Wireless based Smart Sensor Technology for Structural Health Monitoring- Opportunities and Challenges

Priyajit Dash[1*]
Electrical and Electronics Engg Department
BRCM CET, Bahl-127028, Bhiwani, Haryana

Arabinda Sharma[2]
Civil Engineering Department
BRCM CET, Bahl-127028, Bhiwani, Haryana

Abstract*- Industrialized nations have a huge investment in the pervasive civil infrastructure on which our lives rely. To properly manage this infrastructure, its condition or serviceability should be reliably assessed. For condition or serviceability assessment, SHM has been considered to provide information on the current state of structures by measuring structural vibration responses and other physical phenomena and conditions. Smart sensors with embedded microprocessors and wireless communication links have the potential to change fundamentally the way civil infrastructure systems are monitored, controlled, and maintained. The computational and wireless communication capabilities of smart sensors densely distributed over structures can provide rich information for structural monitoring. Structural health monitoring (SHM) is an emerging field in civil engineering, offering the potential for continuous and periodic assessment of the safety and integrity of civil infrastructure. Based on the knowledge of the condition of the structure, certain preventive measures can be taken to prolong the service life of the structure and prevent catastrophic failure. Damage detection strategies can ultimately reduce life-cycle cost. The aim of SHM is to develop automated systems for the continuous monitoring, inspection, and damage detection of structures with minimum labor involvement. Smart sensors, with their on-board computational and communication capabilities, offer new opportunities for SHM. Without the need for power or communication cables, installation cost can be brought down drastically. Smart sensors will help to make monitoring of structures with a dense array of sensors economically practical. Densely installed smart sensors are expected to be rich information sources for SHM. To realize structural health monitoring, employing smart sensor system needs to be designed considering both the characteristic of smart sensor & the structure to be monitored. This paper provides a brief introduction to smart sensing technology and identifies some of the opportunities and associated challenges.

Keywords— SHM, Smart sensor, Wireles communication, Sensor nework

I. INTRODUCTION

Our daily lives are becoming more dependent on civil infrastructure systems such as bridges, buildings, pipelines and offshore structures are valuable national assets that must be maintained to ensure economic prosperity and public safety. Many bridge structures in modern countries have reached their design life and will need to be replaced or retrofitted to remain in service. Thus, the ability to assess the structural condition and possibly increase the service life has been pursued widely by researchers. [1]Structural health monitoring (SHM) is an emerging field in civil engineering, offering the potential for continuous and periodic assessment of the safety and integrity of civil infrastructure. Based on knowledge of the condition of the structure, certain preventive measures can be taken to prolong the service life of the structure and prevent catastrophic failure. [2] The design, fabrication, and construction of smart structures are one of the ultimate challenges to engineering researchers today. Because they form the essence of system intelligence, one of the cores of smart structures technology centers around innovative sensors and sensor systems.SHM represents one of the primary applications for new sensor technologies. [3]. To effectively investigate damage, a dense array of sensors will be required for large civil engineering structures. [4] Structural damage can be caused in various ways. Normal activities can introduce damage to the structure. Buildings can be damaged due to corrosion, aging, and daily activities. Traffic and wind loads cause damage on bridges, while offshore structures suffer from wave loading and corrosion due to the seawater. On the other hand, excessive loads produced by tornados, hurricanes, and earthquakes also can potentially cause damage in structures.[5] To ensure structural integrity and safety, civil structures have to be equipped with SHM, which aims to develop automated systems for the continuous monitoring, inspection, and damage detection of structures with minimum labour involvement. An effective SHM system can in real time, and online, detect various defects and monitor strain, stress, and temperature so that the optimum maintenance of the structures can be carried out to ensure safety and durable service life.[6] SHM has become very important because of modern civil, mechanical structures because of its size and cost involved in it. These mega structures, brides, skyscrapers, off shore wind turbines and wave energy devices are subjected to the external aerodynamic excitations, earth quakes. It has become important to monitor the response of such structure in such loading situations which leads to the defects in these structures and at some point it causes a catastrophic failure of the structure.[7] The civil structures are often exposed to severe loadings during their lifetime, especially at extreme events like earthquake and typhoon, which causes serious concerns on the integrity of the structures that, is closely related to the public safety. Tragic disasters on the civil structures, like collapses of bridges or buildings, often accompany a large number of casualties as well as social and economic problems, thus most of the industrialized countries are on the verge of increasing their budget for SHM of their major civil infrastructures. The SHM system often offers an opportunity to reduce the cost for the maintenance, repair, and retrofit throughout the life-cycle of the structure.[8] SHM systems have emerged to fulfill the need to have control over the integrity of any structure for its full lifetime and to improve nondestructive evaluation and testing techniques.[9]

