Using ZigBee Communication Technology in a Smart Home Wireless Sensor Network

Nazrul Anuar Nayan, Ili A.M. Ikhsan
Dept. Electrical Electronic & System
Faculty of Engineering & Built Environment
Universiti Kebangsaan Malaysia
Bangi, Selangor, Malaysia
nazrul@ukm.edu.my

Yasuhiro Takahashi
Dept. Electrical & Electronic Engineering
Faculty of Engineering
Gifu University, Yanagido, Gifu-shi
Gifu, Japan
yasut@gifu-u.ac.jp

***Abstract*—A wireless communication system is used as a medium for interaction between a microcontroller and home appliances to replace a wired system. The current system uses a wireless local area network (WLAN). However, a WLAN has disadvantages such as delay, jitter and insufficient bandwidth for the transfer of a large quantity of data. The system is also expensive. This paper presents the design and development of ZigBee communication technology, which serves as a communication medium for hardware and sensors in a home automation system for smart homes. A liquid crystal display (LCD) is used to display the system output on a receiver. This study shows that a ZigBee network can be designed and implemented successfully at the prototype level and can be used to develop a home automation system.**

***Index Terms*—Smart homes, topology, wireless sensor networks, ZigBee.**

I. INTRODUCTION

For many years, home automation (HA) has been considered to be a field with a high potential for development [1]. HA can increase the quality of life of residents through the use of monitoring and remote-controlling devices in the home [2]. Most currently available inexpensive home systems use wired technology, which is complex and difficult to install. Various wireless technologies have been developed and introduced into the home environment such as infrared light for short-range applications and wireless local area networks (WLANs), Bluetooth and ZigBee for mid-range applications [3]. These technologies have permeated our daily lives, exhibit outstanding performance, are highly popular and are being used in almost every field.

WLAN smart homes have increased in popularity because of the ease of installation and wide accessibility of this technology by almost all wireless devices. The term ‘smart home’ describes a residence that is equipped with technology to monitor its inhabitants and/or that encourages independence and the maintenance of good health [4]. However, a WLAN home automation system can malfunction, and the system fails when there is no connectivity. The system security is also vulnerable to hackers because IP addresses are required to connect a wireless home automation system to various devices. The WLAN can be accessed by many devices but requires a high bandwidth for data transfer. Thus, WLAN is expensive. In addition, there are delays and jitters in data transmission when too many devices are connected to the wireless system. WLAN needs to be centralized by an expensive super computer and wired system [2]. Furthermore, existing WLAN home automation does not ensure data transmission security.

In this paper, a ZigBee communication technology system is designed and implemented for use in a smart home wireless sensor network. The primary methodology used separates the entertainment/computing wireless devices from the security/home automation appliances. The former devices use a WLAN and the latter appliances use ZigBee.

II. ZIGBEE COMMUNICATION PROTOCOL

Table 1 compares the characteristics of commonly-used wireless communication protocols in home automation. Seo et al. have described home automation using ZigBee short-range wireless communication technology as a system that conserves energy [6]. Moreover, a ZigBee system is interoperable among manufacturers and supports a large number of nodes. The system provides connectivity among various electronic devices as well as an interactive and graphical interface to control these devices [7]. ZigBee is also used in medical applications, i.e., the ZigBee protocol is used to perform continuous, real-time, dynamic detection of physiological parameters such as ECG, blood pressure and oxygen saturation without affecting a user's normal life and to enhance detection accuracy [8]. ZigBee communication technology is designed to bring comfort and ease into peoples’ lives, especially those of the elderly and disabled. The ZigBee protocol uses a radio frequency (RF) communication standard based on IEEE 802.15.4 [2].

The ZigBee protocol is also a personal area network (PAN) in which the reference model is based on an International Standard Organization (ISO) layer model. ZigBee features satisfy market needs including low power consumption, cost-effectiveness, a low cost and a low data rate [9]. ZigBee is the easiest protocol to convert from a wired system and can be used for various applications, as shown in Fig. 1.

Smart appliances can be manipulated from the information received via ZigBee module in a home gateway [10]. As long as signals are being detected by the sensors at the terminal nodes, these signals are transmitted to perform the corresponding tasks.

