Development of a Remote Physiological Index Monitoring System

Boyu Dang[a], Jeffry Pulcifer-Stump[b] and Tolga Kaya[c]
[abc]Central Michigan University, Mount Pleasant, MI 48858
Email: {[a]dang1b, [b]pulci1ja, [c]kaya2t}@cmich.edu

Abstract

In areas such as medical, military and physical exercise, often physiological indexes like temperature, humidity and motion are of great interest. In work, we developed a Wireless Biomedical Sensor Network (WBSN) which is able to wirelessly monitor temperature, humidity and acceleration of a sensor terminal. The designed a sensor network provides a low power, small size and easy-to-use package solution for physical activities monitoring. The system could be potentially used in hospitals, training camps, gyms, and many other places.

The proposed system is designed to collect data from various sensors and then wirelessly transmits that data to a PC station. The PC station displays the real time sensor data onto a Graphic User Interface (GUI) and uploads the information to a MySQL database, which can be accessed by any device through internet. In the designed system, A PIC16 microcontroller is used as the control unit and low power Zigbee modules are implemented for data transmission. In addition, a MySQL database is developed on the remote server to store the data. The GUI used in this work is developed in Eclipse using Java language. The WBSN is able to sends signal at 250 Kbit/sec. With a 30m transmission range, the system has an overall current consumption about 25mA when powered by a 3.3V power supply. This shows great potential in indoor biomedical monitoring, physical training and military activities applications.

1. Introduction

Physiology studies the functions of living organisms. [1] Physiological indexes have crucial roles in many applications including health care, military activity and physical training. In such activities, monitoring organisms' cardiac rhythm, body temperature, blood pressure and many other indexes are highly helpful. As the need for physiological indexes monitoring increasing, more attention is drawn to developing Biomedical Sensor Networks (BSN), which is a network that connects multiple biosensors monitoring patients' vital physiological indexes. [2]

Contemporary BSN incorporates various small and highly efficient sensors to measure patients' biomedical statues. Kaya, Koser and Culurciello have recently developed Integrated Circuit (IC) temperature sensor on a 0.5 µm silicon-on-sapphire process. [3] As the size keeps shrinking, wire connection within the network seems unrealistic. Consequently wireless technology becomes more and more widely used in the BSN communication, known as Wireless Biomedical Sensor

Networks (WBSN). [4] [5] [6] [7] Based on an analysis performed by Jiagen, Sing-yiu, Chin-Woo and Pravin, the key focus in WBSN study is to decrease the size and the power consumption as well as to improve the accessibility of the system. [8]

The size of the sensor node is often one of the most important concerns in a WBSN. The monitoring system should not affect users' physical activities. This ensures data gathered are valid and represent user's real statues. In Ren, Meng and Chen's work, different implementation methods of sensor node are summarized. Some typical methods are swallowed pill sensors, surface mounting sensors on human body and implantable sensors. Swallowed pill sensors contain small sensors and a wireless transceiver that collects pressure, enzymes, acidity and other parameters of the human body. Surface mounting sensors on human body usually wirelessly collect physiological information such as body temperature. Implantable sensors are implanted into the human body and directly measure patients' biomedical indexes such as glucose level. In any kind of these sensors, the size of the node should be kept to a minimum to reduce any restriction on the physical activity. [2]

Power consumption is also a vital parameter in developing WBSN. In small sensor nodes, implementation wire connection is challenging and hence large power supply is often not available. Consequently, typical sensor nodes are equipped with small batteries or energy harvesters. Common examples are small lithium ion battery and vibrational energy harvester. Such harvesters usually produce power in microwatt range. These limited power source leads to high restrictions on power consumption. Therefore, power efficient design is extremely critical when developing WBSN system. [3]

Aside from the size and power requirements, the easiness of data accessing of the system is another design focus during WBSN development. In Lo, Thiemjarus, King and Yang's work developing body sensor network, they point out the critical role of easiness of monitoring. For example in a hospital, it is helpful if every patient's physiological statues can be screen in a central monitoring room. Frequently when supervisors are away from the monitoring room, remote access from mobile devices is also desired. These functions need special developed software to ensure real time monitoring. [9]

