Development of 3-Axes Accelerometer Wireless Sensor Nodes for Pipeline Monitoring

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Development of 3-Axes Accelerometer Wireless Sensor Nodes for Pipeline Monitoring

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ABSTRACT

Wireless Sensor Nodes have been deployed in a wide variety of applications because of their enormous potential to monitor environmental variables. They offer cost effective solution in detecting and localizing leak points in pipeline network. This paper describes the development of 3-axes accelerometer wireless sensor nodes for pipeline monitoring. MMA7361L IC based accelerometer produced by Sunrom was used as the sensing unit, PIC18 microcontroller family forms the processing unit, communication was made possible with KYL-500S mini data transceiver module and the whole unit was powered by a 9V alkaline battery. The PIC18 microcontrollers programmed in embedded C Language receive the signals from the accelerometer and convert them to digital; store the digitalized data to finally deliver them to its KYL-500S transceiver module for transmission. An Operating System (OS) was written to tie the various interfaces together to define how data are acquired, processed and communication setup for interconnection. Universal Serial Bus (USB) connection was implemented to enable communication between the sensor nodes and Personal Computer (PC) which serve as the Base Station (BS). Graphical User Interface (GUI) was developed with Microsoft Visual Studio IDE written in Visual Basic.NET. The designed wireless sensor nodes were tested in the laboratory using the Shake Table method and then deployed on an experimental testbed for measuring vibration on the pipeline surface to determine change in acceleration caused by simulated leakage and data was subsequently recorded at the base station. The developed sensor nodes were compared with standard nodes using IEEE 802.15.4 standard. The developed sensor nodes can also be used for further research activities in wireless sensor network such as structural health monitoring of long span infrastructure and environmental protection.

Keywords: *3-axes accelerometer, KYL-500S, PIC microcontroller, Pipeline Monitoring, Transceiver, Wireless Sensor Node*

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I. INTRODUCTION

Wireless Sensor Network (WSN) has gained significant interest from both research and industrial communities due to their potential to monitor the physical world which may be difficult to access remotely. WSN have enormous potential for improving the functionalities of the different industrial fields, enhancing people's daily lives and monitoring ecological environment [1]. They offer cost effective solution in detecting and locating leak points in pipelines [2] and have already been used on a wide variety of applications such as industrial machine and process control [3], military application [4], building and facility automation [5], fire rescue and medical monitoring [6], others are structural health monitoring, wild life tracking and agriculture [7, 8].

A Sensor Node is a device that translates parameters or events in their physical world into signal that can be analyzed or measured. Wireless Sensor Nodes can be used where wired systems cannot be deployed for example dangerous location that might be contaminated with toxins or be subjected to high temperature. Wireless Sensor Networks consist of a set of sensor nodes capable of sensing, processing, storing and communicating data from one node to another node [9]. However, implementing such networks remains a challenging task due to hardware requirements in terms of data processing and transmission capabilities as well as computational power and limited energy resources. A sensor node consist of four basic units: sensing, processing, communicating and power supply units as shown in Fig.1. Varieties of Sensor Nodes used for various applications are available such as temperature sensors, humidity sensors, pressure sensors, soil moisture sensors, soil temperature sensors, proximity sensors, wind speed sensors, light sensors, and solar radiation sensors.

This paper describes the development of acceleration-based wireless sensor nodes that can be deployed in pipeline monitoring. The developed sensor nodes can also be used for further research activities in WSN such as structural health monitoring of long span infrastructure and environmental protection.

