ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940
International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 9, September 2014

Development of an Acceleration-based Wireless Sensor Node Platform

Nwalozie G.C[1], Azubogu A.C.O[2], Okafor A.C[3], Alagbu E[4]

Department of Electronic and Computer Engineering, Nnamdi Azikiwe University Awka, Nigeria[1, 2, 3]

Department of Electronic Development Institute, Awka, Anambra, Nigeria[4]

Abstract: A wireless sensor network is a distributed network made up of low-power consuming, low cost devices called sensor nodes which combine sensing, computation and communication. Sensor networks have enabled many applications, including remote tracking and monitoring of environments in real-time. It is of great value to use it where human is quite difficult to reach or where there are distributed sources of data. Power consumption and size are the most important consideration when nodes are designed for distributed wireless sensors. Consequently, it is of great importance to decrease the size of a node, reduce its power consumption and extend its life in network. This work describes the design and construction of an acceleration-based sensor node platform intended for use in sensor networks research. The system is made up of a hardware platform and a software stack for drivers and interfacing. The experiment results indicate that the node has the characteristic of high reliability, good stability and ultra low power consumption.

Keywords: Accelerometer, Wireless Sensor, and interfacing

I. INTRODUCTION

Although wireless sensor nodes have existed for decades and used for applications as diverse as earthquake measurements to warfare, the modern development of small sensor nodes dates back to the 1998 with Smart dust project [1] and the NASA Sensor Webs Project [2]. One of the objectives of the Smart dust project was to create autonomous sensing and communication within a cubic millimeter of space. A wireless sensor network is made up of ultra low-power consuming, low cost, distributed devices called sensor nodes that combine sensing, computation and communication. These nodes form part of a larger network, enabling a wealth of information that can be obtained in an instant across many spatially distributed devices covering an area. While a single node's capabilities may be limited, a larger collection can offer new technological and information processing possibilities.

The main components of a sensor node are a microcontroller, transceiver, power source and one or more sensors. The controller performs tasks, processes data and controls the functionality of other components in the sensor node. A microcontroller is often used in many embedded systems such as sensor nodes because of its low cost, flexibility to connect to other devices, ease of programming, and low power consumption. A general purpose microprocessor generally has higher power consumption than a microcontroller; therefore it is often not considered a suitable choice for a sensor node. Digital Signal Processors may be chosen for broadband wireless communication applications, but in Wireless Sensor Networks the wireless communication is often modest: i.e., simpler, easier to process modulation and the signal processing tasks of actual sensing of data is less complicated. Therefore the advantages of DSPs are not usually of much importance to wireless sensor nodes.

Sensor nodes often make use of ISM band, which gives free radio spectrum allocation and global availability. The possible choices of wireless transmission media are radio frequency (RF), optical communication (laser) and infrared. Lasers require less energy, but need line-of-sight for communication and are sensitive to atmospheric conditions. Infrared, like lasers, needs no antenna but it is limited in its broadcasting capacity. Radio frequency-based communication is the most relevant that fits most of the Wireless Sensor Node applications. Wireless sensor nodes tend to use license-free communication frequencies: 173, 433, 868, and 915 MHz; and 2.4 GHz. The functionality of both transmitter and receiver are combined into a single device known as a transceiver.

A wireless sensor node is a popular solution when it is difficult or impossible to run a mains supply to the sensor node. However, since the wireless sensor node is often placed in a hard-to-reach location, changing the battery regularly can be costly and inconvenient. An important aspect in the development of a wireless sensor node is ensuring that there is always adequate energy available to power the system. The sensor node consumes power for sensing, communicating and data processing. This work describes the design and construction of an acceleration-based Wireless sensor node that can be used to monitor the structural health of long distance infrastructure.

II. REVIEW OF RELATED WORKS

The Redwire Econotag [3] is a development board based on a FreescaleMC13224V ARM7 microcontroller with a built-in IEEE 802.15.4 2.4GHz wireless transceiver but is not ZigBee compliant. It features 128kB of flash storage and 96kB of RAM. No sensors are included on the board but 36 GPIO pins are brought to headers for expansion. This board is designed as a development board and not

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940
International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 9, September 2014

suited for practical deployment because there is little allowance for practical work.

