Development of Wireless Magnetic Field Sensor Node Based on Programmable System on Chip Microcontroller

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ABSTRACT

Wireless magnetic field sensor node is a magnetic field sensor that is integrated with microprocessor, wireless communication system, and a small voltage source. That architecture makes it has improvement capability and functionality in order making sensing process. Magnetic field sensor plays a very important part in many application and embedded system. In a wide range of embedded and wireless sensor application, combining a magnetic filed sensor with programmable system on chip microcontroller and wireless system will build a wireless sensor node. Thus that configuration technology inside offer an attractive and low-cost alternative for many intelligent system applications. This paper presents development of wireless magnetic field sensor node prototype. The node prototype built with the low power and a low noise magnetic field sensor based on the Anisotropic MagnetoResistive (AMR) effect, the Programmable Single on Chip (PSoC), a 2,4 GHz radio frequency as wireless communication, and 2 AAA batteries as 3.3 V DC voltage source. Comparing with a conventional implementation, it is smaller and has lower power and costs. Integration of PSoC microcontroller technology in this design allows the developer to rapidly create solutions for any wireless applications, and has unique capabilities that are not present when designing with other microcontrollers. The simple experiment result show that designed wireless magnetic filed sensor node can acquire experiment data (magnetic fileds), and send data processing to the computer monitor over radio frequency communication. Another important aspect is related to the decrease in energy consumption due to the use of fewer and low-power consumption components.

Keywords
Interface, magnetic sensor, sensor node, wireless sensor node, PSoC

1. INTRODUCTION

Magnetic sensors differ from most other detectors because they do not directly measure the physical property of interest. Magnetic sensors, on the other hand, detect changes, or disturbances, in magnetic fields that have been created or modified, and from them derive information on properties such as direction, presence, rotation, angle, or electrical currents. Although magnetic detectors are somewhat more difficult to use, they do provide accurate and reliable data-without physical contact. Devices that monitor properties such as temperature, pressure, strain, or flow provide an output that directly reports the desired parameter. They have been in use more over 2,000 years. Early applications were for direction finding, or navigation. Today, magnetic sensors are still a primary means of navigation but many more uses have evolved. The technology for sensing magnetic fields has also evolved driven by the need for improved sensitivity, smaller size, and compatibility with electronic systems. The newest types of silicon based magnetic sensors will be emphasized-anisotropic magnetoresistive (AMR) and giant magnetoresistive (GMR) sensors.

At the same time, wireless sensor network (WSN) as a promising has prompted the appearance for the development of new magnetic field sensor applications, and research work. With the increasing growth of magnetic field detection has vastly expanded as industry has utilized a variety of magnetic sensors to detect the presence, strength, or direction of magnetic fields. Wireless magnetic sensor networks offer an attractive, low-cost alternative for traffic surveillance on freeways, at intersections and in parking lots. Magnetometers are also used in a traffic surveillance system to detect the presence and estimate the speed of vehicles near street intersections and parking lots [3]. Using magnetic signatures the system could also classify and re-identify vehicles. Responsive Roadways [6], [9], and MIT Intelligent Transportation System [7] are other examples of transportation applications using wireless magnetic sensors.

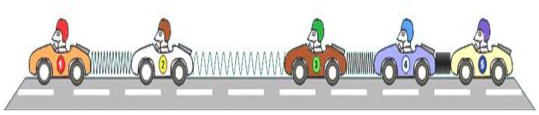


Figure 1: Automatic Car Illustration

This paper proposes development of a wireless magnetic field sensor node prototype. The prototype developed based on Programmable Single on Chip (PSoC), and built using Commercial off-the-Shelf (COTS) components. We also demonstrate promising results through real world experiments performed at laboratory exercises.

The rest of the paper is organized as follows. In Section 2, development the wireless magnetic field sensor node will be discussed, the devices that are used in our implementation described, and then the development program for magnetic field sensors detection is presented. The presented of detailed experimental results is in Section 3, and finally the conclusion is in Section 4.

2. THE DEVELOPMENT OF WIRELESS MAGNETIC FIELD SENSOR NODE

2.1 Architecture

A sensor node is composed of four major blocks: power supply, communication, processing unit, and sensors. The power supply block has the purpose to power the node and usually consists of a battery and a dc-dc converter. The communication block consists of a bidirectional wireless communication channel. Most platforms use a short-range radio. The architecture of wireless magnetic field sensor node proposed is shown in Fig. 2.

