WIRELESS NETWORK SYSTEM BASED MULTI-NON-INVASIVE SENSORS FOR SMART HOME

By

Rudhwan Issa Ahmed

A thesis submitted to the Faculty of Graduate Studies and Postdoctoral Affairs

in partial fulfillment of the requirements for the degree of

MASTER OF APPLIED SCIENCE IN BIOMEDICAL ENGINEERING

(Ottawa – Carleton Institute for Biomedical Engineering (OCIBME))

Department of Systems and Computer Engineering

Carleton University

Ottawa, Canada, K1S 5B6

December 2012

Your file Votre référence
ISBN: 978-0-494-94248-2

Our file Notre référence
ISBN: 978-0-494-94248-2

The undersigned hereby recommend to

the Faculty of Graduate Studies and Postdoctoral Affairs acceptance of the thesis

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Chair, Dr. Howard M. Schwartz, Department of Systems and Computer Engineering

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Carleton University

December 2012

ABSTRACT

There are several techniques that have been implemented for smart homes usage; however, most of these techniques are limited to a few sensors. Many of these methods neither meet the needs of the user nor are cost-effective.

This thesis discusses the design, development, and implementation of a wireless network system, based on multi-non-invasive sensors for smart home environments. This system has the potential to be used as a means to accurately, and remotely, determine the activities of daily living by continuously monitoring relatively simple parameters that measure the interaction between users and their surrounding environment.

We designed and developed a prototype system to meet the specific needs of the elderly population. Unlike audio-video based health monitoring systems (which have associated problems such as the encroachment of privacy), the developed system's distinct features ensure privacy and are almost invisible to the occupants, thus increasing the acceptance levels of this system in household environments. The developed system not only achieved high levels of accuracy, but it is also portable, easy to use, cost-effective, and requires low data rates and less power compared to other wireless devices such as Wi-Fi, Bluetooth, wireless USB, Ultra wideband (UWB), or Infrared (IR) wireless.

Field testing of the prototype system was conducted at different locations inside and outside of the Minto Building (Centre for Advanced Studies in Engineering at Carleton University) as well as other locations, such as the washroom, kitchen, and living room of a prototype apartment. The main goal of the testing was to

determine the range of the prototype system and the functionality of each sensor in different environments. After it was verified that the system operated well in all of the tested environments, data were then collected at the different locations for analysis and interpretation in order to identify the activities of daily living of an occupant.

ACKNOWLEDGMENTS

It is with immense gratitude that I acknowledge the support and help of those who made this thesis both possible and an unforgettable experience for me.

First and foremost, I wish to thank God. I also have immense appreciation for my supervisor, Dr. Mohamed El-Tanany. This work would have not been possible without the enthusiasm, inspiration, and, most of all, remarkable patience of Dr. El-Tanany. I would like to thank Dr. Rafik A. Goubran for giving me the opportunity to work on this research and for his expert guidance and support throughout this academic program.

Besides my supervisor and Dr. Rafik A. Goubran, I would like to thank the remaining members of my examining committee: Dr. Jiying Zhao from Ottawa University and Dr. Fei Richard Yu from Carleton University for their encouragement, insightful comments, and tough questions, which lead me to rethink my research in ways that I could not even have imagined.

Outside of my academic community, I would like to thank Anna Lee-Popham from Palindrome Translation and Editing (palindrome-fr-en.com) for her help in providing high-quality editing of the thesis.

I would also like to thank the Natural Sciences and Engineering Research Council of Canada (NSERC) and Carleton University for the graduate fellowship that made it financially possible for me to complete this thesis as well as for providing a stimulating and engaging environment in which to learn.

I would like to thank my friends Mamatjan Yasin, Wen-Lin Liu, and Laleh Adl, as well as all of those who supported me in any respect during the completion of the thesis.

Lastly, I would like to thank my family for their supports, inspirations, and prayers. Thank you, may God bless you all.

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CHAPTER 1

INTRODUCTION

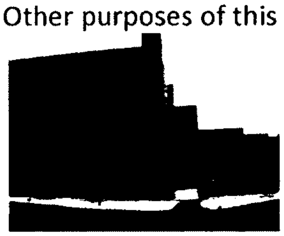
This chapter describes the objectives, brief overview of the research system technology, contributions, and organization of this thesis.

1.1 Objectives

Smart home environments can provide viable alternate living conditions for some aging persons by monitoring the health conditions of the elderly population in real time. Small motors and sensors positioned around the home automatically perform a number of functions, such as opening and closing curtains, turning lights on and off, and raising and lowering sinks and cupboards [1].

The objective of this thesis is to design, develop, and implement a prototype system using smart home technology that utilizes several wireless sensors to remotely detect and monitor an elder's activities of daily living and health condition in their own homes in order to improve the quality of life of the elderly population.

Other purposes of this research are the field testing of the prototype system, utilization of the system to collect



data at different locations and environments, and analysis of the collected data. The field testing of the prototype system was conducted at different locations inside and outside of the Minto Building (the figure to the right) as well as other locations, such as the washroom, kitchen, and living room of a prototype apartment. The main goal of this testing was to determine the range of the prototype system and the functionality of each sensor in different environments. After the system was substantiated as operating well in all of the tested environments, data were collected at the different locations and analysed and interpreted in order to identify the activities of daily living of the occupants.