We designed, prototyped and tested a WBSN for remote physiological indexes monitoring. A compact sensor node with low power was designed using high resolution biomedical IC sensors. The system collects the temperature, humidity and motion states of the environment to provide physiological status of an organism. [10] Then the real time data are transmitted and shown on a PC station and as well as stored in a database which is accessible through internet device such as cellphones. The software for the PC station was developed in Eclipse, a software environment, using Java language. MySQL was used to establish the database. Low power Zigbee wireless transmitters were implemented to assure efficient and qualified data transmission. We designed and tested two prototypes and compared them with the Micaz, which is a typical sensor node available in the market according to a survey conducted by Akyildiz, Melodia and Chowdhury. [11]

2. System Design

The WBSN we proposed features high efficiency, small size, and easy access. The system consists of three components: the sensor terminal, the monitoring terminal and the wireless transmitter connecting them. Figure 1 shows the overview of the system.

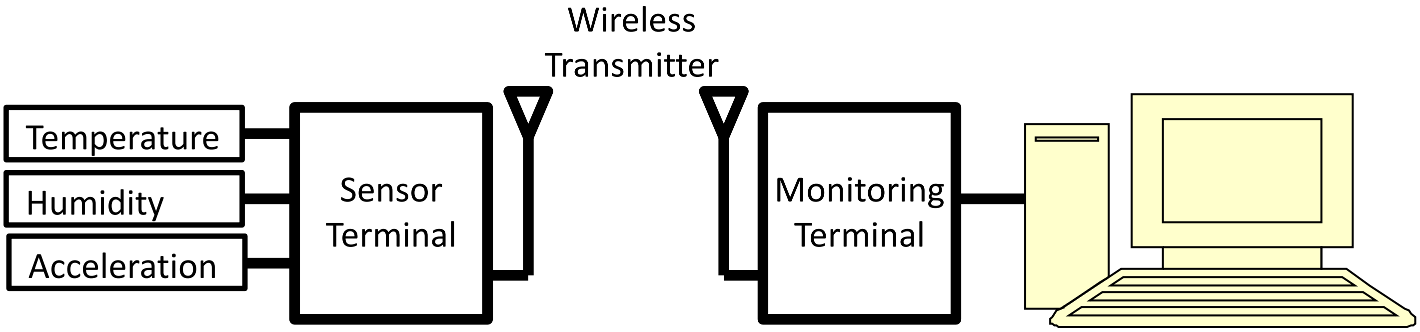


Figure 1. System overview

The sensor terminal collects data from a temperature sensor, a humidity sensor and an accelerometer. It then sends the signal to the wireless transmitter stage. Through the wireless transmitter, the data is fed into the monitoring terminal, where real time data is to users. We prototyped and tested the first design, and then developed a second design based on the testing results. Both designs are shown below.

a) Design I

The first design started with a developed circuit designed by Stephen Sherbrook. [10] This circuit was implemented as the sensor terminal. Then development the entire WBSN began by adding the wireless terminal and the monitoring terminal.

a. Sensor terminal

The sensor terminal is connected to the sensors and collects physiological data from the user. Five analog signals were connected to the system including a temperature sensor, a humidity sensor and an accelerometer(x, y and z). Before the data are fed into the wireless transmitter, they need to be arranged into a single bit digital signal. As shown in Figure 2, an 8-to-1 analog multiplexer was used to combine the data from each sensor into a series analog signal flow. At the same time, V_{DD}, ground and V_{DD} (logic 1, 0 and 1) are filled into the remaining three digits. This provides a starter, or indicator, of one package of data. Then, an 8-bit ADC (analog to digital converter) is used to convert analog signals to digital signals. This generates one package of information stored within eight bytes. This package is then fed into the wireless transmitter. To ensure proper timing for the multiplexer and ADC, a clock system is also developed, which consists of a crystal osillator and a 3 bit counter.

