EVOLUTION ON STRUCTURAL HEALTH MONITORING

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ABSTRACT

Structural Health Monitoring (SHM) systems represent one of the primary field applications for new sensor technologies. In addition, SHM systems can include actuation devices to take proper reaction or correction actions. Different kinds of sensors to monitor stability anomalies of civil structures were been reviewed in this paper. Observation of stability must be durable and reliable for the lifetime of a structure. Reliable methods were necessary to monitor them and ensure their safety and efficiency. This paper briefly describes the current technologies used in structural health monitoring system technology in the monitoring of structures and its challenges. Besides that, passive wireless Frequency Selective Surfaces (FSS) is proposed to address the existing technologies problem.

Keywords: Structural Health Monitoring; damage detection; sensor technology.

Introduction

Structural Health Monitoring (SHM) is defined as an integrated procedure for the detection and characterization of damage to the structure or building. The Structural Health Monitoring (SHM) estimates the condition of structures to ensured structural health is in stable condition. It is also used to detect any movement and changes in structure such as tension and stress that impact system performance at every occasion during the life of structure. The systems were installed on bridges, building and highways in order to improve the capacity of damage detection. The monitoring system is primarily responsible for collecting the measurement output from sensors installed in the structure and storing the measurement data within a central data repository.

Ideally, health monitoring of civil infrastructure consists of determining, by measured parameters, the location and severity of damage in buildings or bridges as they happen. However, most of health monitoring system does not give sufficiently accurate information to determine the extent of the damage. Moreover, existing sensors shows their weakness such as high power consumption, difficult for maintenance and increase the cost in monitoring system.Wired sensor SHM also have a limitations in term to cover large area using hundreds sensor and it is used a combined system of RF communication module, microprocessor, sensing module and battery. In the past, monitoring of structures was usually done by means of visual inspection and tapping of the structures using a small hammer. Recent advancements of sensors and information technologies have resulted in new ways of monitoring the performance of structures. The aim of structural health monitoring is to improve safety and performance of infrastructure by detecting damage before it becomes in critical level. Maintenances of sustain infrastructure system is an essential tool for structural health monitoring. This paper provides a synopsis of a review that will summarize structural health monitoring studies that have appeared in the technical literature between 2008 and 2015. This review concludes by a summarizing progress and development that has been made with regard to critical issues identified in the previous review and identifies new issues.

Different Method Description

A. Monitoring using Passive RFID Tags, (Year – 2008)

This review begins with passive Radio Frequency Identification (RFID) Tags sensor that has been developed in 2008. The RFID tag is a touch sensor system that can measure the loading capacity of the internal structure of the object through some covering materials for structural health monitoring. Various kind of technique has been applied in developing Structural Health Monitoring systems. The sensor is not only for concrete but also can be applied for other materials to monitor the structure of

objects. Moreover, the device does not require a battery, thus it is inexpensive hence this system require little maintenance. In every RFID sensor module have 3 components such as strain gauge sensor, RFID tag and sensor board. The architecture of development system which includes the RFID sensor module that implanted in the structure and measurement module for data acquisition. There are have some component required for sensor board for detection sensor output which is an amplifier circuit. However, the main problem for designing modules is how strain gauge sensor on the board driven by small power supply of the RFID tag. RFID tags exactly require high power consumption for both Analog Digital Converter (ADC) function of RFID and the communication process using RFID tags. Therefore, application is limited for sensor system that has low power consumption without using an amplifier. In order to overcome this problem, development system needed in separation between two sorts of RFID tags for power supply and communication system. This structure realizes stable communication after enhances the system that electricity consumption will generated when RFID used for sensing. Although this RFID sensor realizes as a stable communication and passive RFID with use less power, significant gap still remain. The cost and difficulty for installation this sensor still remain high consideration to execute the maintenance particularly the implanted sensor in the structure. Furthermore the sensors requiring power consumption for communication of strain loading information [1].