To achieve its objectives, this study sought to:

- Examine current conditions and possible future developments of wireless sensor networks pertaining to the field of home care for the elderly population;
- Investigate the reliability of research to date regarding wireless sensor networks that have been developed in the field of monitoring the health care of occupants in their homes;
- Survey the advantages and disadvantages of the various wireless technologies;
- Design, develop, and implement the prototype system; and
- Collect, analyse, and interpret the data.

1.2 Brief overview of the research system technology

In this research, we designed, developed, and implemented a prototype system based on recent advances in low data rate, low-cost, and low-power wireless mesh networking technology. The data rate and capabilities of such technology have been increasing over the past few years, allowing for faster, easier to use, less expensive installation and more reliable wireless connectivity, anytime and anywhere. These advances enable wireless technology to be widely deployed in controlling and monitoring applications. Recent wireless systems consume lower power, have a longer lifetime, and use smaller batteries, and mesh networking provides higher reliability and a more extensive range of functions.

1.3 Thesis Contributions

This research provides at least four contributions to the field of wireless sensor networks for smart home monitoring environments. The developed prototype system:

(1) Includes distinct features, including: six non-invasive sensors, a microcontroller, a power supply, and XBee modules. Also relies on RF transceivers to establish a wireless communication.

(2) Collects multiple data simultaneously to identify both activities of daily living and usage of appliances at different locations and environments.

(3) Contains a number of safety features to ensure proper operation in the event of emergency. The emergency buzzers alert users of any unacceptable change in behaviour of appliances (such as the fridge) and or status of frames (such as windows or doors).

(4) Enables the analysis and interpretation of the collected data that can potentially identify patterns of behaviour of users and recognize the occurrence of any unforeseen abnormal conditions.

1.4 Organization of the Thesis

This thesis is organized into six chapters. Chapter 1 is the introduction. Chapter 2 provides a background about smart home technologies and wireless sensor networking (WSN) technologies and a review of the literature relevant to the thesis, the limitations of the hardware, and past and current smart home research at Carleton University. Chapter 3 concentrates on the design goal, the hardware overview and specifications, and ZigBee technology. Chapter 4 illustrates the hardware and software design and the development and implementation of the prototype system. Chapter 5 focuses on data collection, analysis, and interpretations. Finally, Chapter 6 provides the conclusions, limitations, and suggestions for future research.

CHAPTER 2

BACKGROUND OVERVIEW

2.1 Introduction

The purpose of this chapter is to provide background information relevant to smart home environments and wireless technologies for the smart home.

The chapter is organized into five main sections. Section 2.2 illustrates a smart home environment. Section 2.3 provides information on past and current smart home research at Carleton University. Section 2.4 explains wireless sensors networks. Section 2.5 reviews the relevant literature and presents the limitations of the techniques usually employed in smart home environments.

2.2 An Overview of Smart Homes

A smart home environment is usually equipped with a wireless sensor networks, which is used to relay vital information to a central station. A common definition of a smart home is "a dwelling incorporating a communications network that connects the key electrical appliances and services, and allows them to be remotely controlled, monitored or accessed" [1] [2]; in this context, "remotely" means both within the dwelling and from outside of the dwelling. In other words, a smart home is a living environment that consists of sensors, actuators, networks, and middleware to automatically provide appropriate service to the home's occupants. In other words, a smart home is a house or living environment that contains the technology to allow devices and systems to be controlled automatically [3]. It has major usages for environment, security, home entertainment, domestic appliances, information and communication, and health [4], [5]. As its development and applications become increasingly relevant to both the engineering and healthcare communities, the field of smart home technology is growing rapidly [6], [7]. There are at least 20 different home labs set up for researching smart homes by research groups such as MIT, Siemens, Cisco, IBN, Xerox, and Microsoft. More than 30 appliances, at least 5 network protocols, and over 3 artificial intelligence techniques have been used to conduct the research [2]. From a data transmission point of view, smart home technology can be categorized into three areas [2], [8]: Power line, Busline, and Wireless communication.

- **Power line:** This type of system is made of devices that can be directly connected into the main power supply of the building. The mainstream protocols in Power Line Communication (PLC) technology [2], [8], [9] are X-10, INSTEON, PLC-BUS, LonWorks, and Home Plug.
- **Busline:** This system uses a separate 12-volt cable (twisted pair cabling) to transmit and receive data from the devices. The cable is similar to that used for phone and network service. The mainstream protocols in Busline communication (BLC) technology are EIB, Cebus, Lonwork, and Batibus [2], [8].
- **Wireless communication (Radio frequency (RF) and Infrared (IR) systems):** These systems are the networking alternatives that wirelessly exchange data between sender and receiver, but at a much lower data rate than LAN/WLAN. The representative protocols in this case are Bluetooth, ZigBee/IEEE 802.15.4, or Z-wave [2], [8]-[10].

2.2.1 Radio Frequency (RF)

Radio frequency (RF) transmission is more suitable for our application, due to the following reasons:

- **Mobility:** There is no need for a cable to the location where the display is placed.
- **Installation speed and simplicity:** Installation of additional sensors to various locations can easily be achieved.
- **Cost effectiveness:** New installation is inexpensive.
- **Topology:** Wireless transmission provides extra flexibility in regards to the connection method.

