Design and Analysis of a Wireless Temperature Monitoring System

Nor Alina Khairi[1], Asral Bahari Jambek[2] and Teoh Wei Boon[3] , Uda Hashim[4]
[1,2,3]School of Microelectronic Engineering, Universiti Malaysia Perlis, Malaysia.
[4]Institute of Nanoelectronic Engineering, Universiti Malaysia Perlis
[1]noralina89@gmail.com, [2]asral@unimap.edu.my , [3]teohweiboon@gmail.com, [4]uda@unimap.edu.my

***Abstract* – This paper discusses the design of a wireless temperature monitoring system for industrial application. The temperature sensor detects the surrounding temperature before transmitting it to a receiver. At the receiver, the temperature will be displayed on a liquid crystal display and portable computers for ease of monitoring. This paper highlights the design and verification method to ensure the accuracy of the sensing and transmitting of data. In order to ensure the robustness of the system, the device has been tested in various environment and obstacle. The result shows that the device can accurately sense and monitor temperature with excellent accuracy.**

Keywords: Temperature sensor; Wireless; Remote System; Sensor Monitoring.

I. INTRODUCTION

Wireless devices will be important in future monitoring applications such as in automobiles [1], machines, home automation [2] and buildings [3], for example, industrial machinery and equipment required to be placed in operating condition. In order to maintain and monitor the machine at a specific temperature, information needs to be gathered from a temperature sensor device. By using an effective temperature monitoring system, temperature values can be recorded in real time or displayed on a monitor. These recorded temperatures can be used further to analyse the performance of the machine during a specific period of time.

There are many challenges when designing wireless sensor devices such as the accuracy of measured data and data loss during transmission. Building a wireless temperature monitoring system will be expensive, especially when continuous real time monitoring is needed. Typically, a wireless sensor communication system can be designed using Zigbee, Sensor Tag [4] or Bluetooth devices to transmit and receive the data.

The rest of the paper will be discussed as follows. First, the existing technique to design the wireless monitoring system will be discussed in Section II. The method to design the wireless temperature monitoring system will then be discussed in Section III. Results obtained from the experiment will be discussed in Section IV. Finally, Section V will conclude the paper.

II. LITERATURE

The current market is moving toward wireless technology due to its convenience compared to wired-based systems [5]. This section will review existing methods for designing wireless temperature monitoring systems.

Reference [6] discusses the application of temperature data acquisition and monitoring for a sensor network using ZigBee. This work uses a thermocouple as a sensor input, where it is connected to a cold junction compensator amplifier. After passing through an amplifier, the signal is fed into an analog-to-digital converter (ADC) port at the ZigBee module. The temperature data will be transmitted using Zigbee protocol to a personal computer (PC) at a rate of four samplings per sec.

A wireless sensor network for health monitoring is discussed in [7]. This system uses a network and its subsystems to transmit data to the base server before transmitting it to a PDA or personal computer. [8] discusses remote monitoring for agriculture using a wireless sensor and short message service (SMS). This system sends SMS messages to the farmer when the farm's temperature is either too high or too low. The objective of [9] is to design a health monitoring system for a wireless body area network (WBAN). In this project, ActiS sensors are used to monitor a heart rate signal before transmitting the signal to a personal server through a wireless local area network (WAN).

The wireless temperature monitoring system discussed in [10] uses an active RFID-based system to collect data from locations worldwide. In this project, the sensor detects the temperature and triggers the alarm when the temperature is too high or too low and sends the data wirelessly to the main server.

While most of these devices have high data acquisition rates, they are expensive. In this work, a low cost temperature sensor transmitter and receiver were built. To prevent data loss during transmission, bit checking method was implemented to ensure high measurement accuracy.

III. METHODOLOGY

Fig. 1 shows the overall block diagram of the low cost wireless temperature sensor system. The main components used in this work consist of a microcontroller, an analog to digital converter (ADC) temperature sensor, a transceiver, a receiver, an encoder and a decoder. First, the temperature sensor will detect the room temperature and input the data to an ADC. The ADC will convert the analog signal to digital form for the microcontroller to process the data. Then the processed data will be sent to an encoder before it is transmitted. The receiver will receive the encoded data and pass it to the decoder to recover the original data. The microcontroller will process the data before displaying the data on a laptop computer or LCD.

