Recent Application of Structural Civil Health Monitoring Using WSN and FBG

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Abstract: The objective of this paper is to provide a contemporary look at the current state-of-the-art in wireless sensor and fiber optic sensor for structure health monitoring (SHM) applications and discuss issue related to those system and hence, to make the efficient decision that provided the better system thinking. Specially, this paper provides review about structural health monitoring like, bridges, pipelines etc. using WSN and fiber optic sensor. This paper presents a comprehensive review of wireless sensor and fiber optic sensor for SHM and challenging issue related to the structural health monitoring. It also introduces research challenges and potential applications of the WSN.

Key words: Structural health monitoring %Wireless sensor network %Structural health % Synchronization %NDE %FGB

INTRODUCTION

The damage of civil infrastructural health occurs enormously due to catastrophic events like earthquake, flooding and terrorist attacks. In addition to these events, the structure could undergo gradual deterioration over its life span due to corrosion, fatigue, vibration etc. Given the increasing age of many structures, low-cost structure monitoring systems are required to take necessary precautions accordingly. Most of the structure monitoring methods includes visual checks, which can only identify damages visible on the structure surface. To detect the problems timely and take necessary actions accordingly, there is an urgent need for reliable structure monitoring systems that can automatically and quantitatively analyze the real-time condition of structures [1]. The process of implementing a damage identification strategy for aerospace, civil and mechanical infrastructure is referred to as structural health monitoring (SHM). Here, damage is defined as changes to the material and/or geometric properties of these systems, including changes to the boundary conditions and system connectivity, which adversely affect the overall system’s performance [2].

The general purpose of structural health monitoring (SHM) includes hazard mitigation, improvement of safety and reliability of the structural system, sustainability and life cycle cost reduction. In general, the structural monitoring technology consists of sensing, signal processing, health/damage assessment and system integration [3]. Traditionally, the data acquisition system of the SHM is wired based, which can acquire sensor data periodically. These systems measure structural behavior and assess structural safety circumstances using various types of sensing device certain damage diagnosis and prognosis method [4, 5].

Structural Health Monitoring System is used in the structure for public safety and to detect structural damage and reduce economical cost. There are two techniques for measuring damage detection of structural health, namely “Local” and “Global”. Local techniques detect small defect like micro-crack of the structure, while global techniques detect significant damages which lead to change integrity of the entire structure. Most of the measuring technique is local and few of the Global [6].
Non-destructive evaluation (NDE) technology is to use visual inspection of highway bridges damage. When normal visual inspection is unable to measure the damage then new NDE technologies are used to solve difficult inspection challenges those beyond the capability of normal visual inspections. NDE describe the reliability of both routine and in-depth inspection practices and its support three types of structure: the superstructure, substructure and deck. The reliability and accuracy and identifies factors of NDE method that may influence the inspection results and determines some of the procedural differences that exist between various State inspection programs [7].

Laser-based NDE method measure the distance for highway infrastructure. Some damage location due to corrosion, deterioration, vibration, tilt etc. cannot by these methods and often time consuming and expensive and access is not always possible. The system is capable of measuring over a range of 30 meters with sub-millimeter accuracy [8]. Since, Non-destructive evaluation (NDE) is often time consuming and expensive and access is not always possible [9]. Therefore, Local and global health NDE technique are necessary for monitoring infrastructure damage and several NDE technique are discussed in the article [10]. In every year, current federal spending in the US forreplacemen of structurally obsolete bridges basedon these NDE methods is approximately $10billion [11]. In general, a typical SHM system includes three major components: a sensor system, a data processing system (including data acquisition, transmission and storage) and a health evaluation system (including diagnostic algorithms and information management) [9]. The conventional SHM monitoring system uses cables for data communication. The installation of data cables with sensor increase cost and difficult to installation, maintenance and repair. C More Cable required for installation and difficult installation in the pipe line.

C Sensor data distorted if the cable is damage due to temperature high or any other causes.
C Noise elimination difficult because cable connection.

In recent years, FBG (Fiber Bragg Grating) has been accepted as a new kind of sensing element for structural health monitoring (SHM) in civil infrastructures. The optical fiber sensor based on FBG (Fiber Bragg Grating) are two types of method holographic method and phase mask method. The advantages of the fiber optic sensor multiplexing the large number of sensors along a single fiber, small size and light weight comparing to the wired system. The advantage of the Holographic method: it is easy to adjust the angle between two beams to create different periods. The disadvantage of this method is that a more stable setup is needed and a good coherence light source is also requested in the meantime. The advantage of the mask method is simple great repeatability but the disadvantages of the method only one wavelength can generate of FBG [12]. Some general drawbacks of the optical fiber are:

C Bending angle not more than 90°, otherwise its fragility.
C Need encapsulate (packet) when installed in the practical field.
C High cost and perfect installation in critical situation sometimes so difficult.
C Network structure is being more complex if the civil infrastructure is large.
C More bending angle of the optical fiber more signal loss occurs.