The Libelium Waspmote [4] is a feature-packed sensor board designed around a Atmel ATmega1281 microcontroller with 8kB RAM and 128kB flash storage. It uses a modular approach to every peripheral and is designed to use XBee radio modules of various frequencies that support ZigBee. A GPRS socket, GPS socket and expansion socket provide the use of add-on circuit boards manufactured by Libelium. This board is unsuitable for our use due to its very high price, over $200, and the unnecessary modularity.

Tmote sky [5] is a commercial wireless sensor platform developed by Moteiv, a company founded by some UC Berkeley alumni. Tmote Sky delivers high configurability and interoperability in a small board, about 7x3cm. Its core components are a MSP430 ultra-low power microcontroller by Texas Instruments, a 1MB Flash chip and a Chipcon 802.15.4-compatible transceiver. The node also integrates some light, humidity and temperature sensors. The I/O capabilities of the node are extended by a dedicated USB controller, which allows the node to directly communicate with a PC. A UART port and an I2C bus make the node ready for connection with other integrated chips. As for the radio communication, its transmission range is up to 125m. The MSP430 microcontroller can run up to 8MHz. From the power consumption standpoint, its performance is outstanding. The chip draws only 500uA/MHz in active mode at 3.3V and the consumption drops to less than 1uA while in power down mode. The analog to digital conversion is performed by the microcontroller itself, thanks to the integrated ADC. The available channels are 8and the resolution is 12 bits. The sampling period is lower than 10us. Due to the energy performance of the microcontroller, Tmote Sky shows a consumption of around 22mA when fully active. The module runs a modified version of the TinyOS operating system called Boomerang. The customized operating system is designed to enhance the networking functionalities of the node and the deployment of reliable wireless solution. The node has been demonstrated in real-life applications, like the real-time monitoring of a Fire-fighters team during rescue operations.

The Virtenio Preon32 [6] sensor node is designed around an unnamed ARM Cortex-M3 microcontroller with 256kB of flash and 64kB of RAM. The radio is an unknown IEEE 802.15.4 2.4GHz transceiver that supports up to 250m wireless range when outdoors. It is designed as module to be soldered onto another PCB which provides the interfaces and power. This approach means that the cost to buy the module as well as designing and manufacturing a separate board would have been much more than the cost of producing a single board for a similar amount of work.
Ecomote [7] is an ultra-small wireless sensor node developed by Park, C. and P. Chou at the University of California, Irvine. The mote is not a single chip solution, however it achieves a remarkable result in terms of form factor. The mote is contained 0in a 13x10x8mm volume, including battery. The size reduction is achieved mainly by the choice of a chip integrating both a 8051 computational unit and a radio transceiver, operating in the 2.4GHz band. The MCU offers the standard I/O interfaces (i.e. UART, SPI and I2C), which are made available to external devices by ultra-small size connectors. The developers managed to fit in the small volume various sensors. In particular, a 3-axis accelerometer, a light sensor and a temperature sensor. This makes the sensing capabilities of the node completely equivalent to the Tmote Sky's ones. The memory of the MCU is expanded by an external 32KB SPI EEPROM chip. The MCU incorporates a 9-channel ADC with a resolution ranging from 6 to 12 bits and a maximum sampling rate of 100Ksps.

III. DESIGN CONSIDERATIONS

Sensor Node Characteristics

A microcontroller acts as the central controlling device, while the transceiver enables packets of data to be sent and transmitted. Sensors are used for data collection and in most cases provide purpose to a node. Figure 1 shows a functional diagram of the typical hardware that makes up a node. In such a small system, optimizing every component based on its requirements is critical as it can save development time, board space, and money. This low cost aspect allows for many nodes to be deployed, providing denser coverage and multiple data paths to cope with failure.

In the following sub-sections each of the main components, will be reviewed outlining the ideal characteristics that make a sensor node.

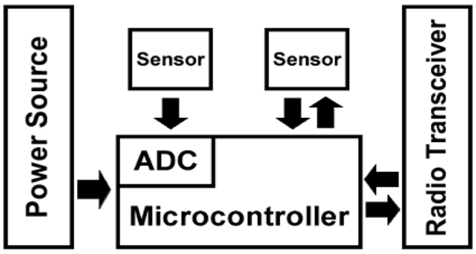


Figure 1: Sensor Node Architecture

(a) Microcontroller

A microcontroller oversees operations of a sensor node and is one of the most important components. Almost every microcontroller family available is different; some may be designed for speed, others for power efficiency. It is a matter of choosing the correct microcontroller for the application and in a sensor node there are various aspects that need to be considered. These include;