B. ZigBee Technology, (Year – 2009)

Over the last few years, Wireless Sensor Networks (WSN) is widely obtained in Structural Health Monitoring application that attracted the researchers because of their capability to monitor with great potential. Wireless Sensor Network based on ZigBee Technology was introduced with an effective and reliable system to overcome currently problems to monitor and maintain the safety of infrastructure. This wireless technology can support structural health monitoring for building, bridge and road. Several types of WSN were developed such as in order to solve the problem for civil structure that shown a great performance and systematic topology, but the wireless module is consumed high power for transceiving the signal and the structure very complicated. Therefore, ZigBee wireless technology was enhanced which has several advantages that used less power consumption compared to conventional Wireless Personal Area Network (WPAN) such as Bluetooth or WiFi. Besides that, the performance of network topology in terms of enhancing the precision time processing was analysed. ZigBee based on Wireless Sensor Network (WSN) that composed several subsystems which is sensor module, computational core and wireless communication. The wireless sensor designs were able to support up to 4 structural sensors simultaneously through 16 bit analog to digital converter. Whilst the sampling frequency can be up to 100 kHz which enough for structural monitoring system. By enhancing power consumption, time synchronization and accuracy data collection with the effective performance, this system also suitable for monitoring in the long distance as bridge, road and high building. However, most of traditional wireless sensor network structure was complicated and increasing the cost. Furthermore, this technology still consuming more power since it is needed to collect real time data in 24 hours per day equivalent to increasing proportional distance. Hence, the low power sleep functions need to be designed to meet a long run of structural health monitoring [2].

C. Acoustic Emission Technology, (Year – 2009)

Previously, application of acoustic emission (AE) technology has been focused for bridge structures health monitoring. AE waves are pressure waves arising from the rapid release of strain energy to keep up with changes in the microstructure of materials. AE waves were recorded by sensors placed on the surface. Sensors have been built with piezoelectric elements which convert the mechanical waves into electrical signals. By analyzed the signals, it provides information about the source of the emission. The systems are very sensitive and have the ability to find the beginning of the source. This system was classified as a passive method and also applied for real time monitoring. Piezoelectric materials are substances that have electromechanical coupling between electrical and mechanical which it will affected by temperature dramatically. AE technology has proved that more efficient and impressive performance based on piezoelectric elements compare to conventional sensors for civil structure monitoring. Unfortunately, both of electrically and mechanically properties elements can affect by unstable temperature. Moreover, material properties can vary significantly with temperature. Although this type of sensor is robust sensor and inexpensive to set up the installation, but there was some weakness regarding this sensor that operating environments were often very noisy, and the signals of acoustic emission were usually weak [3].

D. Optic Fiber Sensors, (Year – 2011)

Recently, Optics Fiber Sensor (OFS) is a sensor that used optical fiber as a sensing element and relaying signal from a remote sensor to the electronics that processing the signal. This sensor normally applied in the various real structures such as civil engineering, oil and gas industry, transportation and renewable energy. Several techniques have been introduced with their own advantages. The main techniques OFS proposed the superior performance which is long gauge technique that using SOFO (both the Static and Dynamic) technology systems to overcome the problem from the conventional OFS technique for the future of OFS for SHM. OFS is usually made of a transducer device, a communication channel and a subsystem for generating and detecting the signal. Optical fiber sensors have been installed on or embedded in the structure of their nervous system. They act simultaneously both as a channel as optical and optical transducers distributed. A pumped optical pulse is launched through fiber. As a result linear or nonlinear characteristic effects produce when the light propagates continuously backscattered in the fiber. Once detected, analyzed and conditioned, the system will deliver an output signal, usually in the electrical domain. The OFS technology has proven to improve quality and impressive performance such as easier installation, maintenance and also good reliability. However, fiber optic sensors is expensive to use as health monitoring because the complicated installation and high cost material. Moreover, the sensor system is prone to damage either when deployed in the field or during working life [4].

E. WSN Technology based on GPS, (Year – 2013)

Recently, much attention has been focused on wireless GPS sensor network for Structural Health Monitoring. A (SHM) wireless GPS sensor network system for monitoring of the displacement of buildings has been enhanced in 2013. The systems consist of multiple sensor nodes equipped with GPS that were installed on the top of the roof of a building. The GPS is used to detect the

position of these sensor nodes during several instants of time. The information is collected through wireless communication. This experiment used 19 sensors node which is installed in a grid on top of building where monitoring by the GPS patch antenna system. The sensor node of a wireless communication consist L1 GPS receiver, GPS antenna and module with low and high power CPU. In the system, the short address is employed as ID in the GPS analysis. Analysis results were compared with the relative position of nodes measured with a tape measure as the real position. As for GPS positioning analysis, a high performance CPU is needed to perform double accuracy arithmetic. Nevertheless, low power consumption is needed in this system due to the sensor node should be operating as long as possible with limited energy. The information will be collected by using wireless communication. These systems were completed within 10 minutes to complete the whole work flow. However, this time is longer than the theoretical estimation time. Although this sensor state can reduce the power consumption but the sensor structure for installation is complex and increasing the cost [5].

