International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-2, Issue-3, March 2015

Monitoring Civil Structures with a Smart Wireless Sensor Network

Snehal S. Somwanshi, Balaji G. Gawalwad

***Abstract*— A wireless sensor network was developed for structural health monitoring to effectively detect, locate, and assess damage produced by severe loading events and by progressive environmental deterioration. Structural response reflects the structural condition as well as the excitation force. Structural health monitoring (SHM) is an active area of research devoted to systems that can autonomously and proactively assess the structural integrity of bridges, buildings, and aerospace vehicles. Recent technological advances promise the eventual ability to cover a large civil structure with low-cost wireless sensors that can continuously monitor a building's structural health. The idea struck into mind that a SHM system should be implemented so that it can monitor structure (two story building) using different surface mounting sensors, these systems can collect various parameters of the structure. The rapid development of wireless sensor network (WSN) technology provides us a novel approach to real-time data acquisition, transmission and processing.This study introduces different approaches of SHM to monitor and measure the acceleration, strain, humidity and temperature of the building.**

***Index Terms*— Structural health monitoring, wireless sensor network, FBG (Fiber Bragg Grating).**

I. INTRODUCTION

Large civil structures such as buildings and bridges form the backbone of our society and are critical to its daily operation. Inspectors typically assess them manually, but a networked computer system that could automatically assess structural integrity and pinpoint the existence and location of any damage could measurably lengthen a structure's lifetime, reduce its operational cost, and improve overall public safety.

Structural Health Monitoring (SHM) strategies measure structural response and aim to effectively detect, locate, and assess damage produced by severe loading events and by progressive environmental deterioration.

A wireless sensor network-based data acquisition system, delivers time synchronized structural-response data reliably from several locations over multiple hops to a base station. It supports flexible self-organizing sensor-network deployments of up to several tens of untethered wireless nodes and avoids the high cabling, installation, and maintenance costs incurred by traditional wired data-acquisition systems. SHM provides a programmable sensor actuator network system that SHM engineers can use to implement algorithms in a higher-level language such as Matlab or C. It uses a two-tier hierarchy, with resource-constrained sensor nodes in the lower tier and more endowed gateway nodes in the upper tier; theoretically, it can scale to hundreds of nodes [1].

Structural health monitoring calls for sensors that are low-cost, low-profile, and power-constraint. It also requires the sensors to form a network to accurately monitor the low-frequency response that often occurs in many civil structures such as long-span bridges. To monitor a structure (e.g. bridge, building), we measure behaviour (e.g. acceleration, vibration, displacement) of structure, and analyze health of the structure based on measured data. Figure 1 shows overall system.

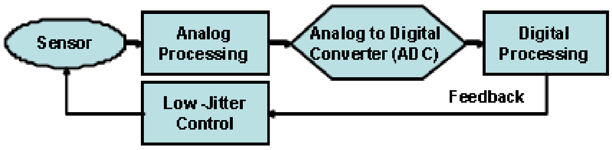

Figure 1: Overall System

However, the existing sensors are either not practice wireless implementation, does not have enough accuracy, or are not cost-effective.

II. THE BENEFITS OF GOING WIRELESS

Automatically acquiring and processing data from the several hundred sensors needed to monitor, say, a moderately sized office building requires us to deploy a network. Naturally, the high cost of cabling required to set up a wired network of this size is a serious impediment to developing large scale SHM systems, but tiny wireless sensors are an easily deployable, low-cost alternative that could bring SHM systems within the realm of practicality. Today's battery-powered, coin-sized devices can contain a processor, significant flash memory, and a low-power radio, together with micro-electromechanical systems (MEMS) sensors capable of measuring vibration. Moreover, these wireless sensor nodes are relatively easy to mount within a few meters of each other. Dense placement greatly increases the spatial resolution of data collection and improves the quality of damage assessment.