2.3 Smart Home Research at Carleton University

Several smart home projects are currently in operation at Carleton University - Canada's Capital University[1].

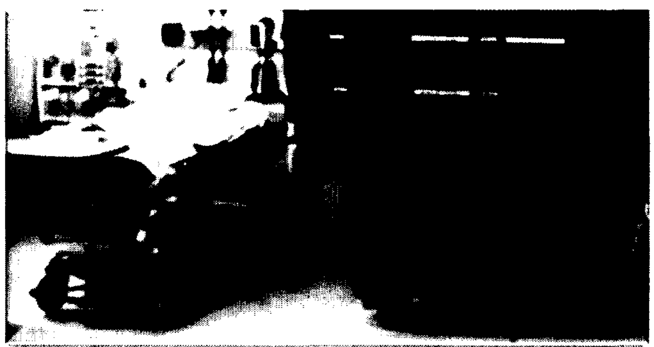


Figure 2.1: Bed-based pressure sensing system architecture of the smart home monitoring system[2]

One of the major concentrations of these projects is on developing sensor networks based on solutions for health care and patient monitoring. These projects incorporate various kinds of sensors technologies, such as

[1] Source: http://www.sce.carleton.ca/dept/index.shtml

[2] Figure 2.1 is adapted (in December 2012) from the Department of Systems and Computer Engineering at Carleton University, website: http://www.sce.carleton.ca/dept/index.shtml

wearable sensors, ambient monitoring, or embedded sensors. Moreover, within the home, "smart" or "intelligent" devices include bed-based optical pressure sense system (shown in Figure 2.1) that track sleeping patterns to detect central Apnoea3 [11]-[15], a system to monitor physiological signals caused by chest movement [16], [17], and a device to measure bed-departure time caused by sit-to-stand pressure [18]-[20]. The smart home includes chest belt devices to measure breathing rate, heart rate, and skin conductance during exercise [21]-[23] systems to track food spoilage in fridges [24], [25]. Carleton University is also currently involved in joint projects with other universities, healthcare institutions, and industries; an example of such a project is the TETAFE research, discussed in section 2.3.1.

2.3.1 Technology Assisted Friendly Environment for the Third Age (TAFETA)

References [26]-[33] present current research involving Carleton University in a joint Ontario-based project entitled Technology Assisted Friendly Environment for the Third Age (TAFETA). The co-lead in this project is SCO Health Service, one of Canada's largest providers of continuing care, rehabilitation, palliative care, and primary care for elderly persons. The project's other members include other healthcare institutions, schools, and industry partners in Ontario, Canada. Its primary mission is to identify and develop technology that will provide a safe living environment that is responsive to the health needs of elderly persons. The objective of this research is to introduce TAFETA's current smart home research. It describes the various sensing technologies currently under investigation in the groups "Independent Living Apartment" laboratory, called the TAFETA Smart Apartment at the Elisabeth Bruyère Hospital (shown in Figure 2.2). At least 50 patients have used the apartment facilities to date.

3 Apnoea is the most prevalent type of breathing disorder (SDB).

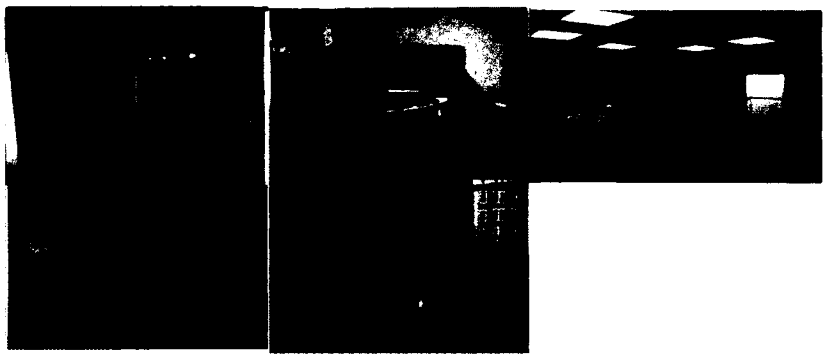


Figure 2.2: TAFETA Smart Apartment[4]

The TAFETA prototype apartment is equipped with several sensors, including magnetic switches to monitor entry into, and exit out of, rooms, thermistors to monitor proper temperature range, accelerometers to detect high impact, radio frequency identifications (RFID) to retrieve misplaced objects, infrared motion sensors to track the presence of motion by the occupant, microphone arrays to detect abnormal sound or calls for help, smart grab bars to aid occupant in the shower and washroom, pressure sensitive mats to monitor occupant's condition at rest, and electronic noses to track food spoilage in the fridge [24], [25].

2.4 Wireless Sensors Networks

The wireless sensor networks (WSNs) is one of the key technologies in the smart home design life cycle. The WSNs in the smart home environment can be thought of as a group of spatially dispersed and dedicated sensors for monitoring and recording the physical conditions of the environment and organizing the collected data at a central location [34]. The WSNs measures environmental conditions such as temperature, sound, vibration,

[4] The figure is adapted (in December 2012) from the TAFETA website: www.tafeta.ca

pressure, humidity, wind speed and direction, pollution levels, motion, light intensity, and proximity to objects. The WSNs is made up of a set of independent sensor nodes, gateways, and software.