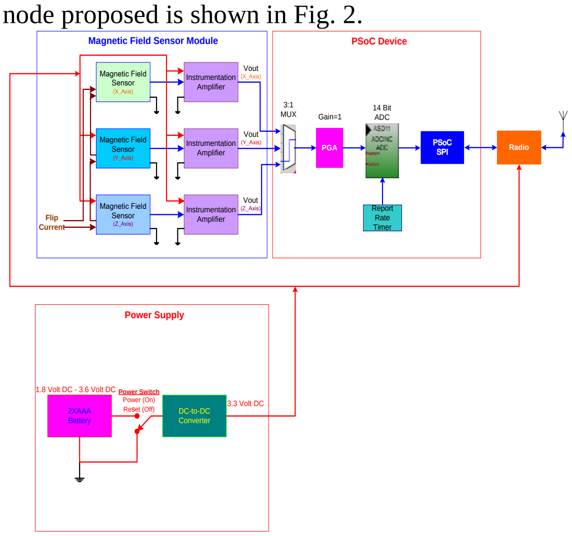


Figure 2: The architecture of wireless magnetic field sensor node

The proposed of wireless magnetic field sensor node is composed of magnetic field sensor module, a processor and radio communication based on the PSoC families, and a power supply module.

2.2 Hardware Description and Development

In the development of wireless magnetic field sensor node, the CY3271 Kit (PSoC FirstTouch Starter Kit with CyFi Low-Power RF) produced and developed by Cypress Semiconductor Corp is used. It allows the developer to rapidly create solutions for any applications. It has unique capabilities that are not present when designing with other microcontrollers. The CY3271 kit also includes a CyFi RF expansion card (FTRF). It contains a PSoC device and a CyFi transceiver (with Radio Frequency (RF) output power up to +20 dBm), a male interface header and a female expansion header.

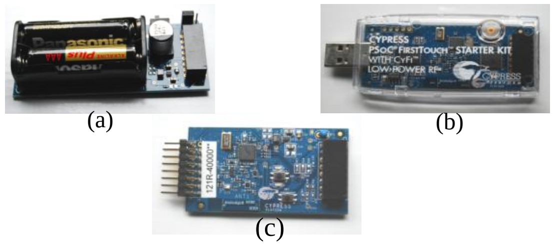


Figure 3: The main hardware of PSoC FirstTouch Starter Kit: (a) Battery module. (b) PC bridge (c) RF expansion module.

Table 1: The PSoC FirstTouch Starter Kit with CyFi Low Power RF has specification.

Operating Voltage	2.4 to 3.6V
Operating temperature	0 to 50°C
Expansion connector can supply	up to 100mA at 3.3VDC
Support for	I2C and up to 5 General purpose IOs
Frequency	2.400 - 2.483 GHz, up to 0 dBm and 2.412 - 2.460 GHz at +20 dBm (PA enabled)
Operating current	Less than 240 mA (Transmit at 20 dBm)
Operating range	up to 1 km or more
Modulation	DSSS, GFSK
Data rates	DSSS data up to 250 kbps, GFSK data rate of 1 Mbps
ADC Resolution	6 to 14 Bit
ADC DataClock	125 kHz to 8 MHz
ADC SampleRate	1.9 sps to 15.6 ksps

2.2.1 The PsoC FirstTouch Starter Kit with CyFi Low-Power RF

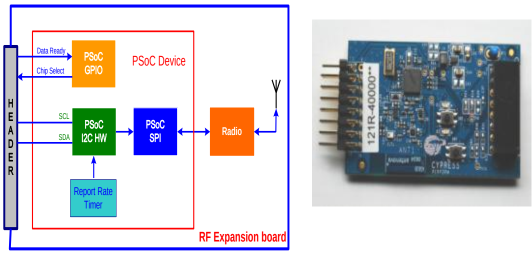
The programmable system on chip microcontroller replaces many micro controller unit (MCU) based system components with a single chip, programmable device. A single PSoC microcontroller offers a fast core, flash program memory, and SRAM data memory with configurable analog and digital peripheral blocks in a range of convenience pin-outs and memory sizes. The driving force behind this innovative programmable system on a chip comes from user configurability of analog and digital arrays, the PSoC blocks.
The CY3271 Kit (PSoC FirstTouch Starter Kit with CyFi Low-Power RF) allows the developer to rapidly create solutions. The CY3271 kit hardware contains a PC Bridge (FTPC) and this acts as a bridge between all boards in the CY3271 system and the PC using a USB-to-I^{2}C interface. It contains a CyFi low-power RF transceiver (with RF output power up to +20 dBm). CyFi is an ultra-reliable 2.4-GHz RF solution optimized for embedded control and uses an

easy to use star network protocol with active power management. It employs Direct Sequence Spread Spectrum (DSSS) and is a PSoC-based solution. CyFi can be used in a wide range of embedded and wireless solutions. When this is combined with an onboard PSoC, it acts as the Hub in CyFi wireless networks.

