

**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

Department of Civil Engineering

University of Moratuwa

Sri Lanka

January 2020

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Thesis submitted in partial fulfilment of the requirements for the degree
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DECLARATION

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Signature of the supervisor:

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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.

ACKNOWLEDGEMENT

I would like to thank and express my sincere gratitude to Dr. C.S. Lewangamage and Prof. M.T.R. Jayasinghe for their trust and guidance throughout my MSc research period. They not only encouraged me in research, also they helped me to develop my confidence in structural engineering. I also would like to thank my co supervisor Dr.K.J.C. Kumara for assisting me through the core electronics part of this research.

Further, I would like to thank Dr. A.P. Darby Reader attached to the Department of Architecture and Civil Engineering of Bath University, for his assistance and knowledge sharing from the beginning of this research.

I would like to express my appreciation to research coordinators of the Department of Civil Engineering, University of Moratuwa; Prof. A.A.D.A.J. Perera, Prof. R. U. Halwatura and Dr. (Mrs). J.C.P.H. Gamage for their comments and insights in all levels of my progress.

Also, I would like to express my gratitude to Prof. J.M.S.J. Bandara and Prof. S.A.S. Kulathilaka who were the heads of the Department of Civil Engineering during the duration of my masters for their help during hard situations. I am extremely grateful to the SRC grant (Grant Number: SRC/LT/2018/07) for providing me financial assistance throughout the year and help for purchasing research related electronic gadgets accessories.

I would like to thank Mr. S. Radershan, Mr. S. Ketharan and Mr. K. Kirishikesan from Computer Science and Engineering department and Mr. A. Thiruventhan from Electronics and Telecommunication department from University of Moratuwa, for their kind help in developing the wireless sensor network and the data sink in UoM web server.

Finally, I would like to thank Mr. Buddhi Sathsara, Mr. Dhanushka Siriwardhana and Mr. Nimalan from Sanken overseas for their approval to access Colombo City Center building and their full support in establishing the sensor network in the building and collecting the data.

Punithavel Vishnu.

TABLE OF CONTENTS

DECLARATION	i
ABSTRACT	ii
ACKNOWLEDGEMENT	iv
LIST OF FIGURES	ix
LIST OF TABLES	ixiii
LIST OF ABBREVIATIONS	xiv
1. BACKGROUND	1
1.1 Introduction.....	1
1.2 Problem identification	2
1.2.1 Structural Health Monitoring (SHM).....	2
1.2.2 Monitoring the structures with low cost involved.....	2
1.2.3 Monitoring structural response.....	3
1.2.4 Importance of monitoring acceleration	4
1.3 Objectives of the study	4
1.4 Outcomes.....	5
1.5 Structure of the thesis	5
2.0 LITERATURE REVIEW	8
2.1 Structural Health monitoring using wireless sensor networks	8
2.2 Structural Health Monitoring Vs Human Health Monitoring.....	8
2.2.1 Human Monitoring	8
2.2.2 Structural Health Monitoring.....	9

2.3	Wireless sensor networks and internet of things.....	11
2.4	The structure of wireless sensor network	13
2.4.1	Sensor Node.....	14
2.4.2	Functionalities of sensor node	15
2.4.3	Wireless Technology Standards used for establishing the network 16	
2.4.4	Radio Frequency or Sub-1 GHz wireless applications	19
2.4.5	Platforms, Micro controllers and Mini computers.....	22
2.5	Data loggers and data sinks.....	24
2.6	Review of wireless sensor networks in civil engineering context	26
2.6.1	Bridge monitoring using wireless sensor networks	26
2.6.2	Application in Xihoumen Bridge.....	30
2.6.3	Monitoring of buildings using wireless sensor networks	33
2.6.4	Applications in canon Tower in Guangzhou, China.....	34
3.0	DESIGNING OF THE WIRELESS SENSOR NETWORK.....	41
3.1	Methodology	41
3.2	Methodology of management of the data until the gateway of the network	42
3.2.1	Processing of data by the components of our system	42
3.2.2	Transmission of data between the nodes.....	56
3.3	Calibration of the acceleration sensors.....	62
3.4	Synchronization of the sensor nodes	67
4.	DATAFLOW OF THE COLLECTED DATA FROM THE SENSOR NETWORK TO THE WEBSITE.....	74
4.1	Transmitting the collected data	75
4.1.1	The infrastructure used for the transmission of data	75