The main wireless components are the transmitter (TX433) and receiver (RX433). For the microcontroller, P89V51RD2 is chosen, which falls under the 8051 microcontroller family. This microcontroller has four 8-bit input and output ports, which can support various input and output configurations. Table 1 shows the summary of the key features for the microcontroller [11].

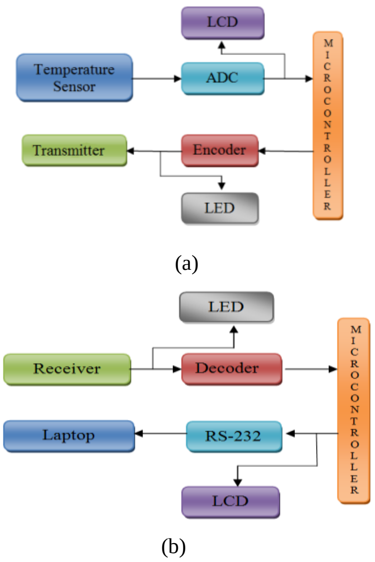
In this work, two microcontroller are used as a transmitter and receiver. The main function of the microcontroller in the transmitter module is to convert the 8-bit data from ADC to 4-bit width. This allows the data to be encoded by the encoder. For ease of debugging, the encoder output is also connected to LCD to display the current temperature value that is being transmitted. The second microcontroller processes the received data and displays the temperature value onto a portable computer or LCD. This work uses the LM35 from National Semiconductor as the temperature sensor. The advantage of this sensor is it produces output voltage that is proportional to temperature (Celsius). Furthermore, it has a large temperature detection range from −55 to +150°C [12]. The radio frequency transmitter is connected to a power supply, an oscillator, a modulator and amplifiers for radio frequency transmission. The radio frequency transmitter uses a frequency-modulated crystal to modulate the signal information onto the carrier frequency, which will be transmitted through the air to the receiver. The transmitter is small and has a low power requirement, but can cover a large distance, a maximum of 50 meters. Fig. 2 shows the overall schematic diagram for the transmitter module.

The software development in this project is divided into 2 parts. These are assembly programming language for temperature sensor data processing and Visual Basic programming software to display the value of temperature on a computer. An assembly language is one of the important programs that had been use in this project. To ensure the received data is accurate, a simple data checking method is used as follows. First, before the temperature value is transmitted, the microcontroller divides the 8 bits of data into 4 pair as shown in Table 2. The encoder will use the original 2 bits and will add an additional 2 bits as checker bit. The receiver will recover the data using the reverse procedure. Table 3 shows the example of a transmitting temperature of 31 °C by using the method mentioned.

IV. Result and Discussion

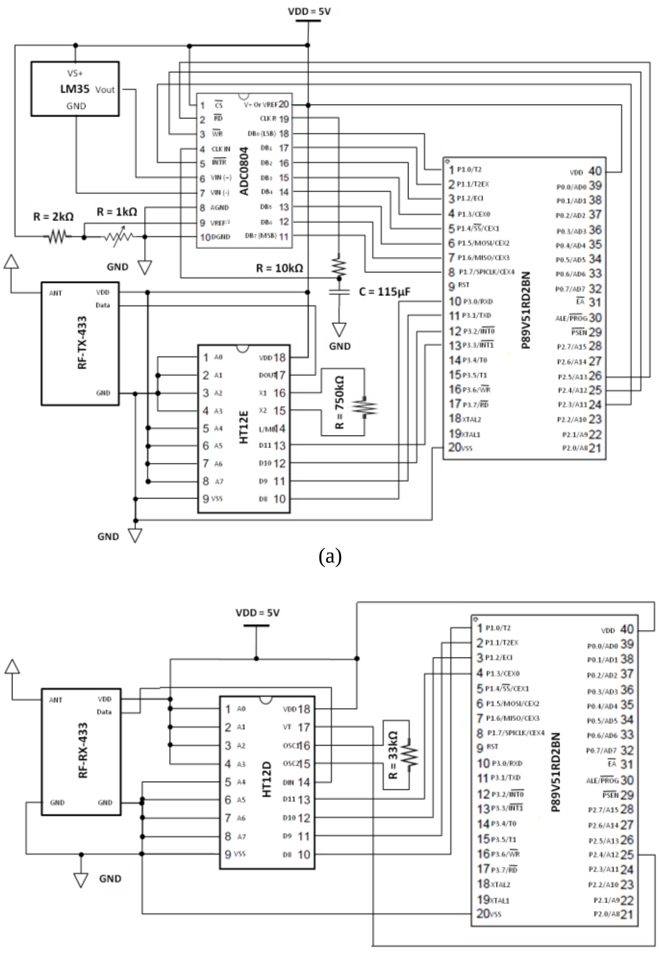
The following section discusses the experiment done to verify the wireless temperature sensor functionality. First, the results of the temperature sensor calibration will be discussed. Next, the verification on ADC functionality will be highlighted. The result of the radio frequency transmission accuracy will be presented next. Finally, the overall system performance will be discussed.

