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Architecture Escort: Structural Health Monitoring System Using Wireless Sensor Network

V. Sasikala[1], J. Selvakumar[2]

[1]PG Scholar, SRM University, Chennai, India

[2]Assistant professor (Sr. Grade), Electronics & Communication Engineering, SRM University, Chennai, India

Abstract: ***Structural Health Monitoring (SHM) system using Wireless sensor Network can provide the necessary collection of data to monitor and maintain the safety of civil structures such as buildings, bridges, tunnels etc. The sensor modules use flex sensors, MEMS accelerometers with battery backup for a period of 12 years life. It also uses renewable energy source to increase the battery life more than 12 years. The flex sensor measures the vertical column loads periodically. The MEMS accelerometer measures the seismic response of the building during an earthquake. The collected information are transmitted to the remote base station by using zigbee transceiver that operates on 2.4GHz band. Based on the data collected from the sensor nodes the base station transmits the status of the structure to the end user via SMS alert by using GSM.***

Keywords: Flux Sensor, Accelerometer, Zig Bee Module

1. Introduction

A SHM system refers to the process of damage detection of civil structures. Traditionally a Structural Health Monitoring system periodically collects the measured output from the sensor modules installed in the structures and updates the health condition of a structure. The sensor modules must be wireless to reduce installation costs, must operate with a low power consumption to reduce servicing costs of replacing batteries. Re-chargeable battery is used for sensor module and an alternative renewable energy - Solar source has been employed to increase the life time of the battery by charging the battery.

The data collected from the sensor modules are transported to the base station through Wireless Sensor Network and from the base station the health of the building is informed to the end user via SMS alert by using GSM. End user is primarily Civil engineers and architects responsible for the building and they are expected to take appropriate action based on the alert.

Wireless sensor network based monitoring systems can potentially enhance the resolution of sensing and provide information at unprecedented levels of granularity. Recently there has been an immense amount of research examining various aspects and issues pertaining to such monitoring networks. However, with the exception of the habitat monitoring project on the Great Duck Island [1], the literature does not contain reports of a sensor network monitoring system deployment in real environments.

Figure 1: Structural Health Monitoring with sensors on a Bridge

Structural Health Monitoring (SHM) focuses on developing technologies and systems for assessing the integrity of structures such as buildings, bridges, aerospace structures and off-shore oil rigs [3].

Most existing SHM implementations use wired data acquisition systems to collect vibration data from various locations in the structure induced by ambient sources (*e.g.,* moving vehicles, wind, waves and earthquakes) and analyze it at a central location.

2. Block Diagram

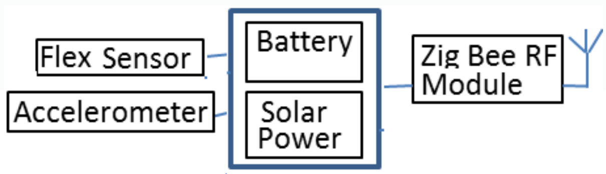


Figure 2: Block diagram of Sensor Module Architecture

3. Explanation of Sensor Module Architecture

The structural health monitoring unit comprises two sensor modules: Flex sensor module and Accelerometer sensor module. The flex sensor modules can be placed at the vertical column to check the load of it. Similarly the accelerometer sensor module can be fixed at the base or roof to monitor the seismic response.

The measured output from the sensor modules is transmitted to the nearby base station which is situated at a distance less than 20 meters through wireless network. The receiver base station receives the data from the sensor modules and process them with the threshold point feed to it and forward the health status of the structure to the end user via SMS alert through GSM. The end user is primarily civil engineers and architects responsible for the building and they are expected to take appropriate action based on the alert. Both the senor modules are powered with battery backup as well as renewable energy source (solar panel) to conserve the power and to increase the life time of the battery.

3.1 Flex Sensor

The flex sensors are analog resistors that convert the change in bend to electrical resistance. More the bend, more the resistance value is. Under flat condition it results with a resistance of 25KΩ and depending on the bending radius of the flex sensor the resistance range varies from 45KΩ to 125KΩ. The connector is 0.1" spaced and bread board friendly. These resistors work as variable analog voltage divider. Inside the flex sensor are carbon resistive elements with thin flexible substrate. More carbon means less resistance. When the substrate is bent the sensor produces resistance output relative to the bend radius. The flex sensor achieves great form-factor on a thin flexible substrate.

