PERFORMANCE ANALYSIS OF STRUCTURAL HEALTH MONITORING EDGE NODE USING ZIGBEE PROTOCOL

Abstract:* *Structural Health Monitoring-the collection and analysis of structural response to ambient or forced excitation is an important application of network embedded sensing with significant commercial potential. The first generation of sensor networks for structural monitoring are likely to be data acquisition systems that collect the data at single node for centralized processing. In this report, we discuss the design and evaluation of ZigBee based wireless sensor network system for structural data acquisition and natural frequencies detection with low power management and secure data transmission. Texas Instrument CC2538 Development kit with Arm Cortex-M3 core, CC2538 RF trans-receiver (IEEE 802.15.4 standard) and z-stack software (ZigBee standard) has been used to implement the generic ZigBee based wireless sensor network node. While designing Edge nodes, I have been concentrating upon selection of ADC with proper sampling frequency, resolution and baud rate selection for UART serial communication modules in WSN node. It has been needed to adjust proper time synchronization between the nodes and packet size of the node.

Keywords: Zigbee, CC2538, ADC, UART, Z-stack

Hardware components are listed below

CC2538 Development kit with CC2538 powerful wireless micro-controller, PCB393B12 single Axis Accelerometer sensor, Signal conditioning circuit.

Software components are listed below

Z-stack software with ZigBee standards, IAR embedded workbench IDE with embedded C language, Python scripting language for GUI (Graphical Interface Language Development).

1. INTRODUCTION

Protection and longevity of buildings and other important structures play a very important role to ensure economic and industrial prosperity of a society. Building structures are important as these are vital to the well-being of our society and the same time it is complex of different materials are used to build these systems and make the system heterogeneous. However, structural systems start degrading due to several reasons as soon as these are put to service. Unexpected loadings, natural disaster of different forms, harsh environmental conditions, lack of appropriate or preventive maintenance become the causes of deterioration of the structural systems [1]. Therefore, it is required to assess the conditions of the structures to make sure that the safeties standards are met during life it's life time and taken the necessary safeguard to control the destruction pre-define. Structural Health Monitoring (SHM) of civil buildings and other structures plays very important role in evaluating the reliability of a building and identifying potential harmful factors, which are essential to the safety.
The main objective of structural health monitoring (SHM) is to provide more reliable data on the actual conditions of a building, detect the appearance and evaluation of any damage present in the structure.

2. LITERATURE SURVEY:

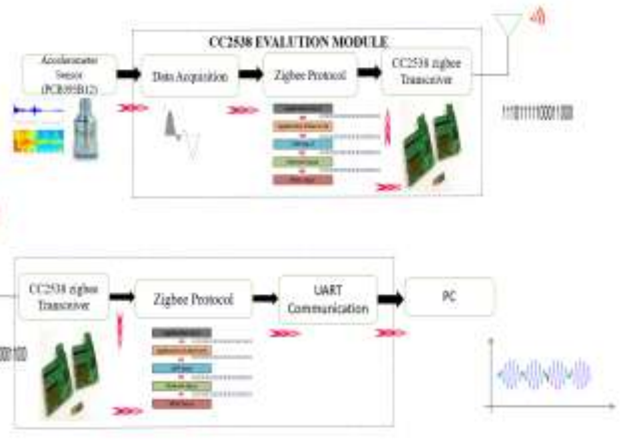
ZigBee is a reliable wireless sensor for short range with low rate. ZigBee has a bit rate of 250 k bits per second as maximum rate. It is designed to be placed at odd-places and finds difficult to replace the nodes. For replacing the nodes ZigBee power should be of battery type by which it can be handled for a long time. If the battery power is for longer duration, then the power acquired by the network is and as well the data rate will be low. And, the battery life is longer it can be used for minimum duty cycles.
ZigBee designed with many features like it is low cost, reliable, it has power to self-heal, it is flexible, and it consumes low energy with this kind of features many applications can be developed.

- Building automation, and centralized lighting, heating, cooling and security.
- Industrial Automation and process control and production system reliability.

Structural health monitoring of civil structure buildings and bridges is the major application of Zigbee. Large number of accelerometer sensors are installed in the building that sends the data to sensor nodes. The sensor nodes send data to server that performs some processing to determine any possible damage in the building. These kinds of sensor networks help in reduction of high inspection costs which are generally required after an earthquake or any calamity that damages the structure.
Each layer is liable for some functions in the network. These layers normally send the data and commands only to the layers directly.

3. IMPLEMENTATION:

Every wireless sensor network system consists of multiple end nodes and routers and single coordinator as per the application requirements. Each node has one or more accelerometer sensors. Developed WSN node has 8 analog channels i.e. we can connect 8 Accelerometer sensors to the end node and router also.