2.4.1 Nodes, Gateways, and Software

The sensor nodes are "self-contained" units, each consisting of a radio frequency (RF) transceiver usually with a single omni-directional antenna, one or many sensors, a low-speed on-board processor (microcontroller, CPUs, or DSP chip), and an energy source (usually a battery or solar cells). Figure 2.3 shows a sensor node. Sensor nodes communicate wirelessly and often self-organize after being deployed in an ad-hoc fashion [35].

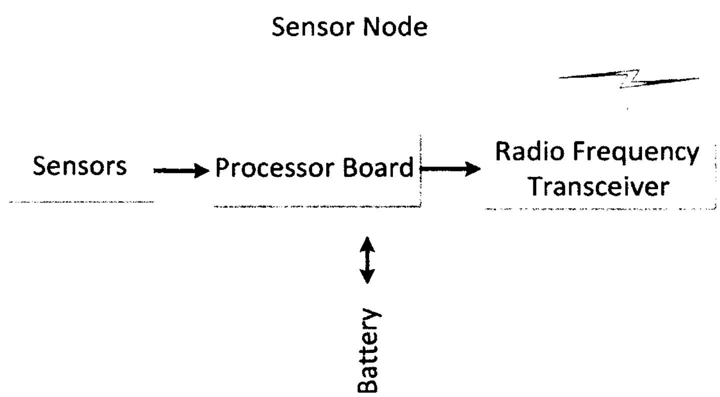


Figure 2.3: Sensor node, including processing board, radio frequency transceiver, and battery

Each node can perform self-diagnosis, which means it can relay data off other nodes within its range until the information reaches its final destination [36]. The range is extended by allowing data to hop from node to node, and reliability is increased by "self-healing," which is the ability to create alternate paths when one node fails or a connection is lost [37]. In addition, when data is transmitted from one node to another, a network-level acknowledgement is transmitted back across the established route to the source node. This acknowledgement packet indicates to the source node whether or not the data packet was received by the destination node. If a network acknowledgement is not received, the source node will re-transmit the data [38].

2.4.2 Wireless Sensors Networks in Healthcare

Wireless sensor networks are an emerging technology [39] consisting of small, low–power, and low–cost devices that integrate limited computation, sensing, and radio communication capabilities. The technology has the potential to have an enormous impact on many aspects of emergency medical care [40]. The typical applications of the wireless sensor biomedical networks (WSBNs) are numerous, including smart home healthcare monitoring, medical device networking for emergency call systems, and data collection for patient monitoring, as detailed below.

2.4.2.1 Smart Home Healthcare

WSN technology allows home healthcare patients to utilize a variety of monitoring devices, such as stethoscopes, glucose meters, and sphygmomanometers (blood pressure), in order to collect data. The data collected from these monitoring devices are securely sent to a medical lab over a cellular network to be analyzed. For example, reference [41] proposed wireless sensor biomedical networking to help older people or patients with chronic disorders by increasing their chances of survival ability; at the same time reduce the time of routine check-up and it's real-time monitoring also allows emergency situation to be handled immediately in the hospital.

2.4.2.2 Emergency Call Systems

Emergency call systems are equipped with WSNs, which allows the residents to call for help if they seek any kind of emergency assistance.

2.4.2.3 Patient Data

In the medical field, WSN technology is used to collect patient's data for medical reasons or to gather additional information for research purposes. WSN technology is embedded in the patient's bedside to facilitate making patient's data widely available in real time for proprietary clinical applications and databases and to eliminate manual data entry. An example of the WSNs in the medical field can be found in a study of sleep patterns to detect apnoea in older adults [11]-[15], which measured chest movement to monitor physiological signals [16] [17] and sit-to-stand timing and symmetry to measure bed-departure timing [18]-[20].

CHAPTER 3

HARDWARE OVERVIEW AND SPECIFICATION

3.1 Introduction

This chapter is organized into thirteen sections: Section 3.2 to 3.4 discusses a literature review and describes hardware limitations as outlined in the literature; the design goal; and an explanation of the wireless technologies. Section 3.5 to 3.8 describes the ZigBee protocol, the topology network; ZigBee outlines the protocol architecture; and a system overview. Section 3.9 to 3.12 provides prototype system overviews, system components, remote station hardware and specifications, and hardware specifications. Lastly section 3.13 to 3.15 explains ZigBee starter development kits, XBee modules, and the base station of the design system.

3.2 Literature Review

This section is dedicated to providing an overview of the relevant literature. The relevant literature is divided into seven streams: wireless sensor networks for home healthcare, XBee wireless sensor networks for temperature monitoring, the design of wireless sensors networking node on ZigBee, the development of a PIC–Based wireless sensor, ZigBee-Based wireless personal area networks for health monitoring, and hardware limitations.

3.2.1 Wireless Sensor Networks for Home Health Care

In reference [42], C.R. Baker et al. present the results of research project where several prototypes for home-health care monitoring were designed. Two of which were dedicated to the design of a wireless sensor system to monitor sleeping position and general health of an infant. The prototypes detected the sleeping position of the infant in order to protect them from Sudden Infant Death Syndrome (SIDS). Due to their tiny nature, premature infants are susceptible to a variety of health problems. An integrated health monitoring device was also developed, and contained within a swaddling baby wrap with strategically placed sensors, to monitor three main factors: temperature, hydration, and pulse rate [42].

