Wireless Sensor Network Based Structural Health Monitoring for Multistory Building

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***Abstract*— Structural Health Monitoring (SHM) is concern with the safety of building structure and the main objective of SHM for multistory building is to diagnose the health of the structure and to monitor its possible damage. Wireless Sensor Network (WSN) is one of the supporting and attractive sensing technologies for SHM as it gives accurate, reliable, and healthier information to the users. In this paper, WSN communication is applied to monitor temperature, humidity, and structural parameter which includes vibration, force and the sensor data stored in database. These stored data are visualized on Dashboard. The original problem of SHM is to find the building damage by monitoring the measured data.**

Keywords*— *SHM, WSN, Database and Dashboard.

I. Introduction

The process of Structural Health Monitoring (SHM) is to implement critical damage detection, locate the damage. This process insures structural integrity and safety which includes the inspection, continuous monitoring of the building. Also, insures service life durability and an effective SHM system helps to analyses the level of stability and to enhance structural sensing capability [1]. Lately, SHM technology-based systems are monitoring in multiple fields such as buildings, bridges, aerospace, vehicles and quickly determining a health level. Conventional monitoring devices are made from matrices of sensors circulated along building to be monitored furthermore associated to central server and handling unit over the wires. Today wireless sensor networks (WSN) has been explored in structural health monitoring systems because it reduces the number of wiring, gives better accuracy for data transmission, reduces the system cost, etc [2]. According to United State Federal, In US 25% of bridges are either physically deficient or functionally superseded, to ensure the human protection SHM is important [3]. From last decade number of sensors network are connected to the WSN, as it is a powerful and low-cost platform furthermore used in many applications like as military, commercial, health, building and industrial [4]. Currently, the condition assessment of existing infrastructure such as bridges largely depends on visual inspection. This subjective and inaccurate condition assessment methodology has been identified as the most critical technical barrier to infrastructure management. These issues have driven the research and development on the continuous observation of civil structure in a proactive manner using measured data and data interpretation algorithms, to evaluate the current condition and to predict the remaining service life of infrastructure [5].

The objective of this framework is to monitor and identify any moment occur in building over the service period. To leverage and increase safety to human life and decrease the maintenance charges of the multistory buildings.

This article is mainly focused on development and integration of WSN based SHM system for multistory building. WSN sensing node is used to measure parameters such as temperature, humidity, vibration, and force, which are highly responsible for smart building monitoring framework and sensors data transmitted wirelessly. Other end gateway hub receives all the sensor nodes data and collected data are stored in MySQL database periodically where user can remotely monitor through the web application. Proposed architecture for the framework is shown below:

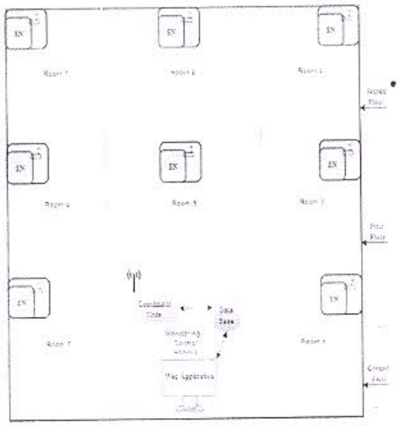

Fig. 1. Architecture of Multi Story Building

The category of this article has reported a new way of dealing that type of situation by providing dynamic thresholding at real-time and has been categorized into following sections: the literature survey has been described in section II. Section III describes the proposed methodology. Section IV has explained the flow chart. Lastly, in section V, described the experimental results. Conclusion and future work described in section VI.

II. Literature Survey

In this section several design, model and research in SHM using WSN is discussed. M. Abdulkarem et al. [6] this article was summarized from 2005 – 2019 in different SHM from many perspectives in different field used WSN. And facing problems to WSNs for SHM to give the solutions offered in previous work. A. B. Noel et al. [4] Review of SHM using WSNs outlining algorithms for crack detection and localization, challenging task to design an outlining network. It's given solution for sensor placement, data processing and time synchronization. Y. Ikemoto et al. [7] developed contactless force sensor framework which measure inner force of structure through quite a few covering materials for the SHM. This framework can be implanted into substances without battery-operated for the reason that framework consists of passive Radio-frequency identification tags designed for power supply and data communication.

