Development Of Smart Structural Health Monitoring System Study Of Bridges Using Internet Of Things

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ABSTRACT

The applications of structural monitoring are moving toward the field of civil engineering and infrastructures. Nevertheless, if the structures have damages, it does not mean that they have a complete loss of functionality, but rather that the system is no longer in an optimal condition so that, if the damage increases, the structure can collapse. Structural Health Monitoring (SHM), a process for the identification of damage, periodically collects data from suitable sensors that allow to characterize the damage and establishes the health status of the structure. Therefore, this monitoring will provide information on the structure condition, mostly about its integrity, in a short time, and, for infrastructures and civil structures, it is necessary to assess performance and health status. The aim of this study is to design an Internet of Things (IoT) system for Structural Health Monitoring to find possible damages and to see how the structure behaves over time.

Keywords: Development, Smart structural, Health Monitoring, Bridges, IoT.

7. INTRODUCTION

1.1 General

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, and 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 is 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.

1.2 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.

1.3 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 co action across the heterogeneous networks and also allow coherent data exchange through the IoT system, various protocols and standards are established.

1.4 Applications Of IoT

- Using this project, we can keep eye on the various bridge in which our proposed model in embedded.
- The project can be further expanded and the various same structured models can be installed over the bridges for themaintenance of the bridges.
- With the help of this model, the presence of the moisture can also be detected and the future disasters can be snuffed.
- We can get the information regarding the health or lifetime of the bridge over our phone via email.
- Additionally, we can maintain any structure for the purpose like moisture detection, change in deflection, etc.

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

1.5 Advantages Of IoT

- It is a robust and easy to use system.
- There is no need for extra training of that person who is using it.
- Proposed system will avoid death of people due to bridge collapse.
- We can determine which bridge requires repairing before it gets break.
- Traffic can be routed prior of Bridge collapse as alert of extreme levels are continuously monitored on IoT server.
- It generates the alert if flow, water level, and the load are increased.
- Early damage detection, Quick action and responses.

1.6 Necessity

Bridge health monitoring is important because it saves more human life. Bridge health monitoring system (BMS) provides previous indication to us where we can easily save too many lives and we can avoid the loss. Their developmental history up to the present time. It also investigates current associated studies in progress and the limitations of contemporary Bridge monitoring system (BMS) technologies, and suggests possible remedial solutions for a follow up bridge monitoring system.

1.7 Objective

The objective of Bridge Health Monitoring System is to provide the necessary information of the structural condition and possible damage in Bridge in order to provide the documented basis for decisions concerning these matters. The overall aims for Bridge Health Monitoring systems are to

- Ensure safe structures.
- Monitoring Structural Performance and Applied Loads.
- Facilitating the Planning of Inspection and Maintenance.
- Validating Design Assumptions and parameters.
- Updating and Revising Design Manuals and Standards.
- Attain safe economic operation.

2. METHODOLOGY

Figure 1 shows the Methodology of the study.