The impedance buffer in the circuit is a single sided operational amplifier used with these sensors. Since low bias current of the op amp reduces error due to source impedance of the flex sensor as voltage divider. The variation in deflection or bending of flex sensor results in variation of resistance itself. The signal conditioning circuit is used to read these resistance changes and it is given to ADC.

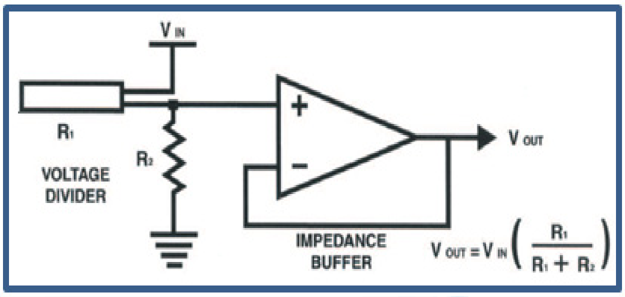


Figure 3: Basic Flex Sensor Circuit

3.2 Accelerometer

It is a complete 3-axis acceleration measurement system. It has a measurement range of ±3 *g* mini-mum. It contains a polysilicon surface-micromachined sensor and signal conditioning circuitry to implement open-loop acceleration measurement architecture. The output signals are analog voltages that are proportional to acceleration. The accelerometer can measure the static acceleration of gravity in tilt-sensing applications as well as dynamic acceleration resulting from motion, shock, or vibration.

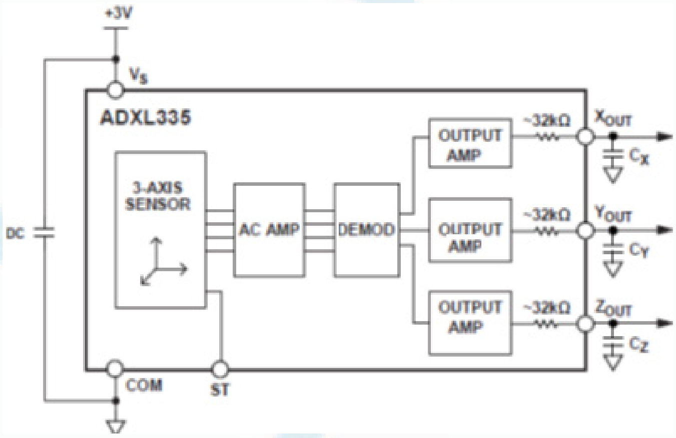


Figure 4: Basic Accelerometer Circuit

The sensor is a polysilicon surface-micromachined structure built on top of a silicon wafer. Polysilicon springs suspend the structure over the surface of the wafer and provide a resistance against acceleration forces. Deflection of the structure is measured using a differential capacitor that consists of independent fixed plates and plates attached to the moving mass.

The fixed plates are driven by 180° out-of-phase square waves. Acceleration deflects the moving mass and unbalances the differential capacitor resulting in a sensor output whose amplitude is proportional to acceleration. Phase-sensitive demodulation techniques are then used to determine the magnitude and direction of the acceleration.

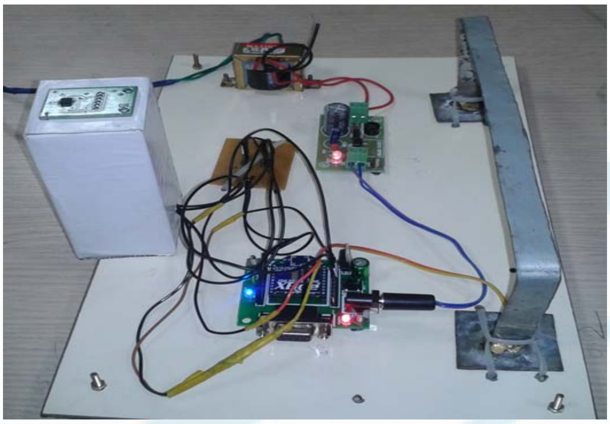


Figure 5: Picture of Sensor Module

The demodulator output is amplified and brought off-chip through a 32 kΩ resistor. The user then sets the signal bandwidth of the device by adding a capacitor. This filtering improves measurement resolution and helps prevent aliasing.