The real challenge, though, is how to develop software subsystems that can support a large scale network of wireless sensor nodes. The batteries on today's wireless sensor platforms barely last a few days, and nodes typically expend a lot of energy in sensing and wireless communication. To conserve energy, sensor node platforms can operate in various low-power modes, with sensor node software intelligently duty-cycling the hardware components. In addition, this software can process data locally to reduce the amount of data

Snehal S. Somwanshi, Asst. Professor, Department of E&Tc, P.R.E.S.'s, S.V.I.T., Chincholi, Tal: Sinnar, Dist: Nashik, Maharashtra, India-422 102. Mobile: +917709346206.

Balaji G. Gawalwad, Asso. Professor, HOD, Department of E&Tc, P.R.E.S.'s, S.V.I.T., Chincholi, Tal: Sinnar, Dist: Nashik, Maharashtra, India-422 102. Mobile: +919822668264.

transmitted wirelessly, a procedure called *innetwork processing*.

Although these techniques are generally useful for a variety of networked sensing applications, SHM places additional stringent requirements on wireless sensor node software. SHM sensors generate data at extremely high rates a single sensor, for example, can generate several hundred samples per second. Data from sensors or a suitably processed representation thereof must be reliably delivered across the network, but reliable communication in very noisy wireless environments is a significant challenge.[2]

This project presents a multi-function sensor that can easily form a smart wireless sensor network by the merit of the ZigBee mesh networking function integrated in the sensor. The radar sensor, integrated with a micro-controller, works in the arctangent demodulated interferometric mode to monitor the structure's displacement with an accuracy of sub-millimeter. Experimental results show that the smart sensor network using the multi-function radar sensors serves as a good alternative for monitoring structural health.

III. SYSTEM ARCHITECTURE

The idea struck into mind that a SHM system should be implemented so that it can monitor structure (two story building) using different surface mounting sensors, these systems can collect various parameters of the structure. The rapid development of wireless sensor network (WSN) technology provides us a novel approach to real-time data acquisition, transmission and processing. In a system of this kind, there are several nodes and a base station. Each node contains a group of sensors and the nodes are distributed on both the floors of the building. Data collected by sensors is sent to the base station via WSN channel. The base station is usually a PC with Graphic User Interface (GUI) for users to analyze current status and alarm automatically when parameters detected is below preset standards. The recorded data can be analyzed using various simulation tools for future correspondence and actions. Structural health monitoring (SHM) can prevent these tragic incidents. For civil engineers, wireless sensor networks (WSNs) are an attractive technology: compared to traditional wired systems, they consistently reduce the installation time and costs and are not subjected to wires wear and tear or breakage caused by harsh weather conditions or other extreme events.

Our aim is to monitor and measure the acceleration, strain, humidity and temperature of the building. The remote access of structure quality measurement parameters using wireless communication facilitates quality control, record keeping and analysis using simulation software at base station. Acceleration, humidity, strain and temperature are the parameters will be analyzed and control. Following will be the steps of idea implementation. Accelerometer sensor measures acceleration and Radar sensor measures displacement by taking double integration of the acceleration data it is possible to obtain displacement and that displacement can be compared with displacement of radar sensor.

1) Measurement of acceleration, humidity, strain, temperature using available sensors, at remote place.
2) To collect data from various the sensor nodes and send it to base station by wireless communication.
3) To control data communication between source and sink nodes (Synchronization using time division).
4) To simulate and analyze quality parameters for quality control. (Graphical and numerical record using MATLAB)
5) To publish the corresponding record over web for public information and further assessment of resource.

Structural response reflects the structural condition as well as the excitation force. By analyzing the response data, SHM strategies are expected to reveal structural condition, such as the damage existence. SHM has seen intense research efforts in mechanical, aerospace, and maritime, as well as civil engineering applications. Buildings are subjected to natural hazards such as severe earthquakes and strong winds, as well hazards such as fire, crime, and terrorism, during their long-term use [2]. To mitigate these hazards, monitoring various risks in a building by an intelligent sensor network is necessary. The sensor network could measure acceleration, displacement, strain, etc. The risk to buildings includes aging of structural performance, fatigue, damage, gas leak invasion, fires, etc. The risk to buildings includes aging of structural performance, fatigue, damage, gas leak invasion, fires, etc. According to the results of risk monitoring, appropriate risk control measures such as structural control, maintenance, evacuation guidance warning, alarm, fire fighting, rescue, security measures, can be applied [3].