2.2.2. CyFi RF Expansion Card

Sensor nodes must communicate among themselves and also to a base station using a wireless communication channel. We explore optical and radio frequency (RF) channels. The sensor node communication channel needs to be bidirectional to support different operating modes, to be energy-efficient, allows setting the output power, and have relatively slow date rate. The range can vary from tens to about a hundred meters magnitude.

The CY3271 kit also includes a CyFi RF expansion card (FTRF) and it is shown in Fig 3. It contains a PSoC device and a CyFi transceiver (with RF output power up to +20 dBm), a male interface header and a female expansion header.



(a) (b)

Figure 4: CyFi RF Expansion Card: (a) Diagram block. (b) Board.

The expansion card serves the following functions:

- Combined with one of the power packs made available with the CY3271 CyFi development kit, it can act as a standalone CyFi wireless node with an on board thermistor that can be used for temperature measurements.
- The male interface header features an Inter-Integrated Circuit (I^{2}C) interface and unused General Purpose Input/Output (GPIO). This enables you to use it as a CyFi low-power RF module for prototyping in your own system.
- With its female expansion header, it can be used as a CyFi low-power module to add wireless connectivity to multifunction expansion boards that are connected to it.

The pin out of the female expansion header is shown in Figure 5.

16	14	12	10	8	6	4	2
P0.2	P0.3	P0.4					
P0.5	P0.6					GND	3.3V
15	13	11	9	7	5	3	1

Figure 5: Pin configuration of female expansion header

2.2.3 Magnetic Field Sensor Module

The sensing unit is composed of a group of sensors, which are devices that produce electrical signals to a change in a physical condition. In this project discusses and uses the **Anisotropic Magnetoresistive** (AMR) as magnetic sensor. William Thompson, later Lord Kelvin, first observed the magnetoresistive effect in ferromagnetic metals in 1856. His discovery had to wait more than 100 years before thin film technology could make it into a practical sensor.

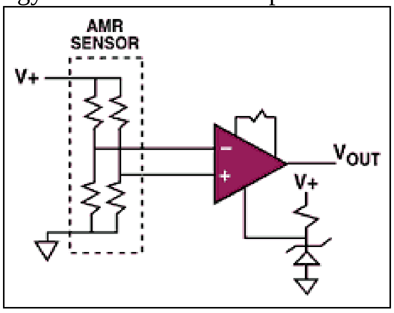


Figure 6: Anisotropic Magnetoresistive Sensor

AMR sensors are well suited to measuring both linear and angular position and displacement in the Earth's magnetic field. In a typical configuration, four of these resistors are connected in a Wheatstone bridge to permit measurement of both field magnitude and direction along a single axis. The bandwidth is usually in the 1-5 MHz range. The reaction of the magnetoresistive effect is very fast and not limited by coils or oscillating frequencies.

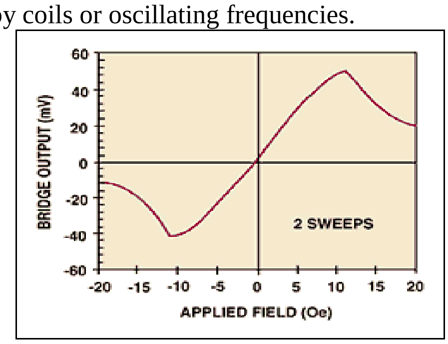
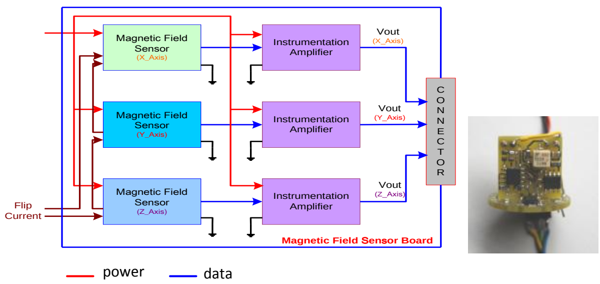


Figure 7: Output of Anisotropic Magnetoresistive Sensors.