Structural Health Monitoring System diagnosis the damage of the structure in advance before the entry system damage. Now a days, wireless sensor network become more popular technique to detect the damage like temperature, measurement, crack detection and define its location with thickness, vibration measurement, tilt measurement, deterioration measurement, Corrosion measurement, acceleration measurement, are widely use because it’s low power profile, low complexity and reliable for transmission than other system. With the recent advances in wireless sensor networks (WSNs) and micro-electro-mechanical-systems (MEMS) technology, the cost of the structural health monitoring system is scale down [13-15].

Theoretical Approach: There are different kinds of wireless sensor network already developed to measure structural health monitoring damages [16]. Smart wireless sensor network based on radar sensor for monitoring displacement of the bridge structure is provided in [17]. In [17] the interferometer radar sensor network, the 2.4GHz single tone base-band signal come from voltage controlled oscillator (VCO) divided into two parts by balun, one part of the signal is amplified and transmit out through the transmitter. Another part of the signal goes
to the demodulator. The receiver received the transmitted signal with vibration information. The received signal is amplified, filtered and feed into the quadrature direct conversion demodulator which mixed the received signal with another output signal come from balun. After demodulation the baseband signal have two component one is In-phase component and Quadrature component. Two components of the signal feed as input of the analog to digital converter (ADC). The output of the ADC interface with ZigBee IEEE 802.15.4 through microcontroller. The radar sensor act as an end device when connect with ZigBee mesh network which is integrated with themicrocontroller. To cover the large area service area, the whole network is divided into sub-network and each router connected with several sensor. If any sensor needed to be add, than just add new subnet IP by verification existing sensor ID(M.XBee). Three types of modulation scheme are available in [17] first one is arctangent demodulation, second one nonlinear demodulation [18] and small angle approximation is third one [19]. It should be noted that sensor must not be placed on ground or reflection plate due to motion have component may cancel each other and accuracy of this system is 1 millimeter.

A complete wireless sensor system for structural health identification under three different environmental loads is designed, implemented, deployed and tested [20]. In this system, spatial jitter to reduce and precision is increased without adding complexity and also scalable to a large number of nodes to allow for dense sensor coverage of real-world structures but its limited by a define measurement length and mandatory time to obtain the final result. A small synchronization error between devices means that the proper mode shapes could not obtained from reality or theoretical calculations of structure is not possible. Without considering this fundamental error, the accuracy of the wireless is degraded due to noise made by the sensors [21, 22]. Frequency decomposition is one of the most widespread method to obtain mode shapes of the structures. The precision in synchronization are directly linked to the correct result and slight delay in the output response has a strong impact on the mode shapes, particularly for high-order modes [22]. The effect of time-synchronization error on SHM applications [23] and how synchronization errors affect the process of obtaining mode shapes and why the synchronization error should be below 1 ms in order to get valid data [24]. After that, some systems are used to minimize synchronization error where each sensor send reference beacon to their neighbors such as RBS [23] FTSP [25], TSPN [26]. Another method to reduce synchronization error using GPS receiver which synchronize the hardware clock with a resolution of within 100 ns but the system consume large, hence cost of the overall system is too high [27]. ZigBee radio protocol is one of the most widespread wireless systems for monitoring structural health because of its low power consumption and high performance in communication and configurability. Although, ZigBee has many advantages, but one of the technical limitation of its transmission bandwidth and data rate, communication range. Those above systems provide good synchronization, but SHM needs to increase time accuracy in order to obtain accurate results. During sampling process for wireless communication some information of the original signal is lost and measurement duration limitation do not allow for a reliable system. To solve this problem, reduce the number of node of the systems which lead to reduce overall system performance. Piezoelectric sensors are used for high precision which implies that their signal should be acquired with high-resolution analog-to-digital converters (ADCs). The minimum synchronization error between two boxes has to be less than 120 µs and the main problem in synchronization is stack layer overhead [20]. Packets are sent via Wi-Fi and Zigbee radio interface is dedicated only to synchronization and Wi-Fi networks are protected by two systems WEP and WPA. Three different tests: firstly, synchronization module is checked in the lab, secondly, an operational modal analysis (OMA) is carried out on a real structure and finally, the signals corresponding to two accelerometers, placed on the structure at the same location [20].