F. Internet of Things (Year – 2013)

Internet of Things is one of the applications that combined environmental sensing with data transmission through wireless communication techniques. This application was proposed the huge amount network sensors for monitoring structure with real time sensing. Principal Component Analysis (PCA) is applied to avoid environment impacts from sensor information which contain both real vibration feature of interferences structure and environment [19]. Hilbert Huang transformation (HHT) is an established method for signal analysis that is deployed for structural health monitoring and analysis after environment interferences has been removed. Elimination environmental interferences from sensor data which contain feature of structure and environmental effects utilized were by Principal Component Analysis (PCA). To detect structural health problems, HHT combined with empirical mode decomposition (EMD) where it was employed for data processing and analysis. This type of sensor is very accurate and robust against the environmental interferences. However, this method used a large amount of sensor to detect the architectural and mechanical structure hence will make it difficult for maintenance and require high cost installation [6].

G. Wind Energy Harvesting system using WSN, (Year – 2014)

Wind energy was efficiently designed and developed for energy harvesting for structural health monitoring application. Previous existing wireless sensor network utilized more power consumption. These methods introduced to storage device instead of batteries by using super capacitor, which cope with eliminate the replacing batteries issues for power management system. In power management system, harvested electrical signal from micro wind turbine generator is in alternating current (AC) form. The bridge rectifiers were needed to convert alternate current to direct current (DC). The wireless SHM has several components such as accelerometer sensor, microcontroller and Xbee transceiver module. This kind of component is to transmit the measured signal from the structure to the base station. The behavior of the structure is measured by using accelerometer sensor and transmitted to the base station, where the measured data is received, processed and displayed in graphical user interface (GUI). Recently, energy storage devices was introduced the supercapacitor that used for applications requiring numerous quick charge or discharge cycles as opposed to long term compact energy storage. The advantages of supercapacitor were improved performance at high and low temperatures, high power density, virtually unlimited number of charge discharge cycles. Moreover, supercapacitor does not have a problem in rate capacity and will last longer [7].

H. River Bridges using Wireless Sensor Network (Year – 2015)

Introduced the Wireless Sensor Network (WSN) to monitor the river bridges has several advantages compared to the wired sensor technique which are less maintenance and equipment cost, low power consumption and low installation cost[20]. Furthermore, the WSN able to control any damage detection from a long distance in various structures [21]. Wireless Sensor Network consists of three parameters for Structural Health Monitoring application such as sensing interface, CPU, and wireless transceiver. The first parameter of subsystem is sensing interface. This multiple sensors were included an interface to access measurement data where it can convert signal by Analog to Digital (ADC) converter and transfer to the computational core. Second subsystem is computational core that required faster computation and higher communication rates. The computational core consist microcontroller or processor for running tasks. However, important key requirements by selecting microcontroller are power consumption, cost, voltage requirements and support external hardware. Another subsystem is wireless transceiver. Wireless system composed RF radio modem and antenna to communicate by exchange data with sensor. Wireless sensor node employed as the collection data information of the structural response from various sensors. This WSN system is Low Rate WPAN which operated on free ISM band (2.4 GHz), adding scalability to data rates, supreme data rate, longer range, less power consumption and use more channels. All parameter of this system were designed for low power consumption and long transmission range but need to keep monitoring where each parameter required the stable energy of batteries.

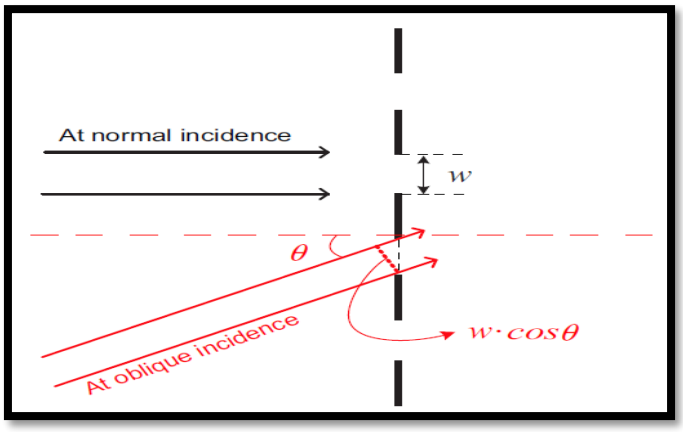
Table 1: Types of sensors categories

Type of Sensor	*Technique & Features*
Passive RFID Tags	Touch sensor system that measure the loading capacity of the internal structure.
ZigBee Technology	Utilized wireless sensor network. enhancing the precision of time Synchronization compared to existing WSN.
Acoustic Emission	Sensors built with piezoelectric elements. Initiation/growth of cracks, yielding, failure of bonds, fiber failure and de-lamination in composites.
Optic Fiber Sensor	Sensing element and relaying signal. Installed and embedded into structure.
WSN Technology based on GPS	Detect the position of sensor nodes on top of building during several instants of time.
Internet of thing	Used combining of HHT and EMD to obtain accurate result and robust against environment interference.
Wind Energy Harvesting using WSN	Used supercapacitor for long term storage energy using WSN
River Bridge using WSN	Composed RF radio modem and antenna to communicate by exchange data with sensor. Higher data rate, longer range, low power consumption.