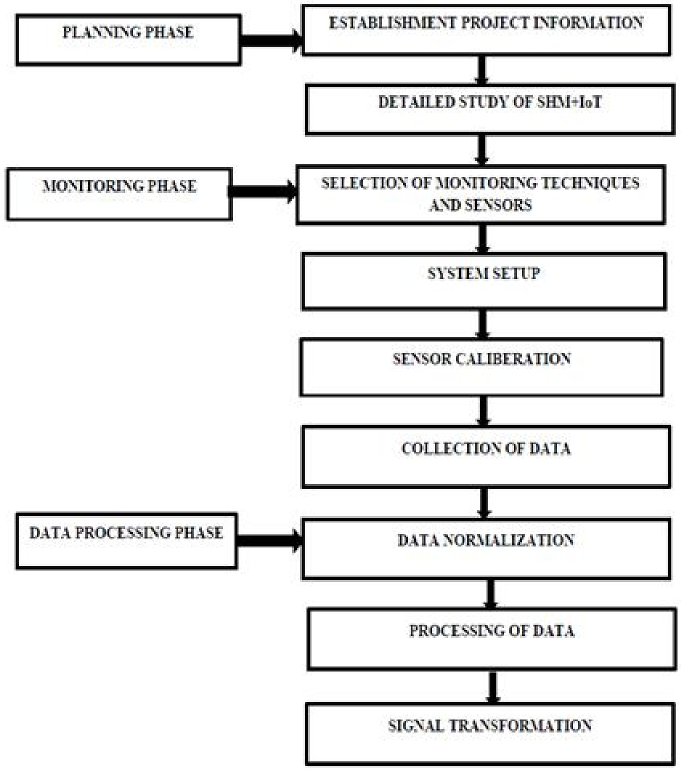

Figure 1 Methodology

3. COMPONENTS DESCRIPTION

3.1 Microcontroller

A microcontroller (MCU for microcontroller unit) is a small computer on a single metal-oxide-semiconductor (MOS) integrated circuit (IC) chip. A microcontroller contains one or more CPUs (processor cores) along with memory and programmable input/output peripherals. Program memory in the form of ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general-purpose applications consisting of various discrete chips.In modern terminology, a microcontroller is similar to, but less sophisticated than, a system on a chip (SoC). SoC may include a microcontroller as one of its components, but usually integrates it with advanced peripherals like graphics processing unit (GPU), Wi-Fi module, or one or more coprocessors. Figure 2 Shows the Micro Controller.

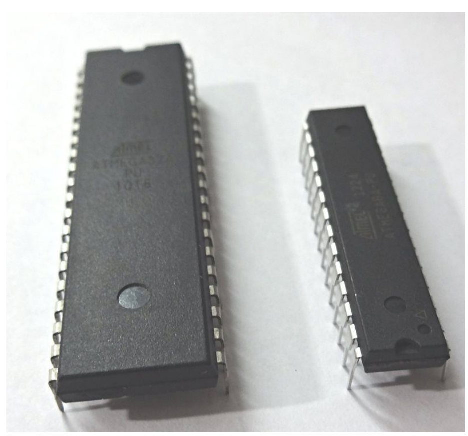

Figure 2 Microcontroller

3.1.1 Principle

A microcontroller is a single chip microcomputer that integrates the main parts of a microcomputer on a chip. The microcontroller was born in the middle of 1970s. After 20 years of development, its cost is becoming lower and its performance is more and more powerful, which makes its application everywhere and in all fields. For example, motor control, bar code reader / scanners, consumer electronics, game devices, telephone, HVAC, building safety and access control, industrial control and automation, and white household appliances (washing machines, microwave ovens). Wellaccording to wiki, a microcontroller (or MCU for microcontroller unit) is a small computer on a single integrated circuit. In modern terminology, it is similar to, but less sophisticated than, a system on a chip or SoC; anSoC may include a microcontroller as one of its components. A microcontroller contains one or more CPUs (processor cores) along with memory and programmable input/output peripherals. Program memory in the form of ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a small amount of RAM.

3.1.2 Application

Microcontrollers are employed in automatically managed inventions and appliances like- power tools, implantable medical devices, automobile engine control systems, office machines, remote controls appliances, toys and many more embedded systems.

3.1.3 Uses

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems.

3.2 Ultrasonic Sensor

An ultrasonic sensor is an electronic device that measures the distance of a target object by emitting ultrasonic sound waves, and converts the reflected sound into an electrical signal. Ultrasonic waves travel faster than the speed of audible sound (i.e., the sound that humans can hear). Ultrasonic sensors have two main components: the transmitter (which emits the sound using piezoelectric crystals) and the receiver (which encounters the sound after it has travelled to and from the target).Ultrasonic sensors are used primarily as proximity sensors. They can be found in automobile self-parking technology and anti-collision safety systems. Ultrasonic sensors are also used in robotic obstacle detection systems, as well as manufacturing technology. In comparison to infrared (IR) sensors in proximity sensing applications, ultrasonic sensors are not as susceptible to interference of smoke, gas, and other airborne particles (though the physical components are still affected by variables such as heat). Figure 3 shows the ultrasonic sensor.

Figure 3 Ultrasonic Sensor

Ultrasonic sensors are also used as level sensors to detect, monitor, and regulate liquid levels in closed containers (such as vats in chemical factories). Most notably, ultrasonic technology has enabled the medical industry to produce images of internal organs, identify tumors, and ensure the health of babies in the womb.

3.2.1 Working Principle

Ultrasonic sensors emit short, high-frequency sound pulses at regular intervals. These propagate in the air at the velocity of sound. If they strike an object, then they are reflected back as echo signals to the sensor, which itself computes the distance to the target based on the time-span between emitting the signal and receiving the echo.As the distance to an object is determined by measuring the time of flight and not by the intensity of the sound, ultrasonic sensors are excellent at suppressing background interference. Virtually all materials which reflect sound can be detected, regardless of their color. Even transparent materials or thin foils represent no problem for an ultrasonic sensor. Micro sonic ultrasonic sensors are suitable for target distances from 20 mm to 10 m and as they measure the time of flight they can ascertain a measurement with pinpoint accuracy. Some of our sensors can even resolve the signal to an accuracy of 0.025 mm. Figure 4 shows the working principle.

