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Highway Bridges Monitoring System Using Wireless Sensor

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Abstract:-**As smart sensor networks and geographical information systems (GIS) are evolving nowadays, applications of remote monitoring in wide spread geographical areas are becoming cost-effective and possible. An example of such applications is the structural health status monitoring of highway bridges that connect roads in both rural and urban areas. Many of these bridges are subject to deterioration due to external and internal factors. Online, real-time structural health monitoring is a resourceful complimentary tool to facilitate rapid field inspection. Bridge maintenance and infrastructure managers can easily use this application to safeguard the performance and safety of these vital structures. This project presents an autonomous sensor network system to monitor structural health in highways bridges. The proposed system consists of Accelerometer, flex sensor, load cell, buzzer, GSM module and wifi . The sensors gather the bridge health signs and transmit them promptly via GSM and wifi to the management and evaluation middleware for further processing. Based on the national bridge inventory rating scale, an early warning fuzzy logic based engine is developed to process the status of a given bridge and alert the concerned operator/s regarding any abnormality. A prototype was built in the laboratory to validate the proposed system. Analysis of testing results and comparisons with existing monitoring systems are also discussed. Operators can access the bridge real-time data through mobile phone. The system is cost effective and user friendly**.

Keywords:-Accelerometer, flex sensor, load cell, buzzer, GSM module and wifi

I. INTRODUCTION

Structures, including pipelines, aircraft, ships and civil infrastructures, such as bridges, buildings, dams, among others, are major parts of society's economic and industrial success. Bridges are one of the critical cross points of a country's transport network but they are expensive to build and maintain. Bridges suffer overall structural deterioration due to aging, overloading and lack of proper maintenance. Therefore bridges are expected to have a higher level of reliable inspection and condition assessment to protect human lives and economic activities from unsafe bridge structures. At present, visual inspections are the most common practice used to monitor the structural integrity of bridges . Mostly, this basic technique has proven to be inadequate to ensuring bridge safety because it doesn't provide enough information to prevent the structure's failures. As Sensor Networks are evolving in the past decade and becoming more cost effective; civil engineers with their counterparts in sensing and communications technologies are seizing the opportunity to design, build and implement continuous health monitoring tools for bridge systems. Many recent studies were focused in developing wireless sensor nodes and platforms for highway bridges. A structural health monitoring system of bridges using bias magnetic field sensor, signal conditioning circuits and impulse radio ultra –wideband transmitter was described. Moreover, a wireless measurement system using wireless sensor network for large bridges was developed. This latter system consists of a build-in Micro-Electro Mechanical Systems (MEMS) accelerometer signal conditioning circuit, microcontroller chip, and central station. The bridge vibration frequency was measured using a pendulum. In-house software algorithm is developed to analyze the accelerometers that reflect the structure vibration. Several others wireless sensor networks based monitoring systems centered as short range communication and other long range communications were repeated. The differences among these systems are the data processing and the analysis algorithms to determine the health of the structure (damage detection algorithm). Some of these algorithms are based on the dynamic index method , static displacement, or static curvature. Others applied wavelet analysis, mode shape and neural networks. Others used the expanded damage detection methods to enhance the monitoring accuracy utilized genetic algorithms and Hilbert Huang Transfer (HHT). To complement the above mentioned systems, a real-time online remote wireless bridge monitoring system is proposed in this project. The system collects the sensor's data from an bridge; evaluates the bridge health status. Information with health history data is provided promptly for bridge safety assessment, to help owners and maintenance authorities make decisions in assigning maintenance budgets. The overall proposed health monitoring system comprises of hardware architectures. The hardware architecture is mainly designed for the data collection process, communications, and data storage. These conditions are classified based on the existing National Bridge Inventory (NBI) rating scale, which is a database used for highway management and resource allocation. Another added value to the proposed system is the early warning indicators by using GSM and wifi module.

Motivation

- At least 23 people have been killed after a bit of an under-construction overpass collapsed in a crowded space of the jap Indian city of Kolkata . Ponte Morandi motorway bridge collapse in Italy as a result of structural defect -43 dead. Not just these two but there are numerous mishaps as a end result of structural defects. To avoid these accidents a system is required which will detect the structural defects and ship the details about the defect to the central control system.

- Many long-span bridges worldwide have already applied such techniques however excessive preliminary price and maintenance along with wired constructions have created severe issues as a outcome of which the desire to utilize traditional methods nonetheless persists.

- If there would be a system which will indicate defects in the bridge, the lot of number of mishaps could possibly be avoided

Background

Bridges are critical in lots of regions, getting used over the centuries for transportation of products, humans and for viewing scenic beauty. Hence this makes it essential to have a system which constantly monitors the structural well being of the bridge and provides needed updates concerning any issues to the concerned authorities and that too in actual time.