Features

- 3-axis sensing
- Small, low profile package
- 4 mm × 4 mm × 1.45 mm LFCSP
- Low power : 350 μA (typical)
- Single-supply operation: 1.8 V to 3.6 V
- 10,000 *g* shock survival
- Excellent temperature stability
- BW adjustment with a single capacitor per axis
- RoHS/WEEE lead-free compliant

3.3 Power Supply

The Unit is powered by Lithium ion battery with solar back-up. Lithium ion battery rating is 3.6 V and solar panel used to charge battery during day time.

3.4 Zig Bee RF Module

Zigbee series 2 RF module used to transmit the data from sensor. The Module used here operates at 2.4 Ghz frequency and consumes low power typically 40mA @ 3.3 V during both transmission and reception mode. Supports RF data as 250,000 bps. Supply voltage range is 2.8 ~ 3.4 V.

4. Base Station

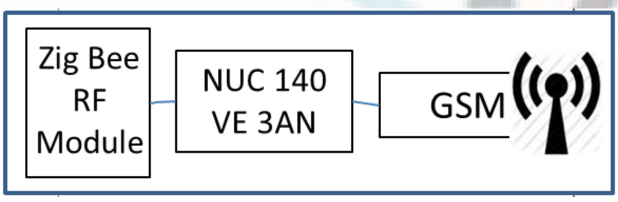
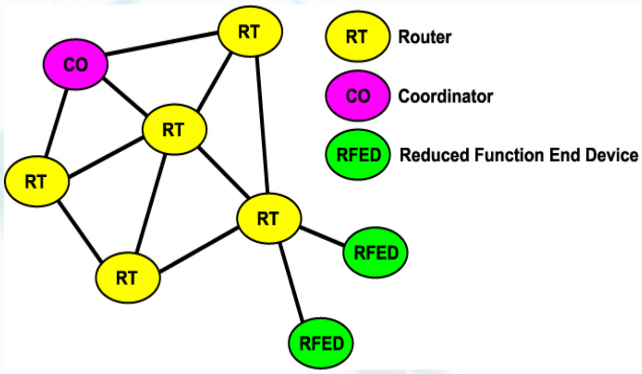


Figure 6: Block Diagram of Base Station

This Base station consists of Zig Bee RF module, ARM CORTEX Processor (NUC 140) and GSM transmission circuit.

4.1 Zig Bee Module

Zigbee series 2 RF module used to transmit the data from sensor. The Module used here operates at 2.4 Ghz frequency and consumes low power typically 40mA @ 3.3 V during both transmission and reception mode. Supports RF data @ 250,000 bps. Supply voltage range is 2.8 ~ 3.4 V. ZigBee is designed as a low-cost, low-power, low-data rate wireless mesh technology. The ZigBee specification identifies three kinds of devices that incorporate ZigBee radios, with all three found in a typical ZigBee network



- **A coordinator**, which organizes the network and maintains routing tables
- **Routers**, which can talk to the coordinator, to other routers, and to reduced function end devices
- **Reduced function end devices**, which can talk to routers and the coordinator, but not to each other

To minimize power consumption and promote long battery life in battery-powered devices, end devices can spend most of their time asleep, waking up only when they need to communicate and then going immediately back to sleep. ZigBee envisions that routers and the coordinator will be mains powered and will not go to sleep.

To illustrate how these components interrelate, consider ZigBee networking in office lighting. Several manufacturers are currently developing inexpensive sensors for fluorescent tubes that let lights be turned on and off by battery-powered wall switches, with no wires between switch and fixture. The light switch is the end device, powered by a button cell battery that will last for years; the switch wakes up and uses battery power only when flipped on or off to transmit the new state to the fluorescent tubes' routers which, as they are already connected to the mains, are not concerned with battery conservation. Any one of the fluorescent tubes can contain the coordinator. The implications are enormous for new office construction – no more electrical runs for lighting, and the ability to reconfigure lighting controls at almost zero cost.

4.2 ZigBee Benefits

Low cost - The typical ZigBee radio is extremely cost-effective. This pricing provides an economic justification for extending wireless networking to even the simplest of devices.

Range and obstruction issues avoidance - ZigBee routers double as input devices and repeaters to create a form of mesh network. If two network points are unable to communicate as intended, transmission is dynamically routed from the blocked node to a router with a clear path to the data's destination.

This happens automatically, so that communications continue even when a link fails unexpectedly. The use of low-cost routers can also extend the network's effective reach; when the distance between the base station and a remote node exceeds the devices' range, an intermediate node or nodes can relay transmission, eliminating the need for separate repeaters

Multi-source products – As an open standard, ZigBee provides customers with the ability to choose among vendors. ZigBee Alliance working groups define interoperability profiles to which ZigBee-certified devices must adhere, and certified radio will interoperate with any other ZigBee-certified radio adhering to the same profile, promoting compatibility and the associated competition that allows the end users to choose the best device for each particular network node, regardless of manufacturer.