PROPOSED FSS AS SENSOR FOR SHM

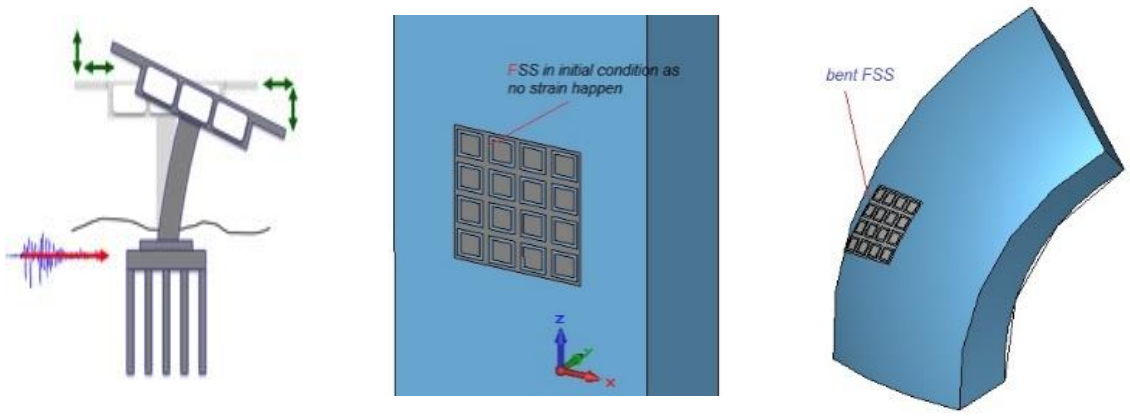
By reviewing all existing techniques of sensor for SHM application shows that the system efficient and exciting. Nevertheless, most of the SHM system required power consumption to be maintained on their system. Moreover, the design is complex resulting in maintenance difficulties. Passive wireless Frequency Selective Surface (FSS) are proposed for dealing with previous work problems. The electromagnetic wave characteristic of FSS will changed due to any structure failure or stress. When a signal arrives at an oblique angle to an FSS with conducting strips periodically separated by w, as illustrated in figure 1, the projected effective separation between each strip (and also the width of each strip) will be reduced by a factor of cos θ. The effective element dimensions seen by the oblique incident wave and accordingly the current induced differs from the scenario when the signal arrives at the FSS at 0°. As a result, the FSS angular response varies. This variation in FSS performance, the incident angle changes can also be demonstrated by the EC equations. These equations which calculate the equivalent inductive and capacitive value of FSS are function of incident angle θ. Therefore, the FSS resonant frequency is also a function of θ and the resonant frequency will shift downwards with increasing θ.

Figure 1: Equivalent projected separation between elements by an obliquely incident signal.



The wireless SHM sensor using frequency selective surface (FSS) is believed to overcome the wired and wireless SHM technologies. The electromagnetic characteristic of FSS is changed by geometric shape change of FSS by mechanical strain or structural failure. It is performed by the theoretical and experimental study of reflected or transmitted microwave signal characteristic change by mechanical strain and structural damage. This passive wireless FSS sensing any changes feature without using RFID chip. In addition, FSS is system cost effective and attempts to detect acceleration of building in high rate data with high sensitivity and send data wirelessly. Following figure 2, illustrate a normal and bending condition of the FSS as the structure change.

Figure 2: Illustration of FSS as a passive sensor



Conclusion

The historical development of wireless sensors and sensor networks intended for SHM has been explored in this paper. It is shows an SHM development since 2008 until 2015. The main objective of this paper is to ensure the structural health of any structure, its function and reduce the probability of collapse during the earthquake or others natural disaster. This paper introduced various kinds of SHM sensing techniques including RFID Tags, Zigbee technology, acoustic sensor, ceramic strain sensor, GPS devices, piezoelectric sensors, and using Wireless Sensor Network (WSN). All of the above existing sensors monitoring techniques are studied and shown their advantages and disadvantages which the major shortages mostly sensors consumed high power, maintenance cost and difficult for installation. Therefore, the contribution passive wireless FSS are proposed to overcome an existing sensors problem especially on power consumption that previous active sensors need to maintained for a long term. In addition, the passive wireless FSS is introduced which it easily to be maintained in a long term without requiring any maintenance and low cost installation.

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