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Smart Buildings Structural Health Monitoring Using Sensor Networks and Machine Learning Algorithms

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Abstract

Nowadays, more attention is given to SHM, with the idea of smart buildings. As in the olden days, buildings are not built with just sand and bricks. Smart buildings integrate structures with technology. The regular maintenance of structures will extend the life of the constructions. It will as well prevent the catastrophic failure. The economy of a country relies on the transportation infrastructures like bridges, railroads, roads, etc. Any failure, which occurs to these infrastructures, will have more effect on the financial system of the nation and invaluable human life. Detection of damage at an earlier stage helps to avoid severe problems. Because it has an impact on the national economy, health monitoring of civil structures is important in the field of civil engineering. Recently, smart structures have attracted more attention, as India is moving towards the establishment of smart cities. Every year India loses many people due to structural collapses. Many investments are made on civil infrastructures like bridges, roads, multistorey buildings, etc. and hence the damages are to be detected at the right moment to avoid the collapse of the entire infrastructure. The proposed research work has taken up WSN based SHM, for crack categorization in the structural element, namely, column. The motivation for the research work is to apply the Computer Science knowledge to the chosen domain and provide a solution for the increasing number of structural collapses occurring every year.

Keywords: Structural Health Monitoring, Machine Learning, Monitoring.

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Introduction

During their entire lifespan, there exists a continuous deterioration of the effectiveness of civil structure due to performance degradation, weather, fatigue, overloading, natural disasters and fabricated actions like the bomb blast, fire, etc. A building consists of different components like slabs, pillars, beams, roof, etc. Each component is built with different strength. The strength of the components is reduced based on their usage. The reduction in strength leads to several damages (Padmapoorani et al., 2023). Damage is defined as the changes caused in a building, which affects its performance. The damages caused based on their magnitude and location is essential to be taken care. When the damage is more, the load-bearing capacity of the construction, which is damaged, is reduced. To ward off the collapse of the building due to the damages caused, timely maintenance is substantive. Structural Health Monitoring is a strategy, which helps to monitor the presence and location of the damage in civil structures using several techniques. Monitoring can be done periodically or when any events like earthquake, fire, etc., occur. After extreme events, a quick study of the effectiveness of the construction is substantive. The observation of structures and the extraction of damage-related measurements are both part of SHM (Yuan et al., 2020). The current condition of the building's health can be examined with the aid of statistical analysis of these metrics. Fig. 1 shows the working of an SHM. In SHM, wireless sensor nodes are deployed at several locations of the structure, which is to be monitored.

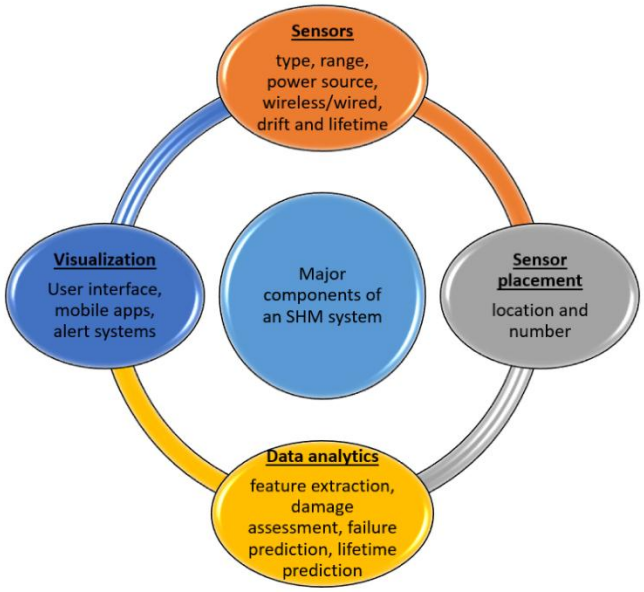


Fig. 1: Sensor Networks for Structures Health Monitoring

Methodology

The present system of health monitoring involves huge cost in cabling, transport of data acquisition system in addition to the prime requisite of the employment of skilled personals during collection of data. As a result, there is increasing interest in creating suitable methods for automated structural health monitoring in the civil engineering domain (Nagayama & Spencer Jr, 2007). More recently, a range of sensors, including optical fiber sensors, Micro Electro Mechanical Systems (MEMS), wireless nodes, piezoelectric sensors, smart wireless sensors, and vision-based displacement measurement systems, have been used for structural health monitoring. An onboard network of sensors for data collection and a few central processors for structural health assessment are the standard components of a Remote Structural Health Monitoring (RSHM) system, as illustrate in Fig. 2. The following crucial characteristics have been taken into consideration when developing wireless smart sensors: sensing ability, wireless communication, on-board processing, plug-in functionality, self-power, and affordability (Flah et al., 2021). The effectiveness of wireless smart sensors makes it possible to install dense arrays of sensors on a sizable civil structure, significantly enhancing the RSHM's quality by providing rich data that diagnostic algorithms may use to identify, locate, and evaluate structural deterioration. This thesis' primary goal is to create smart sensing methods that effectively monitor and evaluate the condition of the current civil engineering structures by utilizing smart sensors and wireless sensor networks. Techniques for evaluating the status of structures were created utilizing the newest smart wireless sensors. Experimental experiments were conducted to evaluate the performance of a number of wireless sensor systems that

were found to be appropriate for structural health monitoring applications. This paper addresses some of the challenges associated with deploying wireless sensors, such as data transfer, meaningful data extraction, sensor sampling rate, etc (Yu et al., 2019). The developed methodologies were successfully demonstrated by deploying the system for condition assessment of railway bridge structures.