AMR sensors offer high sensitivity, small size, and noise immunity. AMR sensors available today do an excellent job of sensing magnetic fields within the Earth's field below 1 gauss. These sensors are used in applications for detecting

ferrous objects such as planes, train, and automobiles that disturb the Earth's field. Magnetic sensors can be classified according to low-, medium-, and high-field sensing range. Devices that detect magnetic fields <1 µG (microgauss) are considered low-field sensors; those with a range of 1 µG to 10 G are Earth's field sensors; and detectors that sense fields >10 G are referred to as bias magnet field sensors.
This application uses the AFF755B is a low noise magnetic field sensor based on the Anisotropic MagnetoResistive (AMR) effect, and it is shown in Fig 8. The magnetic field sensor module is consists of the serial connection of 3 sensors for a 3-axis measurement with typical supply voltages available in battery powered devices. The sensor contains a Wheatstone bridge including a flip coil for offset correction. This measurement principle also reduces the temperature coefficient of the offset by a factor of 100. This sensor is ideally suited for the detection of weak magnetic fields (< 20 µG resp. < 2 nT) including the earth magnetic field. The voltage necessary for driving the required flip-current of 150 mA is smaller than 0.5 V.



(a) (b)

Figure 8: Magnetic Field Sensor Module: (a) Block diagram. (b) Sensor board.

Table 2: Specification of magnetic field sensor module.

Operating Voltage	3VDC
Resolution	2nT
Output Voltage	11.5 mV/V/mT
Flipping current	150mA
Gain	100
Sensitivity	11.5mV/V/mT

For the circuit above, the following equation holds as below:

Vout=1/2Vdd + Gain x SensorSensitifity x Vdd x B (1)

where:

Vout: output voltage of magnetic field sensor module (Vx_Axis, Vy_Axis, Vz_Axis) (Volt)
Vdd: supply voltage of magnetic field sensor module (Volt)
Gain: Gain of Instrument Amplifier of magnetic field sensor module
SensorSensitifity: sensitivity of magnetic field sensor(mV/V/mT)
B: Magnetic Field (nTesla)

Solving for **B** results in:

B= (Vout-(1/2Vdd))/(Gain x SensorSensitivity x Vdd) (2)

2.2.4 Interfacing with CyFi RF Expansion Card

The connection of magnetic field sensor module to the CyFi RF expansion card is shown in Fig 9, and described as follow. The X-Axis output of magnetic field sensor module connect to the port P0.2, the Y-Axis output of magnetic field sensor module connect to the port P0.4, and then the Z-Axis output of magnetic field sensor module connect to the port P0.6 on the female expansion header. The negative (–) supply of magnetic field sensor connect to GND, and the positive (+) supply of magnetic field sensor connect to 3.3 V.

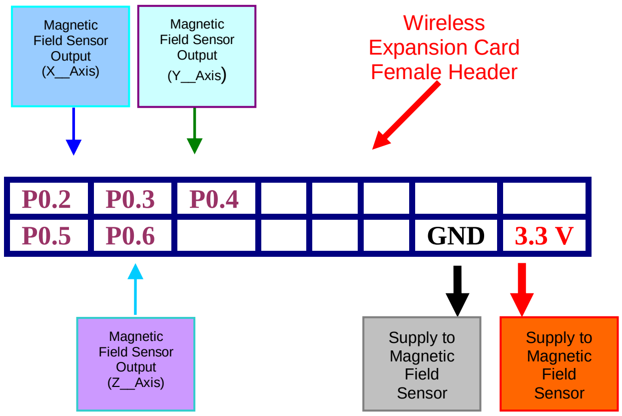
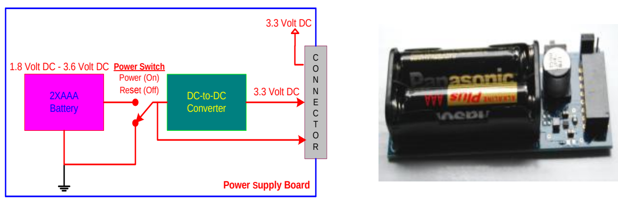


Figure 9: Connection Scheme between Magnetic Field Sensor module and Wireless Expansion Card Female header.