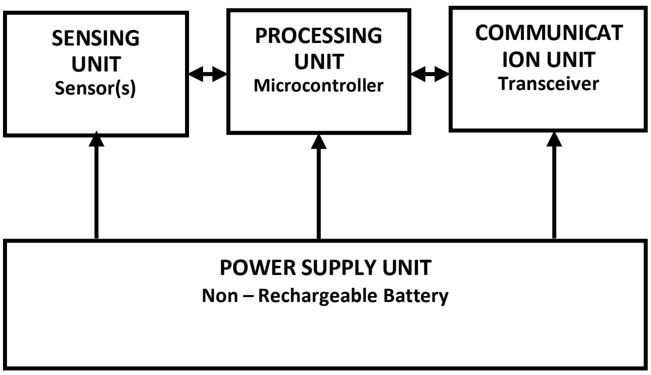

Figure 1: Sensor Node Block Diagram

II. RELATED WORKS

Several researches have been carried out in the area of design and development of wireless sensor nodes for numerous applications. MPWiNodeZ was proposed in [10] based on a wireless microcontroller JN5121 from Jennic incorporation, which comprises of an IEEE 802.15.4 RF transceiver with low power and low data rate module called ZigBee. This device converts raw data from low-cost analog sensors into meaningful information. Besides the microcontroller, it includes an external 12-bit Analogue to Digital (A/D) converter with eight single-ended analog inputs. A wireless sensor node (GAIA Soil-Mote) with a SDI-12 interface and IP67 protection level has been described in [11]. The node allows the installation of a large number of agricultural sensors in a crop with wireless data transfer to a centrally-located base station. Wireless communication was achieved with a transceiver compliant to the IEEE 802.15.4 standard. The software implementation was through an embedded and component-based operating system called TinyOS.

A sensor node capable of microenvironment information acquisition, data preprocessing, and communication with a water potential sensing station has been proposed by [12], ATmega128 microcontroller was selected because of ultra-low power consumption and wide work-temperature tolerance. The data was acquired through eight SHT75 interfaces, eight analogue voltage inputs, a serial interface to canopy temperature sensor, and a pulse signal interface to wind speed sensor. The design of ZigBee WSN nodes were presented by [13] to measure power consumption by the ZigBee radio module and to send the collected data to other network. The Printed Circuit Boards (PCBs) for the system were designed in Eagle CAD (Computer Aided Design) 5.11. The WSN nodes were built using Surface Mount Technology devices mainly. A PIC24 microcontroller family was mounted on the WSN node and programmed in C with mikroC Pro 5.4. The PIC24 microcontroller receives the signals from the sensors and converts them to digital; then it stores the digitalized data to finally deliver them to its ZigBee radio module for transmission. A USB connection was implemented to enable the communication between the WSN node and a PC.

A customized sensor node composed of the ARM Cortex M1 processor with memory, A/D converter with multiplexer, and I/O interface for integrating digital peripherals like USB, UART, SPI, and I^2C was presented by [14]. A sensor node based on GSM technology was proposed by [15]. The two sensors (LM35 and SY-HS-230) were connected to MCP3208 A/D converter and AT89S52 microcontroller. The microcontroller compares the received values from

ADC with the pre-loaded values of temperature and humidity and sends the indication signal. XBee wireless sensor node and network technology by [16] has been introduced by XBee alliance under IEEE 802.15.4 standard. It operates in the 2.4 GHz band with a data transfer rate of 250 kbps and it supports peer to peer, point to point and point to multipoint networking methods. The node comprises of a moisture sensor, microcontroller (PIC 16F876A) and XBee communication module. This node sends data to the hub connected to the PC in order to deposit data into a database.

IHPNode has been developed as a flexible and modular hardware platform for WSN and Internet of Things by [17]. It is based on the MSP430F5438A microcontroller and three RF transceivers, one working in the 868 MHz and two in the 2.4 GHz frequency band. The two of these RF transceivers (CC1101 and CC2500) support flexible proprietary networking protocols, while the third (CC2520) provides a network coprocessor for ZigBee protocol integration. An embedded sensor node microcontroller (TNODE) designed to support wireless sensor network applications with high security demands has been described by [18]. This ASIC chip features a low-power 16-bit IPMS430 processor, DSSS baseband, advanced crypto accelerators, embedded flash and data RAM, and 8-channel 12-bit analog-to-digital converter as well as the advanced low power techniques like clock-gating, power-gating, and frequency-scaling [19].