Low power consumption - Basic ZigBee radios operate at 1 mW RF power, and can sleep when not involved in transmission (higher RF power ZigBee radios for applications needing greater range also provide the sleep function). As this makes battery-powered radios more practical than ever, wireless devices are free to be placed without power cable runs in addition to eliminating data cable runs.

4.3 NUC 140 Processor

NUC 140 Series are ARM Cortex M0 core eembedded micro controller for industrial control and applications with rich communication features. It runs upto 50 Mhz with 128K byte embedded flash and 16K byte embedded SRAM. It also integrates timers, watchdog timer, RTC, PDMA, UART, SPI/SSP, I2C, PWM, Timer, GPIO, LIN, CAN , USB, 2.0 Flash Drive, 12 bit ADC, Analog comparator, low voltage detector and Brown out detection.

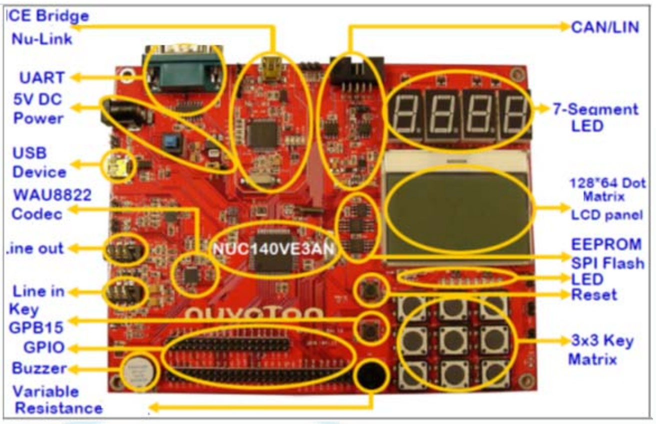


Figure 7: Picture of Novoton Board

Features

- Core – ARM Cortex^{TM} – M0 core runs up to 50MHz
- Build-in LDO for wide operating voltage from 2.5V to 5.5V
- Flash Memory
  - 32K/64K/128 bytes Flash for program code
  - 4KB flash for ISP loader
  - 512 byte page erase for flash
- SRAM Memory
  - 4K/8K/16K bytes embedded SRAM
  - Support PDMA mode
- PDMA(Pheripheral DMA)
  - Support 9 channels PDMA for automatic data transfer between SRAM and pherpherals
- One built-in temperature sensor with 1^{o} C resolution
- Low voltage reset

4.4. GSM

GSM SIM 300 module is a MODEM for transmitting and accepting the data through GSM network. This supports RS232 for supporting development of embedded applications. GSM module is highly flexible plug and play quad band GSM modem for direct and easy integration to RS232 applications.

Figure 8: Picture of Base Station Module

The modem needed only 3 wires (Tx, Rx, GND) except Power supply to interface with microcontroller/Host PC. The built in Low Dropout Linear voltage regulator allows you to connect wide range of unregulated power supply (4.2V -13V). Yes, 5 V is in between!! .Using this modem, you will be able to send & Read SMS, connect to internet via GPRS through simple AT commands.

Features

- High Quality Product (Not hobby grade)
- Quad-Band GSM/GPRS
- 850/ 900/ 1800/ 1900 MHz
- Built in RS232 Level Converter (MAX3232)
- Configurable baud rate
- SMA connector with GSM L Type Antenna.
- Built in SIM Card holder.
- Built in Network Status LED
- Inbuilt Powerful TCP/IP protocol stack for internet data transfer over GPRS.
- Audio interface Connector
- Most Status & Controlling Pins are available at Connector

5. Results

The Flex sensor and accelerometer were mounted on prototype pillar structure to study the performance. We could see a cause and effect relationship between flex sensor and accelerometer. The seismic vibrations (cause) are monitored by accelerometer and deformation of the pillar (effect) was verified in flex sensor data. The threshold limit was set for both the sensor data to trigger the message to be broadcasted via GSM when the threshold limit crosses.