3.2.2 XBee Wireless Sensor Network for Temperature Monitoring

In reference [43], Boonsawat et al. explain an embedded wireless sensor network (WSN) prototype system for temperature monitoring in the management of air-conditioning systems at the Sirindhorn International Institute of Technology (SIIT) in Thammasat University, Pathum-Thani, Thailand. The ultimate goal of the project was to help save energy costs and reduce energy consumption in the building. The system was designed to provide a web user-interface to access the current and past temperature readings in different rooms of the building. The designed WSN system is comprised of a data gateway or a coordinator that wirelessly joins each WSN temperature-monitoring node located in each room. Each WSN node consists of a microcontroller on an Arduino[5] board and an XBee wireless communication module based on the IEEE 802.15.4/ZigBee standards. The

[5] Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software, source: http://www.arduino.cc/

coordinator also has an Ethernet interface and runs a simple data web server. Hence, the coordinator allows data collection over XBee and data access from web browsers.

3.2.3 Design of Wireless Sensors Networking Node on ZigBee

In reference [44], S. Veerasingam et al. propose a portable wireless data-acquisition system for temperature in real time process dynamics. Process variables such as temperature, pressure, flow, or level vary with time in certain applications and such variation is recorded so that a control action can take place at a defined set point. The study proposed an 8 bit embedded platform for a sensor with a network interface using the 802.15.4 ZigBee protocol that is specially designed for the sensor networks. This wireless data logger senses and monitors variations in local temperature and transmits the data within the range to an assigned embedded processor-based server. Received temperature is displayed on a local Liquid Crystal Display (LCD) on the assigned server and simultaneously on a central computing unit placed within range. The central base station receives the data, stores it in the file, and plots the variations.

3.2.4 Development of a PIC–Based Wireless Sensor

In reference [45],Yussoff Y. et al. demonstrate the performance of WSN models that were developed using temperature sensors, a microcontroller, and XBee technology. The project aimed to use the wireless sensor network to compare the actual temperature in different environments and collect data transferred by the sensor. The collected information from the temperature sensor was processed by the microcontroller before it was transmitted to the base station. The microcontroller was programmed to send the data periodically to the base station through the XBee module. Temperature results were displayed at the base station.

3.2.5 Performance Study on ZigBee-Based Wireless Personal Area Networks for Health Monitoring

In reference [46], B. K-P. Koh and P-Y. Kong conducted research on the use of ZigBee wireless personal area networks (WPANs) for real-time health (heartbeat) monitoring to determine an increase in packet delays due to contentions and collisions in transmissions when multiple ZigBee WPANs are in close proximity to each other. They derived mobility patterns from the analysis of a real-time video trace and subsequently estimated the delay performance from the video trace by combining data collected from the ZigBee experiments. As such, for real-time heartbeat monitoring, a WPAN needs to ensure a 300 milliseconds packet delay so that a systole reading can be captured before the next one is generated. The results of the study showed that the requirement of a 300 millisecond packet delay is not met only 11% of the time. Also, when failure occurs, it will last for an average duration of 1.4 seconds.

3.2.6 Temperature Data Logger Using IEEE 802.15.4/ZigBee Protocol

In reference [47], Sehgal el al. propose an 8 bit embedded platform for a sensor with a network interface using the 802.15.4, ZigBee protocol to monitor the variations in local temperature and transmit the data within the range to an assigned embedded processor based server. Received temperature is simultaneously displayed on a local liquid crystal display (LCD), an assigned server, and a computer.

3.2.7 Limitations of Hardware

From the literature review, it can be noted that most of the techniques that have been implanted for the smart home environment have limitations. As a result of these limitations, it would be difficult to gather information needed for our research using the existing techniques. These limitations can be grouped into four categories: number of sensors, power usage, price, and performance.

- **Number of sensors:** Most of the existing techniques are limited to one or two sensors that are focused on one specific objective (e.g., monitoring either temperature, humidity, or motion).Sometimes, it is difficult to obtain reliable information with just one or two sensors. For example, temperature sensors can be suitable for providing information on appliances, but not on other areas, such as monitoring entry into, or exit out of, rooms or buildings.
- **Power usage:** Most of these techniques are off-the-shelf. They are equipped with 2 AA batteries. Depending on the application, for some activities the battery lifetime could last a few days. This can be problematic for us because our applications require long battery lifetimes to enable the continuous monitoring of Activities of daily living of occupants.
- **Price:** As indicated above, most of these devices are off-the-shelf and are too expensive for the context of our research.
- **Performance:** Most of these systems were developed to accommodate the customer. The devices are not flexible; making them "intelligent" in the context of a precise application, such as the monitoring of the elderly population, is a very difficult task. In addition, some sensors do not perform well in some situations. For example, motion sensors can be deceived by warm objects and motionless persons. Ultrasound can be misled by any object. Also, as mentioned above, at times, it is difficult to obtain reliable data with just one sensor.
- **Need for "intelligent" approaches for elderly monitoring:** Aging populations living alone in their home present at least two major associated risks: short-term risks, such as collapse, falling, or stroke, and

long-term risks, such as loss of independence, malnutrition, or insufficient hygiene. Moreover, any abnormal events that happen to an aging person in a home can lead to more serious illnesses or even death. There is a need for technique that can monitor any change in behaviour of the Activities of daily living of these aging populations in their homes to prompt early and appropriate medical or welfare intervention. Furthermore, according to gerontologists, identifying changes in everyday behaviour, such as sleeping, food preparation, housekeeping, and entertainment, is often more valuable than biometric information for the early detection of emerging physical and mental health problems, particularly for the elderly [48], [49].