II. STRUCTURAL HEALTH MONITORING

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. 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.[10] Civil Structural health monitoring under operating conditions has an enormous potential for pre accident prevention and can effectively reduce regular manual checks. Data produced by the continuous monitoring devices at regular intervals with higher accuracy will pave the way to automated asset management [11]. The goal of any SHM sensor network is to make the sensor reading as directly correlated with, and as sensitive to, damage as possible. At the same time, one also strives to make the sensors as independent as possible from all other sources of environmental and operational variability, and, in fact, independent from each other(in an information sense) to provide maximal data for minimal sensor array outlay.[12] The SHM is an emerging technology with multiple applications in the evaluation of critical structures. The goal of SHM research is to develop a monitoring methodology that is capable of detecting and identifying, with minimal human intervention, various damage types during the service life of the structure. SHM assesses the state of structural health and, through appropriate data processing and interpretation, predicts the remaining life of the structure.[13] Civil infrastructure is the foundation of our society and has a widespread impact on the quality of our daily lives. Monitoring the safety and functionality of the world's buildings, bridges and lifeline systems, is critical to improving maintenance practices, minimizing the cost associated with repair and ultimately improving public safety.[14]

To efficaciously investigate both local and global damage, a dense array of sensors is envisioned for large civil engineering structures. Such a dense array must be designed to be scalable, which means that the system performance does not degrade substantially or at all as the number of components increases. In the conventional approach using wired sensors (see Fig. 1), the sheer number of accompanying wires, fiber optic cables, or physical transmission medium may be prohibitive, particularly for structures such as long-span bridges or tall buildings. Consequently, global communication in a wireless fashion that will facilitate low-cost, densely distributed sensing has been distributed. [15] A sensor network directly connected to the central processing hardware, such a system is the most common one used for structural health monitoring studies. The advantage of this system is the wide variety of commercially available off-the-shelf systems that can be used for this type of monitoring and the wide variety of transducers that can typically be interfaced with such a system. For SHM applications, these systems have been used in both a passive and active sensing manner. Limitations of such systems are that they are difficult to deploy in a retrofit mode because they usually require AC power, which is not always available. Also, the direct wired connections to the processing unite make these systems one-point failure sensitive. [12]. Centralized data acquisition and processing schemes (See Fig. 1) that are commonly used in traditional wired sensor systems.