On site testbed wireless sensor network explore different sensing, networking and distributed computing approaches in real application. Depending on bridge characteristics such as age, materials and design, as well as vehicle traffic, each bridge has a fixed schedule of on-site test using strain gauges and/or displacement sensors [28]. During test, a known load is driven on the bridge and the response of the sensors is stored on data-loggers at that time the bridge is either closed down to traffic, or traffic is impeded by the slow passes of the heavy test truck [28]. A 64-node WSN has been developed in the Golden Gate Bridge at San Francisco for monitoring ambient vibrations [29]. On the other hand, a 20-node WSN were implemented in Potsdam, NY, based on strain gauges and accelerometers sensor [30]. Both 64 and
20-node base WSN were short term development not long term. Two types design are done: first one design based on classical balanced Wheatstone bridge and an instrumental amplifier but some problem are found among those amplifier noise, power supply fluctuation. The second one is packaged base using two strain gauge with larger USB connector and able to sense up to 33V external DC voltage [28].

An integrated method is approach to the Design of Wireless Sensor Networks for Structural Health Monitoring based on building’s characterization and monitoring basically vibration base analysis [31]. Structure’s behavior and expected structural response could be exploited in the design of a monitoring network and the performance of the distributed could increase by improving energy efficiency [31]. Modal analysis is the traditional approach for measurement structural health response and natural frequencies, mode shapes and damping ratios consider as a measurement parameter. The problem of modal analysis its high system cost, footprint and small measuring time and did not count white Gaussian noise. But, its advantages that no need to use any controlled solicitation equipment and it is possible to characterize the structure under its normal operating conditions [31]. Various techniques have been developed for modal structural identification recently and these include:

C Time domain techniques, such as ITD (Ibrahim Time Domain) [32], Next (Natural Excitation Technique) and SSI (Stochastic Subspace Identification) [33];
C frequency domain techniques, such as FDD (Frequency Domain Decomposition) [34], Subsequently improved as EFDD, Enhanced Frequency Domain Decomposition [35];
C Time-frequency methods, such as those based on analysis of wavelet transforms [36], Cohen’s class transforms [37] and recently EMD (Empirical Mode Decomposition) [38], mode shape base method (MSBM) [39].

Issue Related To WSN: Depending on the application scenario and specific structure, issues related to WSN for Monitoring Structural Health systems may impose different requirements. The following issue base on the building structure [20, 40].

Quality of Data: Data is the essential evidence which provide information about structural health condition. Quality of data is more important because it carries health condition information of the structure and any data missing became error result in the analysis. During signal processing method, sampling frequency and time synchronization other parameter related to signal processing must be specified accurately. To continue error free analysis, lossless data transmission that means must not be packet/symbol/bit error occur.

Reliability and Scalability: It seems that wireless communication could be unreliable because use a share transmission media and information error is also calculated on probability base. An increases transmission node in the network which leads collision and packet loss, so unknown errors occur with analyzing the result due to lack of reliability.

To cover the large geographical civil infrastructure scalability of the wireless sensor network is most important issue. Scalability of the WSN provides adjustment flexibility with infrastructure for monitoring structural health by adding new transmission node in the network and also defines higher precision of damage detection. Sensor coverage area which define complexity of the scalability to cover the whole services area.

Real-time Response and Lifetime of the Overall: The measurement of the overall system should be real time response after sampled. Efficient design of the fault management solution of the wireless sensor network is another important challenge based on real time environment [41]. Every system is defined by real time response. Data reach with respective node may be delay occurs beyond define real time. The faster real time system response may provide more accurate data and system provides correct decision to make result.

The lifetime of the overall monitoring system should be increase then overall system cost is going down and limited maintenance will be require and system become powerfully efficient.

CONCLUSION

This paper presents a review of recent research and development activities in SHM of civil structures and discusses several technique that evaluate structural damage and issue related to the WSN. Traditionally, wired system is used for collecting sensor data periodically but this system has several disadvantages. The mainissues of WSN are the scalability, accuracy, reliability and data precision. On the other hand, cable based sensor system and fiber optic sensor requires more cable and the overall
system cost is going high. Due to technology advancement MEMS provided low cost sensing device from previous but, it has several dis-advantages like low data rate, transmission rage, sensor coverage area etc.

**Further Recommendation:** We will try to develop the new protocol that provide higher transmission rate with low cost and large scale communication with better reliability, accuracy and scalability also.

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**REFERENCES**