Fig. 3 shows the result of output voltage at various temperatures for the temperature sensor. Based on the room temperature, at 28 °C, the output voltage is 284mv. The collected data show every 1 °C in temperature change equal to 10 mV change output voltage.



(a) (b)

Fig. 1: Block diagram of the wireless temperature monitoring system.



(a) (b)

Fig. 2: Overall schematic diagram for the wireless temperature sensor system (a) transmitter module (b) receiver module.

TABLE 1
SUMMARY OF KEY FEATURES FOR P89V51RD2 [11].

Key Features	P89V51RD2
Operating Frequency	DC 0-40 MHz
Flash Program Memory	64K
Data Memory	1024 bytes
I/O Ports	4 (8-bit I/O ports with 3 high-current Port 1 pins (16 mA each)
Timers	3 (16-bit)
Interrupt	Eight interrupt sources with four priority levels
Serial Communications	SPI and enhanced UART
Power Modes	Power-down mode with external interrupt wake-upand Idle mode
Capture/Compare functions	PCA with PWM

TABLE 2
8 BITS BINARY NUMBER AND ITS RESPECTIVE CHECKER BIT.

	MSB						LSB	
Bit position	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Binary representation for 31°C	0	0	0	1	1	1	1	1
Checker bit	11		10		01		00	

TABLE 3
BIT-CHECKING METHOD TO TRANSMIT BINARY DATA.

Checker Bit	Binary representation for 31°C	Checker bit and original binary bit
00	*11(LSB)*	*00* **11**
01	*11*	*01***11**
10	*01*	*10***01**
11	*00(MSB)*	*11***00**

To verify the ADC function, the temperature is varied to generate various output voltages at the ADC input. Table 4 shows the result of converting analog input to digital output voltage at the various input temperatures. The ADC will producing 8 bits, a number that represents the equivalent temperature value.

The data transmission circuitry module consists of an encoder, transmitter, receiver and decoder. Four LEDs are connected at both the encoder and decoder to allow visual inspection of the transmitted data. Table 5 shows the result of data transmission accuracy. From the table, the data transmission module achieves 98.3% accuracy.

Table 6, 7 and 8 show the result of various measurements done using the wireless temperature sensor at various temperature conditions, distances and obstacles. In this experiment, data are transmitted continuously for one minute. The data received at the receiver are monitored for any errors. The experiment is done in three conditions; open air, two different rooms and two different houses.

From Table 6, only two errors occur within 1 minute when transmitting the data in open air for a distance of 5m. The errors occur due to insufficient current supply to the devices. This problem has been solved by using an addition battery in the system.

After adding an additional battery, the device shows no error as shown in Table 7 and 8. The table shows that once the wireless device obtained enough current from the battery, the device can work well with various distances and obstacles. From the table, 100% accuracy is achieved for an environment with obstacles.

Fig. 4 (a) and (b) show the full implementation for the transmitter and receiver module, respectively. Each of the components in the figure is labelled as shown in Table 9 and 10.