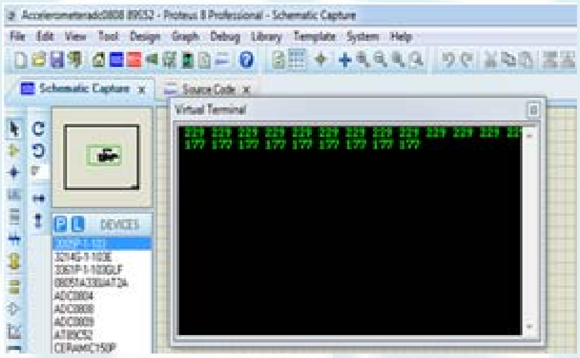


Figure 9: Picture of Simulation results – Accelerometer

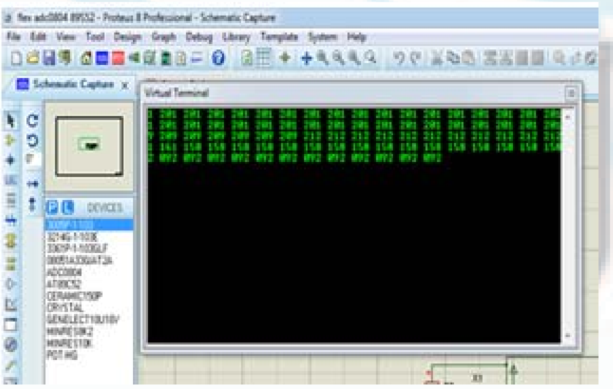


Figure 10: Picture of Simulation results – Flex Sensor

References

[1] Mainwaring, J. Polastre, R. Szewcyk, D. Culler, and J. Anderson, "Wireless Sensor Networks for Habitat Monitoring," in Proceedings of the Workshop on Wireless Sensor Networks and Applications, Atlanta, GA, USA, September 2002.

[2] N. Xu, S. Rangwala, K. Chintalapudi, D. Ganesan, A. Broad, R. Govindan, and D. Estrin, "A Wireless Sensor Network for Structural Monitoring," in Proceedings of the ACM Conference on Embedded Networked Sensor Systems, Baltimore, MD, USA, November 2004.

[3] M. Pozzi, D. Zonta, W.Wang, and G. Chen, "A framework for evaluating the impact of structural health monitoring on bridge management," in Proc. 5th Int. Conf. Bridge Maintenance, Safety Manage., Philadelphia, PA, Jul. 2010, p. 161.

[4] J. P. Lynch and K. J. Loh, "A summary review of wireless sensors and sensor networks for structural health monitoring," Shock Vibrat. Dig., vol. 38, no. 2, pp. 91–128, 2006.

[5] D. Zonta, M. Pozzi, and P. Zanon, "Managing the historical heritage using distributed technologies," Int. J. Arch. Heritage, vol. 2, no. 3, pp. 200–225, 2008.

[6] M. Kruger, C. U. Grosse, and P. J. Marron, "Wireless structural health monitoring using MEMS," Key Eng. Mater., vols. 293–294, pp. 625–634, Sep. 2005.

[7] Amditis, Y. Stratakos, D. Bairaktaris, M. Bimpas, S. Camarinopolos, and S. Frondistou-Yannas, "Wireless sensor network for seismic evaluation of concrete buildings," in Proc. 5th Eur. Workshop Struct. Health Monitor., Sorrento, Italy, Jun.–Jul. 2010.

[8] J. Santana, R. van den Hoven, C. van Liempd, M. Colin, N. Saillen, and C. Van Hoof, "A 3-axis accelerometer and strain sensor system for building integrity monitoring," in Proc. 16th Int. Conf. Solid-State

[9] Sensors, Actuat., Microsyst., Beijing, China, Jun. 2011, pp. 36–39.

[10] Amditis, Y. Stratakos, D. Bairaktaris, M. Bimpas, S. Camarinopolos, and S. Frondistou-Yannas, "An overview of MEMSCON project: An intelligent wireless sensor network for after-earthquake evaluation of concrete buildings," in Proc. 14th Eur. Conf. Earthquake Eng., Aug. – Sep. 2010.

[11] D. Trapani, D. Zonta, F. Larcher, A. Amditis, N. Bertsch, M. Bimpas, A. Garetsos, N. Saillen, J. Santana, T. Sterken, Y. Stratakos, T. Torfs, and D. Ulieru, "Laboratory validation of MEMS-based sensors for post earthquake damage assessment," in Proc. 8th Int. Workshop Struct. Health Monitor, Stanford, CA, Sep. 2011, pp. 2165–2172.