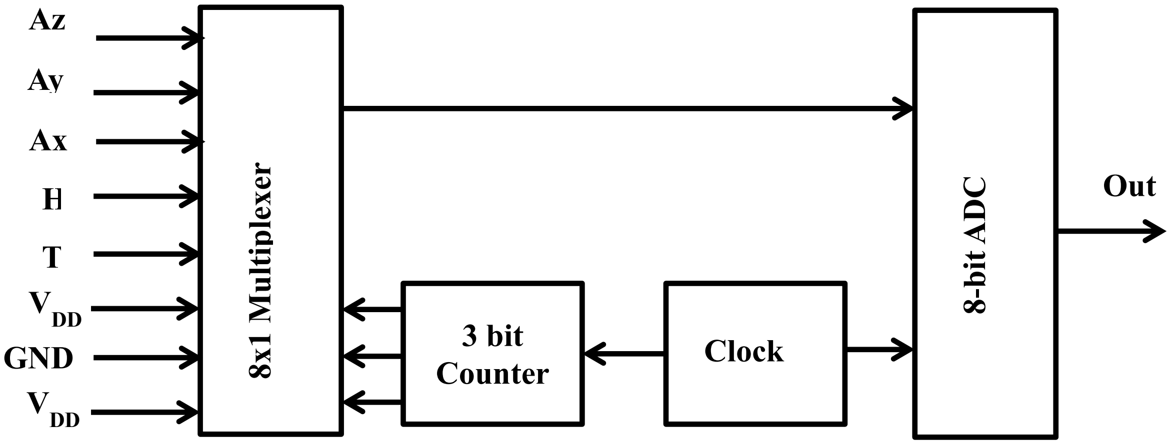


Figure 2. Sensor terminal

b. Wireless transmitter

The wireless transmitter receives data packages from the sensor terminal and feeds them into the monitoring terminal. Considering the balance between the transmission range and the power consumption, an IEEE 802.15.4 wireless transmitter is chosen in the design. IEEE 802.15.4 transmitters feature low power and small size with low rate. These features make it a good candidate for sensor network communication. In this particular design, two Xbee Series 1 modules are used as a transmitter pair in the system. One is connected to the sensor terminal as a signal transmitter, and another is connected to the monitoring terminal as a signal receiver. During transmitting, it achieves a 30m indoor range consuming 45 mA when powered by a 3.3V supply. [12]

c. Monitoring Terminal

The monitoring terminal receives data packages from the wireless transmitter, decodes the signals with a PC station and delivers the information to the user. It provides users an easy access to the instant data from sensor nodes. As shown in Figure 3, firstly the data is fed into an Arduino Uno microcontroller and then to the PC station through UART serial communication. This design allows users to connect multiple sensor nodes to the monitoring station, which is an important feature for network capabilities. When receiving data, the PC decodes the digital signals to physiological data. Then it displays and plots the data for users to monitor these physiological indexes. This is achieved by a program we developed on the PC station.