In reviewing the existing techniques, we have concluded that there is a need to design and develop techniques that meet the needs of the elderly population and achieve high levels of accuracy, while also being portable, easy to use, and cost-effective. The necessary system would be able to continuously monitor relatively simple parameters to measure the interaction between participants and their environment.

3.3 Design Goals

Unlike old-style networks, sensor design networks are influenced by many factors. The core factors that need to be understood as a first step to making an informed choice are: environment, fault tolerance, transmission media, hardware constraints, sensor node size, power consumption, expandability, network topology, product cost, and security and different methods and standards of wireless communication. It is important to examine these factors when designing sensors because they serve as guidelines for the design of a protocol or an algorithm for wireless sensor networks. In addition, these influencing factors enable the comparison of different schemes [50], [51]. To deal with the technical challenges of designing an efficient wireless network based on multi-sensors for the smart home, the following design goals need to be satisfied.

3.3.1 Environment

Sensor networks are expected to be able to operate within different environments, from hospitable to extremely hostile. They must be autonomous and operate in high volumetric densities unattended. The system must have fault tolerance to respond gracefully to unexpected hardware or software failure.

3.3.2 Fault tolerance

There are several levels of fault tolerance. The level of fault tolerance should meet the environment to which the system will be exposed. For example, remote stations deployed in a hospitable environment, such as in a house, monitoring temperature, humidity, or light may require low tolerance levels to continue to operate compared to those deployed in an extremely hostile environment, such as around machinery or in a battlefield, ocean bed, factory, or disaster or toxic area.

3.3.3 Transmission Media

Remote stations in the wireless sensor network communicate with each other through transmission media. These communication media can be established through infrared, radio, or optical radios. There are advantages and disadvantages to each of these media. The optical communication medium consumes low amounts of energy and provides high levels of security; however, it requires line-of-sight and is sensitive to atmospheric conditions. The infrared communication medium does not require an antenna to operate, but it has limited broadcasting capacity. The radio communication medium is the best choice of the three communication media even though it requires an antenna. One option for the radio communication medium is through industrial, scientific, and medical (ISM) bands, which are unlicensed bands and bands allocated for low power devices. To guarantee that the spectrum is used fairly, the unlicensed bands need to follow national usage requirements.

3.3.4 Hardware Constraints

The main functions of the sensor node network (remote station) in the field are to detect events, process data, and then transmit the data to the base station. The remote station is made up of the following four basic components (as shown in Figure 3.1): sensing unit, processing unit, transceiver, and power unit.

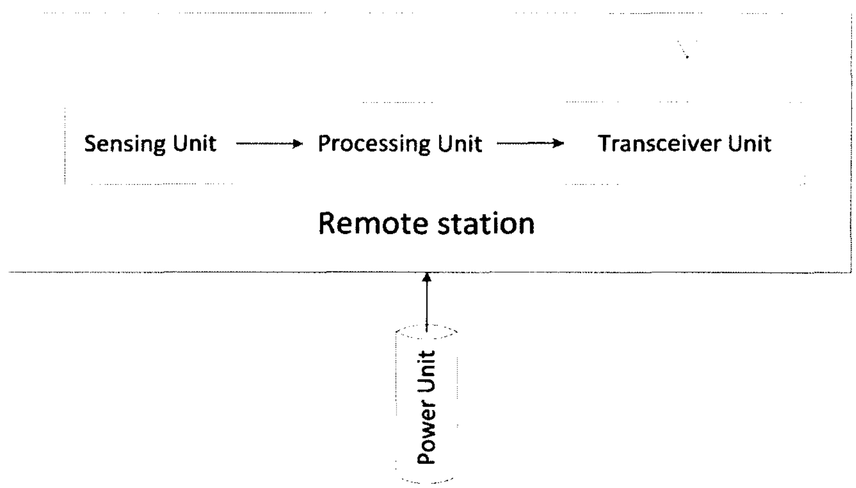


Figure 3.1: Generic figure of sensor node

- **Sensing unit:** The sensing unit is composed of sensors. Sensors are devices that detect or measure a physical condition (such as heat, light, sound, pressure, magnetism, or motion). The analog voltage or signals generated by corresponding sensors based on the observed phenomenon are converted to digital form by analog-to-digital conversion (ADC), processed, and then transmitted to the processing unit for further processing analysis. These tasks are the major sources of power consumption in the sensing unit.

- **Processing unit:** The processing unit can be a microcontroller or microprocessor. Its main responsibilities include responding to the sensing unit, processing data, and controlling the functionality of other components in the remote station.
- **Transceiver:** The transceiver unit is used to connect the remote station to the network. Within the transceiver, a source of power consumption for radio usage in the remote station evolves in five modes: transmit, receive, idle, command and sleep.
    - **Idle mode**: The RF module (node) is in Idle mode when it is not receiving or transmitting data.
    - **Transmit mode:** The RF module (node) is in Transmit mode when it is transmitting data.
    - **Receive mode:** The RF module (node) is in Receive mode when it is receiving data.
    - **Sleep mode:** The RF module (node) is in Sleep mode when it is not being used and enters low-power consumption.
    - **Command mode:** The RF module (node) is in Command mode when it is modifying or reading the RF module parameters.