TABLE 1. COMPARISON OF CHARACTERISTICS OF BLUETOOTH, WLAN AND ZIGBEE [5]

Characteristics	Bluetooth	WLAN	ZigBee
Protocol (IEEE)	802.15.1	802.11b/g	802.15.4
Range (meters)	10	50-100	10-100
Data rate (bits/s)	1 M	11 & 54 M	20, 40 & 250 k
Battery lifetime (days)	7	0.5-5	>100
Operating frequency (Hz)	2.4 G	2.4 G & 5 G	868 M, 902 -926 M & 2.4 G
Complexity	High	High	Low
Power consumption (mW)	198	1050	72
Security	64 &128 kbits	IEEE802.11i (WPA2)	128 bit AES & application layer security
Application	Wireless communication	Internet, website & e-mail	Control & Monitoring

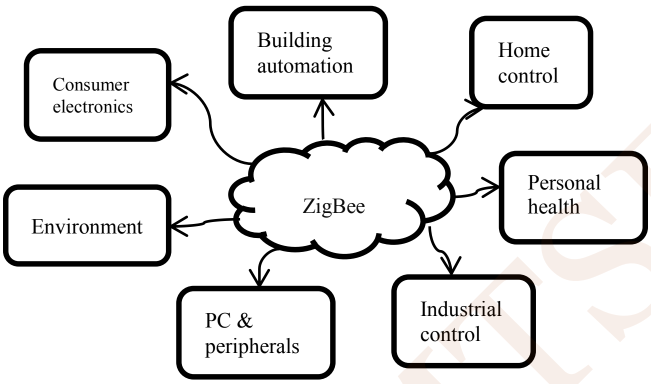

Fig. 1. ZigBee applications

A network system is challenged when both ZigBee and Wi-Fi modules are transmitting data at the same time. However, ZigBee and Wi-Fi modules can be integrated through an Arduino controller to simultaneously operate two different network protocols and data transfer actions [11]. ZigBee has a low packet throughput, a standard-based wireless network, and low regional quality of service (QOS), high security and reliability [12]. Although ZigBee provides an efficient wireless home area network (HAN), it is not widely used at present.

Every ZigBee network has three main components: a coordinator, routers and end devices. The functions of the coordinator are to transmit data and manage the other functions that define the network. The routers provide a communication medium between two devices. The routers also support and can be connected to the existing network and serve as transmitters or receivers.

The routers are connected to end devices, other routers and the coordinator. The end devices send or receive data to/from the routers or the coordinator and can also send or receive information from other end devices [13].

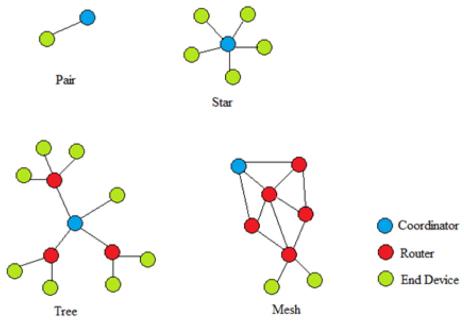

Fig. 2. ZigBee network topologies.

Figure 2 shows the four types of topologies for the ZigBee communication protocol. The simplest topology is the pair topology. In the pair topology, only two devices are connected: either an end device is connected to a coordinator or an end device is connected to a router. This topology is also known as a point-to-point topology. The second topology that can be used in the ZigBee communication protocol is the star topology. In the star or point-to-multipoint topology, the router or coordinator is placed in the center of the network and is connected to many end devices or routers. This topology broadcasts information from the coordinator to all the end devices or routers. The mesh and tree topologies are complex. The networks for both these topologies consist of three primary components.

ZigBee is often confused with XBee. In fact, these modules are distinct from each other: ZigBee is a communication protocol, whereas XBee supports ZigBee [13].

The XBee module can be used as a medium for interaction and a communication module between microcontrollers and serves as a wireless network for data transfer. Two types of XBee devices are used in home automation: XBee S1 and XBee S2.