S. H. Ali et al. [8] induced analysis of acceleration information gathered by accelerometer sensors by the side of different locations of bulky encumbered bridge that counted in strongly in addition to un-strongly then signal processing technique is using at Karachi port traffic. Accelerometer sensors have connected to the WSN. S. Wijetunge et al. [9] have modified the current communication protocols or structure a totally new communication protocols to totally fulfill the prerequisites of WSN for SHM because none of the generally accessible communication protocols fulfill all the prerequisites related with SHM framework.

F. P. Pentaris et al. [10] presents the comparison of wired and wireless SHM framework and challenges of wireless SHM. Wired SHM experiment setup implants thirty years and six years old educational building to find out the buildings age, response to seismic activity and weather conditions. S. Soijoyo and A. Ashari [11] have described the different wireless network topology used for Zigbee data transmission.

K. Shahzad and B. Oelmann [12] in this research comparative study of ZigBee, BLE and Wi-Fi for raw data transmission verses In-sensor processing. If transmitting a raw data used high- throughput wireless transceiver and less amount of data transmuted rather than In-sensor processing transmitting less amount of information so less power consumes. C. Rainieri et al. [13] presented a seismic protection and load monitoring system, and gives a solution to build a dependable SHM framework.

III. METHODLOGY

A. Designing of Sensor Node

This part of system mainly consists three sensors DHT22, Piezoelectric and Flexiforce sensor which are interfaced with Arduino Nano microcontroller along with XBee S2 module, which is also embedded with specified microcontroller for wireless communication with router/coordinator node. For receiving the sensor data, XBee PRO S2B RF module as coordinator for wireless communication as well as send data to database server.

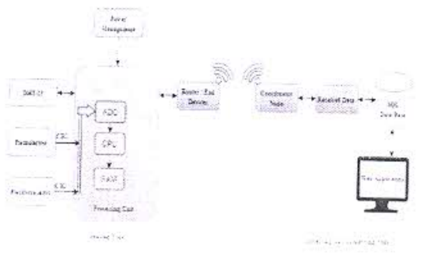

Fig. 2. Block Diagram

Arduino Nano has10 bit analog to digital converter with 8 analog channel and 22 digital input pins, UART, I2C, SPI interface. It has 2KB SRAM, 1KB of EEPROM and 16MHz clock speed [14].

DHT22 is one wire interfaced digital sensor that measures temperature and humidity. It is operating range 0-100% humidity, -40~80°C temperature and supply voltage 3.3-6V DC. This sensor is highly sensitive for thermal comfort [15].

Temperature and humidity data consist of integral and decimal part. The equation for data as follows:

DATA = 8integral bits RH data + 8 decimal bits RH data + 8 integral bits T data + 8 decimal bit T data + 8check-sum bits.

If transmission of data is correct then check-sum should be: -

Check-Sum = 8 integral bits RH data + 8 decimal bits RH data + 8 integral bits T data + 8 decimal bit T data.

Piezoelectric Sensor is basically converting mechanical stress to electric charge. Its operating temperature -20C~+60C, strain sensitivity 5V/µ Єand operating voltage +5V. The essential aim is to calculate vibration in the buildings. Where the output voltage is directly proportional to the asset of vibration.

FlexiForce sensor is used to measuring the applied and presence physical force in an area. Resistance of the FlexiForce sensor differs as physical force on the sensor high or low. At the point when no weight is being applied to the sensor, sensor resistance will be higher than 1MΩ. The solider push on the sensor's top head, the lower the resistance among the two points drops. To make a voltage divider circuit combining with FlexiForce sensor and static resistor, that can produce a variable voltage that can be read by a microcontroller's ADC [16].

Voltage divider circuits contains power source diagonally two resistors in series, one is the sensor and second is fixed resister. Circuit diagram shown below:

Fig. 3. Voltage Divider Circuit used for FlexiForce Sensor

Where the output voltage equation is:

$$V_{out} = V_{cc}\,(R/R+R_s)$$

In the data sheet graph resistance vs force is exponentially shown so apply the power equation for calculating the force value:

$$y = ab^t$$

Where: y is the output value of the force, a and t is the coefficient, b is the ratio R_s/R_0 of the sensor.