2.2.5 Power supply module

The power supply block has the purpose to supply the energy to the node, and usually consists of a battery, but sometimes a DC-DC converter is used to boost the battery voltage. A voltage regulator can be added, whose purpose is to maintain the output voltage at a fixed value. The power supply module that use in this project is shown in Fig 10. It supplies 3.3 V DC to other modules in wireless magnetic field sensor node. The energy source of this module is 2 AAA batteries.



(a) (b)

Figure 10: Power supply module: (a) Block diagram. (b) Power supply board.

2.3 Software Development

All tasks in the wireless magnetic field sensor node will be translated using PSoC Designer 5.0 in chip level design mode. PSoC Designer is the integrated development environment (IDE) where all PSoC projects are created, edited, built, and debugged.

In generally, the main task is described as follow. The voltages on the X, Y, and Z axes of the Magnetic Field sensor module are measured directly with a single 14-bit Analogue Digital Converter (ADC) by multiplexing the input ports. The magnetic field sensor module has an internal gain and thus Programmable Gain Amplifier (PGA) set by 1. The block diagram of the system is shown in Fig 11.

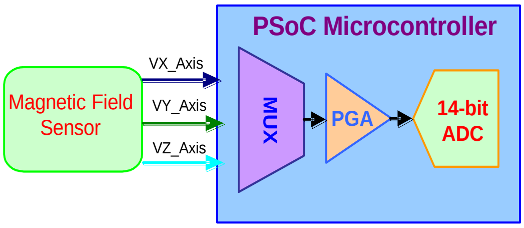
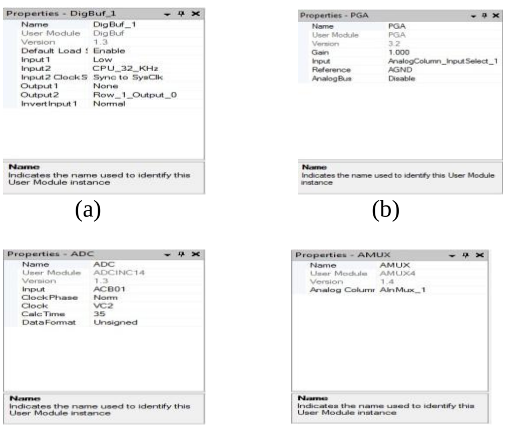


Figure 11: System Block Diagram

The output of the ADC block can be processed using digital blocks, and transmitted using the SPI digital communication modules available in this chip. The voltages on each axis after converting to digital data are stored in the I^2C RAM buffer. These values are transferred over the I^2C Bridge and displayed using the Sense and Control Dashboard (SCD) in the host Personal Computer (PC).

2.3.1 User Modules and Routing

The User Modules required in this design to read magnetic field are as follows:



(a) (b)

(c) (d)

Figure 12: (a) Buffer User Module, (b) PGA User Module, (c) ADC User Module, (d) AMUX User Module.

The routing in PSoC Designer shows the user modules are place in the analog blocks is shown in Fig 13. The multiplexed input is fed through a PGA User Module. This voltage is then buffered and passed onto the ADC user module. A 14-bit digital representation is then used to represent the voltages on X-Axis, Y-Axis, and Z-Axis of magnetic field sensor module. The user module Analogue Multiplexer (AMUX) selects which voltage is been converted. For each axis connection (X-Axis, Y-Axis, and Z-Axis of magnetic field sensor circuit), the ADC input is sampled and the ADC counts are converted to the voltage equivalent value, and uses this data to calculate the actual magnetic field.

Figure 13: Analog Blocks used in Design.

2.3.2 Device Template

In order for the information received by the Hub to be displayed using the Sense and Control Dashboard (SCD), it is necessary to create a device template for the application. The device template informs the SCD of how many bytes are expected, what type of variables are used, text on the x and y axis etc. The device template describes the size of magnetic field value variables (iBx, iBy, iBz) are 4 bytes (Float32). The starting bit of iBx is bit 0 and nTelsa is the label on the y axis as unit of magnetic field on X-Axis. It indicates that no scaling factor is used. There is also an iBy variable. The starting bit is bit 32, and iBy is the label on the y axis as unit of magnetic field on Y-Axis. It also indicates that no scaling factor is used. The next variable is iBz variable. The starting bit is bit 32, and iBz is the label on the y axis as unit of magnetic field on Z-Axis. It also indicates that no scaling factor is used.

The wireless magnetic field sensor node prototype implemented, as show in Fig 14.

Figure 14: Wireless magnetic field sensor node.