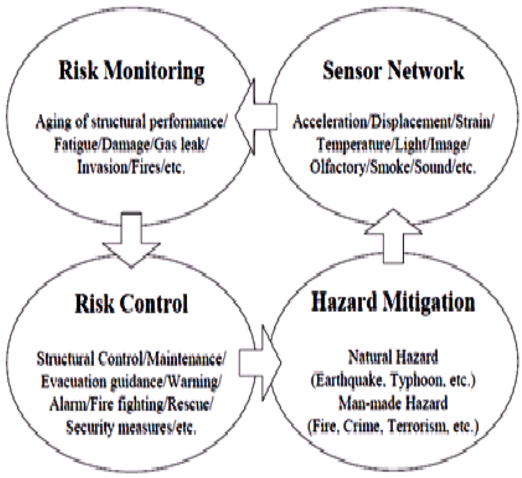

Figure 2: Building Risk Monitoring

IV. LITERATURE SURVEY AND TECHNOLOGICAL SURVEY

Only within the past century have scientists used electronic devices to verify the behavior of materials used to construct our society's infrastructure. As electronics technology has evolved, it has become more commonly available, and useful, to structural engineers in both the research and professional arenas. Today, it would be almost impossible to find a consultant who does not use computers as a design aide. Increasingly, monitoring the health of structures will not be solely a function of an annual physical, or visual, inspection by structural engineers. Engineers now, and in the future, will need to use technology in the field to help them verify the behavior of that which they have learned to analyze and design. As more structures are instrumented, we will learn more about their behavior and this can lead to more economical ways to build and maintain them [4].

As an outcome of the combination of computer technology, communication technology and sensor network technology, it is regarded as the first of 21st century top 10 new technologies that changed world. With strong data capture and process abilities, it has very expansive application foreground in the fields of military, environment monitoring, disaster prevention and biomedicine, especially in some special fields such as environment monitoring and disaster rescue with nobody on duty, it has advantages that traditional technologies could never compare.

Zigbee is a newly rising short-distance, low-complexity, low-speed-rate, low-cost and low-consumption two-way wireless communication technology or wireless net technology that applies direct serial spread spectrum technology. The working frequencies bands include 868MHz (for Europe), 915 MHz (for the U.S.A) or 2.4 GHz (Global) ISM Frequency Bands. Comparing with other wireless network technologies, it is easily-applicable, low-consumption, strong-networking ability, high-reliability and low cost. This technology is based on high security IEEE 802.15.4 protocol that uses 128 bit security [5].

An accelerometer is an electromechanical device that measures acceleration forces [6]. These forces may be static, like the constant force of gravity pulling at our feet, or they could be dynamic - caused by moving or vibrating the accelerometer. There are many types of accelerometers developed and reported in the literature. Fiber Bragg gratings are formed by a periodic perturbation of the core refractive index of an optical fiber. Coupling between modes of the fiber may thus be achieved. A popular FBG couples a forward-propagating mode into its contra directional propagating version. With an adequate design this reflective coupling may be limited to a narrow spectral range, typically to a few hundred picometers [7].Humidity of the building can be measured by using HS220 sensor by mounting the sensor on the surface of the building[8].

V. THEORETICAL DETAILS AND ANALYSIS

Structural Heath Monitoring (SHM) is the term applied to the process of periodically monitoring the state of a structural system with the aim of diagnosing damage in the structure. Over the course of the past several decades there has been ongoing interest in approaches to the problem of SHM. This attention has been sustained by the belief that SHM will allow substantial economic and life-safety benefits to be realized across a wide range of applications. Several numerical and laboratory implementations have been successfully demonstrated. However, despite this research effort, real-world applications of SHM as originally envisaged are somewhat rare. Numerous technical barriers to the broader application of SHM methods have been identified, namely: severe restrictions on the availability of damaged-state data in real-world scenarios; difficulties associated with the numerical modeling of physical systems; and limited understanding of the physical effect of system inputs (including environmental and operational loads) [9].