3.1 WSN System Block Diagram for Building Health Monitoring

According to the block diagram, structure response flow from the structure to host computer i.e. end device to coordinator can be represented in the following aspects;

1. Data Acquisition.
2. Zigbee Protocol.
3. CC2538 Zigbee Transceiver.
4. Data transfer from coordinator to host PC
5. GUI implementation details.

The WSN node consists of CC2538 Evaluation Module and PCB393B12 Accelerometer sensor. The CC2538 has 2 UART and I2C, 2 SPI modules with 8-analog channels for sensors connection.

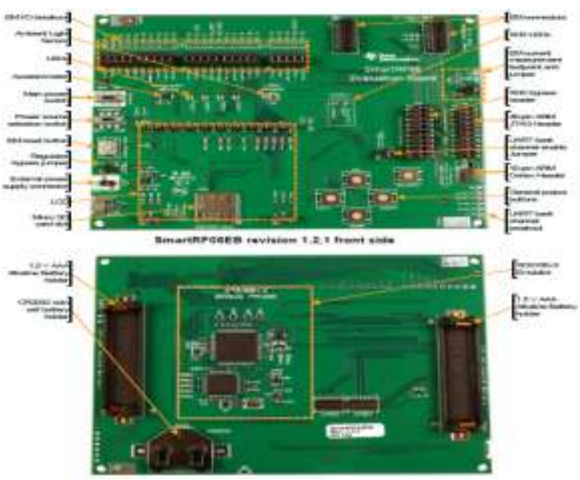
4. RELATED WORK:

The brief introduction of different modules used in this project is discussed below:

4.1 CC2538 Micro Controller

4.1.1 WSN Node with CC2538 Wireless RF Transceiver

The CC2538 is a RF-radio chip microcontroller family from Texas Instrument built around a 16-bit CPU. It is designed for low cost and, specifically, low power consuming embedded applications since it supports 3 low power modes which can disable the clocks and CPU, resulting in current consumption even less than 1μA.
However, the CC2538 microcontroller is not having an external memory bus, so the memory is limited to on-chip memory up to 512KB, 256KB or 128KB of In-System Programmable Flash which may be too small for applications that require large buffers or data tables.
The following figure-4.1.2 gives the hardware configuration of the SmartRF06 evaluation configuration.



4.1.2 Smartrf06 Hardware Configuration

4.2: Accelerometer Sensor (PCB393B12)

PCB393B12 is ICP piezo-electric 1-axis accelerometer with good sensitivity. Table-1 represents the specifications of the sensor.

Table 1: PCB393B12 Accelerometer Sensor Specification

4.3. Software Components

S. No	Parameter	value
1	Sensitivity	10V/g
2	Measurement range	0.5 gpk
3	Frequency range	0.10 to 2000Hz
4	Excitation Voltage	18 to 30 VDC
5	Constant Current Excitation	2 to 20 mA

IAR embedded work bench IDE for developing ZigBee protocol with embedded C language [25].
Z-Stack-MESH profile [21].
Z-stack is software which has been implemented by Texas Instrument. It is following the ZigBee & IEEE 802.15.4 standard. The Architecture of Z-stack is shown in figure-4.3.1

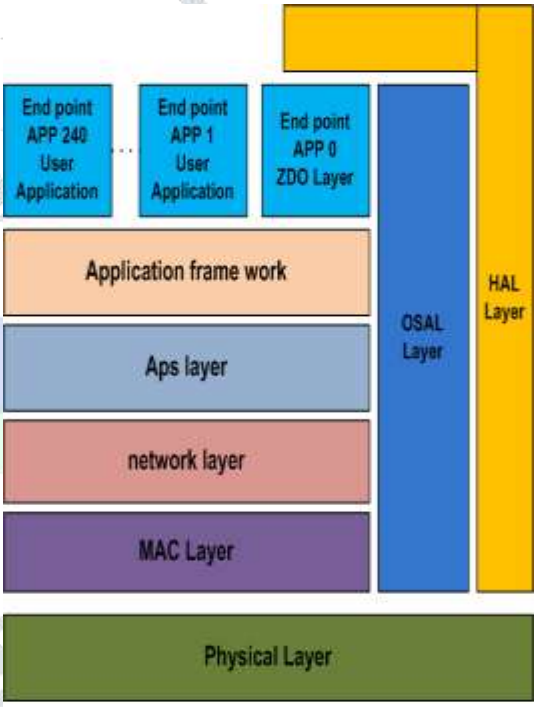


Figure 4.3.1: Z-stack Protocol Architecture

Z-stack is having the following layers:

- APP (Application layer).
- HAL (Hardware Abstraction Layer).
- MT ()
- NWK (Network Layer).
- OSAL (Operating System Abstraction Layer).
- Profile (Application Frame work development).
- Security (Security provide both NWK & MAC layers).
- ZMac (Sub-MAC layer and
- SPI protocol Implementation for providing services to CC2538 RF Transceiver (IEEE 802.15.4 Standard)).

