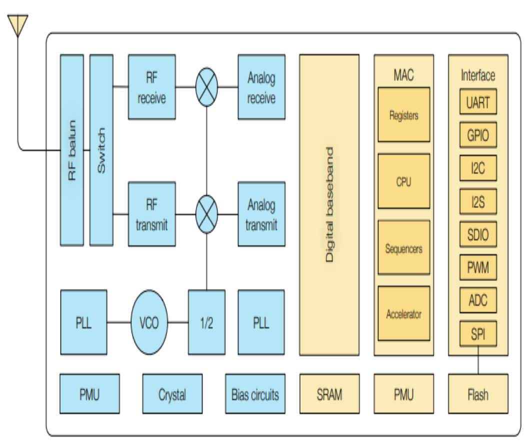


Fig. 5 Functionality of ESP8266EX

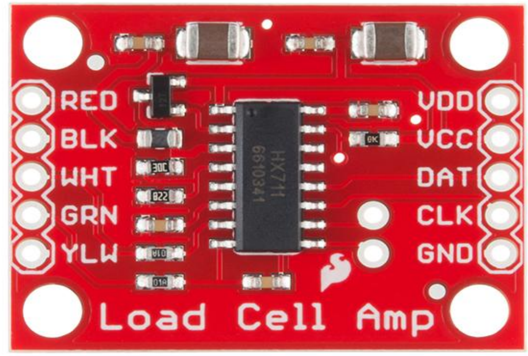
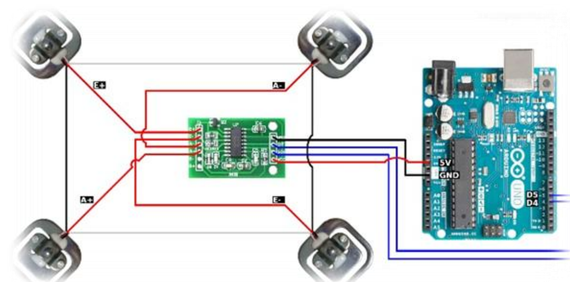


Fig. 3 HX711 module

- software used
  1. Arduino IDE
  2. Blynk Interface

- Language



1. Embedded C

Fig. 4 Circuit Diagram For IOT

Codes For Processor

```
#define BLYNK_TEMPLATE_ID
"TMPLkrd_BxfX"
#define BLYNK_DEVICE_NAME "Weight
Monitor"
#define BLYNK_AUTH_TOKEN
"OBwqk2IC63K6KnCnLkd4otu3D8zbpPlR"
#include "HX711.h"
#include <ESP8266WiFi.h>
#include <Blynk.h>
#include <BlynkSimpleEsp8266.h>
#define BLYNK_DEBUG
#define BLYNK_PRINT Serial
BlynkTimer timer;
char auth[] =
"OBwqk2IC63K6KnCnLkd4otu3D8zbpPlR";
const char *ssid = "M52 5G"; // replace with your
wifi ssid and wpa2 key
const char *pass = "xmhu9496";
```

```
WiFiClient client;

// HX711 circuit wiring
const int LOADCELL_DOUT_PIN = 14;
const int LOADCELL_SCK_PIN = 12.;

HX711 scale;
float weight;
float m;
float s=0;
float newton;
float calibration_factor = 6942.00;
float z = (2.91*0.000001);

void setup() {
 Serial.begin(115200);
 Blynk.begin(auth,ssid,pass);
 scale.begin(LOADCELL_DOUT_PIN,
LOADCELL_SCK_PIN);
 scale.set_scale();
 scale.tare();
 long zero_factor = scale.read_average();

 Serial.println("Weighing scale");
}
void loop() {
 Blynk.run();
 scale.set_scale(calibration_factor);
 weight = scale.get_units(5);
 newton = weight*9.81;
 m = (newton*0.3)/4;
 s = (m/z)/1000;
 if(newton > 0)
 {
  Serial.print("Measured Weight in Newton: ");
  Serial.print(newton);
  Serial.println("N");
 }
 else
 {
 Serial.print("Measured Weight in Newton: 0");
 Serial.println("N");
 }
 Blynk.virtualWrite(V0, newton);
 BLYNK_LOG("%d",newton);
 if(s > 0)
 {
  Serial.print("Stress Measured in N/m2 is: ");
  Serial.print(s);
  Serial.println("N/m2");
 }
 else
 {
  Serial.print("Stress Measured in N/m2 is: 0");
  Serial.print("KN/m2");
 }
 Blynk.virtualWrite(V1, s);
 BLYNK_LOG("%d",s);
}
```

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

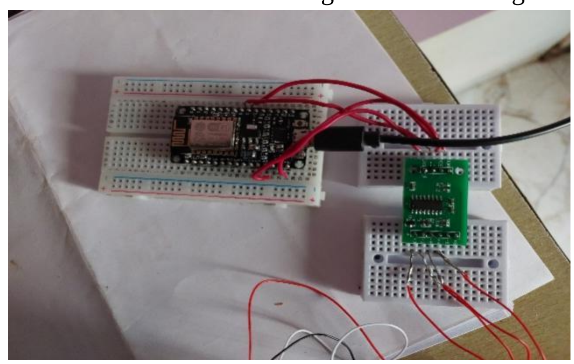


Fig. 6 Actual IOT system

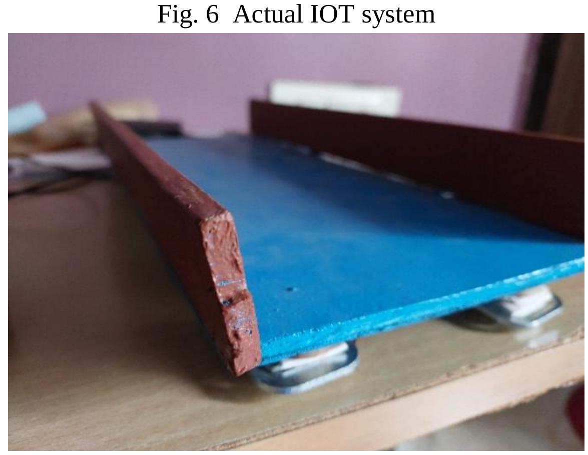


Fig. 7 Bridge With Load Cells on Pier

VI. RESULTS

The results obtained by System And Results Calculated Manually Are

Sr.no.	Load (N)	Stresses on Bridge(KN/m^2)	
		calculated	observed
1	10	171.42	172
2	20	514.297	514
3	30	771.446	771.5
4	40	1028.59	1029

Manual Calculations
Dimensons For Bridge
Length = 0.3m
Breadth = 0.14m
Depth = 0.05m
$Z = (BD^3)/6$
$Z = 2.9166 * 10^{-6}\ m^4$
M (Max Bending Moment with point load) = WL/4
For W(Point Load)= 10N
M = 10*0.3/4
M = 0.5 Nm
σ (Max Stress) = M/Z
$\sigma = 0.5/(2.9166*10^{-6})$
$\sigma = 171.42\ KN/m^2$

VII. CONCLUSION

This project provides an explorative approach to the various potentialities that technology raises in terms of internet of Things, automation, monitoring, and management of civil engineering situations.

The tools used represent accessible and reasonable choices to be used in school rooms and instructional laboratories for beginners.

By observant Calculation we are able to Conclude the The planned system provided reliable results. This integration of views is an endeavor to introduce a rigorous scientific approach to civil engineering arithmetic into technology and art.

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