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Wireless Sensor Networks for Structural Health Monitoring

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Abstract: *The use of different sensing technologies within the structural systems for monitoring their health is of increasing interest now-a-days. Wireless sensors and sensor networks are now considered as substitutes for traditional wired monitoring systems. The main advantage of wireless structural monitoring systems is that they are inexpensive to install because extensive wiring is not required between the data acquisition system and the sensors. Wireless sensors play an important role in the processing of structural response data. This paper presents a study on the existing wireless sensor networks that can be employed for monitoring the structural systems and also their hardware and software platforms.*

Index terms*: Sensing platform, Snowfort, Structural health monitoring, Wireless sensor networks*

I. Introduction

Our lives rely heavily on civil infrastructure in which industrialised nations has huge investments. The stability and reliability of such civil infrastructure is very vital for supporting the economy of our society. The structures like bridges, dams, buildings, aircrafts etc ensure not only the economic but also the industrial prosperity of the society. These structures are often affected by harsh loadings and by other natural catastrophes like earthquakes, cyclones etc. Hence there is a need for a rational and economic approach for monitoring the civil infrastructure throughout their lifespan.

The engineering community has always been in search of new technologies and analytical methods that can be used to rapidly identify the onset of a structural damage in any infrastructure. The recent development in the field of wireless communication has reduced the cost of installation of structural monitoring systems. Structural monitoring systems are employed to monitor the structures during earthquakes, winds, loading etc. An important component of the structural health monitoring systems is the network of sensors along with the damage detection algorithm. Wireless sensors are not just sensors. They are actually the data acquisition nodes to which structural sensors can be attached. They are the platform in which the wireless communication elements and mobile computing converge with the sensing transducer. The interest in wireless sensors was mainly due to their low cost of installation.

The quest for a wireless sensor network for monitoring the structural health of buildings has evolved over several decades. This wireless sensor network can be applied to buildings, bridges, habitat, pipelines etc. The wireless sensing unit, wireless communication networks and the decision support system form the main components of the wireless monitoring system. The platform for the implementation of this wireless sensor network has to undergo many challenges such as simplicity, durability, adaptability, intelligence and reliability.

II. Related Works

A.Sensor Andrew Architecture

It is an architecture to support large scale sensing and actuation. Its range of applications include monitoring of power and its control, water distribution monitoring, infrastructure monitoring, social networking etc. The design goals for this architecture are large scale monitoring and control, ease of use and management, security and privacy ,scalability ,sharing of infrastructure, evolvability and robustness. The communication requirements for this architecture include point to point and multicast messaging, support for tracking of data, privacy, security, messaging formats etc.

To satisfy these requirements, XMPP (Extensible Messaging and Presence Protocol) is employed .It is an open internet protocol which was initially used for online communications. The format for defining the XMPP include a client identification , a domain name and a name space. It support publish-subscribe messaging. A sensor over XMPP (SOX) library is developed to provide tools and interfaces for the Sensor Andrew applications. The other components are the transducer layer, gateway layer and the agent layer. The end-point sensors or actuators are the elements of the transducer layer. This layer passes information to an internet connected device which is a part of the gateway layer. Different types of transducer devices are required due to the heterogeneous nature of Sensor Andrew. The gateway layer consists of devices that have access to the internet[4]. From the transducer layer, information is passed to the gateway layer using low-level protocols. From the gateway layer ,the messages are passed to the server layer using the XMPP. The agent layer consists of the XMPP servers along with various client applications called agents. The purpose of the server layer is to provide a simple means for applications running on desktop-class machines to communicate with each other[4].

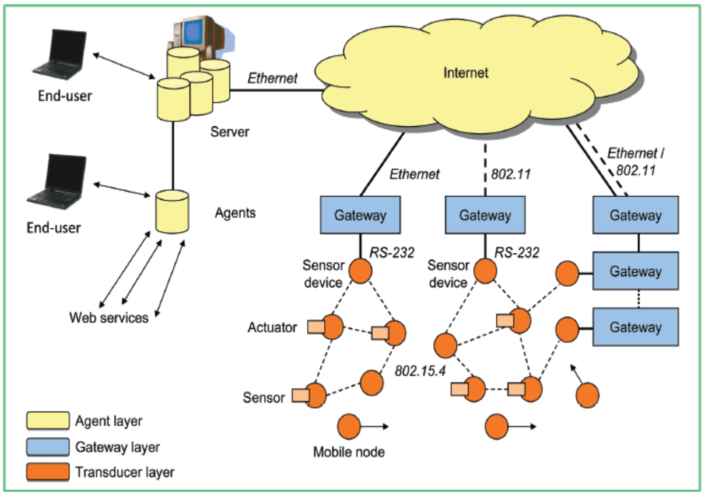

Figure 1:Three tiered architecture of Sensor Andrew

There are a few limitations for this architecture. One of them is lack of ability to capture meta-information about virtual sensors. Another limitation is that the all messages need to pass through a server even if the process could be completed with a point to point message[3]. Also large amount of information can degrade the performance.