4.1.2	Selecting the suitable communication standard for data transmission	78
4.1.3	Selecting a suitable format for transmission.....	78
4.2	Managing the mass collected data.....	79
4.2.1	Storing the raw data for easy access	79
4.2.2	Storing the data in a suitable data schema	80
4.3	Creation of a website.....	81
4.3.1	The architecture of a web-based platform	82
4.3.2	Web-based technologies used in the system.....	83
4.3.3	Visualization of data	86
5.0	Cost Comparison of Structural Health Monitoring Projects.....	89
5.1	A review of similar systems and the costs associated with the nodes of the system.....	89
5.1.1	A modular based, real time embedded system to monitor structures	90
5.1.2	Structural Health Monitoring in highways.....	91
5.1.3	Designing a wireless sensor unit for a smart civil structure.....	93
5.2	Cost analysis of a node of this system	95
6.0	Application of Developed Wireless Sensor Network in Target Building	98
6.1	Damping /System damping	98
6.2	Experimental modal analysis	99
6.2.1	Sensing response of the structure due to ambient vibrations.....	100
6.2.2	Details of the building	101
6.2.3	Finite element model of the building.....	102
6.2.4	Range test before mounting the sensors and locating sensor	104
6.2.5	Fourier transform and peak picking method.....	108

6.3	Modal damping ratios and mode shapes	109
6.4	Modal Assurance Criteria (MAC).....	110
7.0	Conclusions and Recommendations	114
7.1	Discussion and conclusions.....	114
7.2	Limitations and future studies	116
	REFERENCES.....	118
	APPENDICES.....	125
	APPENDIX A: Laboratory Synchronization data	127
	APPENDIX B: Sample of the data generated from our system.....	130
	APPENDIX C: Matlab code of data extraction and modal parameter extraction ...	141

LIST OF FIGURES

Figure 2.1. Locating sensors in human body and monitoring the health remotely.	8
Figure 2.2.(a)Applications of SHM in aerospace applications, (b)Bridge monitoring using sensors,(c) applications of SHM in transport sectors (d) Oil rigs being monitored to prevent fatigue failures	9
Figure 2.3. Schematic diagram of Internet of Things.	11
Figure 2.4. Hierarchy of Wireless Sensor Network.	14
Figure 2.5. Architecture of a sensor node.	14
Figure 2.6. Data flow within a sensor network	16
Figure 2.7. HM-10 CC2540 4.0 BLE Bluetooth UART transceiver	17
Figure 2.8. ESP8266 Wi-Fi module	18
Figure 2.9. ZigBee Module-AB S2-2mw with wire antenna	19
Figure 2.10. Narrowband Vs Spread band	20
Figure 2.11. MSP430 Launch pad	23
Figure 2.12. (a) Microprocessor (b) A minicomputer (Raspberry Pi)	23
Figure 3.1 Wireless sensor network representation	43
Figure 3.2. (a)Star wireless topology representation (b)Ring wireless topology representation (c)Mesh wireless topology representation (d)Star-mesh wireless topology representation (e)Cluster tree wireless topology representation	44
Figure 3.3. Adafruit 14-bit 3 axis accelerometer MMA8451	46
Figure 3.4. Structure of a piezoelectric accelerometer.....	46
Figure 3.5. Piezo resistive accelerometer.....	47
Figure 3.6. (a)Capacitive MEMS based accelerometer (b)Detailed view of a capacitive MEMS based accelerometer.	48
Figure 3.7. Block diagram of MMA8451.	49
Figure 3.8. Texas instruments CC1310 Development board	50
Figure 3.9. Functional block diagram of CC1310	51
Figure 3.10. Concept of Torsion two acceleration components.....	52
Figure 3.11. Texas Instruments CC3220SF development board	52
Figure 3.12. Hardware overview of CC3220SF.....	54