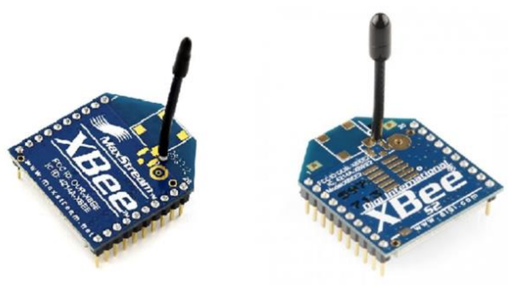

Fig. 3. XBee Series 1 and Series 2 modules.

A. XBee Series 1

The 2.4 GHz XBee module enables easy and simple communication between a microcontroller and a serial port. This module is a very reliable system that supports point-to-point and point-to-multipoint communication. This module has a power output of 1 mW.

B. XBee Series 2

The difference between Series 1 (S1) and Series 2 (S2) is that the latter enhances the power output of the antenna to 2 mW. S2 also enhances the data protocol of the XBee module. S2 is similar to S1 in enabling simple and easy communication between microcontrollers and supporting point-to-point and point-to-multipoint communication.

Figure 3 shows the XBee modules S1 and S2, and the characteristics of these modules are shown in Table 2.

TABLE 2. CHARACTERISTICS OF S1 AND S2 XBEE MODULES [14]

	Series 1	**Series 2**
Distance (m)	30	40
Optimal range (m)	100	120
Transmitter/ receiver current (mA)	45/50	40/40
Firmware	802.15.4	ZigBee
Digital input	8	11
Analog input	7	4
PWM	2	No
Point-to-point & point-to-multipoint topology	Yes	Yes
Mesh & tree topologies	No	Yes

III. STRUCTURE OF THE DEVELOPED SMARTHOME

In this section, the underlying concepts and a brief description of the developed system are presented, followed by an explanation of the software and hardware design of the system. This system controls several devices in the home including magnetic locks, lighting fixtures and curtain blind controllers. The system primarily operates over a wireless sensor network using the ZigBee protocol. This system can be classified into four components: control, communication, sensors and I/Os. The control module is the primary component and the brain of a system that consists of a microcontroller PIC16F877A. The communication module enables communication between the user interface devices and the microcontroller. The sensor component consists of magnetic door locks, PIR motion sensors and IR sensors. The I/O module consists of a touch panel LCD that enables a user to choose suitable conditions and displays data output. Figure 4 shows a developed smart home.

Once a user logs into and has been authenticated by the system, the user can control and monitor home appliances from the central touch-control panel. The working principle of the system is shown in Fig. 5. After logging into the system, the user can choose a condition. The XBee device sends a signal to the receiver. The receiver module detects and receives the signal, and the control module sends a signal to a sensor module according to the condition.

This system uses the following software: X-CTU, Visual Basic.Net and MPLab. The X-CTU software configures the XBee module. The Visual Basic.Net software is used for the graphical user interface and the touch-control panel, whereas the MPLab software is used to write the computer program for the control module. Fig. 6 shows how an XBee module is configured.

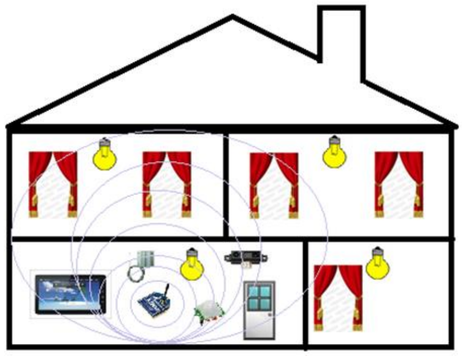

Fig. 4. Developed smart home

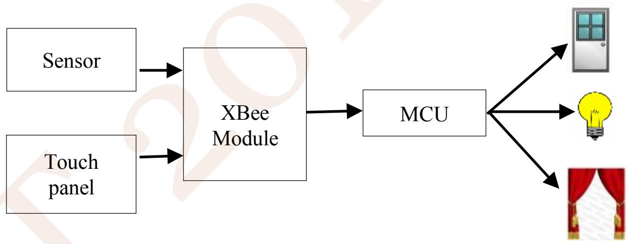

Fig. 5. Working principle of the system.