- **Power Consumption**

A microcontroller's architecture can be optimized for speed or power consumption. In a WSN, which must run off a battery for a great length of time, a microcontroller optimized for low power is important. In order to minimize power consumption, a node should spend most of its life in a sleep mode; therefore a low current draw when asleep is essential. This varies between microcontrollers, architectures and the various states of sleep but tends to range from less than 1µA to 100µA. Active mode power consumption is a useful metric too, and becomes more important the longer a node spends in wake periods. This tends to range between 1mA to 10mA for small, low-powered microcontrollers, but varies depending on attributes such as the built-in peripherals, clock speed, and size of the memory and location of program execution.

- **Memory**

Flash memory and RAM quantities should be chosen to suit the application as both can be expensive in terms of cost and size. In general, more RAM equals more wafer real estate and more power required to keep this volatile memory refreshed. This leads to higher costs through less manufacturing yield, and the larger wafer may require a larger package.

- **Peripheral Support**

A microcontroller consists of pins that serve varying functions such as serial communications, timer outputs, comparisons, analogue and digital inputs and outputs; even USB connections. There is a desire to minimize the pin count as a smaller package can lead to lower costs and a smaller footprint. A problem is that microcontrollers tend to integrate more functions than the quantity of pins allow. This leads to pin multiplexing where each pin can have a variety of functions that are selectable via software. When selecting a microcontroller, knowing what types of pins are going to be used can help to ensure the microcontroller will serve all the required inputs and outputs without the need for an external I/O controller to provide the additional interfaces. For a sensor node many different types of pins are required: typically a radio is interfaced over a high speed SPI channel; sensors can require a variety of interfaces such as I^2C, I^2S, analogue-to-digital converters (ADCs), and interrupt enabled GPIO. Additional pins are required for clocking systems, programming, and outputs to interfaces such as LEDs. I^2C is a half-duplex serial bus that can operate from 400KHz and each device on the bus has a unique 7 bit address assigned by its manufacturer.

(b) Radio Transceiver

The transceiver allows two-way radio communication between nodes in order to distribute information, e.g., routing sensor data to a base station. The choice of transceiver has a big impact on power consumption as the transceiver, when it is idle, sending or receiving data, will generally consume more power than any other component. A few important characteristics of a transceiver define how well it will perform in a sensor network application these characteristics include;

- **Frequency**

Most sensor nodes make use of ISM regions in the 300 to 3000MHz Ultra High Frequency band, in particular the license free regions around 430MHz, 900MHz and 2.4GHz. In New Zealand this is referred to as the Short Range Devices bands [8]. Areas within these bands are free to use so long as rules are followed, in particular staying within specified centre and deviation frequencies, and output power. Using ISM regions allows the use of commonly available radio transceivers, and the radios can provide long ranges with high bit rates.

- **Data Rate**

In most cases wireless sensor network applications need very little data through-put as they tend to only transmit periodically and in low bit quantities [9]. For example, they generally are not used in applications for streaming audio or video. Low data rates help offer greater range but at the expense of longer periods spent in a high current consuming, transmitting state. Therefore it is beneficial to determine the data rate needed for the intended application when choosing a transceiver. Fortunately almost all ISM transceivers have a wide programmable speed from 500kbps down to near zero kbps.

- **Transmit/Receive Power**

The maximum transmission power of a radio transceiver is an important factor as it determines the signal strength of a transmitted wave. The stronger the signal then the further it will travel. All spectrum allocations come with legal limits on power output when transmitting to limit exposure and biological effects on absorbing matter. Finding a transceiver that can closely match this limit is good because this platform will be used in multiple roles and having a transceiver that can be very powerful in one application while weak in another, all via software, will help extend its battery life and usefulness.

Although transmitter power mainly determines the transmission distance, other factors such as receiver sensitivity, antenna gain and efficiency, and the modulation scheme all have an impact on range.

- **Power Consumption**

The radio transceiver will most likely be the largest power consumer in the circuit as it tends to draw tens of milliamps in both transmit and receive states. This means choosing a transceiver with a small current consumption for a given output power, compared to other transceivers, will help extend the battery life available. Transmission power is also a good way of reducing the current consumption and lessening this is a sure way to extend a battery's life.