3. EXPERIMENTAL

3.1 Experiment setup

General steps to be followed while using the wireless magnetic field measurement system expansion board are as follows:

1. Connect the RF Expansion Board to the PC Bridge.
2. Insert the PC Bridge into any free USB port of the PC/laptop.
3. Open PSoC Programmer, and load the appropriate .hex file from the Hex Files folder located on the computer.
4. Set **Device Family** to 27x43, **Device** to CY8C27443 and click **Program**.
5. Disconnect the RF Expansion Board from the PC Bridge, leaving the Bridge connected to the computer.
6. Attach the magnetic field sensor and the RF Expansion board to the battery pack as shown in Fig. 14.
7. Switch on power to the RF Expansion Board by sliding the ON/OFF switch on the battery pack towards the RF Expansion Board.
8. Open the SCD software.
9. Place the PC Bridge in Bind mode using the SCD software.
   - Click **Manage** to set up the sensor network.
   - In the Manage Network screen, click **Add** to add a new node.

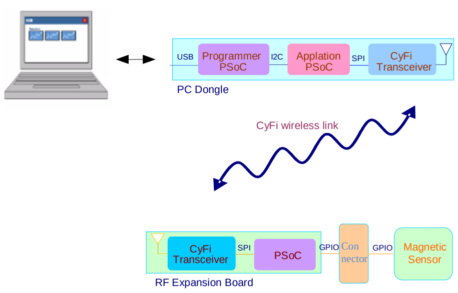


Figure 15: Configuration experiment setup

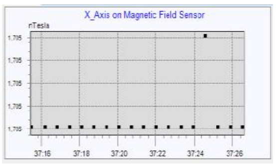
   - On the Node Binding screen, click **Begin Binding**.
   - After activating this function, you have approximately 20 seconds to press the bind button on the RF Expansion Board.
   - Verify the success of the bind.
10. Click **Next** to go to the Node Binding (2 of 2) window. In this window, assign a name to the newly bound node. On the Node Configuration pane, click **Load Node configuration from a file** and load the appropriate device template file from the Configuration Files folder located on the computer.
11. Select graphical or textual mode of data display. The data is displayed in graphical or text format on the SCD screen.
12. Click **Apply** on all successive dialog boxes until the main SCD window reappears

3.2 Experiment Environment

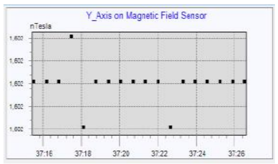
A weak magnetic fields magnet (app: 1.4 – 1.6 nT) is placed close to the magnetic field sensor module (app: 1.5 – 2 cm). The configuration is as shown in Fig.15. The wireless magnetic field system using the PSoC FirstTouch starter kit was programmed to acquire data from the magnetic field sensor every second and to send the data to a PC bridge. The PC Bridge was also attached to a Laptop running SCD. At the time measurement, a weak magnetic fields magnet was moved in the directions: X-axis, Y-axis, and Z-axis respectively.

3.3. Result

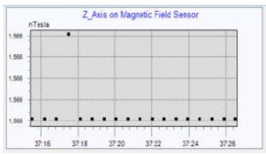
The received data appear on 3 windows on the SCD. The first window is the magnetic field on X-axis, second window is the magnetic field on Y-axis, and the next is the magnetic field on Z-axis. The graphs of measurement result are show in Fig. 16 as an example.



(a)



(b)



(c)

Figure 16: (a) X-Axis Sensor and Control Dashboard Windows. (b) Y-Axis Sensor and Control Dashboard Windows. (c) Z-Axis Sensor and Control Dashboard Windows.

4. CONCLUSIONS

Wireless magnetic field sensor node presents fascinating challenges for the application of distributed system. It also provides accurate and reliable data-without physical contact. In this work, a wireless magnetic field sensor node prototype has been developed and deployed.

The result of simple experiment show magnetic fields from a small magnetic field source can be read well by AMR sensor and transmitting the collecting data to the monitoring computer by wireless. The monitoring computer display the history and trends magnetic field data on the interactive Graphical User Interface (GUI) but the resolution and data rate should be improvement to find smoother graphic.

This work can inspire the user create another sensor board by self, and then connects it to the PSoC module (RF Expansion Card), which both supplies the board with power, and enables starting logging and transmitting sensor data (from the specific sensor) to a PC/laptop using CyFi Low-Power RF. Furthermore, RF Expansion Card can be re-used as a wireless module for development a prototyping purpose, making simple wireless monitoring and data acquisition for various appropriate applications.

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