Software System Design

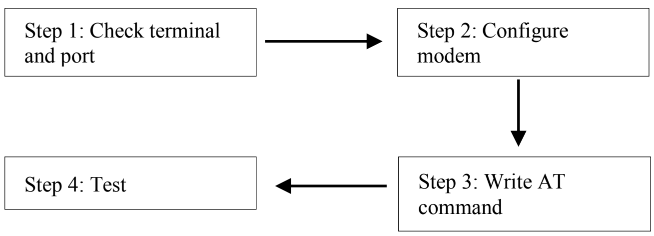

Fig. 6. XBee module configuration.

The X-CTU software provided by Digi-International is recommended for the testing and configuration of the XBee module. The baud rate must first be configured for the software to communicate with the XBee module. Data can then be transmitted and displayed from the Xbee module.

The Visual Basic.Net software is used for the graphical user interface (GUI) at the central control panel at which the user can choose the smart home conditions. The control panel consists of login and main menus. At the main menu, the user needs to enter a user identification and password for security purposes.

Next, various options can be chosen from the main menu. The three user options are as follows: an "In" option (which automatically switches on the home appliances), an "Out" option (which automatically switches off the home appliances) and a "Manual" option with which the user can manually switch the home appliances on or off. A flowchart for the control panel system is shown in Fig. 7.

The program starts with the user being required to key in a username and a password to unlock the security system. Once the user enters the correct username and password, the system deactivates the security and proceeds to the main menu. If the user enters an incorrect username or password, the user can try again up to five more times. If the user enters an incorrect username and password after five unsuccessful attempts, a buzzer sounds as an alert that someone is trying to hack into the system. This function serves to protect the house from potential intruders. As previously stated, the main menu system displays three modes. The user needs to choose one mode for the automated house system. This system can control all the electronic components remotely throughout the house. The user can choose to control the system automatically or manually. If the automatic mode is chosen, triggers are activated when certain programmed conditions are met. For example, if no-one is in the kitchen but motion is detected in the hallway, the system will not switch on the kitchen light and will turn on the light in the hallway. The system will save energy by determining if any lights have been left on or if the curtains are open when no-one is in the house and turn the lights off and draw the curtains. When the system is in manual mode, the user or home owner can choose to dim the lights or turn the lights on when the user is on vacation. If there is no motion or no choices are made, the security system is re-activated after 30 seconds.

For the sensor module and the control module, MPLab software is mainly used to monitor the microcontroller and the sensors. This system receives signals from the transmitter module, and the output data appears on the LCD.

Hardware System Design

Figure 8 shows the circuitry of this system. The system consists of four primary components: a control component, a sensor component, a communication component and an output component. For the control component, the controller consists of Visual Basic.Net and the microcontroller. The microcontroller controls the sensors and the output for this system. For instance, if the sensors detect changes or differences, the sensors send signals to the microcontroller. The microcontroller produces outputs for these conditions. The sensor component is also the primary component of this system. Three sensors that can be used: a PIR motion sensor, an IR sensor for light detection and a magnetic switch sensor for door security. The device used for the communication component of this system is an XBee S1 1-mW antenna that enables the ZigBee network to transmit and receive signals within 100 m. In this study, an LCD and LEDs are used to indicate the output. The LCD displays the output for the system, and the LEDs indicate the status of the lights, curtains and door security.

A. Microcontroller

The microcontroller unit is composed of a PIC16F877A (which is the brain of the system), a voltage regulator and other peripheral circuits. A PIC16F877A was chosen for this study because it is easy to program and can execute coding in 200 ns. This microcontroller consists of 8 bits with a 40-pin package. Fig. 9 shows the PIC16F877A pin configuration