(c) Sensors

There is a vast range of sensors available that can be interfaced to with a microcontroller. When choosing the right sensors for a node, consideration must be given to the way that it is interfaced; its characteristics compared to similar sensors, such as accuracy; and its power consumption. If a sensor board is used in a variety of purposes then it makes sense to design modularity into it and allow customization. A recurring theme is minimizing the power consumption of a component in order to maximize the battery life. Sensors should be chosen in such a way that power consumption is minimized.

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 9, September 2014

Minimal sleep and sensing currents, low turn on and off times, the time it takes for a sensor to be ready to accurately sense, and the time it takes to generate a sensor reading, can all affect power consumption in varying manners.

A sensor's input and output interface can limit accuracy, features, and the number of pins used on the microcontroller. Reading accuracy can be diminished if, for example, an analogue sensor is outputting into a 10-bit ADC on a microcontroller but if an equivalent 12-bit digital sensor is available, then the digital sensor will provide more accurate readings. Digital sensors tend to use serial interfaces such as SPI and I^2C, which can enable access to internal registers for enabling features or setting threshold values.

(d) Power Source

Batteries provide a low cost, easily available and high capacity source of power, and have become synonymous with mobile devices. And this is no different in sensor networks. This area, with its ultra low power consumption and duty cycle, presents an opportunity for the application of advanced small-scale power generation, such as solar generation or parasitic energy harvesting. Analysis and application of these possibilities is out of the scope of this project, so conventional chemical energy is pursued due to its easy and constant high power.

A regulator is a system that takes a varying input voltage and outputs a constant predetermined voltage. Regulators are useful due to most components having a small and specific working voltage range but power sources can vary in voltage.

IV. COMPONENTS SELECTION

The major objective of this work is to design and develop an acceleration-based Wireless Sensor node that can be used to monitor the structural health of long distances infrastructure. The designed node consists of a sensor board. A sensor board is equipped with Micro-Electro-Mechanical Systems (MEMS) accelerometers for measuring vibration. MEMS accelerometers can be made much less expensive than piezoelectric ones, while the use of wireless links can save significant wiring cost for data communication and power. Each component was carefully selected to ensure it was the correct choice for the sensor node and there would be no compatibility issues.

(i) The sensing unit

The acceleration based sensor used in this work, is an MMA7361L IC based sensor, produced by Sunrom Technology India shown in Fig.2 below. The sensor can measure acceleration, tilt, and vibrations with two levels of selectable sensitivity. Accelerometer sensor can measure static (earth gravity) or dynamic acceleration in all three axes.

Accelerometer sensor measures level of acceleration where it is mounted this enable the measurement of acceleration/deceleration of object like car or robot, or tilt of a platform with respect to earth axis, or vibration produced by machines. Acceleration is a vector force which has direction and measured in meters per second squared (m/s^2). Earth produces gravitational acceleration on all objects on earth. By monitoring the three axis acceleration one can measure the level of tilt of any platform.

Figure 2: Acceleration-based sensor

(ii) The Processing unit

For this design, the PIC18F2620 Microcontroller from Microchip is selected. The PIC18F2620 belongs to the sub-family PIC18F2525/2620/4525/4620 of the Microchip Programmable Interface Controller (PIC) family of chips. This sub-family offers the advantages of all PIC18 microcontrollers – namely, high computational performance at an economical price – with the addition of high endurance, Enhanced Flash program memory. This family also introduces design enhancements that make these microcontrollers a logical choice for many high-performances, power sensitive applications. The various features of the PIC18F2620 are as shown in Table 1.

Table 3.1: Features of PIC18F2620

Features	PIC18F2620
Operating Frequency	DC-40MHZ
Program Memory (Bytes)	65536
Program Memory (Instructions)	32768
Data Memory (Bytes)	3968
Data EEPROM Memory (Bytes)	1024
Interrupt Sources	19
I/O Ports	Ports A, B, C, (E)
Timers	4
Capture/Compare/PWM Modules	2
Enhanced Capture/Compare/PWM Modules	0
Serial Communications	MSSP, Enhanced USART
Parallel Communications (PSP)	No
10-Bit Analog-to-Digital Module	10 input channels
Resets (and Delays)	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), MCLR (optional), WDT
Programmable Low-Voltage Detect	Yes
Programmable Brown-out Reset	Yes