Current advancements in sensing applied sciences and the rise of IOT have led to the event of automated bridge-monitoring techniques. Many lengthy span bridges worldwide have already applied such methods but excessive initial value and maintenance along with wired structures have created serious points as a outcome of which the desire to utilize traditional strategies still persists. In this project the idea of IOT primarily based bridge health monitoring is proposed. Different types of sensors hooked up to the bridge input various parameters similar to vibration, shocks, extreme temperatures and flood level, course of them utilizing microcontrollers according to the set threshold and eventually send the readings wirelessly utilizing RF transmitters. For the prototype bridge maintenance, we are designing a model which contains sensors which reads the value and compare them also sends the values to the maintenance officers. The system is able to generate the buzzer at the critical situation. The interface might be opened on any digital system with lively internet connection.

Objective and Scope of the Project

The objectives and Scope of this project are as follows

- To design and develop a sensor interface to detect and inform the base station of bridge structural health monitoring.
- To develop a system for Monitoring and analysis of bridge safety.
- To develop a IOT primarily based web application to access information on internet.

II. HARDWARE

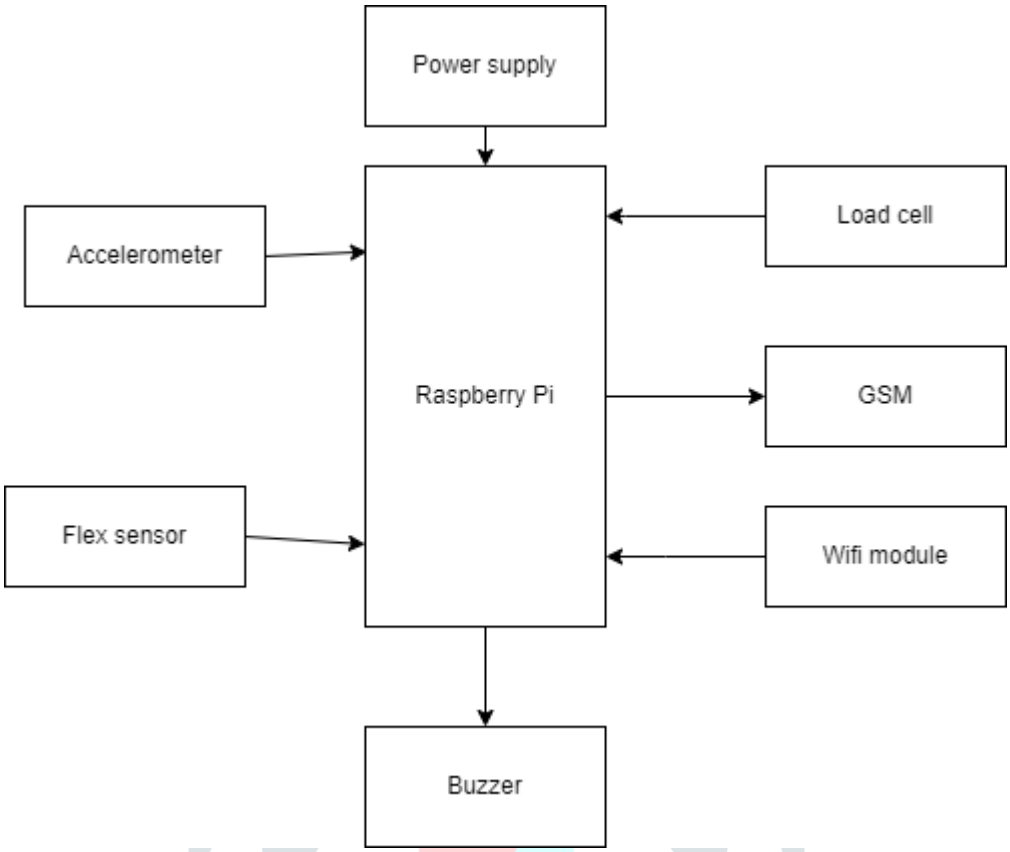


Figure. Block Diagram

Block diagram components

1) Power supply
2) Raspberry Pi
3) Accelerometer
4) Flex sensor
5) Load cell
6) GSM
7) Wifi module