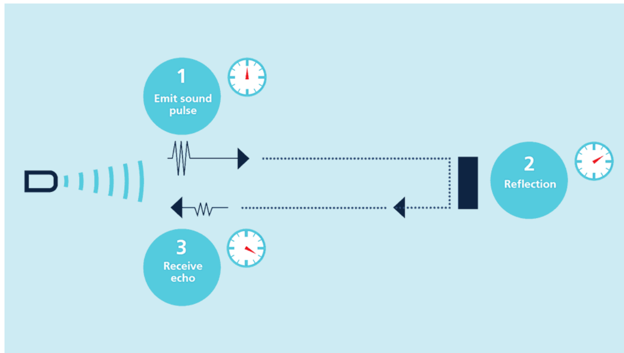

Figure 4 Working Principle

Ultrasonic sensors can see through dust-laden air and ink mists. Even thin deposits on the sensor membrane do not impair its function.Sensors with a blind zone of only 20 mm and an extremely thin beam spread are making entirely new applications possible today: Fill level measurement in wells of microtiter plates and test tubes, as well as the detection of small bottles in the packaging industry, can be implemented with ease. Even thin wires are reliably detected.

3.2.2 Application

Ultrasonic sensors have been used throughout many applications and industries. They are used within food and beverage to measure liquid level in bottles, they can be used within manufacturing for an automated process and control maximizing efficiency on the factory floor.

3.3 LCD Display

A liquid-crystal display (LCD) is a flat-panel display or other electronically modulated optical device that uses the light-modulating properties of liquid crystals combined with polarizers. Liquid crystals do not emit light directly, instead using a backlight or reflector to produce images in color or monochrome. LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images with low information content, which can be displayed or hidden, such as preset words, digits, and seven-segment displays, as in a digital clock.
They use the same basic technology, except that arbitrary images are made from a matrix of small pixels, while other displays have larger elements. LCDs can either be normally on (positive) or off (negative), depending on the polarizer arrangement. Figure 5 shows the LCD display 6x2.

Figure 5LCD display 6x2

4. IDENTIFYING CRACK IN BRIDGES

4.1 Load Acting on Bridges

Different types of loads on bridges are discussed in this research. Correct identification of the load to be considered during the design and construction is very important.

4.1.1 Imposed Traffic Loading

Imposed traffic loads consist of those forces induced by road or rail vehicles on the bridge. Bridge traffic can be vehicular, rail or pedestrian/cycle or indeed any combination of these. Depending on the design code, the type and intensity of the design vehicle changes Bridge traffic loading is often governed by trucks whose weights are substantially in excess of the legal maximum. Bridge traffic loading is applied to notional lanes which are independent of the actual lanes. Eurocode normal loading consists of uniform loading and a tandem of four wheels in each lane. Often, vehicular loads are multiplied with an impact factor to consider the dynamic effects of traffic.

4.1.2 Impact Loads

Most bridge analysis is based on static linear elastic principles. Accidental collision of vehicles on the piers and parapets induces additional forces. Collision of a vehicle with a bridge is highly non-linear.

4.2 Crake Identification of Bridge

Cracking in concrete bridge decks, particularly at its early age have significant effects on the serviceability and performance of the bridge. Many studies were conducted to develop a non-destructive method to detect cracks on concrete bridge decks. Recent developments in the sensor technology enhanced the wide use of miniature sensors in the bridge performance and maintenance fields. In 2002, that the plastic optical fibers could be used to detect hairline cracks, failure cracks and also for monitoring the crack propagation in the concrete structures. Although the aforementioned techniques were successfully used to detect cracks in concrete bridge decks, they could not give an explanation for the occurrence of such cracks or when these cracks initiated, which represents the first step to treat such a problem. Therefore, many researchers started to instrument the bridge deck to monitor the deck performance in an attempt to find out the reasons for crack development.

4.3 Measuring Instrument

4.3.1 Sensors

In general, the basic instrumentation program is concerned with two types of measurements: strains, as they affect the ultimate strength of the structure and deflections, as they affect its serviceability. The main objective of this study is to identify the contribution of temperature variations as well as material and structural factors that lead to early age cracking in the concrete bridge decks. This would require capturing the strain and axial deformation for long-term behavior of the bridge due to seasonal effects and short-term behavior under traffic loads. The instrumentation plan, the selection of the type of the sensors to be installed and the data acquisition system used to capture the data plays an important role in this project. The different categories of the sensors used for this project are:

- Displacement Transducers
- Thermistors

4.3.2 Displacement Transducer

Displacement transducers are designed to measure the expansion or contraction, movements across the cracks or joints. Transducer employs a shaft coupled to a spring, which in turn is coupled to a vibrating wire element. Movement of the shaft changes the tension in the spring and in the wire causing a corresponding change in its frequency. The vibrating wire transducer measures the output in terms of frequency, hence useful for long lengths application without appreciable vibration or noise in the signal. It is commonly used for measuring the crack openings, axial deformation, creep characteristics of structures and materials. Most of the transducers are provided with a thermistor for temperature measurement. There are many types of displacements transducers that can be used for displacement measurement. The transducers used in this project are:

- Crack-meter
- Convergence meter

Figure 6 shows the displacement transducer.