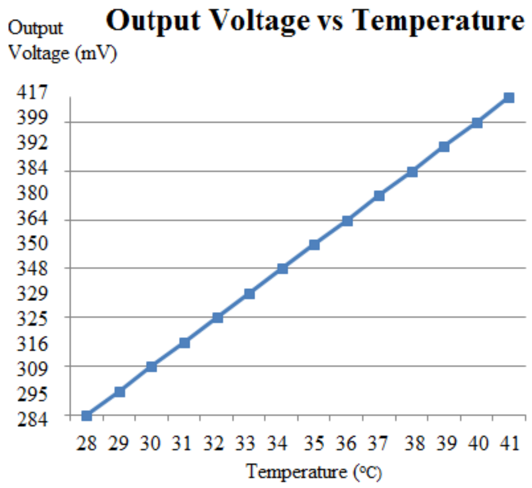


Fig. 3: Output voltage temperature sensor versus temperature reading.

TABLE 4
DIGITAL OUTPUT VOLTAGE RESULTS

Vin (mV)	Temperature (Celsius)	LED at Pin11 - 18
223	22	00010110
309	30	00011110
348	34	00100010
384	38	00100110
399	40	00101000

TABLE 5
COMPARISON BETWEEN ENCODER INPUT AND DECODER OUTPUT

Pattern send for encoder	No of data transfer	No of correct data received	No of wrong data received
0010	20	20	0
1111	20	20	0
0011	20	19	1
1100	20	20	0
0101	20	20	0
1010	20	19	1
Total data	120	118	2

TABLE 6
RESULTS OBTAINED FROM OPEN AIR (NO OBSTACLE)

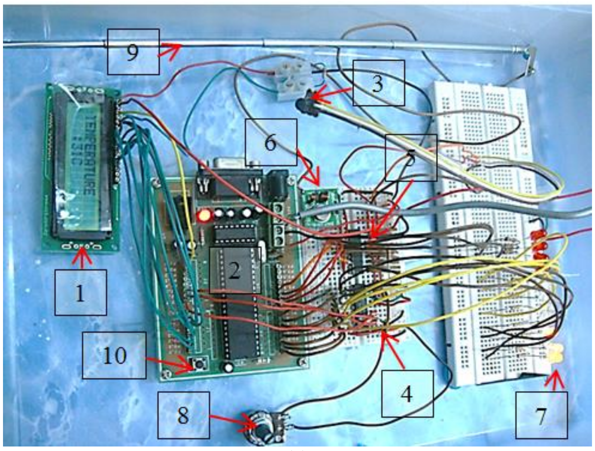
Distance (in meter)	Errors obtained within 1 minute
1	0
5	2
15	0
50	0

TABLE 7
RESULTS OBTAINED FROM TWO DIFFERENT ROOMS (WITH ONE WALL AS AN OBSTACLE)

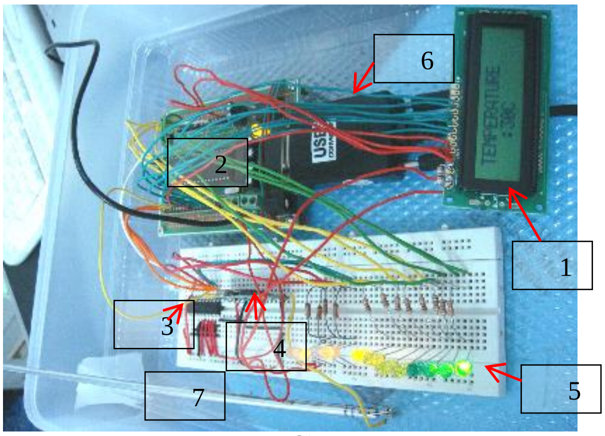
Distance (in meter)	Errors obtained within 1 minute
1	0
5	0
15	0
50	0

TABLE 8
RESULT OBTAINED FROM TWO DIFFERENT HOUSES (WITH SEVERAL WALLS AS OBSTACLES)

Distance (in meter)	Errors obtained within 1 minute
1	0
5	0
15	0
50	0



(a)



(b)

Fig. 4: Full Schematic for (a) Transmitter (b) Receiver

V. CONCLUSIONS

Wireless devices are the most popular applications in today's consumer market. The aim of this work is to design a low cost accurate wireless temperature monitoring system. The device can perform temperature sensing, and transmit and receive the data. The result shows that the wireless temperature sensor can perform accurately in various conditions and at various distances. A maximum 50-meter distance can be used to transmit the temperature by using 5 volt input power. The next part of the work will investigate reducing the size and operating voltage to ensure the device can be used in a low power environment.

