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Smart Sensors and Wireless Technology for Scrutinizing Civil Infrastructure

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Abstract— As the human civilization is growing day by day, the nations are making huge investments in infrastructure and its provision or service ability. Now a days, it becomes very important to monitor the conditions or serviceability of these civil infrastructure in time due to everyday abrasion caused by nature calamities, physical or chemical actions. For this purpose structural health monitoring has been taken into consideration for endowment of information about the situation of civil structures, but estimation of the structural condition or state is quite a challenging task. While the research & work on structural health monitoring is still going on, a smart sensor offers new opportunities for structural health monitoring. 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 present an idea about smart sensor, their generation and how these to be employed and controlled in the structural health monitoring.

Index Terms— Health monitoring, smart sensor, civil infrastructure, wireless technology, signal processing, structural monitoring

1 INTRODUCTION

THE present world scenario envisages a tremendous growth in civil infrastructure and infrastructure which needs to be managed first and foremost. Malfunctioning of any of these structures can cause large economic loss which is detrimental condition for the nation and its individuals.

Hence, the civil infrastructure system needs to be monitored, controlled and maintained. Smart sensors for application to civil engineering structures were presented by the different researchers [1],[2]. With the growing needs and demands of the society there is an increase in the complexity of the technology. In the growth and prosperity of society, civil infrastructures or industries etc. plays a significant role. As a result the design, fabrication and construction of these structures are one of the greatest challenges in front of the engineers at present. Because of these smart structures, there is need for smart intelligence to monitor and control these structures thus involving the need for innovative sensors and sensor system. Due to the intervention and wide use of the sensor technology in the field of structural health monitoring and control system, the integrity of the structures can be maintained by providing increased safety to the public as well as to the economy of the country. As the sensor system alarms for any structural damage at an early stage, prevents the structure from reaching their limit stage and mitigate the structural dynamic response thereby reducing the cost, labor and time required to repair any critical damage [3].

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The design, fabrication & execution of the idea for construction of smart structure require smart idea and present ultimate challenges to engineering researches nowadays [4]. The integrity of smart structure lounges around sensor & similar systems. Hence for structure health monitoring & control system, smart sensor are used nowadays. 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 designed & 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. 1). The microprocessor used for analog to digital conversion, digital processing, calculation etc., should have the characteristic to facilitate self- diagnostics and self adaptation function [5].

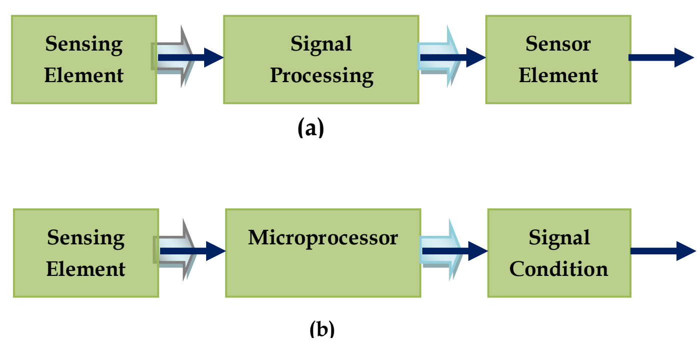

Figure. 1 (a) Traditional sensor, (b) Smart sensor.

Now a days there is wide usage of smart sensors in different fields. When different sensors were implemented, the wireless communication appears to be an attractive aspect. Hence wireless technologies come into the picture and were first introduced in 1996 [6]. With the recent advances in the field of electronics and communication and specifically in VLSI and Micro-Electro-Mechanical Systems (MEMS) technology have led to the emergence of Wireless Sensor Networks (WSN) as a novel class of networked embedded systems [7],[8]. This results in the reduction of the size and the cost of the sensor system. The "Smart Dust" [9] project at Berkeley explores the limits on size and power consumption in autonomous sensor nodes; The Wireless Modular Monitoring Systems (WiMMS) [6] was proposed for civil structures. A laboratory prototype of Wireless Sensor Local Area Network (WSLAN) for health monitoring of offshore platform is developed [10]-[15] and showed the wireless integration of MEMS and surface acoustic wave (SAW) employing interdigital transducers (IDT) [16]-[18].