Possible wasteful energy consumption in sensor node could be due to the following reasons:

- **Idle:** Idle attending to the channel waiting for possible traffic.
- **Retransmitting of data:** Due to the occurrence of a collision
- **Overhearing:** When a sensor sends a packet to the wrong recipient.

- **Over-emitting**: When sensors receive data when they are not ready for them.

It is recommended to avoid using the idle mode when it is not transmitting or receiving data to reduce power usage in the unit.

- **Power unit:** Power consumptions can be divided into three categories: sensing, communicating, and data processing. A more detailed discussion of this unit can be found in the power consumption section.

3.3.5 Sensor Node Size

Since the sensor nodes are deployed in the hundreds or thousands, they are designed to be small with limited resources such as energy, computational power, and available storage. All of the components in the remote station may need to fit into a matchbox-sized module [52]. The required size may be even smaller than a cubic centimeter [53].

3.3.6 Power Consumption

Advances in microelectronic technology have made it possible to design sensor nodes of small physical size, on the order of one cubic centimeter [53]. Although the size has made the wireless sensor network usable in many different applications, at the same time the size affects certain resources such as energy, computational power, and available storage. Sensor nodes are equipped with a limited energy source: batteries. Their lifetime, therefore, depends on the lifetime of the batteries. Depending on the application, the lifetime of the sensor node can be only few days, which is unacceptable in areas of application that require constant monitoring. In addition, hundreds or thousands of wireless sensor networks are often deployed in harsh and hostile environments. In these contexts, after the deployment phase occurs, it is difficult to have access to the nodes to recharge or replace batteries.

In some applications (such as home automation or Smart energy) where line power is readily available in places where the sensors nodes are placed, the line power can be used so that sensor nodes can have an unlimited supply of power resources for the applications. In this respect, the nodes are partially a wireless system. Although the nodes are not portable, the data transmission occurs in a wireless manner.

3.3.7 Expandability

Depending on the application, the number of sensor nodes deployed in the field may be in the order of hundreds or thousands. New scheme systems must be able work with this numbers of stations. The design goal is to develop flexible and scalable architecture that can accommodate the requirements of new sensor nodes in the same infrastructure.

3.3.8 Network Topology

The topology network is important; it is the structure that allows standard wireless devices to have multiple simultaneous connections. It is also one of the ways that the different wireless standards are distinguished. In theory, a wirelessly enabled device can connect to any compatible wireless devices within transmission ranges. It is important to understand what the new device will be connecting to. Network topology is an important feature of device connectivity. Not only does it allow devices to have multiple connections, but it also allows devices to join and leave the network at any time. Network topology is one of the important methods to distinguish the diverse standards of wireless connections. In short, topology is a method of making and securing connections, managing power consumption, transmitting different types of data, and coexisting with other radios. Remote stations are deployed unattended in high volumetric densities and harsh environments. The stations are prone to frequent failure and make topology network maintenance a significantly challenging issue. Topology maintenance and changes can be viewed in three phases [50], [51]: pre-deployment and deployment, post-deployment, and re-deployment of additional nodes.

3.3.8.1 Pre-deployment and Deployment

In the pre-deployment and deployment phase, the systems for initial deployment must [50], [51]:

- Reduce the installation cost;
- Eliminate the need for any pre-organization and pre-planning;
- Increase the flexibility of the arrangement; and
- Promote self-organization and fault tolerance.

3.3.8.2 Post-deployment

The common issues that affect sensor node topologies after deployment that should be avoided are usually related to improper position, reachability due to jamming, noise, moving obstacles, energy availability, or malfunctioning of the nodes [50]-[52], [54]. These issues should be taken into account. It must be recognized that node failure could be cause by inefficient energy and that the node may be a target for deliberate jamming. In this way, sensor network topologies are prone to frequent changes after deployment [50], [51].

3.3.8.3 Re-deployment of Additional Nodes

Re-deployment of new nodes to replace malfunctioning nodes should be able to be easily achieved and these new nodes should also able to join the network or organize the network without any problem.

3.3.9 Product Cost

As we have indicated, the sensor nodes are deployed in the thousands. The price of the sensor nodes is determined by a single sensor node. The price of a single node should as cheap as possible; otherwise it is wise to use a commercial product.

3.3.10 Standard

Devices from a diverse range of suppliers need to interact with each other. It is, therefore, important to determine a standard to establish communication to each other's devices. This allows all of the devices that adopt the standard to work together or share elements of their design. Choosing standards is an important task because it has a reference a protocol stack that extends up through enough layers to provide the ability to design interoperable application.

3.3.11 Security

Sensor networks can be deployed into any environment, from harsh to hostile. They are not protected from physical attack; anyone can have access to the location where they are deployed. This is major security concern related to the wireless networks because anyone can gain access to sensitive information by listening to transmission messages and can even modify the message and retransmit it to its intended destination.

The following elements of network security are necessary to ensure a secure network [55]:

- **Secrecy or confidentiality:** Secrecy provides privacy and protects information from being intercepted. Even if someone intercepts the information, the information would have no meaning.
- **Authentication:** Authentication methods verify the identity of a person or computer accessing the network.
- **Integrity:** Integrity maintains data consistency and prevents tampering with information.
- **Nonrepudiation:** Nonrepudiation provides proof of origin to the recipient.