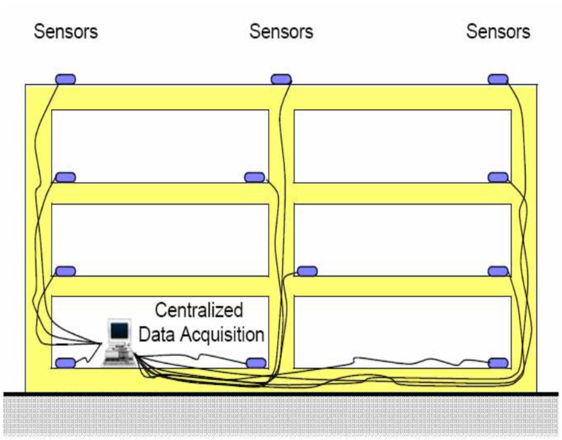

Figure 1. Traditional SHM System using Centralized Data Acquisition

III. SMART SENSORS

Smart sensors with embedded microprocessor & wireless communication lines have the potential to fundamentally change the way as civil infrastructure systems are monitored, controlled, and maintained. The sensor is a device which is de-signed & used to acquire information from an object and transfer it into an electrical signal. It consist of 3 parts-the sensing element (*e.g.* resister, capacitor, transistor, diode etc.), Signal conditioning & processing (*e.g.* amplification, filter) and Sensor interface (*e.g.* plugs etc.). Smart sensor differs from the standard integrated sensor in its intelligence capabilities i.e., its on board microprocessor (Fig. 3). The microprocessor used for analog to digital conversion, digital processing, calculation etc., should have the characteristic to facilitate self- diagnostics and self adaptation function. [16] Wireless smart sensors (WSS) differ from traditional wired sensors in significant ways. Each sensor has an on-board microprocessor that can be used for digital signal processing, self-diagnosis, self-calibration, self-identification, and self-adaptation functions. Furthermore, all WSS platforms have thus far employed wireless communication technology. WSS technology has seen substantial progress through interdisciplinary research efforts to address issues in sensors, networks, and application-specific algorithms. [17]

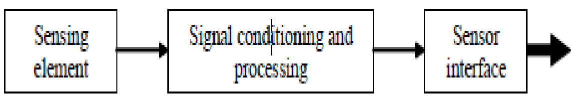

Figure 2.Traditonal sensor

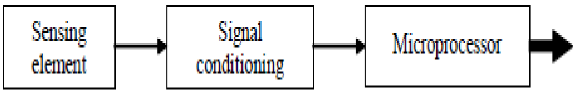

Figure 3.Smart sensor

The size of smart sensors has been decreasing with time. The use of Micro Electro Mechanical Systems (MEMS) has made possible the dream of having ubiquitous sensing and in particular small “smart” sensing. MEMS devices are manufactured using vary large scale integration technology (VLSI) and can embody both mechanical and electrical functions. MEMS can be used in an environment to both sense and actuate. Sensing requires that a physical or chemical phenomenon be converted to an electrical signal for display, processing, transmission, and/or recording. [3] Finally, all smart sensors to date are wireless, with data transmission based on radio frequency (RF) communication. There exist several protocols for transmitting data. One of the most popular is Bluetooth, a short-range radio technology aimed at simplifying communication among Net devices, as well as between devices and the internet. Smart sensor as define herein has four important features: (i) on-board Central-Processing- Unit (CPU), (ii) small size, (iii) wireless, and (iv) the promise of being low-cost. [2] The sensor unit consists of a microprocessor, radio modem, data storage, and batteries. To save battery life, most of the time the sensor unit is in a sleep mode, periodically checking its hardware interrupts to determine if there are external events that require attention. Building on the work demonstrated a proof of concept wireless sensor that utilized standard integrated circuit components. This unit consists of an 8-bit ATmel microcontroller with a 4 MHz CPU that can accommodate a wide range of analog sensors. The communication between the sensors is done via a direct sequence spread spectrum radio. Some units use the 14-bit digital output with an anti-aliased digital signal of the ADXL210 accelerometer. In other units, a high performance planar accelerometer is used along with a 16-bit analog to digital (A/D) converter. [3] The essential difference between a standard sensor and smart sensor is the latter’s flexible communication and information processing capability. Each sensor has an on-board microprocessor that can be used for digital signal processing, self-diagnostics, self-identification, and self-adaptation functions. [4]