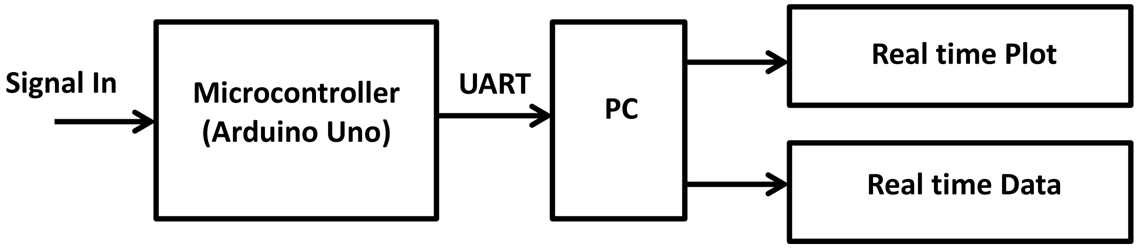
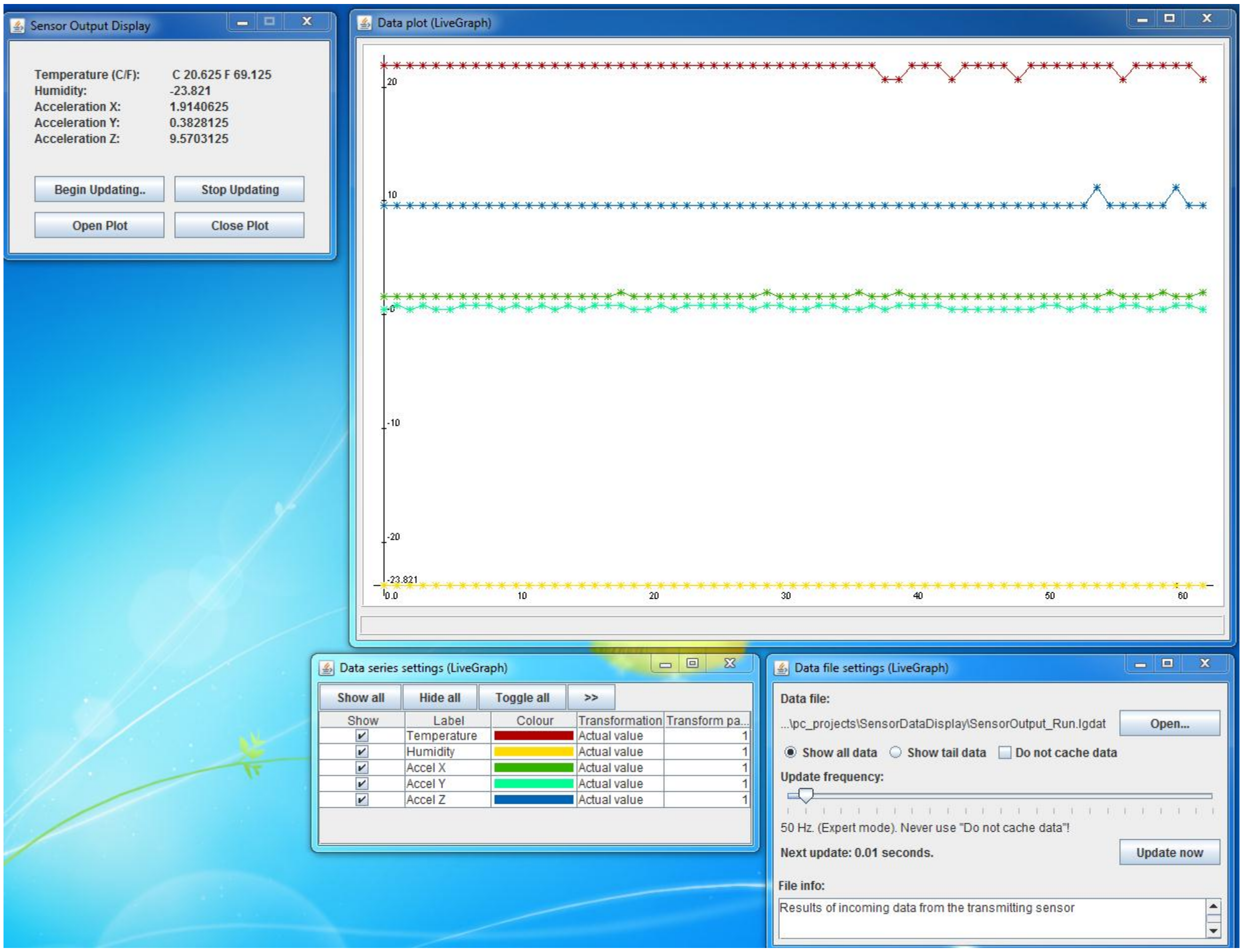


Figure 3. Monitoring terminal

The program we developed on the PC station allows the user to view the real time data on a graphical user interface (GUI). The data displayed contains the temperature, humidity, and accelerometer x, y and z axis in a text format. This interface creates real time plots, which help users to understand the trends. This program is developed using Java as a programming language under Eclipse.

The program first sets up serial communication with the microcontroller using the RXTX library. A filter is then built to process only valid data. This is achieved by only extracting the eight bytes package only after the first full three bytes starter is received, which is embedded in each data package, generated by the sensor terminal. This filter plays an important role since it ensures the program only processes valid data. Then the digital data package is converted to physical reading and transmitted to the GUI. As shown in Figure 4, the GUI uses LiveGraph's API (assisted programming interface) to help generate real time plots.