TABLE 9
COMPONENTS IN TRANSMITTER PART AS SHOWN IN FIG. 4(A)

No	Components (model)
1	LCD (DS-LCD-JHD162A)
2	Microcontroller board (P89V51RD2)
3	Temperature sensor (SN-LM35DZ)
4	Encoder (IC-HT-12E)
5	ADC (IC-ADC-0804)
6	Transceiver (RF-TX-433)
7	LED
8	Variable resistance (1 kΩ)
9	Antenna
10	Reset button

TABLE 10
COMPONENTS IN RECEIVER PART AS SHOWN IN FIG. 4(B).

No	Component
1	LCD (DS-LCD-JHD162A)
2	Microcontroller board (P89V51RD2)
3	Decoder (IC-HT-12D)
4	Receiver (RF-RX-433)
5	LED
6	RX232
7	Antenna

REFERENCES

[1] Tavares, J., Velez, F.J., Ferro, J.M., "Application of wireless sensor networks to automobiles," *Measurement Science Review*, Vol. 8, Secion 3, pp: 65-70, 2008.

[2] "ZigBee Home Automation Public Application Profile", ZigBee Alliance, Rev 25, Ver 1.0, 2007.

[3] Yu, Y., Prasanna, V.K., Krishnamachari, B., "Information Processing and Routing in Wireless Sensor Networks," World Scientific Publishing Co., 2006.

[4] "Zigbee Sensor Tag Data Sheet", Pultronics Inc.

[5] George W. Irwin, Jeremy Colandairaj and William G. Scanlon, "An Overview of Wireless Networks in Control and Monitoring," *International Conference on Intelligent Computing (CHINE 2006)*, Vol. 4114, pp. 1061-1072, 2006.

[6] Cai Bin, Jin Xinchao, Yan Shaomin; Yang Jianxu; Zhao Xibin; Zou Guowei; " Application research on temperature WSN nodes in switchgear assemblies based on TinyOS and ZigBee," *4th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT)*, 201, pp: 535 – 538, 2011

[7] G. Virone, A. Wood, L. Selavo, Q. Cao, L. Fang, T. Doan, Z. He, R. Stoleru, S. Lin, and J. A. Stankovic, "An Advanced Wireless Sensor Network for Health Monitoring," *Transdisciplinary Conference on Distributed Diagnosis and Home Healthcare (D2H2)*, April 2-4, 2006.

[8] Zhang Zuojing; Zhang Haihui; "Design of Wireless Monitoring and Warning System for Protected Agriculture Environment," *6th International Conference on Wireless Communications Networking and Mobile Computing (WiCOM)*, pg: 1 – 5, 2010.

[9] Emil Jovanov, Aleksandar Milenkovic, Chris Otto and Piet C de Groen, "A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation," *Journal of NeuroEngineering and Rehabilitation*, pp: 2:6, 2005.

[10] Namjun Cho; Seong-Jun Song; Sunyoung Kim; Shiho Kim; Hoi-Jun Yoo, "A 5.1-μW UHF RFID tag chip integrated with sensors for wireless environmental monitoring," *Proceedings of the 31st European Solid-State Circuits Conference (ESSCIRC)*, pp: 279 – 282, 2005.

[11] "P89V51RB2/RC2/RD2: 8-bit 80C51 5 V low power 16/32/64 kB Flash microcontroller with 1 kB RAM," Datasheet from Philips Electronics, Rev. 03, 02 December 2004.

[12] "LM35 Precision Centigrade Temperature Sensors," National Semiconductor Corporation, November 2000.