A. Acceleration

MEMS accelerometers are one of the simplest but also most applicable micro-electromechanical systems. They became indispensable in automobile industry, computer and audio-video technology. This seminar presents MEMS technology as a highly developing industry. Special attention is given to the capacitor accelerometers, how do they work and their applications. An accelerometer is an electromechanical device that measures acceleration forces [6]. These forces may be static, like the constant force of gravity pulling at our feet, or they could be dynamic - caused by moving or vibrating the accelerometer. There are many types of accelerometers developed and reported in the literature. The vast majority is based on piezoelectric crystals, but they are too big and too clumsy. People tried to develop something smaller, that could increase applicability and started searching in the field of microelectronics. They developed MEMS (micro electro mechanical systems) accelerometers.

B. Strain and Temperature

In recent years, FBG (Fiber Bragg Grating) has been accepted as a new kind of sensing element for temperature and strain measurement for structural health monitoring (SHM) in civil infrastructures. Cost of FBG fabrication, high-quality FBG demodulation system, practical encapsulation (package) techniques and indirect FBG-based sensors, and practical applications are the cores for FBG to be widely popularized in infrastructures. In this paper, firstly, the FBG fabrication and demodulation The optical fiber sensors for the measurement of strain have been under development for a number of years and a lot of are shapes to embed within the structural material for the purpose of feature of optical fiber sensors is their inherent ability to serve as both the sensing transmission medium.

Dynamic Strain Measurement Using FBG Sensors:

Recently, many researchers have demonstrated that the FBG sensors can be used to measure the strain of a Structure under static loadings. The resolution of FBG sensors also gives a reliable data while comparing with the traditional RSG sensors. Under this situation, applying the FBG sensors to the dynamic measurement becomes an interesting topic in civil engineering. Since the “smart structure” concept gradually rises up in civil engineering, there is a need of large amount of sensors in the structure. The main reason to use the FBG sensors is that they can solve the complex wire problems if there are hundreds of sensors on the structure. On the other hand, the FBG sensors have another advantage: sequential measurement.

C. Humidity

Humidity of the building can be measured by using HS220 sensor by mounting the sensor on the surface of the building.

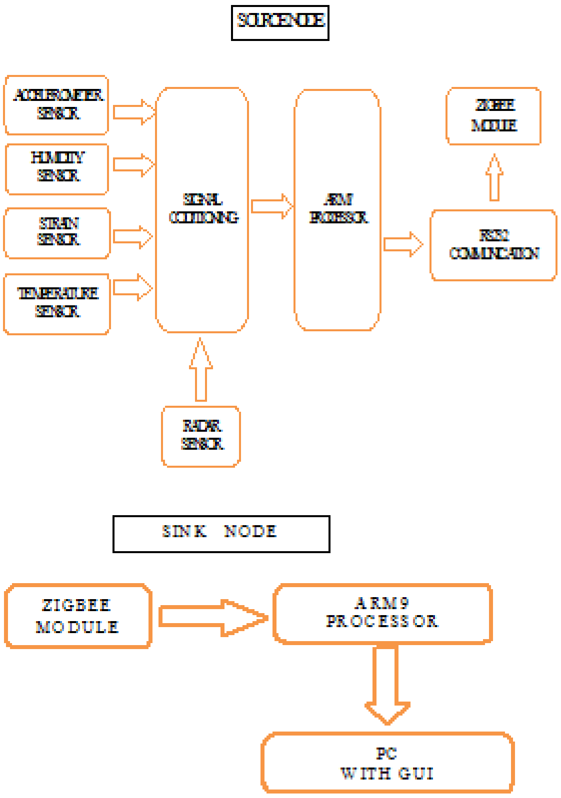

Figure 3: Block Diagram of Structural Health Monitoring For Building

The structural monitoring system includes three parts, one is the collection of the parameters of the buildings, transmission using Zigbee module and the other is the monitoring centre system. The system components are showed in above Figure.

- **Sensor Node**
  1. Accelerometer sensor.
  2. FBG strain sensor.
  3. FBG temperature sensor.
  4. Radar sensor.
  5. Humidity sensor.