B.Structural health monitoring using smart sensors

Wireless communication becomes more attractive and efficient when more wireless sensors are involved. It reduces the high cost assosciated with the use of wired sensors. Structural health monitoring strategies are employed for the structural response and for the detection, location and assessment of damage produced at the time of heavy loading and environmental degradation.

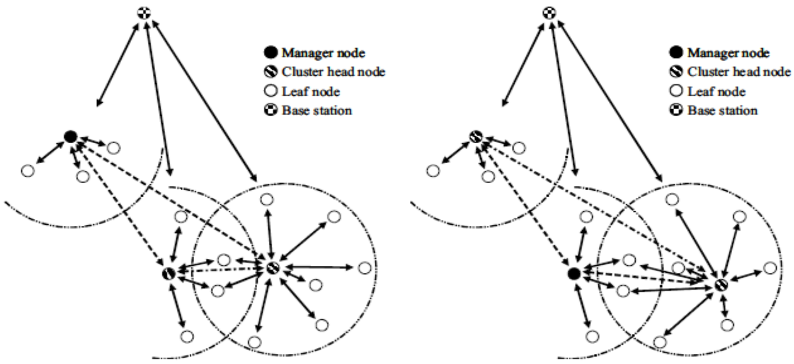

Figure 2.SHM system architecture: Different roles are assigned to nodes (a) and (b).

It employs a homogeneous configuration with only one type of node. This leads to the development of a simple network system. All the nodes in the structure are considered as the leaf nodes. Any node in the local sensor community is assigned as cluster head[5]. It communicates with the nodes in the neighbouring communities. Manager node is responsible for time sharing among the clusters. This helps to avoid RF interference. A gateway between the smart sensor node and the PC is the base station node. The commands and parameters are send to a smart sensor network from the PC with a user interface via the base station. A significant feature of this configuration is that provides robustness to node failure[5]. The sensor platform for SHM is Imote2. TinyOS is the operating system employed for smart sensors. The services which are not provided by the TinyOS is offered by middleware services.

There are a few challenges in using smart sensors for structural health monitoring. Inspite of the existence of large number sensors, there is always lack of appropriate sensors needed by the civil engineers. Also some smart sensors are not capable of measuring physical quantities precisely. Power consumption is another important challenge. Wiring power to large number of sensors consumes more time and increases the cost of installation. Smart sensors have limited memory space. Hence it is difficult to implement methods that make use of large computational matrices.

III. Snowfort-A New Wsn Platform

Snowfort stands for Sensor Network:Open and Wireless for daTa analytics. It is an open source wireless sensor system designed for infrastructure and environmental monitoring[1].Snowfort meets all the requirements of a wireless sensor platform. Certain features like data compression and online reconfiguration are introduced to reduce power consumption [1].The careful design of the MAC layer of the wireless communication protocol enables to achieve reliability and durability. Single hop network topology is used to achieve simplicity and scalability. Based on high performance computation intelligence is provided[1].

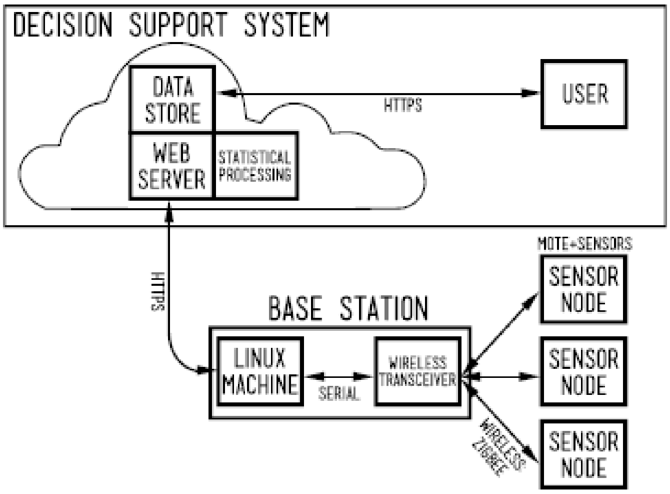

Figure 3. System architecture of Snowfort

The four main parts of Snowfort are the wireless sensor mote, a base station ,a cloud interface and a web interface. The sensing unit is the wireless sensor mote. The base station connects many nodes to constitute a network. The decision support system comprises of the cloud server and the web interface.

A wireless sensor mote is a battery powered sensor system which consists of memory, transceiver and microprocessor. It is used for the data collection, compression and transmission to the base station. It consists of ADCs , DACs and I2Cs for connection and communication with electromechanical sensors. Contiki is the operating system employed in Snowfort.

The main functions of the base station include receive data from the motes, control the communication in a network, transmit data to the cloud server . It contains a CC2420 transceiver and runs in a Linux machine(Raspberry Pi). The base station can access internet via high data rates. It runs a Python script to execute the protocol to the motes,for decompressing the data received from motes and transmission to the cloud server.

The decision support system (DSS) is an important element in the environmental monitoring applications. The processing and storage unit is the cloud server which also act as the web server for the front end user interface. The three components of the cloud server server are a data storage, a web server, and a statistical data processing unit.