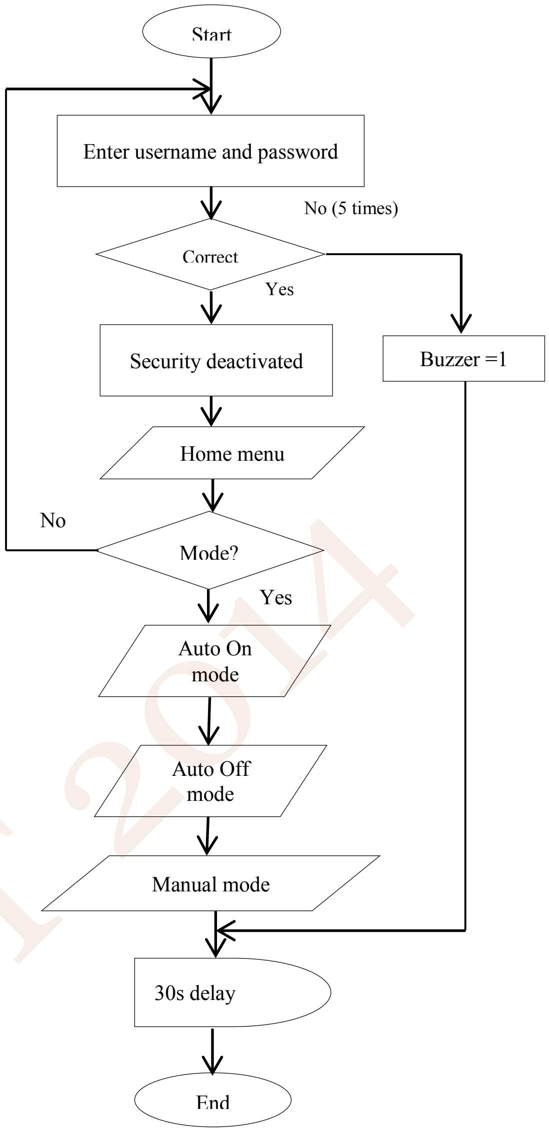

Fig. 7. Flowchart of a smart home wireless sensor network.

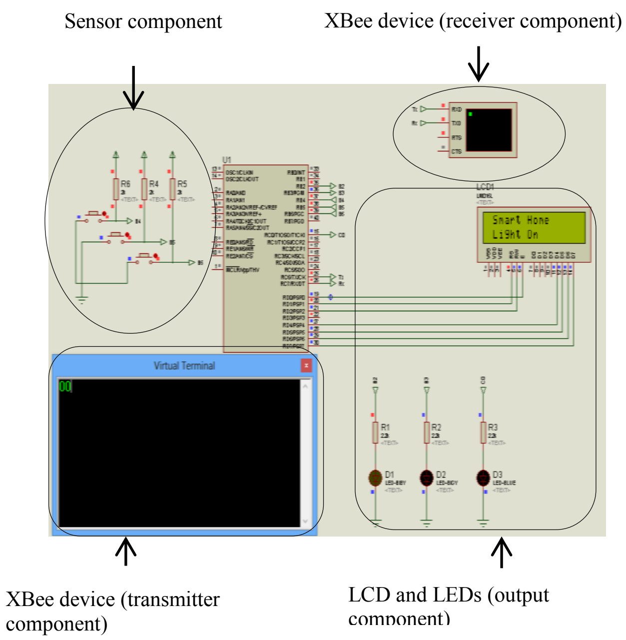

Fig. 8. System circuitry

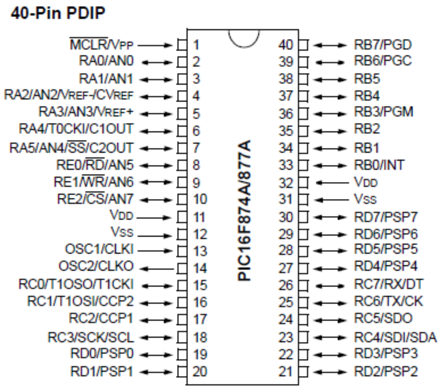

Fig. 9. PIC16F877A pin configuration.

B. *Sensors*

In this study, three sensors are used for home automation: PIR motion sensors, infrared transmitters and receivers and magnetic switches for the doors. These sensors provide inputs to the microcontroller, and the microcontroller displays the outputs on the LCD.

