# DEVELOPMENT OF LOW COST ONLINE STRUCTURAL HEALTH MONITORING SYSTEM FOR CIVIL INFRASTRUCTURES USING WIRELESS SMART SENSORS

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Degree of Master of Science

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## DECLARATION

Here by I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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The above candidate has carried out research for the master's thesis under my supervision.

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Name of the supervisor:  Dr. K.J.C. Kumara.

Signature of the supervisor: …….  Date: ……

# ABSTRACT

Over the last few decades number of tall buildings has seen an exponential increase. At present tallest ever building under construction measures 1000m vertically, and the height of future buildings is likely to be even higher. Monitoring the behaviour of tall buildings using them as living laboratory is extraordinarily important in an international context to optimize its performance. Structural health monitoring is a new paradigm which facilitates the purpose of monitoring buildings or any other infrastructure on real time basis. Structural health monitoring has seen various advanced developments in recent past. Wired sensor networks were used to monitor the target at the beginning. In modern days wireless network with higher number of nodes is used to monitor the target very precisely.

In this research a wireless sensor network which is capable of sensing ambient vibrations in terms of accelerations was developed. The sensors mounted in each node are capable of measuring very small vibrations (1 mg range). The communication between each node was established using wireless network protocol, sub-1 GHz (Radio waves) which is very efficient in terms of long-range communications, power consumption and penetration through obstacles. When it comes to collecting data using wireless sensor networks, there are inherent challenges such as time synchronisation, scalability, packet handling (collision), packet loss, data storage, power consumption etc. However, accuracy of time synchronisation was identified to be the most crucial problem as far as interpretation of results is concerned. Two methods of time synchronization were checked in laboratory level. One method is known as receiver to receiver model and other one is centre to receiver model. Wireless sensor network was checked for its performance in laboratory level and accelerometers were calibrated using shaker table which has accurate analog sensors and digital accelerometers which are already calibrated in laboratory level.

Completely developed wireless sensor network which is capable of collecting synchronous data, was established in a target building of 48 floors with 185m height. The locations of sensors were predetermined using mathematical model made using finite element package, ETABS. Bi directional acceleration data was collected with sampling frequency of 100 Hz. Collected data was chunked and converted into frequency domain from time domain using fast Fourier transform algorithm and modal damping ratios, peak acceleration corresponding to particular frequency and modal displacement were extracted.

Extracted modal damping ratios were compared with the damping ratios suggested in various codes and it could be observed that the calculated modal damping ratios are higher than the

values that are suggested by various codes. The mode shapes plotted using the building response data showed a good agreement with the mode shapes produced by Operational Modal Analysis.

**Keywords:** Ambient vibrations, low cost accelerometers, Tall buildings, Wireless sensor network, Time synchronization, Cascading effect, Inundation area, Compensations, Damage prediction, Real time monitoring, Structural health monitoring.

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Punithavel Vishnu.

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| | |
|---|---|
| SHM | Structural Health Monitoring |
| MAC | Modal Assurance Criteria |
| FEMA | Federal Emergency Management Agency |
| UDA | Urban Development Authority |
| IoT | Internet of Things |
| NB-IoT | Narrow Band Internet of Things |
| WSN | Wireless Sensor Networks |
| WMS | Wireless Monitoring System |
| PCB | Printed Circuit Board |
| SN | Sensor Node |
| CH | Cluster Head |
| MN | Master Node |
| ALU | Arithmetic Logic Unit |
| OMA | Operational Modal Analysis |
| FFT | Fast Fourier Transform |
| MEMS | Micro Electro Mechanical Systems |
| ISM | Industrial, Scientific and Medical |
| MEMS | Micro electro mechanical systems |
| ADC | Analog to digital converter |
| RTOS | Real Time Operating System |
| PP | Peak Picking |

| | |
|---|---|
| MAC | Modal Assurance Criteria |
| MAC | Media Access Control |
| WSN | Wireless Sensor Network |
| PAN | Personal Area Network |
| MEMS | Micro Electro Mechanical Systems |
| RoHS | Restriction of Hazardous Substance directive |
| $I^2C$ | Inter Integrated Circuits |
| SDA | Serial Data |
| SCL | Serial Clock |
| SPI | Serial Peripheral Interface |
| MOSI | Master Out Serial In |
| MISO | Master In Slave Out |
| SS | Slave Select |
| UART | Universal Asynchronous Receiver and Transmitter |
| MPLS | Multi Protocol Label Switching |
| GSM | Global System for Mobile Communications |
| GSA | Geographical Service Area |
| BSC | Base Station Controller |
| NSS | Network Sub System |
| GSM | Global System for Mobile Communications |
| GPRS | General Packet Radio Services |
| SMS | Short Message Service |
| VoIP | Voice over Internet Protocol |

| | |
|---|---|
| LPWAN | Low Power Wide Area Network |
| XML | Extended Mark-up Language |
| SGML | Standard Generalized Mark-up Language |
| SQL | Structured Query Language |
| DDL | Data Definition Language |
| NoSQL | Not only SQL |
| HTTP | Hyper Text Transfer Protocol |
| HTTPS | Hyper Text Transfer Protocol Secure |
| HTML | Hyper Text Mark-up Language |
| CSS | Cascading Style Sheets |
| JS | JavaScript |
| SNR | Signal to Noise Ratio |
| OS | Operating System |