(iii) The Radio Frequency (RF) Transceiver

For this design, the KYL-500S Mini-size Wireless Data Transceiver Module (see figure 3) from Shenzhen KYL Communication Equipment Co., Ltd is chosen for data transmission and reception. The KYL500S is a low-frequency line-of-sight radio that operates in the 400MHz-470MHz frequency range within the ISM band covering a distance of 1000metres at 1200bps. It is usually used for restricted space application. With TTL interface, it is widely used for micro-controller wireless communication

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940
International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 9, September 2014

and other TTL level port communication systems. The features and power specification of the KYL-500S transceiver device made it a choice for this development see Table 2:

Table 2: Technical Specifications of KYL500S

Power Output	50mW(Default), (10~100mW optional)
RF Line-of-sight Range	1000m@1200bps; 600m@9600bps
RF Effective Rate	1200/2400/4800/9600/19200bps
Space Channel	1MHz(Default),(12.5/25KHz/other customization)
Bandwidth	<25KHz
Receiver Sensitivity	123dBm@1200bps(1% BER)
Networking Topology	Point-to-point, point-to-multipoint
Supply Voltage	5V DC (default), 3.3-3.6V(optional)
Transmit Current	<40mA
Receive Current	<20mA
Sleep current	< 30uA
Communication Mode	Half-duplex
Frequency Band	400-470MHz MHz
Channel	8(default),16/32/64(optional)
Operating Temperature	40 ℃ ~+85 ℃ (TCXO)
Antenna Base	50 Ω , SMA

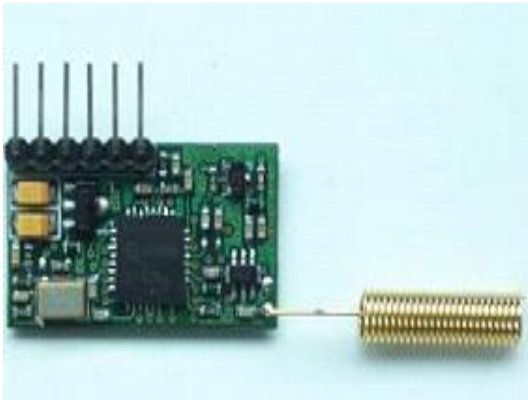


Figure 3: KYL500S RF transceiver

(iv) The power unit

The main source of DC power to the developed node is the 9V battery connected to the node. For applications that draw fairly large amount of current at some point, a DC-DC down-converter is used. The DC-DC down converter acts to step-down high DC voltages to a required output voltage. The most commonly used DC-DC converter and applicable here is the voltage regulator. The voltage regulator is an integrated circuit (IC) that converts voltage from one level to another by regulating and maintaining the output voltage at a set point The Integrated Circuit (IC) LM7805CV regulator was used to perform voltage regulation and stabilization for other standard +5V power requirement for most of the components within the node. Fig 4 shows the circuit used to achieve voltage regulation and stabilization.

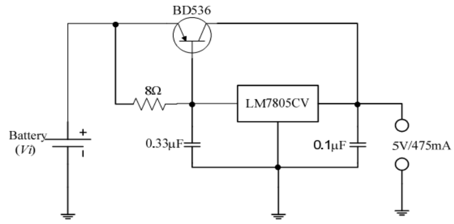


Figure 4: Voltage regulation Circuit

V. SYSTEM DESIGN

Hardware Design

The Wireless sensor network consists of a simple linear network of custom m ade sensor nodes. The decision to develop these custom made sensor nodes is based on cost reduction, unavailability of standardized industrial nodes for the required parameter ranges, coverage distance needed. The principal hardware used in this development includes;

- PIC18F2620 microcontroller
- Accelerometer (MMA7361 Model: 1156)
- KYL-500S Transceiver
- 9V battery terminal for mobile operation
- LM7805CV voltage regulator
- RS232 serial port connector for connection to PC COM port

The sensor node is implemented by connecting all the selected units together in a single circuit as shown in the circuit diagram. The circuit diagram of the designed (see figure 5) shows all terminal connections to sensor, transceiver, and digital I/O for data interfaces to the PIC18F2620 microcontroller device. Figure 6 shows the dimensions and layout of the developed wireless sensor node, while Figure 7 shows the developed sensor node.