PIR motion sensor – This sensor is normally used for security; however, in this experiment, PIR motion sensors are used to detect the presence of humans to switch the lights on and off in a house. This sensor is a pyro-electric device that detects changes in the infrared level emitted by the surrounding environment. The sensor is also sensitive to the infrared heat energy emitted by human beings. The sensor is activated when it receives a strong signal from the I/O pin. Figure 8 shows the PIR motion sensor.

Wired magnetic switch – This switch is a sensor with many functions. The primary purpose of this switch is security. The sensor consists of two magnets and a reed switch. The sensor is deployed at the doors of a house. If any motion is detected when the user is not at home, an alarm is sounded to alert the neighbourhood. The circuitry of the sensor is normally closed. The wired magnetic switch is shown in the figure below.

IR sensor transmitter and receiver – The IR sensor transmitter and receiver are used in the control system. The IR sensor is used to detect the brightness level outside the house. If the exterior environment is brighter than the interior of the house, the curtains are opened to allow sunlight to enter the house. Figure 10 shows an IR sensor transmitter and receiver.

C. *Receiver*

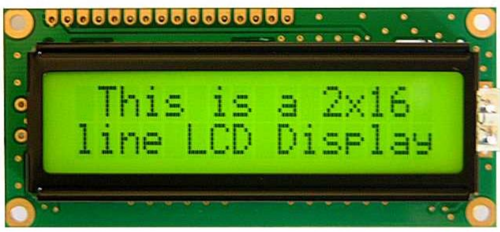

Fig. 10. Liquid crystal display.

The receiver component displays the results. In this prototype, the system output data are shown on a LCD that can display characters and the output of the system. A LCD model QY-1602A is used. Figure 10 shows the LCD component. The pin configuration used to connect the LCD to a microcontroller is shown in Table 3. A variable resistor is used to control the LCD brightness, which can be adjusted by the user. Pins 4 to 6 are used for the interaction between the LCD and microcontroller and are connected to the I/O Port D microcontroller. Pins 11 to 14 are the data bus pins. Table 3 shows the pin configuration.

IV. RESULTS AND DISCUSSION

A home automation system is tested using software and hardware simulations. First, XBee devices are configured to ensure that the XBee devices can interact with each other to transmit and receive data. Next, a programming code is written for the GUI using Visual Basic.Net software. After the microcontroller is tested, a Proteus simulation is used to test the sensors to ensure that they can provide inputs to the microcontroller. Finally, all the tests are combined in an integrated system test. Both tests are required to ensure that the XBee devices, the microcontroller, the GUI interface and the system function efficiently.

TABLE 3. LCD PIN CONFIGURATION

Pin	Name	Pin configuration
1	VSS	0 V
2	VCC	5 V
3	VEE	Variable resistor
4	RS	RD4
5	R/W	RD5
6	E	RD6
11	DB4	RD0
12	DB5	RD1
13	DB6	RD2
14	DB7	RD3

A. *X-CTU Software Configuration*

To enable the XBee devices to interact with each other, the devices must be configured with source and destination addresses. The XBee devices can interact with each other if the device settings are the same. For instance, if the baud rate used by the XBee device (A) is 9600, then the XBee device (B) baud rate must also be 9600. Fig. 11 shows the configuration of the XBee devices.

B. *GUI using Visual Basic.Net*

For the transmitter, the GUI in Visual Basic.Net serves as the control panel for the home automation system. This GUI offers a user three mode choices for the house. In this system, the user needs to enter a user name and password to successfully deactivate the security. However, if the user fails, a house alarm is automatically activated. Fig. 12 (a) shows the home screen where the user name and password can be entered.

After the user successfully enters the password, the main menu screen appears. The user can choose three modes from the main menu screen. The main menu window is shown in

Fig. 12 (b). When the user chooses the manual mode, the manual screen also appears, and the user can choose to switch a light on or off and open or close a curtain.