XBeeS2 Pro module is used for transmitting and receiving radio frequency data and works on network layer which stands for IEEE 802.15.4 to support progressive mesh routing capabilities. This module works on operating frequency at

By dashboard, the client can remotely associate with the database of the framework and opt from the offered facilities. Some facilities of this technology are the order of execution of current test, the administration of stored information scrutinize previous carried out data and, inclusion of new remote sensor hubs to a system.

IV. Flow Chart

The flow chart of the framework is exposed in figure2, all multistory building parameters value is read from the sensors and transmitted through the XBee S2 module, then Gateway node receives the data and stored in MySQL database. Further dashboard live data monitoring is performed.

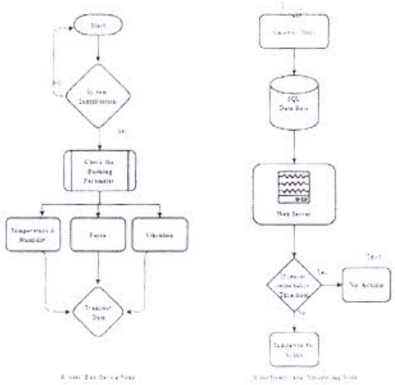

Fig. 7. Flow Chart of the proposed framework

V. Result & Discussion

This section describes result. Four individual sensing nodes are shown in Fig. 8 and each sensing node has the same architecture. The sensor data is being transmitted wirelessly through XBee S2 module.

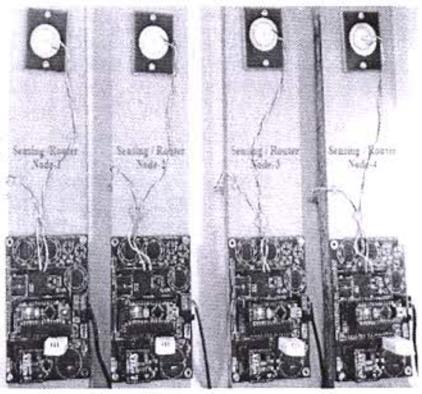

Fig. 8. Designed multiple sensing node for SHM

Fig.9 displays real time monitoring of the multiple sensing node data. Which includes temperature, humidity, vibration, and force.

Fig. 9. SHM real time parameters data monitoring on dashboard

Fig.10 shows when some external force and vibration is applied on respective sensor, the values of force and vibration get varied and, when no force and vibration is sensed, the values remain unchanged. Dashboard helps to monitor any changes in multistory building. Whereas, force calculation unit is lb.

Fig. 10. Shows force and vibration sensor value changes monitors on dashboard

All sensors data are stored in MySQL database with five second interval.

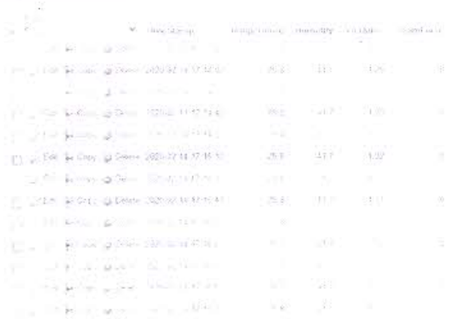

Fig. 11. ISL201 SHM parameters data stored in MySQL database

2.4GHz, and RF data transmission rate 250Kbps and consumes low power [17].

Complete WSN based SHM sensing node has been designed below. Sensing node is a combination of sensors, microcontroller, and ZigBee module. Sensors are monitor the multistory building load, vibration, and environment. And this sensing node transmitting the sensors data periodically.