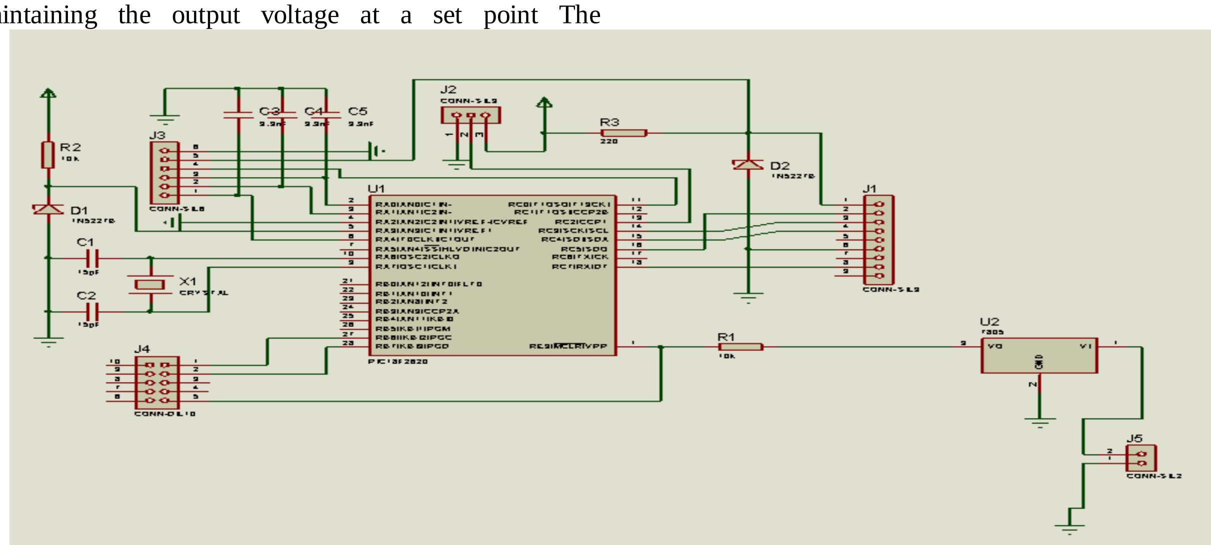
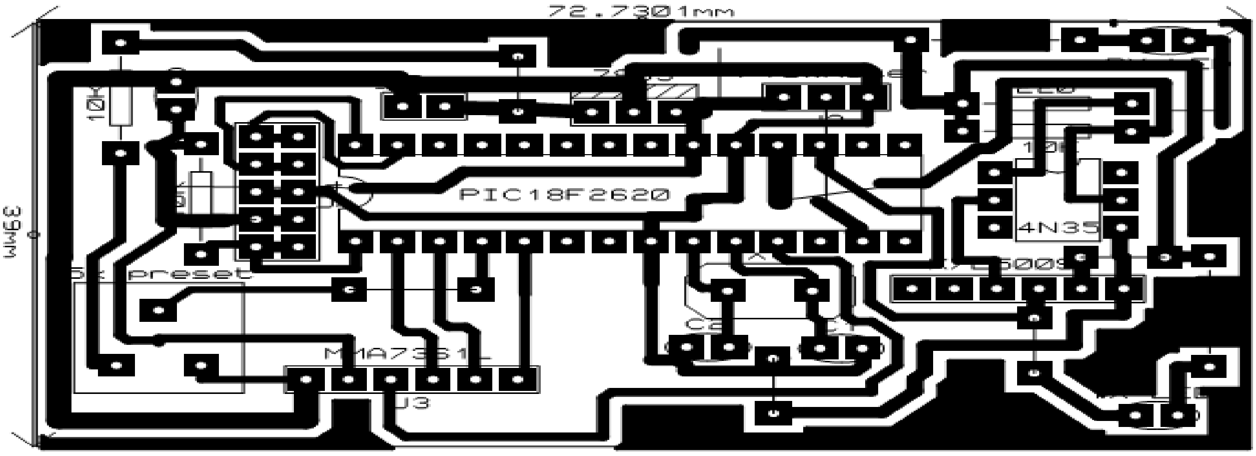