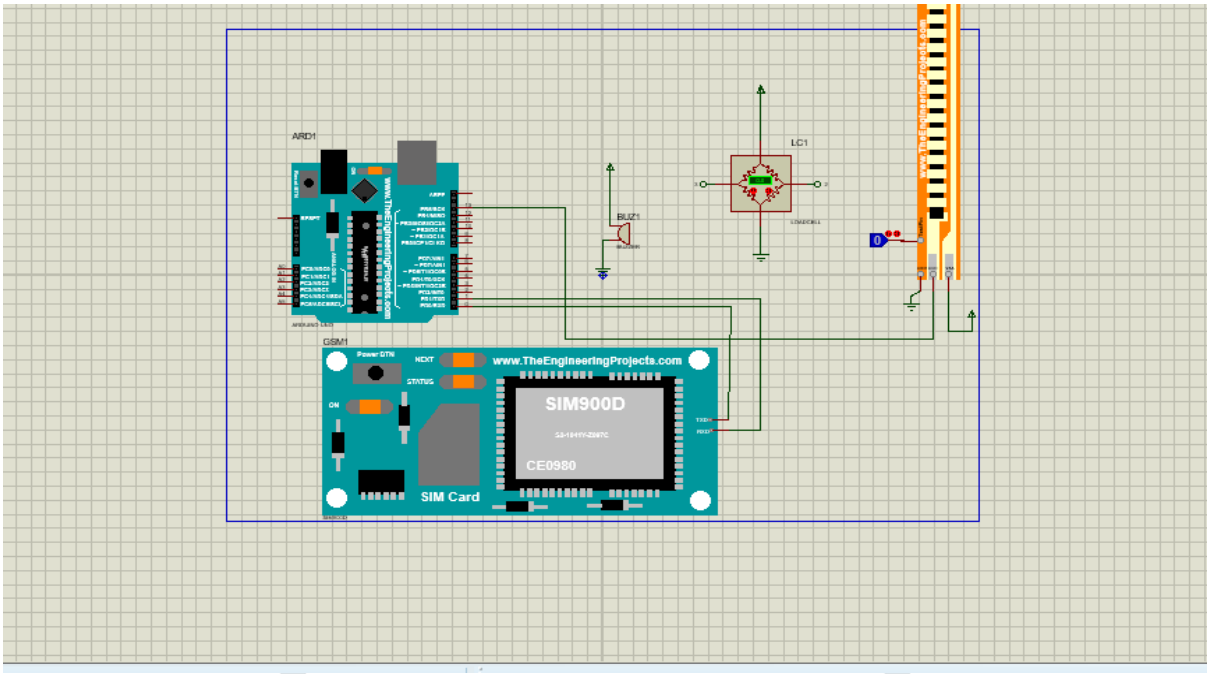
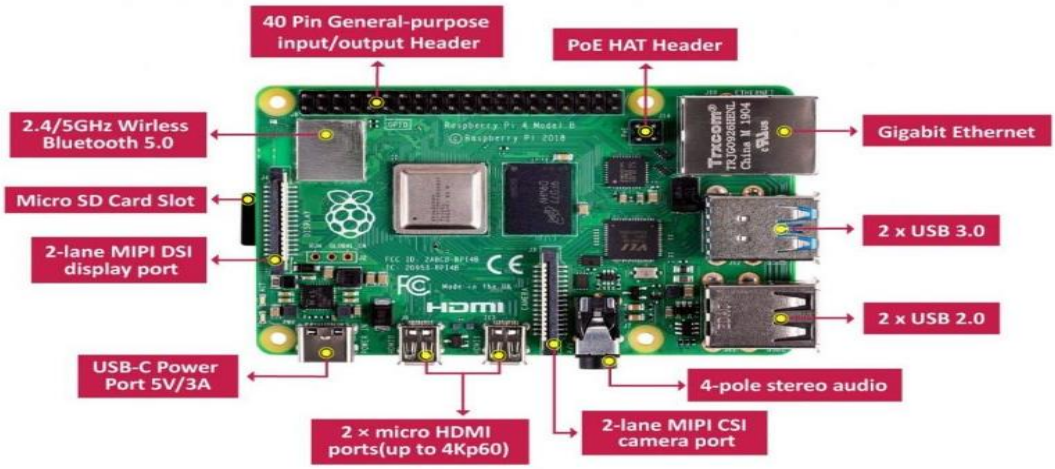


Figure. Circuit Diagram

A. Power supply: Power supply of 5V is required.

B. Raspberry Pi:

Raspberry Pi is define as the minicomputer. Size like of credit card that is interoperable with any input and output hardware device like a monitor, a television, amouse, or a keyboard – effectively converting the set-up into a full-fledged PC at a low cost.