5. CONCLUSION:

The Structural Health Monitoring system using wireless sensor network of civil buildings health monitoring has been developed successfully. Developed system consists of three end nodes and coordinator. Before validating the developed system on real-time structure, testing had been done in laboratory environment with one end device to coordinator, double end devices to coordinator and three end devices to coordinator networks by changing the sampling frequencies, data packet size and packet to packet delay of end nodes. Finally deploy the implemented system with optimized design parameters on CEERI Tower and developed the GUI (Graphical User Interface) for displaying each floor of structure response in frequency and time domain along with first three natural frequencies corresponding amplitudes in Python scripting environment.

6. ACKNOWLEDGEMENT

We would like to thank all the authors of different research papers referred during writing this paper. It was very knowledge gaining and helpful for the further research to be done in future.

7. RESULTS:

7.1 Single End node to Coordinator

The experimental setup of single end node to coordinator had been shown in figure-30. Testing of WSN system is being done at 10Hz, 100Hz, 1 KHz and I Vpp input signals. Those are generated using function generator in laboratory.

Design parameters are:

- DC Sampling frequency = 5KHz
- DC reference = 2.5 V.
- UART baud rate = 460800.
- Packet Size = 60 bytes
- Delay between packets =3.66mSec

Results are obtained after conducting the experiment with different input signals and successful reception of the signals which have been sent without data loss. Received signals are represented in frequency domain and time domain as show in following figure-7.1.1, 7.1.2, and 7.1.3.

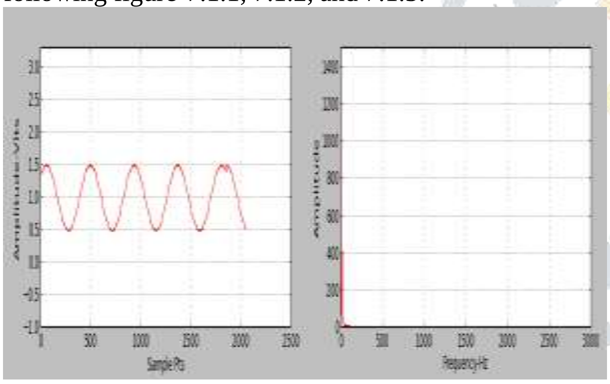


Figure 7.1.1: 10Hz, 1Vpp signal, data packet size 60

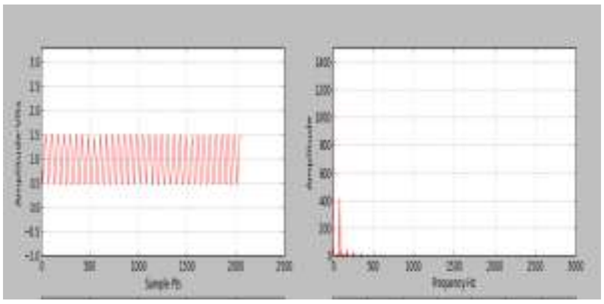


Figure 7.1.2: 100Hz, 1Vpp Signal, Data Packet Size 60

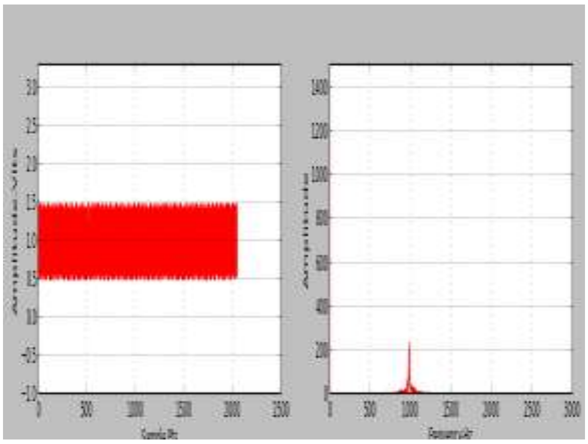


Figure 7.1.3:1khz, 1Vpp Signal, Data Packet Size 60

7.2 Multiple End nodes to coordinator

We have been conducting the experiments with double end node to coordinator and 3-end nodes to coordinator. Signals are provided to end nodes in the network by using function generator in laboratory environment. Obtained results are shown in figures-7.2.1 and 7.2.2 without data loss in transmission.