Figure 5: Circuit Diagram of the Developed Wireless Sensor Node

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 9, September 2014



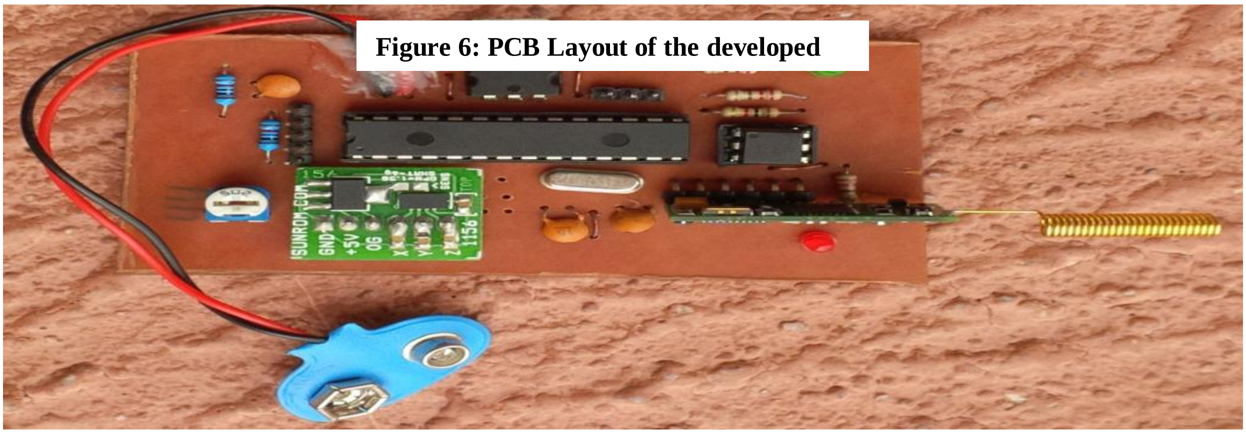


Figure 6: PCB Layout of the developed

Figure 7: Developed Node

Software Design

In order to debug and demonstrate that the hardware was working and capable of performing as required, software was developed to interface to the devices, along with any necessary drivers.

A very basic operating system that collected and transmitted sensor data was written to tie the various interfaces together and demonstrate a complete working node. In addition to demonstrating basic functionality of each component, there was a need to know if it could operate in a way that was suitable for a sensor node.

For data to be logged into the PC from the wireless sensor nodes, and for the PC to send commands and receive data, there must be a link. The PC can communicate through various terminals—Parallel port, Serial (RS232) port, Universal Serial Bus (USB), Ethernet port. The RS232 terminal is simple and can be made to connect TTL based devices through protocol conversion.

In this work, a wireless modem is developed by adding a RS232 to TTL converter chip to a KYL-500S transceiver as shown in Figure 8.

The modem is made to derive its power from the PC's USB port while data are communicated through the RS232 serial port.

Figure 8: RS232 to TTL Modem

A PC-side graphical user interface was developed to make interaction with node possible via a computer. The GUI was developed by Microsoft Visual Studio IDE and written in Visual Basic.NET. The choice was determined by the fact Visual Studio allows users to develop complex user interfaces with little effort and Visual Basic.NET offers built-in objects for the management of communication via serial ports. This was judged of help, since the communication with the node relies on the KYL500S radio which can be interfaced to a PC via a serial link.

VB.Net is an object oriented software language that enhances the construct of well defined sets of graphical objects for user interface development and data linking. VB.Net also gives access to the PC's serial

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

communication (COM) port. The COM port is RS232 enabled and gives access to any RS232 protocol based device. These properties are desirable for the monitoring system to completely have access to the PC and for users to view acquired data. Figure 9 shows the main GUI for user data view and control.

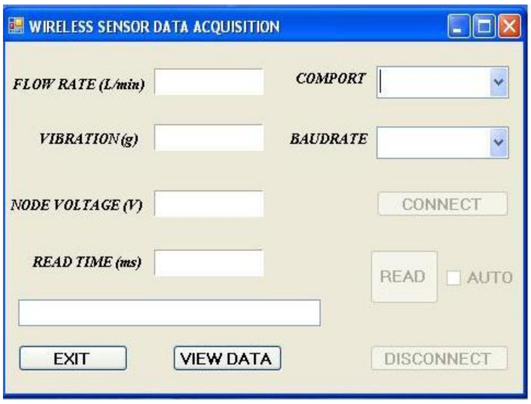


Figure 9: Screen shot of the GUI for data acquisition

VI. SYSTEM TESTING

The system essentially comprises of two basic parts, namely: the hardware and the software parts. So far, the two parts have been implemented. A systematic test of the hardware is to be done. At this point, the embedded software is loaded to the microcontroller and every aspect of the hardware tested. The shake table experiment is used to test the accelerometer while the result is observed on the GUI. This test is carried out to determine the operational state of the entire system including the hardware and software. If the coding of the software has run – time error, it will be revealed at this stage. When the desired result is obtained the overall system test is certified to have met the design specification. After the correction of the errors encountered during the initial systems test, the overall system test was carried out and the required result was achieved with the hardware and software parts harmoniously working together. Figure 10 shows a screen shot of the GUI when the system is being tested, which confirm that the developed acceleration-based sensor node is working as stated as the node was able to pick the vibrations of the table occasioned by the shaking of the table and wirelessly transmit same to the base station attached to a PC where the result is displayed on the developed GUI.