III. METHODOLOGY AND SYSTEM DESIGN

The fundamental objective of any wireless sensor system is to sense, process, and communicate the sensed data of interest to the central unit wirelessly. This paper describes the development of 3-axes accelerometer wireless sensor nodes to monitor pipe induced vibration non-invasively. The designed system composed of sensor nodes, each of which consists of a sensor board, a microcontroller and the communication was made possible through a wireless transceiver.

A. Hardware Design

The hardware consists of custom made sensor nodes. The decision to develop these custom made nodes was based on unavailability of standardized industrial nodes for the required parameter transmission range needed for intended application. The principal hardware used in the development includes:

- Accelerometer (MMA7361 Model: 1156)
- PIC18F2620 microcontroller
- KYL-500S Mini Size Transceiver
- 9V alkaline battery for mobile operation
- RS232 serial port connector to Serial-USB adapter
- USB to serial cable for connection to PC serial port

➢ **Sensing Unit**

The Accelerometer (MMA7361L IC based) is a sensor that can measure the dynamic acceleration, tilt or periodic vibration of a physical device in x, y and z-axes. It is produced by Sunrom Technology in India. The sensor consumes a low amount of power during operation with 3.3V optimal voltage and current of 400µA.

Figure 2: Accelerometer sensor module [20]

➢ **Processing Unit**

The processing unit uses PIC Microcontroller which is a processor with in-built flash memory, RAM and ADC courtesy of Microchip Electronics in China. It belongs to the sub-family PIC18F2525/2620/4525/4620 of the Microchip PIC family of chips with the following advantages: high computational performance at an economical price and low-energy consumption.

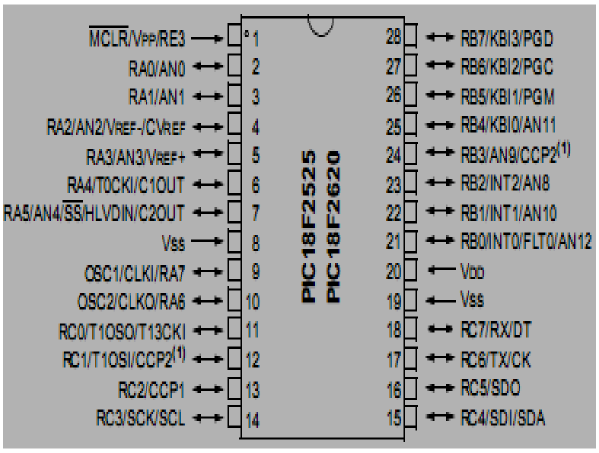

Figure 3: PIN layout of PIC18F2620 [21]

➢ **Transceiver Unit**

The most important requirement for a sensor node is a radio with low energy dissipation during transmission and reception since the system was powered by non-rechargeable batteries for portability. KYL-500S wireless data transceiver module from Shenzhen KYL

Communication Equipment Co. Ltd, in China was chosen. It is a mini-size RF transceiver with line-of-sight radio that operates in the 400-470MHz (433MHz optimal) frequency range and within the ISM (Industrial Medical and Scientific) band covering a distance of about 1km at 1200bps. It is usually used for restricted military space application. With TTL interface, it is widely used for microcontroller based wireless communication and other TTL level port communication systems. Tables 1 and 2 show the Wireless Transceiver Module technical specifications, pin definitions, and connection methods.

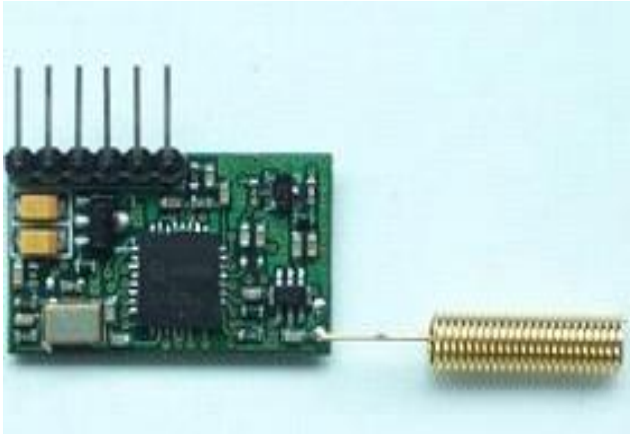

Figure 4: KYL500S RF transceiver [22]