- **Receiver Node**
  1. PC with GUI (Simulation in MATLAB): visualizes data in real time

D. Accelerometer Sensor

Figure 4: Accelerometer Sensor

dIGITEXX d110-U (uniaxial) or d110-U (triaxial) accelerometer sensors used in structural health monitoring for many applications. d110-U (uniaxial) or d110-U (triaxial) accelerometers are force balanced electro-mechanical capacitive accelerometers. They have wide dynamic range excellent bandwidth and ultra low noise floor while still operating at highest performance commercially available. Available as uniaxial or triaxial these sensors provide electrostatic feedback without magnetic components [6]. The accelerometer's high resolution and accuracy make them ideal for structural health monitoring [10].

E. Radar Sensor (D1S Radar Distance Sensor):

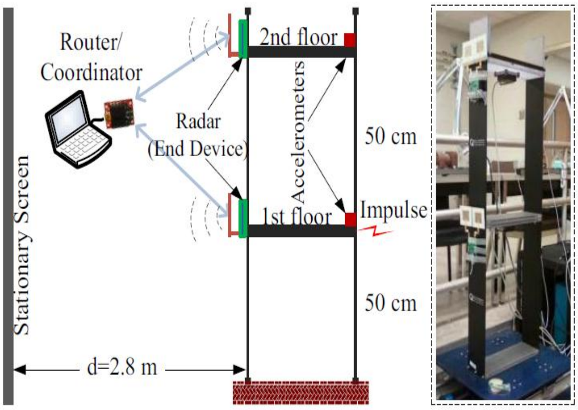

Figure 5: Experimental setup for acceleration and distance measurement

- D1S Radar Sensor is a rugged distance sensor for a wide range of applications.
- Works in harsh conditions such as vapor, dust, smoke, rain or other small particles.
- Measurement signal is not affected by wind or temperature changes
- Measure distance to objects down to 30 cm.

F. FBG (Fiber Bragg Grating) Strain and Temperature Sensor (OS3155)

Working principle

Fiber Bragg gratings are formed by a periodic perturbation of the core refractive index of an optical fiber. Coupling between modes of the fiber may thus be achieved. A popular FBG couples a forward-propagating mode into its contra directional propagating version. This is achieved by adding a periodic variation to the refractive index of the fiber core, which generates a wavelength specific dielectric mirror. A fiber Bragg grating can therefore be used as an inline optical filter to block certain wavelengths, or as a wavelength-specific reflector. Fiber Bragg Gratings are made by laterally exposing the core of a single-mode fiber to a periodic pattern of intense ultraviolet light. The Braggs wavelength is given by: $\lambda_{Bragg} = 2n_{eff}\,\Lambda$

- FBG is a longitudinal periodic variation of the index of refraction in the core of an optical fiber.
- The spacing of the variation is determined by the wavelength of the light to be reflected.