Temperature (C/F): C 20.625 F 69.125
Humidity: -23.821
Acceleration X: 1.9140625
Acceleration Y: 0.3828125
Acceleration Z: 9.5703125

Show	Label	Colour	Transformation	Transform pa...
☑	Temperature	🟥	Actual value	1
☑	Humidity	🟨	Actual value	1
☑	Accel X	🟩	Actual value	1
☑	Accel Y	🟩	Actual value	1
☑	Accel Z	🟦	Actual value	1

Data file:
...\pc_projects\SensorDataDisplay\SensorOutput_Run.lgdat
● Show all data ○ Show tail data ☐ Do not cache data
Update frequency:
50 Hz. (Expert mode). Never use "Do not cache data"!
Next update: 0.01 seconds.
File info:
Results of incoming data from the transmitting sensor

Figure 4. PC monitoring program

d. Result

Following the first design, a PCB prototype is built. A 38.3mm X 69.4mm PCB board for the sensor terminal combined with an Xbee transmitter is developed and packaged in a box. The circuit is powered by three rechargeable AAA batteries. Figure 5 shows two pictures of the prototype. Based on the testing result, the sensor terminal consumes 49.58mA current when transmitting signals. In an indoor building, the system achieves a 45.11m transmitting range. According to the test results, the PC station decodes the signal accurately and creates plots without noticeable delay.

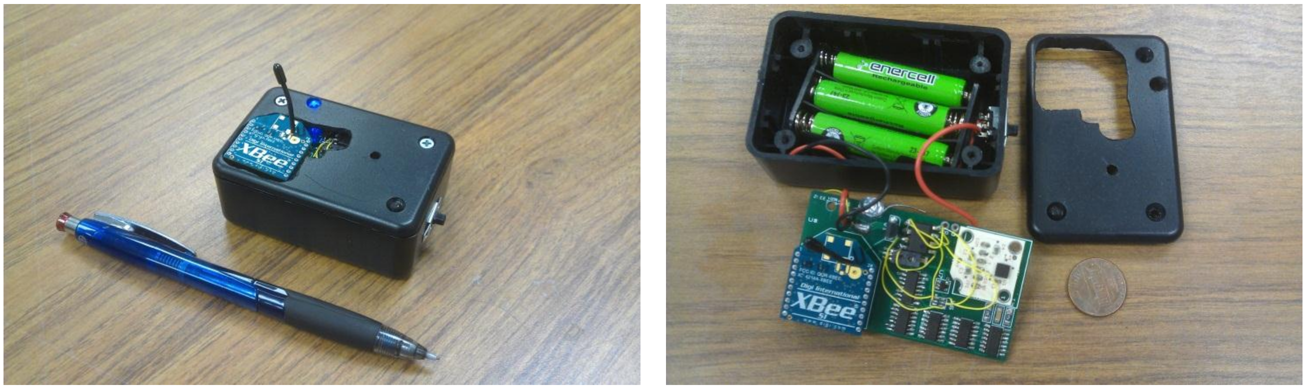


Figure 5. Prototype 1

When reviewing our first design, we found that the sensor terminal could be further optimized to reduce the power consumption as well as the size. High performance yet low power components could be chosen. In addition, due to the limitation on the 8-bit ADC, which provides only 256 counts, the resolution of the sensing signal suffers. These concerns lead to our second design.

b) Design II

For most physiological indexes monitoring applications, the size and the power consumption of the system are most important design aspects. In design II, the system still consists of a sensor terminal, a wireless transmitter and a monitoring terminal; however, to better meet the power and size requirements, several important changes are implemented on the components level.

a. Sensor Terminal

The sensor terminal collects physiological data from the user. Comparing to the first design, a microcontroller was chosen to replace all the discrete components. Taking advantage of the powerful PIC16LF1823 low power microcontroller, this design greatly simplifies the circuit yet enhances the capability of the system. The circuit becomes programmable. The flexibility is also increased so that the circuit gains expansion capability. By using the microcontroller, highly precise digital sensors can be easily incorporated into the system through serial communication. The built-in 10-bit ADC also provides good resolution when using analog sensors. Specifically, the temperature sensor used in this design is ADT7410, and the accelerometer used is ADXL345; both are 16-bit high resolution digital sensors. The humidity sensor selected is HIH-5131, a low voltage analog humidity sensor. As shown in Figure 5, the temperature sensor and the accelerometer send data to the microcontroller through I^2C (inter-integrated circuit) communication. The humidity sensor sends an analog signal to the microcontroller, which is then converted to a 10-bit digital number. The microcontroller arranges each signal into a 2-byte digital number and sends them with a starter to the wireless transmitter.