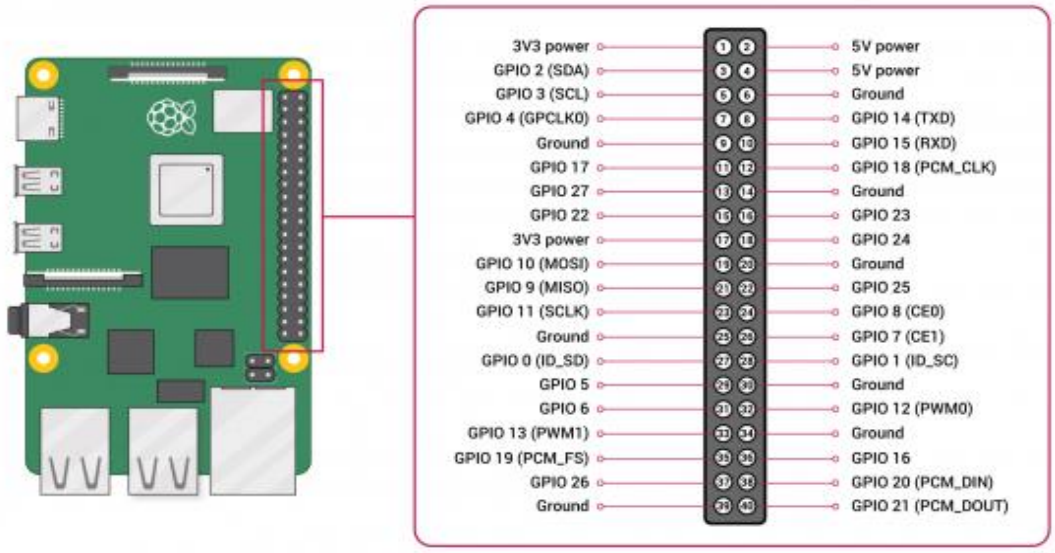


Figure. Raspberry Pi

Features of Raspberry Pi:

1. Central Processing Unit (CPU)

Every computer has a Central Processing Unit, and so does the Raspberry Pi. It is the computer's brain and carries out instructions using logical and mathematical operations. Raspberry Pi makes use of the ARM11 series processor on its boards.

2. HDMI port

Raspberry Pi board has an HDMI or High Definition Multimedia Interface port that allows the device to have video options of the output from the computer displayed. An HDMI cable connects the Raspberry Pi to an HDTV. The supported versions include 1.3 and 1.3. It also comes with an RCA port for other display options.

3. Graphic Processing Unit (GPU)

This unit, GPU or Graphic Processing Unit, is another part of the Raspberry pi board. Its primary purpose is to hasten the speed of image calculations.

4. Memory (RAM)

Random Access Memory is a core part of a computer's processing system. It is where real-time information is stored for easy access. The initial Raspberry Pi had 256MB RAM. Over the years, developers gradually and significantly improved the size. Different Raspberry Pi models come with varying capacities. The model with the maximum capacity presently is the Raspberry Pi 4 with 8GB RAM space.

5. Ethernet port

The Ethernet port is a connectivity hardware feature available on B models of Raspberry Pi. The Ethernet port enables wired internet access to the minicomputer. Without it, software updates, web surfing, etc., would not be possible using the Raspberry Pi. The Ethernet port found on Raspberry computers uses the RJ45 Ethernet jack. With this component, Raspberry Pi can connect to routers and other devices.

6. SD card slot

Like most other regular computers, Raspberry Pi must have some sort of storage device. However, unlike conventional PCs, it does not come with a hard drive, nor does it come with a memory card. The Raspberry Pi board has a Secure Digital card or SD card slot where users must insert SD cards for the computer to function. The SD card functions like a hard drive as it contains the operating system necessary for turning the system on. It also serves to store data.

7. General Purpose Input and Output (GPIO) pins

These are upward projecting pins in a cluster on one side of the board. The oldest models of the Raspberry Pi had 26 pins, but most have 40 GPIO pins. These pins are pretty sensitive and should be handled carefully. They are essential parts of the Raspberry Pi device as they add to its diverse applications. GPIO pins are used to interact with other electronic circuits. They can read and control the electric signals from other boards or devices based on how the user programs them.

8. LEDs

These are a group of five light-emitting diodes. They signal the user on the present status of the Raspberry Pi unit. Their function covers:

PWR (Red): This functions solely to indicate power status. When the unit is on, it emits a red light and only goes off when the unit is switched off, or disconnected from the power source.

ACT (Green): This flashes to indicate any form of SD card activity.

LNK (Orange): LNK LED gives off an orange light to signify that active Ethernet connectivity has been established.

100 (Orange): This light comes on during Ethernet connection when the data speed reaches 100Mbps.

FDX (Orange): FDX light also comes during Ethernet connection. It shows that the connection is a full-duplex.

9. USB ports

Universal service bus (USB) ports are a principal part of Raspberry Pi. They allow the computer to connect to a keyboard, mouse, hard drives, etc. The first model of Raspberry Pi had only two USB 2.0 ports. Subsequent models increased this number to four. Raspberry Pi 4 and Pi 400, much newer models, come with a mix of USB 2.0 and USB 3.0 ports.

10. Power source

Raspberry Pi has a power source connector that typically uses a 5V micro USB power cable. The amount of electricity any Raspberry Pi consumes depends on what it's used for and the number of peripheral hardware devices connected.