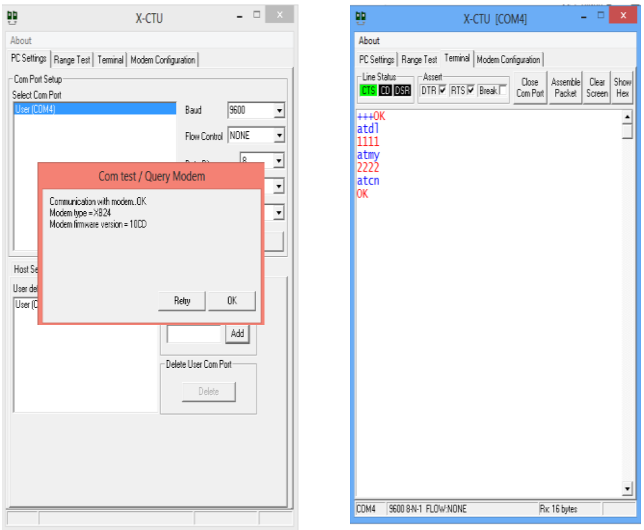

Fig. 11. Configuration of XBee devices

Once the user enters the modes, the device sends signals to the XBee: the receiver component receives the signals and executes the commands. The manual screen is shown in Fig. 12 (c).

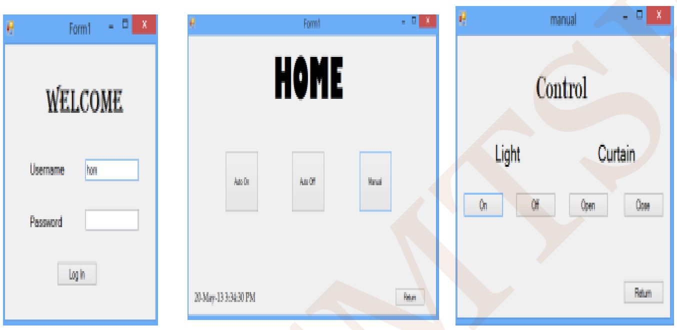

Fig. 12. (a) Home menu, (b) main menu and (c) manual menu.

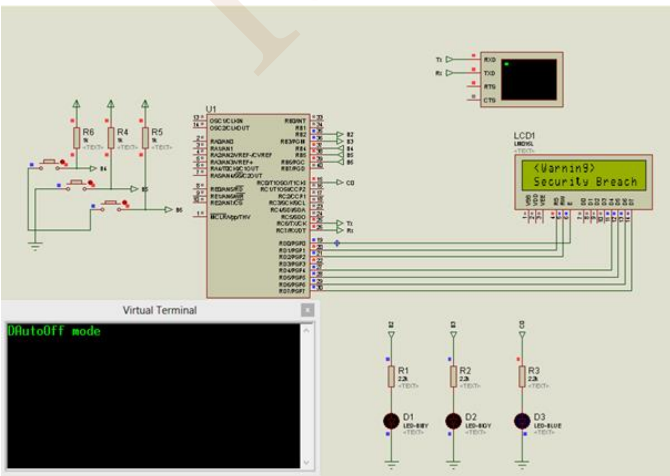

Fig. 13. Proteus simulation

C. Proteus simulation

A Proteus simulation is used to test the programming code before it is entered into the actual devices. This simulation ensures that the programming code functions effectively in the virtual devices. Once the output can be displayed in the Proteus simulation, the microcontroller is programmed for the integrated system. The virtual terminal for the Proteus simulation includes the XBee devices, the PIC16F877A for the microcontroller, the LCD and the LED that indicates the outputs. The switches indicate the sensors. The simulation is shown in Fig. 13.

D. Receiver

The LCD of the receiver is used to display the system output. Fig. 14 shows the LCD display for each condition.

Fig. 14. LCD output

V. CONCLUSIONS

The ZigBee network is not widely used in the communications field; however, in this study, it was clearly shown that this network is suitable for home automation primarily because of its low data rate. Thus, existing wired home automation systems can be replaced by more cost-effective wireless home automation systems. The underlying concept and development of the ZigBee home automation network have been presented in this paper. The complete development of the system has been illustrated as a detailed schematic. The interaction between Visual Basic.Net and the microcontroller using XBee devices and the sensitivity of the sensors used in this study were also investigated. The home automation sensors were demonstrated to be sensitive and therefore effective. In the future, this home automation system could be implemented for phone applications such as Android, iOS, Windows and Symbian.

ACKNOWLEDGMENT

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