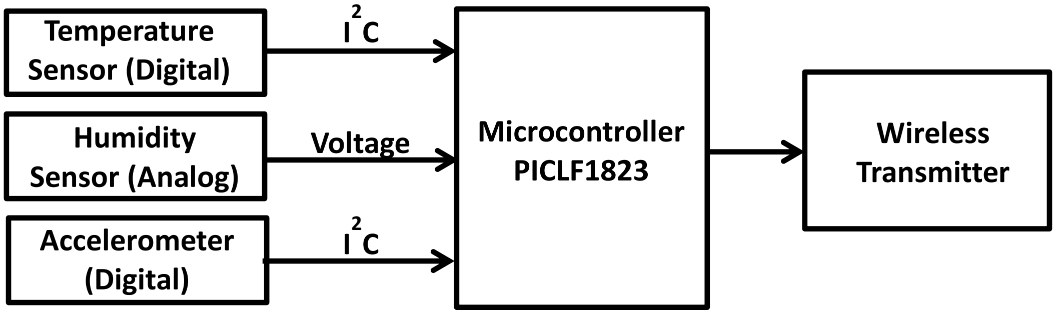


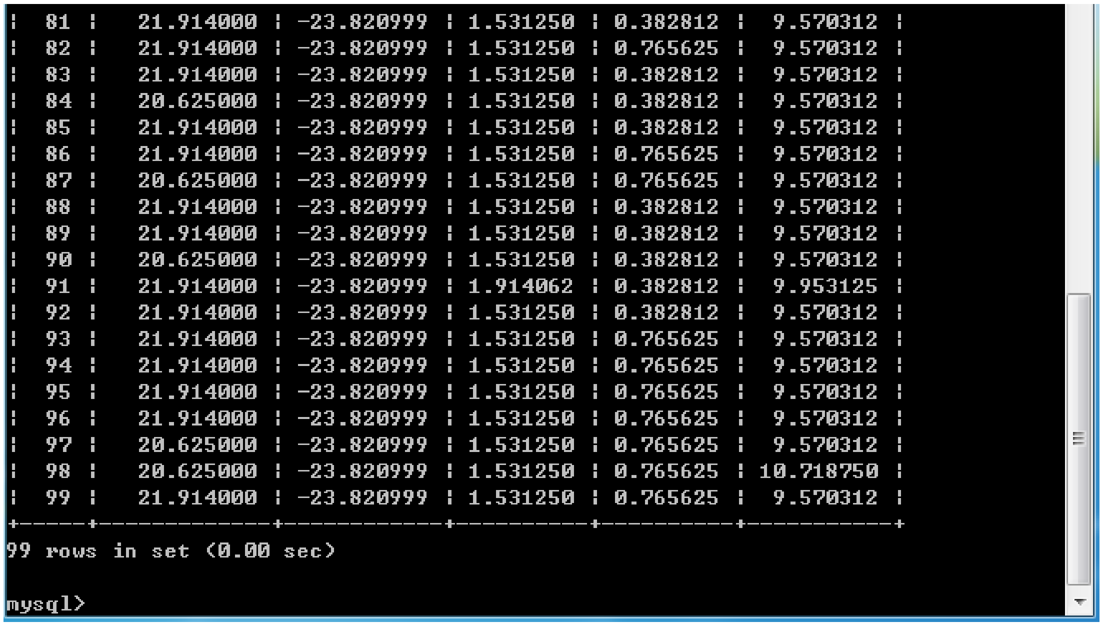
Figure 5. Sensor Terminal 2

b. Wireless transmitter

The wireless transmitter acquires data from the sensor terminal and sends the signal to the monitoring terminal. In the second design a Zigbee wireless transmitter is chosen. It follows IEEE 802.15.4 protocol but features greater efficiency. Specifically, MRF24J40MA wireless transmitter module from Microchip is selected. Similar to the XBee module, a MRF24J40MA pair is implemented in the system: one is connected to the sensor terminal as the transmitter and the other one is connected to the monitoring terminal as the receiver. Serial Peripheral Interface (SPI) protocol is used to communicate between the module and the microcontrollers. MRF24J40MA achieves 30m indoor transmitting range with only 23 mA and 3.3V supplied, which is about half of the power consumption of the Xbee module. [13]