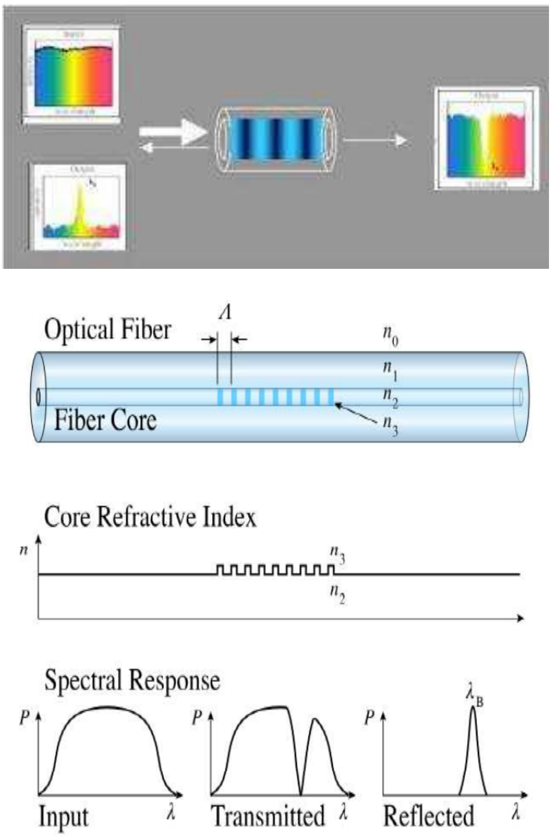

Figure 6: Working Principle For FBG (Fiber Bragg Grating) Sensor

The OS3155 is a rugged strain gage with integrated temperature compensation. Both strain and temperature compensation measurements are based on fiber Bragg grating (FBG) technology. Optimized for outdoor installations on steel structures, the os3155's stainless steel carrier holds the FBG in tension and protects the fiber during installation. Since there are no epoxies holding the fiber to the carrier, long term stability is ensured by design [7].

Figure 7: FBG Sensor for Temperature And Strain Measurement

G. HUMIDITY SENSOR HS220

This module converts relative humidity intothe output voltage.

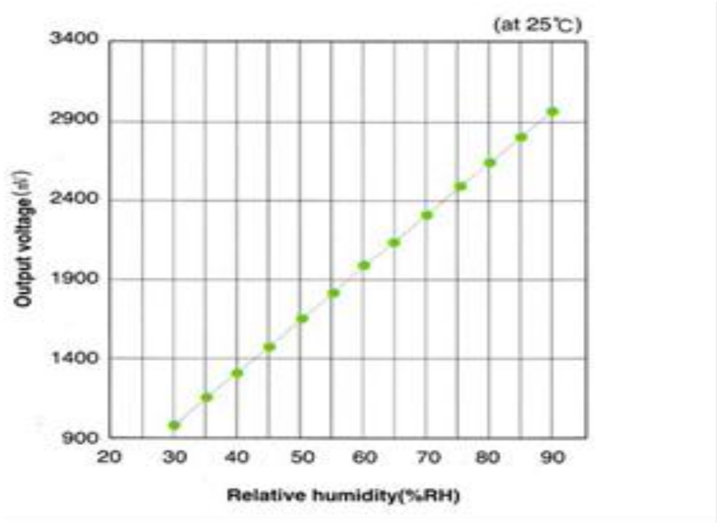

Figure 8: Graph of Relative Humidity Vs Output Voltage

VI. APPLICATIONS

- Civil infrastructure
- Dams, dikes, hydroelectric power plants, pipelines, canals, tunnels, ports, harbours, waterways, and marine terminals, etc.
- Manufacturing equipment.
- Aerospace systems.
- Mechanical equipment

VII. FUTURE SCOPE

- In order to monitor Structures at different sites, future works can be focused on establishing a system with more sensor nodes and more base stations.
- We can also use our system to monitor Bridges, dam road tunnels, Aircraft parameter continuously.
- We can use GPRS, GSM module in place of ZIG-BEE module.
- We can also use solar panel instead of battery operated power supply.
- Structural health monitoring (SHM) will be an important component of the next generation satellites and space transportation vehicles.
- In order to monitor building parameter in different sites, future works can be focused on establishing a system with more sensor nodes and more base stations. Connections between nodes and base station are via WSN, while connections among different base stations are via Ethernet. The Ethernet can also be connected to Internet so that users can login to the system and get real time Structure quality data faraway. Another interesting field lies on the optimization of power consumption and data throughput of the WSN. The wireless data acquisition from remote places and database storage is the supporting structure of the system which can be used for further research studies .

VIII. CONCLUSION

By monitoring building parameters we conclude that this project not only useful for acquiring building parameter data but also we can analyze and control it to prevent tragic accidents. This Project describes a wireless sensor network for structural health monitoring. A wireless sensor node equipped with a 3-axis digital accelerometer and a temperature and humidity sensor, Radar sensor, strain sensor is presented. A Matlab program running on an external PC connected to the sink node processes and visualizes in real-time the data received from the sensor nodes by Implementing WSN for SHM to prevent tragic incidents. Graphical representation and numerical record of all parameters are helpful for civil engineers to take corrective action for that building.

ACKNOWLEDGEMENT

The authors extend their appreciation to the S.V.I.T. Nashik for providing a strong platform.

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