How does Raspberry Pi work?

Raspberry Pi is a programmable device. It comes with all the critical features of the motherboard in an average computer but without peripherals or internal storage. To set up the Raspberry computer, you will need an SD card inserted into the provided space. The SD card should have the operating system installed and is required for the computer to boot. Raspberry computers are compatible with Linux OS. This reduces the amount of memory needed and creates an environment for diversity.

After setting up the OS, one can connect Raspberry Pi to output devices like computer monitors or a High-Definition Multimedia Interface (HDMI) television. Input units like mice or keyboards should also be connected. This minicomputer's exact use and applications depend on the buyer and can cover many functions.

C . Accelerometer:

ADXL335 - Triple Axis Linear Accelerometer sensor with module:-

Description:-

The ADXL335 is a 3-axis linear accelerometer sensor that measures acceleration along the X, Y, and Z axes. It provides an output voltage proportional to acceleration, which can be easily read by a microcontroller or other processing device. The sensor operates over a wide voltage range and has a low power consumption, making it well-suited for portable and battery-powered applications. The ADXL335 can detect acceleration in the range of +/-3g, making it suitable for detecting motion and tilt in a variety of applications, such as gaming, human-computer interaction, and vibration measurement. The device is available in a small, surface-mount package, making it easy to integrate into compact systems.

An accelerometer is an electromechanical device that will measure acceleration force. It shows acceleration, only due to cause of gravity i.e. g force. It measures acceleration in g unit.

ADXL345 is a Breakout board for the Analog Device's ADXL345 triple axis accelerometer. The module is populated with MOSFET based Voltage level conversion circuitry to enable you to interface different type of microcontrollers (3V3 & 5V). Apart from the above all, necessary components like decoupling capacitors ,filter capacitors ,pull up resistors and LED are also populated on board.

It is ideal for motion and acceleration sensing applications.It is a low-power, 3-axis MEMS accelerometer modules with both I2C and SPI interfaces.

The ADXL345 features 4 sensitivity ranges from +/- 2G to +/- 16G. And it supports output data rates ranging from 10Hz to 3200Hz such as the Arduino.

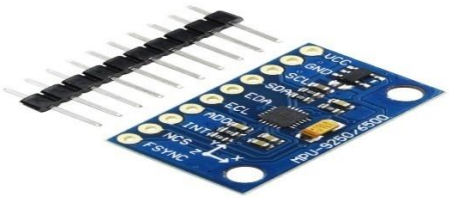


Figure. Accelerometer

Working:-

The ADXL335 is a MEMS (Micro-Electro-Mechanical Systems) based accelerometer that measures acceleration by detecting changes in capacitance. The sensor consists of a poly silicon structure suspended above a substrate with a fixed electrode. When acceleration is applied, the poly silicon structure moves, changing the gap between the poly silicon and the electrode. This change in gap is proportional to the acceleration and is converted into an electrical signal by the built-in capacitance-to-voltage converter.

The sensor has three parallel capacitive sensing elements, one for each axis, and each element is connected to a dedicated amplifier. The amplifiers output a voltage proportional to the acceleration in each axis. The output signals are then combined and fed to the output pins (X, Y, and Z). The sensor operates on a supply voltage of 1.8V to 3.6V and consumes very low power, making it suitable for battery-powered applications.

The ADXL335 is a complete, self-contained accelerometer and requires no external components. It can be used in a wide range of applications, such as motion detection, tilt sensing, and vibration analysis. The output signals can be easily processed by a microcontroller or ADC to determine the magnitude and direction of acceleration.

D. Flex Sensor:

A flex sensor is a kind of sensor which is used to measure the amount of defection otherwise bending. The designing of this sensor can be done by using materials like plastic and carbon. The carbon surface is arranged on a plastic strip as this strip is turned aside then the sensor's resistance will be changed. Thus, it is also named a bend sensor. As its varying resistance can be directly proportional to the quantity of turn thus it can also be employed like a goniometer. The pin configuration of the flex sensor is shown below. It is a two-terminal device, and the terminals are like p1 & p2. This sensor doesn't contain any polarized terminal such as diode otherwise capacitor, which means there is no positive & negative terminal. The required voltage of this sensor to activate the sensor ranges from 3.3V -5V DC which can be gained from any type of interfacing. This sensor works on the bending strip principle which means whenever the strip is twisted then its resistance will be changed. This can be measured with the help of any controller.This sensor works similar to a variable resistance because when it twists then the resistance will be changed. The resistance change can depend on the linearity of the surface because the resistance will be dissimilar when it is level. When the sensor is twisted 450 then the resistance would be dissimilar. Similarly, when this senor is twisted to 900 then the resistance would be dissimilar. These three are the flex sensor's bending conditions.