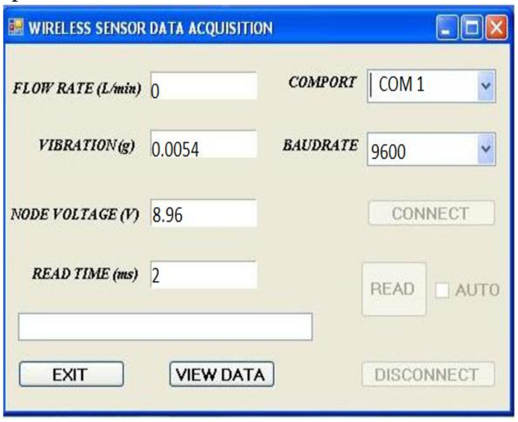


Figure 10: Screen shot of the GUI during system Test

VII. CONCLUSION

The design and construction of an acceleration-based wireless sensor node has been implemented in this project. The design followed a detailed review of the existing system, modeling of a new system and subsequently designing the envisaged system. The end result is a system which can automatically indicate the vibrations on the surface of any structure. The system offer portability and smart concept in monitoring and indicating level of vibrations within the structure. The system was designed to be easy for users of any educational background. The detailed analysis of this project design is made available to expose the underlying technology of this project and related projects.

REFERENCES

[1] Kris Pister, "Autonomous sensing and communication in a cubic millimeter," July,2001.[Online]. Available: http://robotics.eecs.berkeley.edu, accessed on August, 2014.
[2] Delin K., Jackson S., and Some R., "Tech Brief: Sensor Webs ",NASA's Jet Propulsion Laboratory, September, 2007.
[3] Redwire LLC. Econotag WSN Node. http://www.redwirellc.com/store/node/1, July 2014.
[4] Libelium Comunicaciones Distribuidas S.L. Waspmote. http://www.libelium.com/products/waspmote, July 2014
[5] Kris Pister, " Basis for Moteiv's Tmote Sky platform". http://www.bsac.eecs.berkeley.edu, accessed July 2014
[6] Virtenio GmbH. Preon32. http://www.virtenio.com/en/products/radio-module.html, August 2014.
[7] Chou, P. H. Eco: Ultra-compact wireless sensing system. http://www.ecomote.net/.
[8] Yuanwei Jin and Ali Eydgahi. "Monitoring of distributed pipeline systems by wireless sensor networks". In Proceedings of the 2008 IJAC-IJME International Conference, Nashville, TN, USA, 2008.
[9] Stoianov, I., Nachman, L., Madden, S., and Tokmouline, T. "PIPENETa wireless sensor network for pipeline monitoring." Proceedings of the 6th international conference on Information processing in sensor networks, ACM, 264-273, 2007
[10] Mehdi Hassani, HamedTebianian, S. Mekhilef and AmirhosseinMehbodniya Design and Implementation of a Level Detector IEEE International Conference for Technical postgraduates (TECHPOS 2009) 14-15 Dec. 2009, Kuala Lumpur, Malaysia, pp.11-15.
[11] L. K. Baxter, Capacitive Sensors. Design and Applications.NewYork: IEEE Press, 1997.conference on computer science and information technology, ICCSIT 2010; Vol-4, pp.628-632.
[12] Jin, Y., and Eydgahi, A. "Monitoring of distributed pipeline systems by wireless sensor networks." Proceedings of the 2008 IAJC-IJME International Conference.
[13] Turner N.C., "Hardware and Software Techniques for Pipeline Integrity and Leak Detection Monitoring", SPE paper 23044 presented at the Offshore Europe Conference, Aberdeen, Sept. 3-6, 1991
[14] Muhlbauer, K.W., Pipeline Risk Management Manual, 2nd Edition. Gulf Publishing Company,Houston, Texas, 1996