The web server receives data from the base station and handles request from the end users. Also it sends commands from end users to the base station. Different base stations can post to the server at the same time . HTTPS protocol is the protocol used for communication between the web server and the base station. In the data storage unit ,the data is stored in two databases. The raw data is stored in the first database. The second database stores cleansed real-time data which can be used for statistical modelling[1]. By calling a standard API , the formatted data is inserted into the appropriate database by the web server. Here MySQL Python library is used to implement both the databases.

IV. Hardware Design Of Wireless Sensor Platform

Wireless sensor is the fundamental building block of a wireless sensor network. The performance of a structural health monitoring system depends entirely on the wireless sensor chosen. Hence it is very essential to select the suitable wireless sensor. Wireless sensors mainly consists of three or four functional subsystems namely wireless transceiver, sensing interface, computational core and an actuation interface .

The sensing interface converts the analog output of the sensors into a digital form that can be processed by digital electronics. The sensing transducers can be connected to this interface. Its quality depend upon the sample rate, conversion resolution and the number of channels available on its analog – to - digital converter.

Depending on the monitoring application suitable sensing unit must be selected. The data collected by the interface is then stored and processed in the computational core. It makes the data into a form that is best suitable for the communication. It is actually a microcontroller that store programs in the Read Only Memory(ROM) and the measured data in the Random Access Memory (RAM) . The microcontroller may be 8-, 16- or 32 bit. Clock is the internal element of every microcontroller. The speed at which the programs can be executed by the microcontroller depends on the speed of the clock.

Another important element of the wireless sensor network is the wireless transceiver. It is used for both transmission and reception of data. It is an electronic component that can interact with other wireless sensors and transfer data from remote components. The wireless technologies that are in great use now-a-days include Bluetooth , Zigbee , 802.11 . They operate on unlicensed frequency bands that is 900MHz, 2.4GHz, 5.0GHz.

Based on a selected radio band, two types of signals can be transmitted. They are narrow band and spread spectrum signals. In narrowband wireless communication, all of the data is modulated upon a single carrier frequency. Spread spectrum wireless signals are preferred because they make the wireless communication channel more reliable. The different spread spectrum techniques are direct sequence spread spectrum (DSSS) and frequency hopped spread spectrum (FHSS). The range of the wireless sensor transceiver should also be well considered. The amount of power consumed by the transceiver is directly correlated to the range of the wireless transceiver. During the propagation of a wireless signal in space from an antenna, its power lost is proportional to the wavelength of the band and inversely proportional to the square of the distance from the transmitter. The amount of power lost also depends upon the material through which the signal penetrates.

The next subsystem of the wireless sensor network is the actuation interface. It enables the wireless sensor to interact directly with the physical system in which it is installed. An actuation interface can be used to command both actuators and sensors. Its integral element is the digital to analog converter (DAC). It converts the digital output of the microcontroller into an analog voltage signal.

V. Software Design

In order to automate wireless sensor operations and to process structural response data , integrated and embedded software is required. This embedded software is often structured as hierarchial layers. The lowest layer is the OS which hides the implementation details of the underlying wireless sensor hardware from upper software layers. All the above layers are the layers of software. Their function is to collect and store the data and to communicate with other sensors. They are also used for the execution of damage detection algorithms in the case of structural health monitoring. The embedded OS is very essential for the efficient management of hardware operation and also to form effective network topologies.

The most widely used OS for the embedded wireless sensor networks is the TinyOS. It is an open source OS which is available for the public. It is written in NesC which is a high level programming language based on C. The functions of TinyOS are to collect data from interfaced sensors, to process sensor signals, and to utilize the radio for communication with other wireless sensors. Concurrency is an important feature of the embedded OS. It makes the wireless sensors capable of performing the network communication task and the local tasks like data processing at the same time.

In the case of structural health monitoring, the collocation of computing power with the sensor makes the wireless sensor networks differ from the traditional structural monitoring systems. This power is used by the wireless sensor to self-interrogate the collected structural response data. Thus the structural damage can be detected by the in-network processing of data. This autonomous execution of damage detection algorithm by the wireless sensor is an important step towards automated SHM[2]. But this in-network processing consume huge amount of energy from batteries. Hence local data processing is more energy efficient which also preserves the battery life.

Various algorithms were described for monitoring the structural health of buildings. In the first proposed method , immediately following a seismic event the general structural state was detected. Another method was based on the Fast Fourier Transform(FFT).This FFT provides the frequency response functions(FRFs) of instrumented structures[2]. In some other methods, modal frequency was considered as the primary damage indicator. But this method lacked sensitivity in structures. Another was a decentralised method for damage detection by using a network of motes.

VI. Conclusion

Wireless sensor networks are very essential for monitoring the civil infrastructure. Its ease of installation and low cost makes it more popular than the traditional wired systems. A study has been made on the about the different wireless sensor networks that are designed for the structural health monitoring. Most of the existing networks suffer from the major problem of power consumption. Hence a new wireless sensor network namely Snowfort has been proposed that involves low power consumption. A study has also made regarding the hardware and software platforms used for the implementation and simulation of these wireless sensor networks.

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