Figure. Flex Sensor

E. Load cell :

A **load cell** is a force transducer. It converts a force such as tension, compression, pressure, or torque into an electrical signal that can be measured and standardized. As the force applied to the load cell increases, the electrical signal changes proportionally. The most common types of load cell used are strain gauges, pneumatic, and hydraulic. A Wheatstone bridge is a four-armed bridge of resistors, usually having three fixed resistors and one variable resistor. The variable resistor is the sensing element or the strain gauge. If the resistance changes in the variable resistor relative to the others, current will pass through a meter. Basically, the Wheatstone bridge converts the change in resistance due to strain into a measurable electrical signal.

Figure. Load Cell

Features:

1) Full Scale Output (FSO): Electronic output expressed in mV/V. Measured at full scale.
2) Combined Error: percent of the full scale output that represents the maximum deviation from the straight line drawn between no load and load at rated capacity. Often measured during decreasing and increasing loads.
3) Non-Linearity: The maximum deviation of the calibration curve from a straight line drawn between the rated capacity and zero load. Measured on increasing load and expressed as percent of full scale output.

F. GSM :

GSM or Global System for Mobile Communication is a Wireless Communication standard for mobile telephone systems. It was developed by the European Telecommunications Standards Institute (ETSI) as a replacement to the 1st Generation Analog Cellular Network.Hence, GSM is often called as the 2nd Generation Digital Cellular Network or simply 2G. From its deployment in Finland in the year 1991, GSM has grown rapidly with an estimated market share of over 90% in more than 200 countries. A GSM/GPRS Module is an IC or chip that connects to the GSM Network using a SIM (Subscriber Identity Module) and Radio Waves. The common radio frequencies in which a typical GSM Module operates are 850MHz, 900MHz, 1800MHz and 1900MHz.Since it is not possible to interface a GSM/GPRS Module directly to an external device like a microcontroller. It consists of the GSM/GPRS Module, slot for inserting a SIM Card, RS-232 Interface for connecting with computer or a microcontroller, signal status LED, power supply and a provision for connecting microphone and speaker.Each GSM/GPRS Module is unique and it can be differentiated by its IMEI Number. IMEI or International Mobile Equipment Identity Number is a 15 – digit unique number associated with mobile phone, satellite phones and other GSM Network devices.

Figure. GSM Module

Description:-

The SIM800L is a compact, quad-band GSM/GPRS module designed for global market. It is designed for use in applications that need to communicate with a GSM network, such as sending SMS messages, making voice calls, and connecting to the Internet using GPRS. Some key features of the SIM800L include low power consumption, small form factor, and an industry-standard interface for easy integration into a wide range of applications. The module is compatible with AT command set, which makes it easy to use and integrate into an existing system.

- **Software specifications:-**

Proteus:

Proteus is an electronic design tool, it allows to carry out electrical and electronic simulations in a very simple way, it is an intuitive program, easy to use and that has also become very popular in recent years because of how easy it is to simulate Arduino boards. It is a software suite containing schematic, simulation as well as PCB designing.

- **ISIS** is the software used to draw schematics and simulate the circuits in real time. The simulation allows human access during run time,thus providing real time simulation.
- ARES is used for PCB designing.It has the feature of viewing output in 3D view of the designed PCB along with components.
- The designer can also develop 2D drawings for the product.

III.DEPLOYMENT OF THE SYSTEM

This study investigated the Zhengdian Highway Bridge in Wuhan, China (Figure 10a), a prestressed, concrete structure, simply supported slab bridge. It is a series of simply supported spans without connection. The entire bridge is 484.36 m long, with 187.82 m of highway in the south–north connection line. The main bridge is 296.54 m long, which consists of 18 spans of 16 m each and two bridge abutments. Table 3 shows the detailed parameters of the bridge. A 3D finite element model for the bridge was developed to determine the best position for the sensor nodes.

- **Finite Element Analysis**

Integral modelling method with ANSYS software was used. The concrete structure is a SOLID65 unit, which is adopted to simulate 3D reinforced or nonreinforced concrete model. Eight nodes are defined. Each node has three degrees of freedom, that is, translation of the x, y, and z directions in the node coordinate system. For the unit of end bearing section, x, y two-way constraint is applied to simulate the fixed support and y-way constraint is to simulate the sliding support. Figures 10b and 10c show the integral analysis model. To analyse the strain of the key section under the most unfavourable load, a balanced and anunbalanced load (Figure 11) in bridge horizontal direction is used, the maximum strain value is then obtained. The bridge is a simply supported slab bridge that has a static set structure, so the force applied to it is determinate. The mid-span, quarter-span, and fulcrum sections are compared. The results of the finite element static analysis show that the maximum strain value of the monitored.