Figure 6 Displacement Transducer

4.3.3 Crack Meter

The Geokon Model 4430 deformation meter (Crack-meter) is designed primarily to measure axial strains or deformations in concrete structures. The transducer can beem bedded in concrete, in series to give the total deformation pattern along that axis. The transducer consists of a vibrating wire sensing element in series with a precision music wire, which is coupled to a movable shaft. As the shaft moves out of the sensor body, both the spring and the vibrating wire elongate causing a change in their tension, which is measured in terms of frequency of the vibration

4.3.4 Accelerometers

Accelerometers are sensors that measure acceleration and vibration. They can have from one to three axes of measurement, where the axes are orthogonal to each other. Common types of accelerometers include piezoelectric, capacitance, null-balance, resonance, piezoresistive, and magnetic induction. When attached to a bridge member, vibration causes the accelerometer to send electric signals to a computer for conversion to units of acceleration. Figure 7 shows the accelerometers.

Figure 7 Accelerometers

4.3.5 Thermometers

Thermal sensors quantify temperature. Two basic methods for measuring temperature are contact and non-contact. Bridge applications call for contact devices, which need a sensor input or have an integrated sensor. Two common sensor types include vibrating wire temperature sensors and resistance temperature sensors. Figure 8 shows the thermometers.

Figure 8 Thermometers

4.3.6 Fiber-optic Sensors

Fiber-optic sensors can perform the function of any conventional sensor, including those used in bridge applications. Optical fibers have very high band widths, and they are di-electric, so they are not subject to interference from electromagnetic waves. Fiber-optic sensors can function under adverse conditions from temperature, pressure, and toxicity .Fiber-optic sensors monitor structural health by sending light beams down optical fibers at regular intervals and measuring the change in time-of-flight. There are a few types of fiber-optic sensors currently being used in bridge applications. These types include Fabry-Perot sensors and Fiber Bragg Grading sensors, which measure interference fringes and frequency, respectively. A third type uses Brillouin Optical Time-Domain Reflectometry (BOTDR)

4.4 Internet Of Things (IoT)

IoT and related technologies can help transportation infrastructure manager's better monitor and manage aging structures more effectively. As use cases for IoT technology continue to emerge in the transportation and logistics sector, from predictive fleet and freight management to autonomous cars, another potential use case could be evolving under the wheels of the industry's vehicles. Transportation infrastructure roads, bridges, tunnels, shipping ports, airports and more also need to be managed and monitored to ensure ongoing usability and, more importantly, safety. As these infrastructure elements age, this need only becomes more critical. Figure 9 shows the process layout.

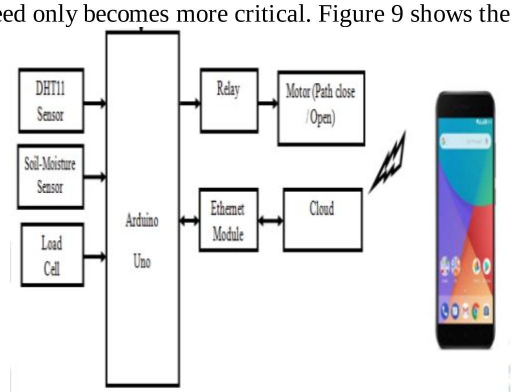

Figure 9 Process Layout

The overall architecture of development of an IoT based bridge safety monitoring system which is as follows, explains the functionality of the project, various modules and their respective functions are given. The overall architecture diagram is shown in the figure. There are three different modules in this project. The bridge safety monitoring and tracking system will sense various factors like soil moisture, temperature, humidity and load on the bridge. At critical conditions an alarm will be generated and the roads will be closed using the "AUTO-BARRIER" the bridge might be given the governing room to stop vehicles immediately. Power required to perform the above operations will be taken from the sound energy generated from the vehicles. The overall system includes the following modules.