Table 1: Technical Specifications of KYL-500S [22]

Features	KYL-500S Transceiver Module
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	< 20µA
Communication Mode	Half-duplex
Frequency Band	400-470MHz (433MHz)

Table 2: JPI Pin definitions and connection methods

Pin	Signal name	Function	Level	Communication with terminal
1	Gnd	Ground of power supply	-	Ground
2	V_{cc}	Power supply: 5V DC	-	-
3	Rxd/TTL	Data receiving	TTL	Rxd
4	Txd/TLL	Data transmitting	TTL	Txd
5	Slp	Sleep control	-	Sleep signal
6	Self test	Factory testing	-	-

- **Power Unit**

A wireless sensor node needs a steady and reliable power supply source that provides the necessary voltage for sensor information gathering, data processing and transmission. This power can be derived from an AC or DC source. Derivation from AC sources required conversion from AC to DC which may contain ripples. Power derivation from a DC source on the other hand tries to remove all these ambiguities but with the introduction of a life span limitation. The nominal battery voltage for most readily available alkaline AA battery is 1.5V/cell. This voltage is not large enough to power most conventional systems. Portable equipment that need higher voltages use this battery with two or more cells connected in series for higher voltages or cells connected in parallel for higher currents. The sensor, processor and transceiver for this design are intended to be driven by a 5V DC source. Hence, to achieve this aim, a number of cells can be combined in series to produce the required 5V, the number of cells required is given as

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$$N = \frac{V_{source}}{V_{cell}} \quad (1)$$

Where N = number of cells, V_{source} = required source voltage and V_{cell} = Cell Voltage.
Thus, N = 5/1.5 = 3.33
This shows that more than three cells will be required since 3 cells gives 3×1.5V = 4.5V. This is however less than the intended 5V supply and using four cells on the other hand will produce 4×1.5V = 6V, a voltage larger than required and capable of blowing up most 5V specified devices. To overcome this challenge, a DC-DC converter could be used. The dropout voltage for any regulator is equal to the minimum allowable difference between output and input voltages, if the output is to be maintained at the correct level as:

$$V_i = V_o + V_{drop} \quad (2)$$

Where V_i = input voltage, V_o = output voltage and V_{drop} = dropout voltage.

The LM7805 regulator used provide 5V, at a dropout voltage of 2.5V and current of 500mA at the output, the input voltage must not be lower than 5V + 2.5V= 7.5V to run the developed nodes. As stated in (2), the minimum input voltage will be: $V_i = V_o + 2.5V = 5V + 2.5V = 7.5V$. In this paper, 9V alkaline battery was used as the major source of DC supply because it was readily available, high battery capacity, consumes less space and cost effective.

The sensor node was implemented by integrating all the units in the block diagram of Fig. 5. Fig. 6 shows the PCB layout and dimension of the developed sensor node. The developed sensor node before packaging is shown in Fig. 7, and Figs. 8 and 9 show the developed sensor node at packaging and after packaging with battery respectively.