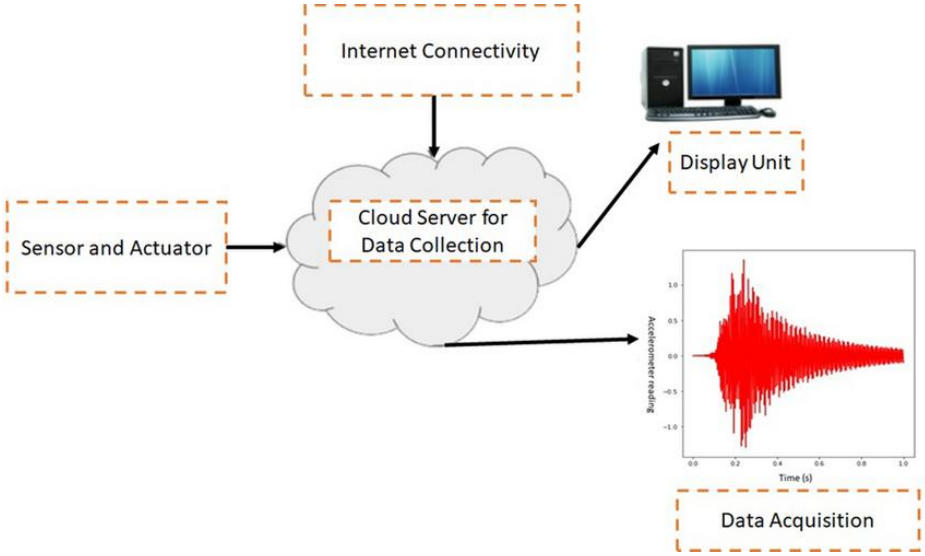


Fig. 2: Working of an SHM

Experimental Results

To receive the data from the wireless sensor via the gateway and send it to the host PC via the comport terminal, a special tool has been built. The data can be downloaded from the wireless sensor at real time using the developed tool (Oh et al., 2017). As illustrate in Fig. 3, the developed program has separate modules for analysis of the measured data. This module extracts the relevant signal information from the field measurement data with noise using wavelet-based approach.

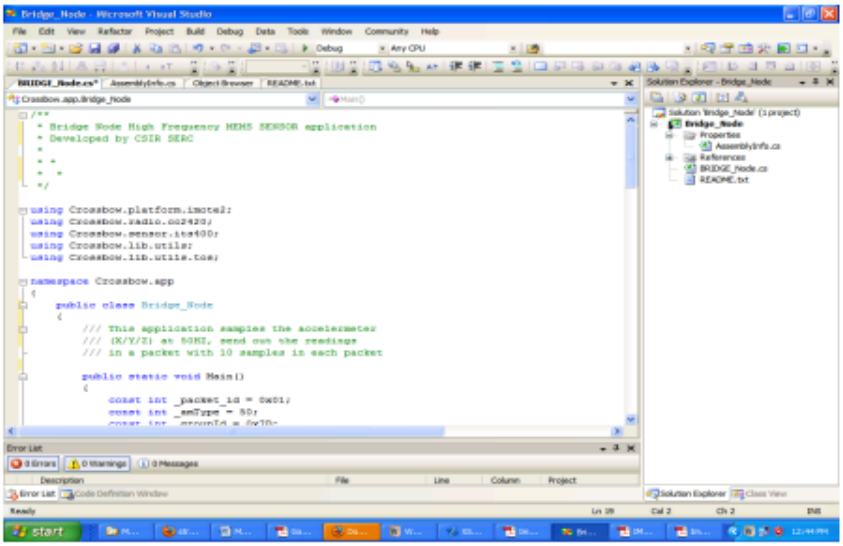


Fig. 3: Development of Program for Wireless Structural Health Monitoring Applications

For identifying the frequency components in a signal, the Fast Fourier Transform (FFT) is an ideal instrument. Signals are subjected to mathematical alterations in order to extract additional information that is not easily accessible in the raw signal. A link between a signal in the time domain and its representation in the frequency domain is defined by the Fourier transform (Kapoor et al., 2022). Waspmote wireless sensor platform has options for integrating micro-SD cards for local data storage. The program developed for waspmote wireless sensor platform has options for storing the measured data locally at the wireless node and also can process the data at node level and send only useful structural information to the control system (see Fig. 4).