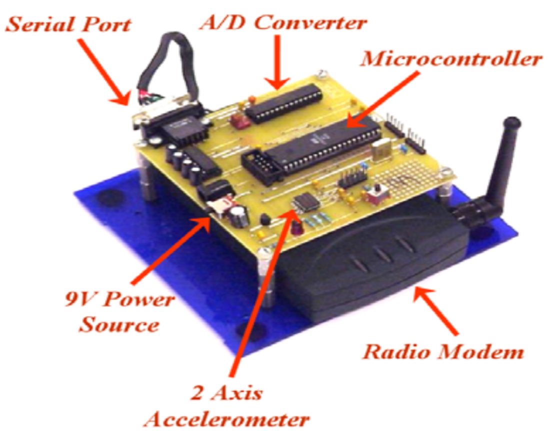

Figure 4. Prototype Smart sensor

Rapid advances in sensors, wireless communication, MEMS, and information technologies have the potential to significantly impact SHM. To assist in dealing with the large amount of data that is generated by a monitoring system, on-board processing at the sensor allows a portion of the computation to be done locally on the sensor’s embedded microprocessor. Such an approach provides for an adaptable, smart sensor, with self diagnosis and self-calibration capabilities, thus reducing that amount of information that needs to be transmitted over the network. .[3] integration of wireless communication technologies into SHM methods has been widely investigated in order to overcome the limitations of wired sensing networks. Wireless communication can remedy the cabling problem of the traditional monitoring system and significantly reduce the sensing system maintenance cost. [12]

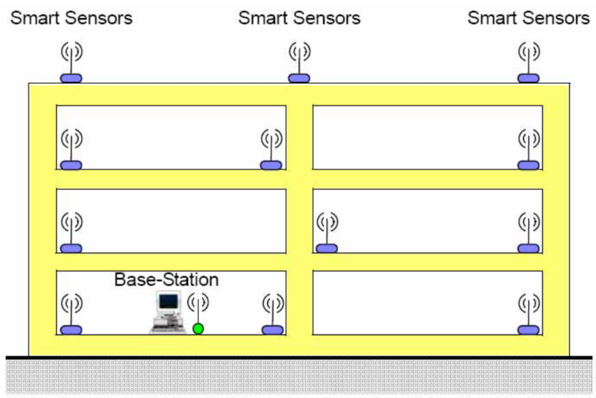

Figure 5. SHM System with Smart Sensors.

IV. OPPORTUNITIES

The use of smart sensor can provide a better platform for structural health monitoring as civil infrastructure are getting older day by day and need to have more attention. The ability to continuously monitor the integrity of civil infrastructure in real-time offers the opportunity to reduce maintenance and inspection costs, while providing for increased safety to the public There are several methods of structural health monitoring but those are time consuming, expensive and complicated too. The smart sensor will be a effective tool for taking the proactive decision regarding SHM. The complexity of cabling all traditional sensors and connecting together in a network for SHM will be reduced since smart sensor is wireless. Few examples of smart sensor applications are mentioned below.

1. Validation of an integrated network system for real-time wireless monitoring of civil structures has been analyzed.[2]
2. The bridge activities has been monitored.[17]
3. The SHM framework is experimentally verified on networks of Imote2s using the 5.6 m-long, three-dimensional truss structures.[10]

V. CHALLEGES

Although the opportunities of smart sensor for structural health monitoring offered significant benefits but there are certain challenges to smart sensor for structural health monitoring are limited resolution of A/D converter in smart sensor which restricts higher accuracy, proper synchronization for sensor measurement required otherwise there maybe chances of phase error occurrence, limited memory of smart sensor will add difficulties for continuous SHM, in a massive distributed sensor network it is very difficult to continuously send and receive data, continuous energy supply for smart sensor for making it functional is also difficult, limited bandwidth of smart sensor makes difficult for speedy data transmission and can hinder the real time application, Security Issues must be taken into account to ensure that the information sent through the network is not compromised modified or denied. Authentication schemes, including encryption and decryption of data, as well as assessing the risk of a given environment, should be considered apart from these difficulties there may be software issues data assumption for real time application may not be used by smart sensor in distributed computing environment.

VI. CONCLUSION

Smart sensor technology for structural health monitoring is in improving stage people around the globe not accepted this technology. Smart sensor is having lots of advantages over traditional sensor but it has certain challenges required to overcome as mentioned in this paper. From a civil engineering perspective, SHM is expected to provide an efficient and effective tool for management of civil infrastructure since this infrastructure is very valuable asset, which keeps the economy and people's life running. There is need of other engineering discipline to focus on smart sensor technology for making more suitable for monitoring civil infrastructure. If we can able to overcome the associated challenges on smart sensor technology then it smart sensor can be best tool for structural health monitoring.