Figure 3.13. Pin layout of CC3220SF Development board	55
Figure 3.14. Pin layout of Raspberry Pi 3B+	55
Figure 3.15. Connections between the components in an I2C communication system.	57
Figure 3.16. Signal interpretation by the SDA and SCL lines in I2C protocol.	58
Figure 3.17. A captured packet in an I2C protocol-based communication.....	59
Figure 3.18. Communication between devices in an SPI based communication.....	59
Figure 3.19. Signal interpretation between devices in an SPI based communication	60
Figure 3.20. Connections in a UART communication protocol	61
Figure 3.21. Structure of a data packet sent through UART protocol	62
Figure 3.22. Shaker table	63
Figure 3.23. (a)acceleration vs time graph using sine sweep method with a calibrated accelerometer and an accelerometer which should be calibrated. (b) Fourier transformation graph of (a). (c) zoomed in graph of (a). (d) zoomed in graph of (b)	64
Figure 3.24. (a)Arrangement of all the accelerometer sensors for calibration (b)Sensor nodes placed on the shaker table	65
Figure 3.25. Acceleration components of the accelerometers placed in the shaker table	66
Figure 3.26. The FFT graph drawn using the data obtained during the sine-sweep method	67
Figure 3.27. Representation of time slots and counter method used in Glossy.	68
Figure 3.28. Synchronization methodology used in our system	70
Figure 3.29. Synchronization simulation used in our system	71
Figure 4.1. The Dataflow of the collected data from the sensor network to the website.....	74
Figure 5.1. (a) A similar ADC converter DC1151A similar to Hi7188 ADC converter (b) Motorola 68HC11 development board (c) Hi7188 Microcontroller chip (d) 3 axis high precision accelerometer Kistler 8352A2.....	90

Figure 5.2. (a) Hitachi H8/329 microcontroller. (b)Radiometrix RF module 418MHz (c) Analogue thermistor module KY013 (d)SGA series analogue strain gauge signal amplifier.	92
Figure 5.3.(b) ADXL345 Accelerometer sensor. (b) ADXL345 Accelerometer sensor. (c) Texas Instrument ADS8167 ADC convertor. (d) Atmel Atmega256 Microprocessor.	94
Figure 5.4. Outer appearance of the node of this system	95
Figure 5.5. The arrangement of the components inside the project enclosure of a node	96
Figure 6.1. Colombo City Centre. (The target building)	102
Figure 6.2. Mode shapes and natural frequencies of the building	103
Figure 6.3. Range test done in the open air with RF transmission.....	106
Figure 6.4. Sensor Locations.....	107
Figure 0.5 : Depiction of establishing sensors in sequential manner.....	107

LIST OF TABLES

Table 2.1. Comparison between critical phases of man and the structure	10
Table 2.2. Comparison between Micro controllers and Microcomputers.....	24
Table 2.3. Modal parameters of canon tower identified.....	40
Table 2.4 Natural frequencies and modal damp ratios of the building considered...	43
Table 3.1. Specifications of MMA8451.....	49
Table 3.2. Specifications of bma222.....	54
Table 3.3. Summary of all the synchronization sessions	73
Table 5.1. Cost associated with the components of a node of the system.....	93
Table 5.2. Cost associated with the components of a node of the system.....	95
Table 5.3. Cost associated with the components of a node of the system.....	98
Table 5.4. Cost Summary.....	99
Table 6.1 Summary of natural frequencies	104
Table 6.2 Modal participation ratios and sum of first 5 modes in both X and Y directions.....	106
Table 6.3. Range test done in open air with our system	105
Table 6.4 Summary of Natural frequencies and comparison between FEM and OMA values.....	109
Table 6.5 Modal damping ratios with natural frequencies.....	110

LIST OF ABBREVIATIONS

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 ² C	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