Figure 7.2.1: CC2538 Zigbee Coordinator Node

Figure 7.2.2: CC2538 Zigbee End Device Node

Design parameters of the developed WSN system:

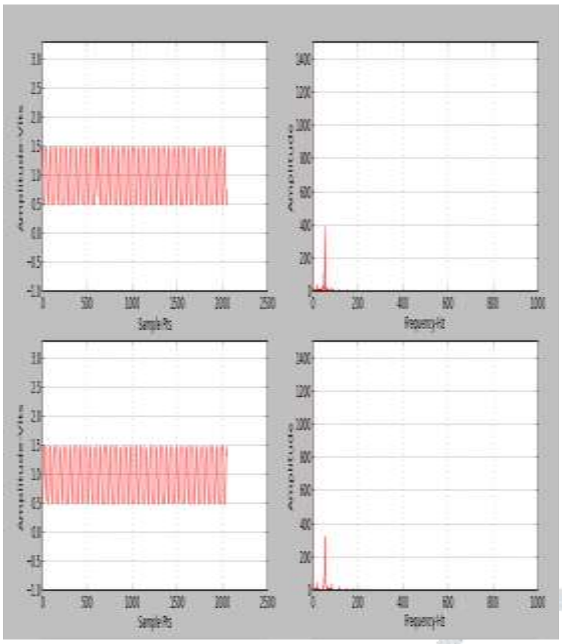


Figure 6.2.3: 50Hz, 1Vpp Signal

7.3 Real-time SHM of CEERI-TOWER with developed WSN system

Set up of developed wireless sensor network system consisting of PCB393B12 Accelerometer sensor along with end node is being placed on each floor of the CEERI tower (9 floor structure) as shown in figure-32 Coordinator is placed at the 2nd floor of the structure. It has to collect data from all end devices which are there in the network of each floor. The actual sensor, end node and supported hardware required on each floor are shown in figure below.

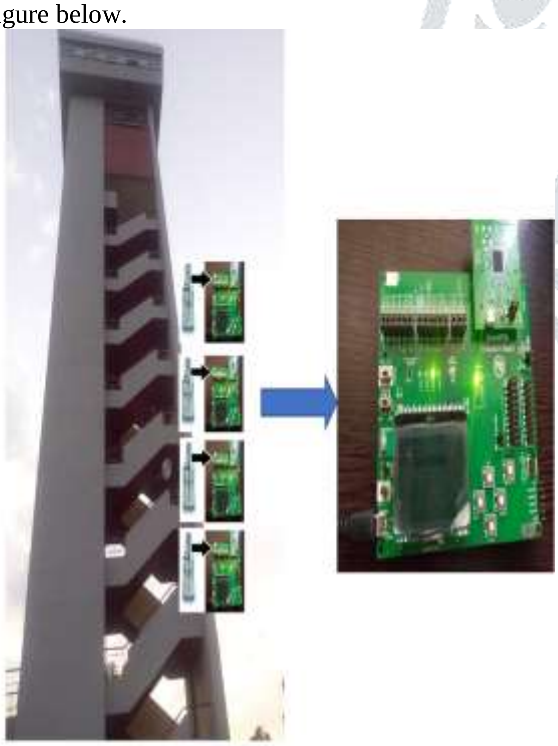


Figure 6.3.1: CEERI TOWER with developed WSN system

Below figure shows the PCB393B12 Accelerometer sensor which is powered by Signal conditioning developed by piezotronics. Sensor signal is connected to end node through amplifier circuit which is shown in figure battery mounted on it. The requirement of amplifier circuit before end node had to be discussed in application development chapter.

Figure 7.3.2: End node, Amplifier circuit wit sensor

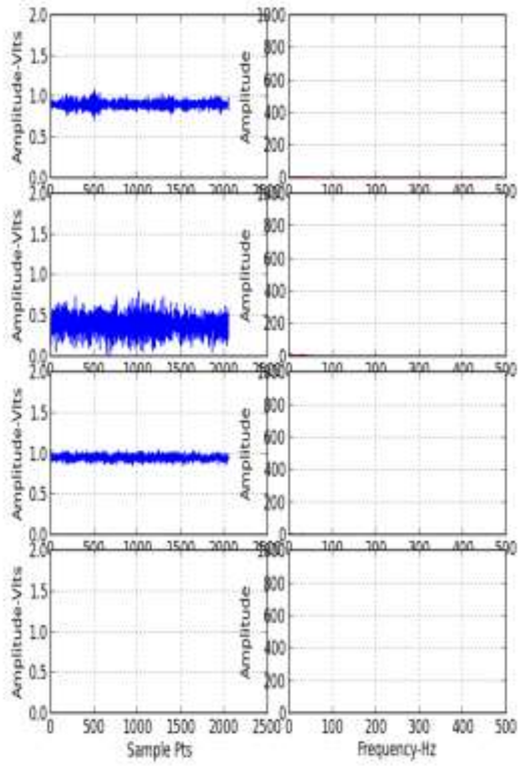


Figure 7.3.3: Final GUI For SHM Of Civil Buildings Using WSN System

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