VII. REFERENCES

[1] Shinae Jang , et al. , “Structural health monitoring of a cable-stayed bridge usingsmart sensor technology: deployment and evaluation,” Smart Structures and Systems, Vol. 6, No. 5-6 ,pp.439-459, 2010.
[2] Sundaram, B. Arun, et al. "Wireless sensors for structural health monitoring and damage detection techniques." Current Science(Bangalore) 104.11, 2013.
[3] Spencer Jr, Billie F., Manuel Ruiz-Sandoval, and Narito Kurata. "Smart sensing technology for structural health monitoring." Proceedings of the 13th World Conference on Earthquake Engineering. 2004.
[4] Spencer Jr, B. F., et al. "Smart sensing technology: a new paradigm for structural health monitoring." Proc. 39th Joint Panel Meeting on Wind & Seismic Effects, UJNR. 2007.
[5] Yong Gao, and Billie F. Spencer Jr. Structural health monitoring strategies for smart sensor networks. Newmark Structural Engineering Laboratory. University of Illinois at Urbana-Champaign, 2008.
[6] Sun, M., W. J. Staszewski, and R. N. Swamy. "Smart sensing technologies for structural health monitoring of civil engineering structures." Advances in Civil Engineering 2010.
[7] Chougule Prasad Devendra., et al. “Design of low cost wireless sensornetwork for health monitoring of larger structures.” 5th International Conference on Structural Health Monitoring of Intelligent Infrastructure, Cancún, México, December 2011
[8] Soojin Cho., et al. "Smart wireless sensor technology for structural health monitoring of civil structures." Steel Structures 8.4, pp.267-275, 2008.
[9] P.M. Monje., et al. "Integrated electronic system for ultrasonic structural health monitoring." 6th European Workshop on Structural Health Monitoring. 2012.
[10] Nagayama, Tomonori, and Billie F. Spencer Jr. Structural health monitoring using smart sensors. Newmark Structural Engineering Laboratory. University of Illinois at Urbana-Champaign., 2007.
[11] Alahakoon, Sanath, Daluwathu MG Preethichandra, and E. M. I. M. Ekanayake. "Sensor network applications in structures–a survey." EJSE Special Issue: Sensor Network on Building Monitoring: From Theory to Real Application, pp. 1-10, 2009.
[12] Park, Gyuhae, et al. "Energy harvesting for structural health monitoring sensor networks." Journal of Infrastructure Systems 14.1, pp. 64-79, 2008.
[13] Gaurav Bharadwaj., et al. "Structural Health Monitoring and Wireless Damage Detection with Piezoelectric Wafer Active Sensors." International Journal of Advanced Research inElectronics, Communication & Instrumentation Engineering and Development, 2014.
[14] Jennifer A. Rice., et al. "Flexible smart sensor framework for autonomous structural health monitoring." Smart Structures and Systems, Vol. 6 , 2010.
[15] Swati Sharma., et al. “Structural health monitoring using smart sensing technology,” International Journal of Engineering Research & Technology, Volume 1, 2014.
[16] Jyoti singh., et al. "Smart Sensors and Wireless Technology for Scrutinizing Civil Infrastructure." International Journal of Scientific & Engineering Research, Volume 4, , May-2013.
[17] B.F. Spencer Jr. and Soojin Cho. "Wireless smart sensor technology for monitoring civil infrastructure: technological developments and full-scale applications." Proceedings of World Congress on Advances in Structural Engineering and Mechanics, Seoul, Korea. 2011.
[18] Spencer, Billie F., Manuel E. Ruiz-Sandoval, and Narito Kurata. "Smart sensing technology: opportunities and challenges." Structural Control and Health Monitoring 11.4, pp. 349-368,2004.