As the sensors were used to monitor the large civil structures, [19],[20] discussed an approach using sensors and wireless communication technology to monitor the health of large civil structures remotely using spread-spectrum wireless modems, data communication software and conventional strain sensors. Their work described examples of condition-based health-monitoring systems that use cellular and through wire for data retrieval. [21] presented a novel idea about self-sufficient sensors in which these type of (*i.e.* generates its own Power) wireless sensors were achieved. Sensors have revolutionized through various stages. The first generation sensors were merely simple arrangement of simple electronics. The second generation were purely analog systems with electronics as remote control for the sensors . In third generation the first stage of amplification was done on the sensor chip itself. In fourth generation more analog and digital were fabricated on the same chip itself making it addressable and self testing and in the fifth generation data conversion is done on the same chip itself making it addressable, self testing and communicates over a bidirectional bus.

2 SMART SENSORS AND ITS TECHNOLOGY

A smart sensor is an assembly of the sensing element and associated electronics elements for signal conditioning and data processing on the single chip. The overall working or implementation of smart sensors requires 3 main circuit blocks: the signal processing, the digital control & manipulation and the external communication & bus interaction.

2.1 Signal Processing

The sensor records signals of varying amplitude which are low in magnitude & sensor interface usually exhibit high impedance at the frequency of interest. Signal processing sensors perform a number of function like signal amplification, impedance transformation, impedance transformation signal filtering and buffering and multiplexing. Amplification of signal is necessary to increase the amplitude of the signal for enhancement of the signal to noise ratio thus reducing the effect of noise from the environment. Also allowing full initialization of the dynamic range of an analog to digital converter. Now a days CMOS amplification is used for the purpose of amplification as they provide high gain & high input impedance. CMOS amplification are 3-5 times smaller than bipolar amplification thus making it relatively simple and compact circuit and are also compatible with high diversity circuitry on the same chip [22].

2.2 Digital Control and Manupulation

After the digitization of the sensor data there are number of errors and shortcomings that occurs like self-testing, fault detection and correction and linearity correction, so analog to digital converters are used now a days utilizing switched capacitor circuits and resistor circuits which had helped in the integration of high density CMOS digital circuitry of very high accuracy analog to digital converters [23],[24].These techniques help in the integration of high diversity CMOS digital circuitry and lower power communication in analog function [25],[26].

2.3 Communication and Bus Interaction

Smart sensor should be capable of interacting with the higher level controller that manages the overall system. The smart sensor exchanges its data or information by using a dedicated interface between the smart sensor circuitry & microcontroller using a bus. Two issues are of particular importance first, each smart sensor should be capable of interfacing with different buses & bus protocols. Research & work is going on to develop a standard bus for sensor application to optimize functionality, speed and overall cost [27]. Second is the communication interface & its complexity *i.e.* in the most complex from the communication interface should have the ability to receive and transmit the information over the bus at high speed within interfaces.

3 WORKING OF SMART SENSORS

As the wireless signal radiates from an antenna in open space, it loses power which is proportional to the wavelength of the radio band and inversely proportional to the square of the distance from the transmitter [28]. It results in reducing transmission power directly as a amount to inversely proportional of the squared distance. It draws a conclusion that data across a number of short-range radios is more energy efficient than using a single radio capable of transmitting to longer ranges [29]. The signal power is reduced when radio waves come across boundaries such as walls and floors. Referred to as path loss, the amount of power lost by the wireless signal is dependent upon the material through which the signal must penetrate. The experiential studies to quantify the propagation distances of wireless signals within structures when communicating with different frequency bands have been undertaken by different researchers [30]-[32] and they also measured the range and amount of data loss of different wireless sensors operating in the unlicensed ISM bands in various structural monitoring applications.

4 MONITORING CIVIL INFRASTRUCTURE

Structural health monitoring and control represent the primary application of new sensor technology structure. At present, the sensors have become a key component in different fields including automotive, medical, aerospace and industrial process control [33]-[36].

Fig. 2 shows functional subsystems i.e. sensing interface, the computational core, wireless transceiver and an actuation surface. The sensing interface is responsible for converting the analog output of sensors in digital form for further processing by digital electronics. The quality of sensor interface depends upon the conversion resolution, sample rate and number of channels available on its analog to digital converter. After detection of data from the sensing interface, it is stored and processed for communication by computational core. Computational core consists of microcontrollers and memory. Memory RAM and ROM are used for storage and data interrogation program respectively. The last element actuation interface helps the wireless sensor to directly interact with the physical system in which it is installed. The actuation interface consists of digital to analog converter which converts digital data generated by microcontroller into a continuous analog voltage output to command active sensors and actuators with analog signals. Another component of wireless radio which is having a bidirectional interface with the computer core is used to transmit and receive data with other wireless sensors and data servers [37].