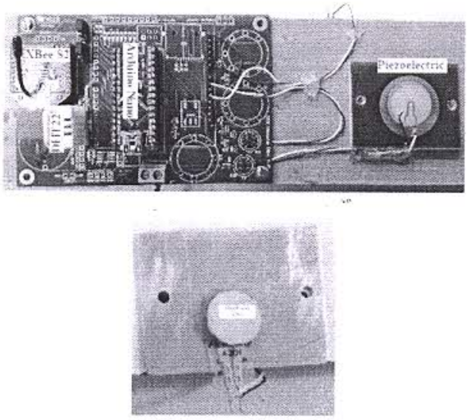

Fig. 4. Front side and back side of WSN Sensing Node

B. WSN Communication Protocol

Comparison chart between ZigBee, Bluetooth and Wi-Fi and ZigBee communication devices are used in our framework because its specification matched in our systems. But this proposed framework used Zigbee module for data transmission because it worked on Mesh topology, less power consumption and detection range 10-100 meter furthermore all features of this module matched with proposed framework. For mesh topology communication XBee End node, Router as well coordinator must be configured in API mode.

TABLE 1. Comparison chart of three WSN communication devices [12]

Device	ZigBee	BLE4.0	Wi-Fi
Data Rate	250 Kbps	1 Mbps	54 Mbps
Detection Range	10-100 Meter	10 Meter	100 Meter
Power Consumption	Low	Very Low	High
Frequency	2.4 GHz	2.4 GHz	2.4 and 5.0 GHz
Network Topology	M2M, Mesh, Star, Cluster Tree	M2M, Star	M2M, Star
WLAN	Not required	Not required	Required

C. WSN Topology

In this article, ZigBee module were preferred for the WSN. For the data transmission several topologies are available in WSN but this proposed framework used Mesh topology because breakdown of single network does not affect the whole network, fault tolerance easily improves, also there is no requirement for centralized management. Mesh Topology picture shows below:

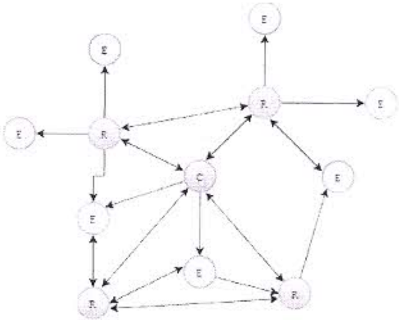

Fig. 5. Mesh Topology Diagram

Table 2. Comparison chart of three WSN topology [11]

Topology	Description
M-M	It communicates to one direction networks.
Star	Easy installation and wiring, Easy fault detection, no interference occur to the system while joining and removing gadgets.
Tree	Mostly software and hardware industries are supported.
Mesh	All devices are attached to each other, centralized management is not required and fault tolerance easily improves.

D. Coordinator Node

The gateway/coordinator node is primary component of the complete remote framework subsequently it is liable for coordination of every sensor hubs of the system and, also, is the gateway giving correspondence the remote outer server. Since coordinator hub gives access to the wireless sensor network, it is the important part of the whole network [18]. Gateway hub receives information by sending information's to the sensor hubs, temporarily it stores the transmitted information into the MySQL database from the WSN and transfers the information to remote outer server by means of web. Just a single coordinator hub is required for every sensor node although, if the quantity of sensor hubs is high, the system can be isolated into sub-systems, which are constrained by one coordinator hub.

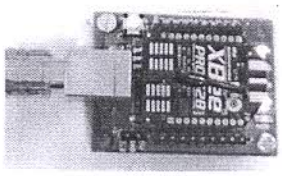

Fig. 6. Coordinator Node

Fig.6 XBee PRO S2B radio module/coordinator node received the sensors data from sensor hub and provides bidirectional communication for the sensor hub effectively.

E. User Interface

The administration of the framework is performed through a middleware that goes about as a bridge between a database and the sensor hub. Users can monitor current multi-story data on dashboard.

VI. Conclusion

When subjected to severe load a building may sustain damage due to earthquake or when its structural material deteriorates. Also, densely distributed sensors are deployed to measure structural responses and gives the current and previous parameters values of the multistory building. WSN connect sensor node through its intelligent. SHM is a connexion area, which has variety of sensor and data processing technologies. Mesh topology have been calculated as the main component, which was consider carefully while designing the WSN. This framework is successfully developed and integrates in CSIR-CEERI Integrated System Laboratory building.

Our futuristic work, research for using machine learning and deep learning algorithm can predict the fault detection, and behavior of the SHM system.

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