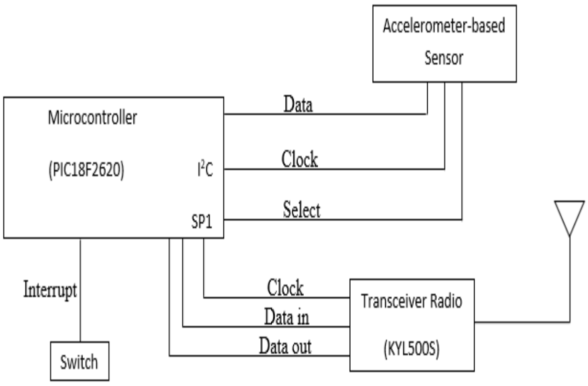

Figure 5: Node Hardware Block Diagram

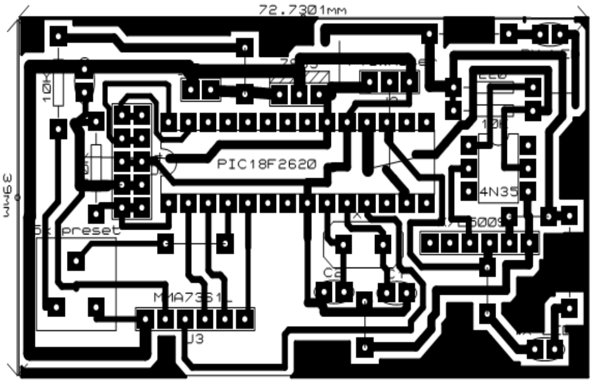

Figure 6: PCB Layout of the developed Node

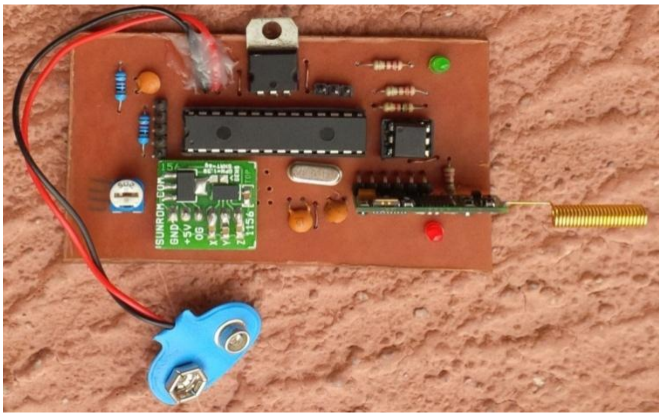

Figure 7: Developed Node before packaging

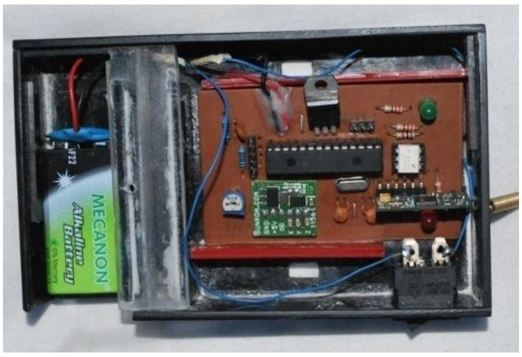

Figure 8: Developed Node at packaging with battery

Figure 9: Developed Node after packaging with battery

A wireless modem was developed by adding a RS232 to TTL converter chip (MAX 233) to a KYL-500S transceiver as shown in Fig. 10. The modem derives its power from the PC's USB port while data was communicated through the RS232 serial port as shown in Fig. 11.

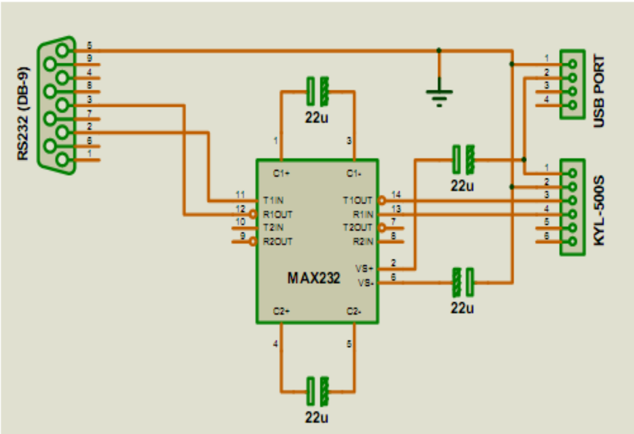

Figure 10: RS232 to TTL Modem Implementation Circuit

Figure 11: RS232 to TTL Modem

B. Software Design

An OS that coordinate the collection and transmission of sensor data was written to tie the various interfaces together and demonstrate a complete working node. The OS defines how data are acquired, processed and communication setup for interconnection. The software code was written in Embedded C programming language.