c. Monitor terminal

In addition to the monitor terminal in the design 1, a database feature is added to the system. A MySQL server is used to store the data and it is located in the research lab. After the data enters the PC station, the data is fed into the MySQL database and then become accessible from any device through internet. Figure 6 shows a screen shot of a remote PC accessing. The database contains a table, in which the columns represent the temperature, humidity, x, y, and z axes acceleration respectively.



```
|  81 |    21.914000 | -23.820999 | 1.531250 | 0.382812 |  9.570312 |
|  82 |    21.914000 | -23.820999 | 1.531250 | 0.765625 |  9.570312 |
|  83 |    21.914000 | -23.820999 | 1.531250 | 0.382812 |  9.570312 |
|  84 |    20.625000 | -23.820999 | 1.531250 | 0.382812 |  9.570312 |
|  85 |    21.914000 | -23.820999 | 1.531250 | 0.382812 |  9.570312 |
|  86 |    21.914000 | -23.820999 | 1.531250 | 0.765625 |  9.570312 |
|  87 |    20.625000 | -23.820999 | 1.531250 | 0.765625 |  9.570312 |
|  88 |    21.914000 | -23.820999 | 1.531250 | 0.382812 |  9.570312 |
|  89 |    21.914000 | -23.820999 | 1.531250 | 0.382812 |  9.570312 |
|  90 |    20.625000 | -23.820999 | 1.531250 | 0.382812 |  9.570312 |
|  91 |    21.914000 | -23.820999 | 1.914062 | 0.382812 |  9.953125 |
|  92 |    21.914000 | -23.820999 | 1.531250 | 0.382812 |  9.570312 |
|  93 |    21.914000 | -23.820999 | 1.531250 | 0.765625 |  9.570312 |
|  94 |    21.914000 | -23.820999 | 1.531250 | 0.765625 |  9.570312 |
|  95 |    21.914000 | -23.820999 | 1.531250 | 0.765625 |  9.570312 |
|  96 |    21.914000 | -23.820999 | 1.531250 | 0.765625 |  9.570312 |
|  97 |    20.625000 | -23.820999 | 1.531250 | 0.765625 |  9.570312 |
|  98 |    20.625000 | -23.820999 | 1.531250 | 0.765625 | 10.718750 |
|  99 |    21.914000 | -23.820999 | 1.531250 | 0.765625 |  9.570312 |
+-----+--------------+------------+----------+----------+-----------+
99 rows in set (0.00 sec)

mysql>
```

Figure 6. Database accessing

d. Current progress

The second design is finished and under testing. The sensor terminal is powered by a 100mAH Lithium Coin rechargeable battery, VL-3032. After the testing is completed, a 40mm X 40mm PCB prototype will be developed. Based on estimation, it consumes about 25mA current when transmitting and still keeps a 30m indoor range. This would be a promising result for most indoor medical applications.

c) Analysis

A comparison among design 1, design 2 and a product from the market, Micaz is shown in the Table 1. Overall our design 2 has improved power consumption and size comparing to Micaz. By using efficient Zigbee module, our design has more than 30m transmission rage, which is further than Micaz, but still keeps low current consumption. The system achieves a 250 kbps data rate, which is sufficient for sensor applications. In addition, the use of advanced IC sensors also allows our system keeping a small size as well as low power. The circuit current of design 2 is only 1mA, which is much lower than Micaz 8mA current consumption. The overall size of design 2 is similar to the size of Micaz. But the use of a lithium battery further increases the portability of the sensor node. It has only 3.8mm thickness comparing to 14mm thickness of AA battery used by Micaz. In addition, the design provides software monitoring system that enables users an easy access through internet. For future improvement, a sleep mode could be developed to further optimize the power consumption. The wireless transmitter could be turned off when data transmission is not needed.