4.5 DATA MONITORING

4.5.1 Bridge Monitoring Instrumentation

4.5.1.1 Sensor

An ultrasonic sensor is an instrument that measures the distance to an object using ultrasonic sound waves.An ultrasonic sensor uses a transducer to send and receive ultrasonic pulses that relay back information about an object's proximity. High-frequency sound waves reflect from boundaries to produce distinct echo patterns.

4.5.1.2 Ultrasonic Sensors Work

Ultrasonic sensors work by sending out a sound wave at a frequency above the range of human hearing. The transducer of the sensor acts as a microphone to receive and send the ultrasonic sound. Our ultrasonic sensors, like many others, use a single transducer to send a pulse and to receive the echo. The sensor determines the distance to a target by measuring time lapses between the sending and receiving of the ultrasonic pulse. The working principle of this module is simple. It sends an ultrasonic pulse out at 40kHz which travels through the air and if there is an obstacle or object, it will bounce back to the sensor. By calculating the travel time and the speed of sound, the distance can be calculated. Ultrasonic sensors are a great solution for the detection of clear objects. For liquid level measurement, applications that use infrared sensors, for instance, struggle with this particular use case because of target translucence. For presence detection, ultrasonic sensors detect objects regardless of the color, surface, or material (unless the material is very soft like wool, as it would absorb sound.) To detect transparent and other items where optical technologies may fail, ultrasonic sensors are a reliable choice.

4.5.1.3 Ultrasonic Sensors used

Our ultrasonic distance, level, and proximity sensors are commonly used with microcontroller platforms like Raspberry Pi, ARM, PIC, Arduino, Beagle Board, and more. Ultrasonic sensors transmit sound waves toward a target and will determine its distance by measuring the time it took for the reflected waves to return to the receiver. This sensor is an electronic device that will measure the distance of a target by transmitting ultrasonic sound waves, and then will convert the reflected sound into an electrical signal. Ultrasonic sensors are also used in obstacle avoidance systems, as well as in manufacturing. Our Short-range sensors offer the opportunity for closer range detection where you may need a sensor that ranges objects as close to 2cm. These are also built with very low power requirements in mind, as well as environments where noise rejection is necessary.

4.5.1.4 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. Figure 10 shows the LCD display.

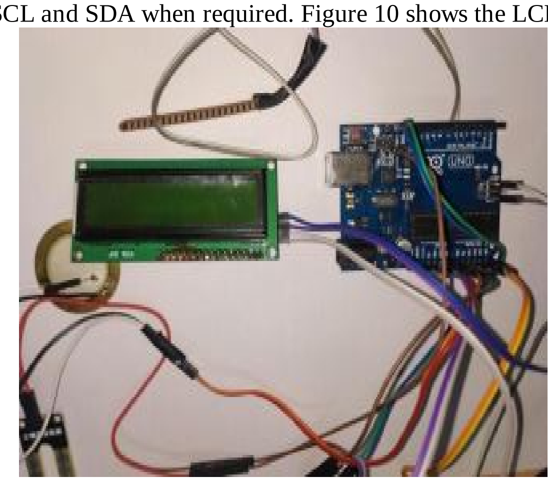

Figure 10 LCD Display

Figure 11 shows the Processing layout.

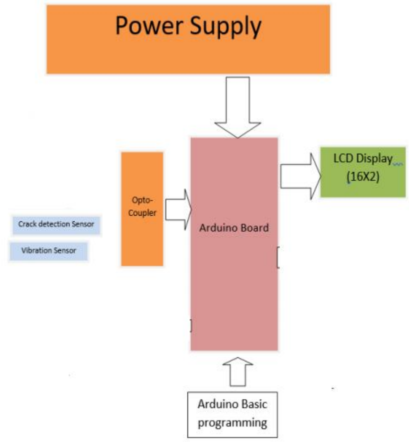

Figure 11 Processing Layout

4.6 DATA ACQUISITION

The data acquisition portion of the WINS Process involves selecting the number, types and locations of sensors to be used along with the data acquisition hardware. Other considerations that must be addressed include how often the data should be collected and how to normalize the data. There are several key components of this system:

- Micro-sensors with built-in a-to-d conversion capability,
- Wireless data transmission,
- Power source, and
- A local excitation sources.

5. CONCLUSION

Developing a bridge monitoring system is challenging task hardware and software can make this process much smoother. Based on the literature, the bridge monitoring system has been processed with the functions of ultrasonic sensor. In this research study, the sensor application could interface with the mobile phone and achieve the monitoring system. The sensor recognizes the crack effectively which is formed due to load on bridge. In future the experimentation could be carried based on this proposed methodology of bridge monitoring system. The load test should be conducted on the slab whereas the vibration and deflection could be found through IoT process.

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