C. PC-side GUI

The Graphical User Interface (GUI) was developed using Microsoft Visual Studio IDE and written in Visual Basic.NET. VB.Net gives access to the PC's serial communication port. These properties are desirable for users to view the acquired data. Fig. 12 shows the main GUI for user data view and control.

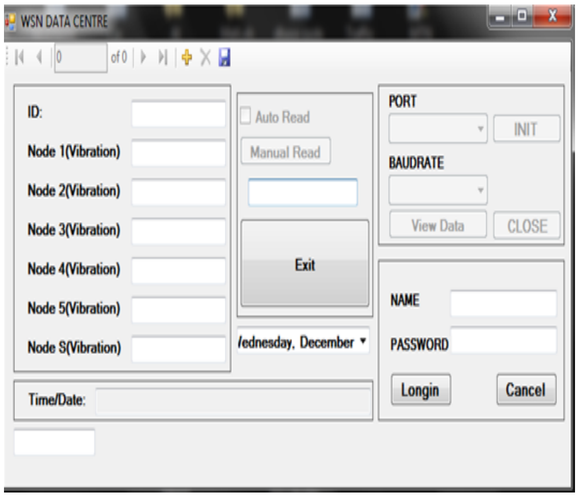

Figure 12: Screen shot of the GUI for data acquisition

IV. RESULTS AND DISCUSSION

The designed sensor nodes were tested in the laboratory using the Shake Table experimental method and then deployed on an experimental testbed for measuring vibration on the pipeline surface to determine the change in acceleration caused by the simulated leakage. Data collated were subsequently recorded at the base station. Shake Table method is an experimental techniques used in simulating vibration by shaking the table and observing the response of the sensor node to vibration in the laboratory before deployment. The nodes were deployed on the testbed for experiment after confirming that it is working according to design specifications. The experiment was done in stages corresponding to various degrees of leakage that were emulated and data were recorded at the Base Station.

For computational capabilities, the developed nodes were tested by transmitting known packets and measuring the response time. These nodes were compared with some of the existing nodes using IEEE 802.15.4 standard with data rate of 20 to 250Kb/s base on the operating frequency and the comparison showed that they are in line with the standard as shown in Table 3. The operating voltage is in line with the IEEE 802.15.4 standard voltage range for Wireless Sensor Networks (3-5V). The power consumed which is the product of operating voltage and active state current is better than some of the existing nodes. This implies that designed node has longer network lifetime when operated in the same mode. Although the execution time and node size (excluding battery size) is slightly higher compared to the existing nodes but it is still in complaint with the set standard. The high cost of production is as a result of shipping cost and exchange rate as at the time of production.

Table 3: Comparison of the designed node with existing nodes using IEEE 802.15.4

Evaluation Parameter	Designed Node	Mica2 mote	Imote2	TelosB Node	Tmote Sky	Ecomote
Operating Voltage	5V	3.3V	4.5V	3V	3.6V	3V
Active state current	40mA	45.1mA	66mA	24.8mA	44mA	36.7mA
Active state power consumption	200mW	148.83mW	297mW	74.4mW	158.4mW	110.1mW
Execution Time	5.71ms	5.5ms	5.1ms	5.43ms	5.5ms	4.0ms
Size (Excluding Battery Pack)	7.27 x 3.9cm	5.8 x3.2cm	3.6 x 4.8cm	6.5 x 3.1cm	7 x 3cm	1.3 x1.8cm
Production cost	$243	$150	$176	$100	$95	$57

V. CONCLUSION

In this paper, development of 3-axes accelerometer sensor nodes was achieved. The sensor nodes were developed by integrating the various hardware units together with an operating system for interconnection. The sensor nodes incorporate Micro-Electromechanical System (MEMS) for measuring vibration on the surface of pipeline to determine the change in acceleration caused by the simulated leakage. The developed sensor nodes has better power consumption when compared with some of the existing ones using IEEE 802.15.4 standard and can also be used for further research activities in Wireless Sensor Network such as structural health monitoring of long span infrastructure and environmental protection.

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