Table 1. Comparison among Micaz, the design 1 and the design 2

	Micaz	Design 1	Design 2
Range(indoor)	20-30m	45.11m	30m
Current consumption	17.4mA	49.58mA	25mA
Data Rate	250kbps	100bps without microcontroller	250kbps
Transmitting protocol	Zigbee 2.4G IEEE 802.15.4	IEEE 802.15.4	Zigbee 2.4G IEEE 802.15.4
Transceiver Model	CC2420	XBEE Series 1	MRF24J40MA
Control unit	ATmega128L	Discrete digital logic gates	PIC16LF1823
Circuit Power Consumption	8mA(without Sensors)	5mA(with Sensors)	1mA (with Sensor)
Board Size	58mm X 32mm	70mm X 40 mm	40mm X 40mm
Power supply	2 X AA batteries	3 X AAA batteries	1 X lithium battery

3. Summary

We design, prototyped and tested a WBSN system that can monitor physiological indexes remotely. The system contains a small size, highly efficient wireless sensor node that is able to collect data from multiple biomedical sensors. The PC station could accurately display real time data to users through the Java program developed. In addition, a database feature is implemented that enables users to easily access the data through internet. The low power, small size and easy access to data features make it a promising system for biomedical monitoring, physical training and military activities.

Relevance to engineering education

This work is a research experience outside our course work. Designing and testing such a big system required incorporating knowledge from multiple fields including communication, circuit analysis, microelectronics and digital circuits. It helped to gain a deeper understanding on electrical engineering and engineering in general. The research requires a lot of independent study, in which many problems encountered were beyond our knowledge. In addition, after going through the research experience, scientific approaches to engineering problems were advanced. Typical engineering development process includes problem defining, benchmarking, designing, prototyping and testing was performed throughout this project. This experience helps greatly in other projects and our career development.

Bibliography

[1] C. L. Prosser, Comparative Animal Physiology, Environmental and Metabolic Animal Physiology, Hoboken, NJ: Wiley-Liss. pp. 1-12, 1991.

[2] H. Ren, M. Q.-H. Meng and X. Chen, "Physiological Information Acquisition through Wireless Biomedical Sensor Networks," *International Conference on Information Acquisition,* 3 July 2005.

[3] T. Kaya, H. Koser and E. Culurciello, "Low-voltage temperature sensor for micropower harvesters in silicon-on -sapphire CMOS," *Ekectronics Letters,* p. Vol. 42 No.9, 27 April 2006.

[4] A. Pohl, "A Review of Wireless SAW Sensors March 2000, pp. 317-332.," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Vol. 47, No.2,,* pp. pp. 317-332., March 2000.

[5] M. Michael, "Plug-and –Play Sensors in Wireless Networks," *IEEE Instrumentation & Measurement Magazine,* March 2001.

[6] S. Tseng, C. Tsai, Y. Lai and W. Fang, "A Wireless Biomedical Sensor Network using IEEE802.15.4 LiSSA 2009, pp. 183 - 186.," *Life Science Systems and Applications Workshop,* pp. 183 - 186, 2009.

[7] M. Suster, D. Young and W. Ko, "Micro-Power Wireless Transmitter for MEMS Sensing and Communication Applications," *Microelectromechanical Systems Conference,* pp. 25-28, 2001.

[8] D. Jiagen, C. Sing-Yiu, T. Chin-Woo and V. Pravin, "Singal Processing of Sensor Node Data for Vehicle Detection," *Intelligent Transportation Systems,2004. Proceedings. The 7th International IEEE Conference,* pp. 70-75, October 2004.

[9] B. Lo, S. Thiemjarus, R. King and G. Yang, "BODY SENSOR NETWORK – A WIRELESS SENSOR PLATFORM FOR PERVASIVE HEALTHCARE MONITORING," *The 3rd International Conference on Pervasive Computing,* vol. 13, May 2005.

[10] S. Sherbrook and T. Kaya, "Development of a Physiological Activity Monitoring Platform," *American Society for Engineering Education (ASEE) North Central Section Conference,* 2012.

[11] F. I. Akyildiz, T. Melodia and R. K. Chowdhury, "A survey on wireless multimedia sensor networks," *Computer networks,* vol. 51.4, pp. 921-960, 2007.

[12] D. International, "XBee Multipoint RF Modules," 2007. [Online]. Available: http://www.digi.com/products/wireless-wired-embedded-solutions/zigbee-rf-modules/point-multipoint-rfmodules/xbee-series1-module#docs. [Accessed 04 02 2013].

[13] Microchip, "2.4 GHz IEEE Std. 802.15.4™ RF Transceiver Module," 02 01 2008. [Online]. Available: http://www.microchip.com/wwwproducts/Devices.aspx?dDocName=en535967. [Accessed 04 02 2013].