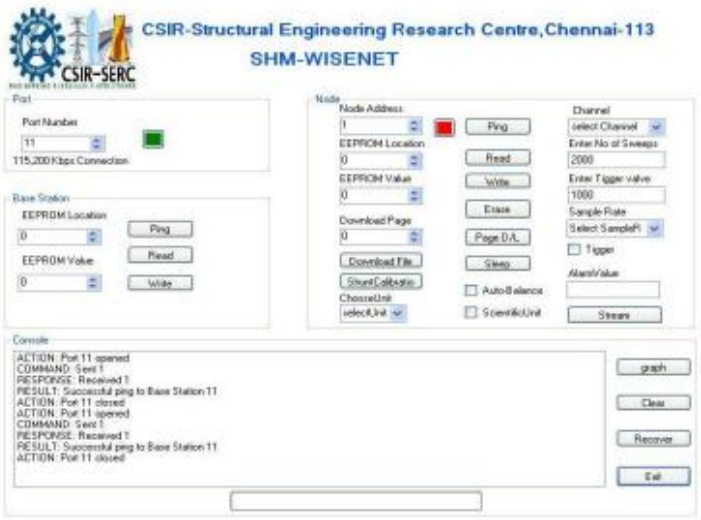


Fig. 4: Screenshot of the Developed Software Tool

The node's configuration options are accessed via the configuration icon on the menu screen. To begin the test, click the "Start" icon. During the test, the data obtained from the WSN node is seen using the online monitor icon. To add a new user or remove an existing one, utilize the user icon. After the test is finished, the data is viewed for analysis using the offline viewer. The user can learn more about the bridge connection and parameter settings by clicking on the help icon. The strain value is initialized using the offset button (Sofi et al., 2022). To examine the node's status, click the node status button. In order to acquire the data from the WSN node, configuration of the node needs to be done first. New configurations can be created or existing configurations can also be loaded to the WSN node, as shown in Fig. 5.

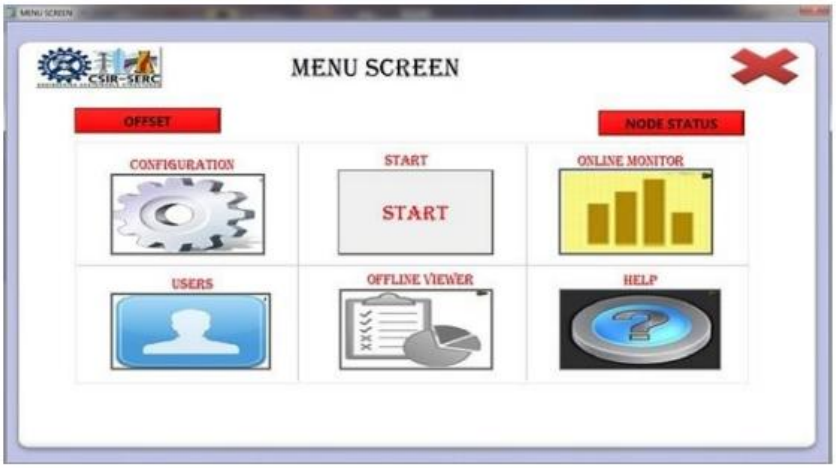


Fig. 5: Main Screen of the Developed Software Tool

The measured responses were analysed for detecting damage at real time. WSN is being developed to address the limitations of existing SHM techniques. WSN provides a framework to be employed for SHM applications that will incorporate the latest sensors, wireless communication and information technologies. WSN involves distributed sensor processing that basically consists of central control station which can handle health monitoring of multiple structures from different sensor clusters simultaneously. Smart wireless sensor nodes with industrial components are deployed that operates in real time on-site to acquire the parameters like strain, vibration etc. the basic component of a wireless smart sensor in the microprocessor which performs the node level computations and make the sensor to be smart. Smart sensors can store data, analyse data at the node level, make decisions, and transmit results thanks to a variety of programs that can be programmed in the microprocessor. To raise the SHM's quality, these intelligent wireless sensors can be installed in various places across a building. These wireless sensors offer sufficient data for SHM algorithms to evaluate the structure's condition.

Conclusions

New possibilities for smart building technology are being created by recent developments in sensor-based data collection and analysis. Smart buildings have merged technology and architecture. Structural buildings are vulnerable to several types of damage during the course of their lifetime. The entire building will deteriorate as a result of these problems. In constructions like bridges, which span many miles, manual inspection takes a long time and is very labour-intensive. In order to save lives and property, buildings must be rehabilitated as soon as possible. The ability of structural health monitoring (SHM) to track and predict occurrences that could have an impact on the buildings' health. The building's condition is checked on a regular basis or whenever something like an earthquake, fire, etc. happens. Sensors in the proposed research project assess the physical factors—such as temperature, corrosion, etc.—that cause cracking in the structural element, specifically the column. The Cluster Heads (CH) then send the data to the Remote Monitoring System (RMS) for analysis. By choosing the best CH via a soft computing technique, congestion is prevented during data transfer.

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