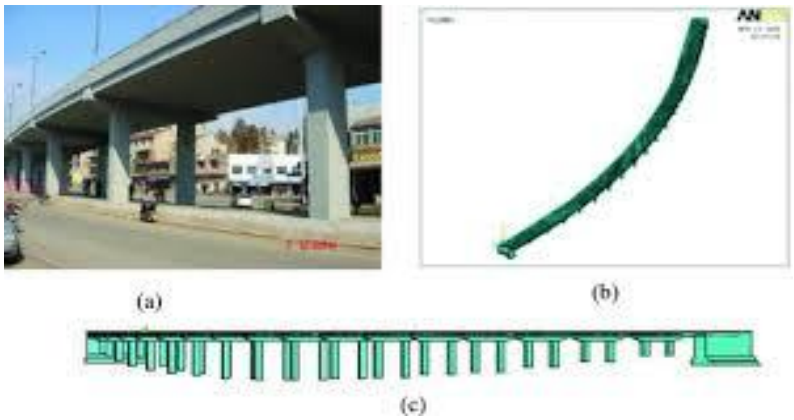


Figure. Test Structure

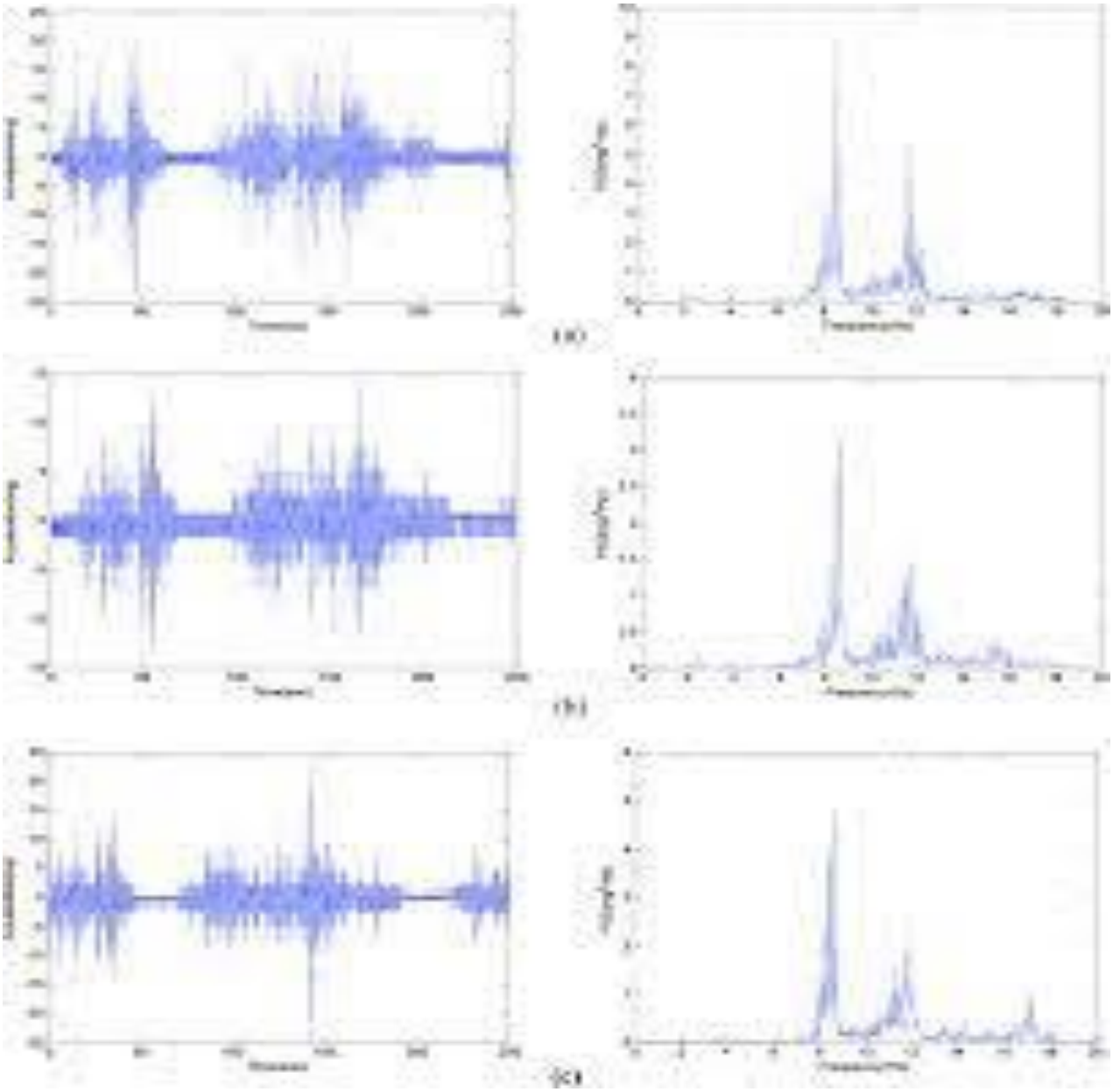


Figure. Accelerations in Bridges

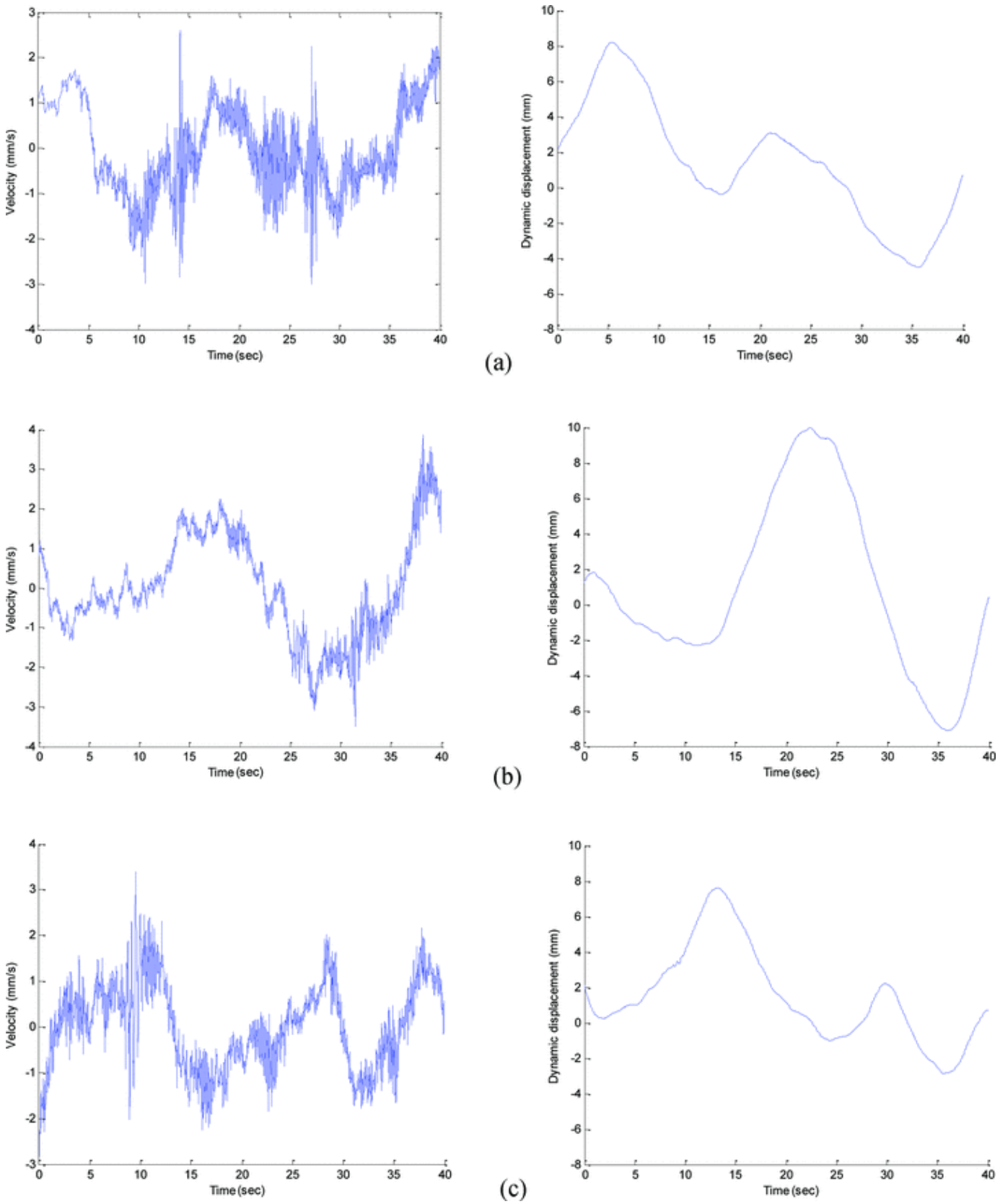


Figure. Velocity and Dynamic Displacement in Bridges

V. ADVANTAGES

- Low cost and highly economical.
- Low power consumption.
- Easy to maintain.
- User friendly

VI. CONCLUSION

Wireless sensor networks are becoming popular day by day. With the latest rise in IoT and wireless sensing real time bridge health monitoring has become quite advance and futuristic. This has also made monitoring accurate and easily accessible by everyone. Problems accruing due to co-axial cables and optical fiber cables as well as the cost are also reduced. Reliability and ease of this system is another benefit. This technology can provide early defect detection which will be helpful in avoiding loss of country economy and most importantly human life.

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