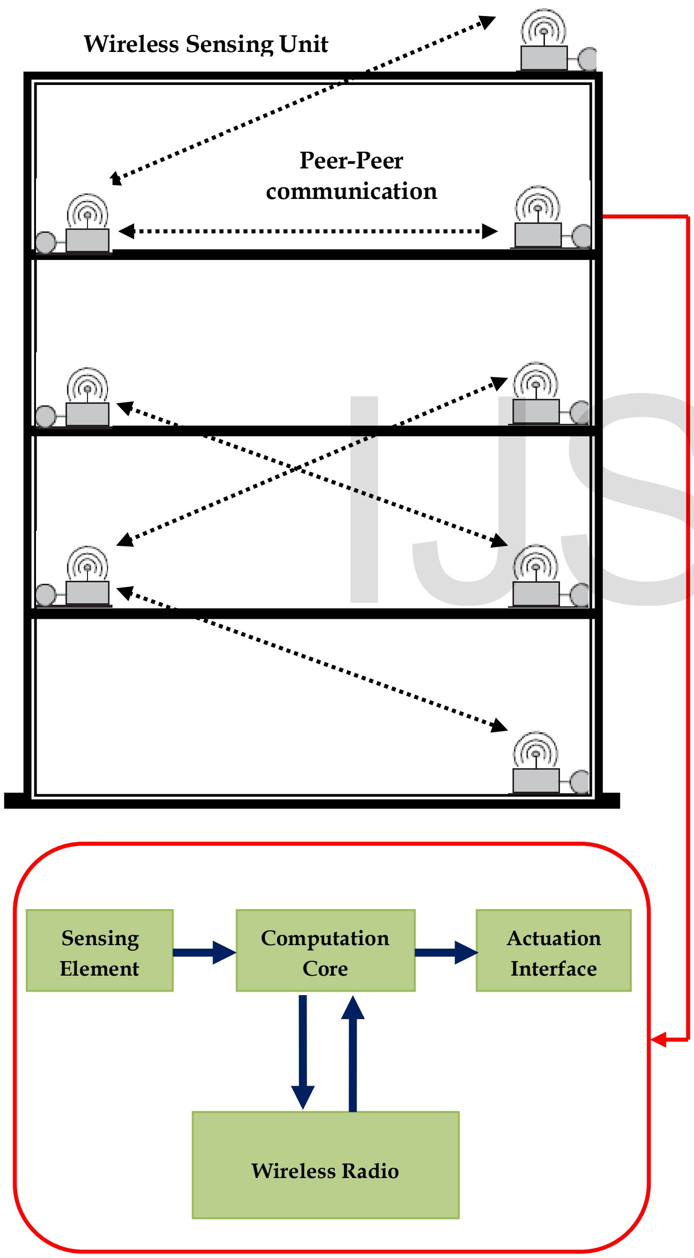

Figure. 2 Functional subsystems of wireless sensor for structural monitoring applications [38].

The structure monitoring system primarily collects the measured output from sensors installed in the structure & store measured data within the central data repository for accurate and correct measurement. For this conical cables are used but their installation in structure are expensive i.e. signal monitoring systems installed in tall buildings have been reported to cost in excess of $5000 (USD) per sensing channel. The problem of high cost in installation and maintainence wires was also reported within aircrafts, ships and other large structural systems [39]. A large number of damage detection methods have been proposed as reported by [40].

Damage detection methods have been classified into 2 types: locally-based and global based damage detection method. A local based damage detection method identifies damage based on screening structures at their component or subcomponent length scales. Global based damage detection refers to numerical method that considers global vibration characteristics of a structure to identify damage [41]-[46]. Wireless sensors represent potential sensing technology to economically realize structural health monitoring. As the costs continue to decline with the deployment of wireless sensors, local based damage detection is also increasing. Active sensors like piezoelectric pads are used for localized structural health monitoring [47]-[52].

Due to increasing complexity of structural technologies with increasing needs and demands, there is also an increase in the cost of the smart sensors due to the more use of wired cables as they are cabled structures that are used for the monitoring of these structures as more wired cables were used. Hence, wireless sensors were introduced and now a days used widely to combat the problem of cost and complexity and making it easy for the engineers to use the wireless sensors in various engineering disciplines. Currently there exists a large number of different academic and commercial wireless sensor platforms [53]-[57].

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