3.4 Wireless Technologies

Besides ZigBee, several other technologies were investigated in terms of their features such as power consumption, distance, data rate, data delivery, cost, learning curve, size, installation, usability, portability, and reliability. The potential wireless technologies that were investigated included Wi-Fi, Bluetooth, Ultra wideband (UWB), Wireless Universal Serial Bus (USB), Infrared (IR) wireless, and XBee. These technologies are discussed very briefly below and their advantages and disadvantages are outlined in the Appendix A.

3.4.1 Wi-Fi

Wi-Fi is a wireless local area network (WLAN) that uses high frequency radio waves to transmit and receive data over distances of a few hundred feet. The technology is based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards. The main application for Wi-Fi is to provide wireless high-speed Internet and network connectivity. Many computer-associated devices, such as video game consoles, home computer networks, and mobile phones, are supported by Wi-Fi.

3.4.2 Bluetooth

Bluetooth is one of a standard of wireless radio technologies that utilizes short distance radio waves to transmit signals over short distances. Bluetooth technology was originally regarded as a wireless alternative to RS-232 data cables. The technology is suitable for applications that are between different electronic devices, such as cars phones, mobiles, laptops, headsets, and various other devices.

3.4.3 Ultra wideband (UWB)

Ultra wideband (UWB) technology operates on the 3-10GHz frequency band on an unlicensed basis. With regulatory approval in major markets worldwide, this technology has gained broad industry use as evidenced by its selection for the WiMedia standard in addition to Wireless USB and high-speed Bluetooth. UWB is used in wireless networking to achieve high bandwidth connections with low power utilization by using a large portion of the radio spectrum. UWB technology has potential applications in consumer electronics and wireless personal area networks (PAN) ranging from digital camcorders and DVD players to a mobile PCs and a high-definition TVs (HDTV). However, the most recent applications target sensor data collection, precision locating, and tracking applications.

3.4.4 Wireless Universal Serial Bus (USB)

Wireless Universal Serial Bus (USB) is an industry standard for wireless networking based on Ultra wideband (UWB) signalling technology. Wireless (USB) is a short-range, high-bandwidth, low-power wireless radio communication protocol that employs a computer's USB ports for wireless local networking for applications such as USB products.

3.4.5 Infrared (IR) wireless

Infrared (IR) is a wireless technology that is used for short-medium-range communications and control devices or systems that convey data through IR radiation. IR wireless technology is utilized for applications such as intrusion detectors; home-entertainment control units; robot control systems; medium-range, line-of-sight laser communications; and cordless microphones, headsets, modems, printers, and other peripherals. Although some systems operate in line-of-sight mode with a visually unobstructed straight line through space between the transmitter and receiver, other systems operate in diffuse mode, also known as scatter mode. These kinds of systems can function when the transmitter and receiver are not directly visible to each other. An example of such a system is a television remote-control box [56]. The remote-control box does not have to be pointed directly at the set, although the box must be in the same room as the set or just outside the room with the door open.

3.4.6 Radio Frequency Identification (RFID)

Radio frequency identification (RFID) is rapidly becoming the technology of choice for automatically identifying people or objects. It is small, inexpensive, and not based on line-of-sight operation. A RFID system typical consists of an RFID reader (or transceiver) and an RFID tag (or transponder). The RFID reader components consist of a RFID transmitter, one or more antennae, and an RFID receiver to allow encoded data to be transmitted and received from a tag or tags to be processed. A typical tag may contain a digital microchip attached to antennae to send, receive, and process decoded data.

3.4.7 ZigBee

Based on our investigation, the most suitable wireless technology for this research is ZigBee. The ZigBee technology is widely used in smart home systems. This technology is designed for a low data rate, low power consumption, low-cost, wide coverage, and wireless mesh networking standard communications protocol for wireless smart home control and monitor system. Table 3.1 illustrates comparison of ZigBee to these potential wireless technologies. The comparison is mostly based on the following technical features: range, frequency band, bandwidth, network topology, power, and security.

	ZigBee	Wi-Fi	Bluetooth	Z-wave
IEEE Spec.	802.15.4	802.11x	802.15.1	N/A
Operating Frequency Band	868 MHz (EU), 900-928 MHz (NA), 2.4 GHz (Global)	2.4 and 5 GHz	2.4 GHz	900 MHz
Bandwidth	20, 40 and 250 Kbits/s	11 & 54 M bits/sec	1 M bits/s	40 Kbits/s
Range (meters)	10-100 m	50-100 m	10 m	30 m
Networking Topology	Ad-hoc, peer to peer, star, or mesh	Point to hub	Ad-hoc, very small networks	Mesh
Network size	65536	32	7	232
Power Consumption	Very low	High	Medium	Very low
Security	128 AES plus application layer security		64 and 128 bit encryption	
Applications	Control and monitoring	Wireless LAN	Device Connectivity	Control and monitoring

Table 3.1: Comparison of ZigBee with other wireless protocols

3.5 ZigBee Protocol

ZigBee is a wireless communication standard based on IEEE 802.15.4 low-rate wireless personnel area network (LR-WPAN). The standard was established to meet the needs of low-cost, low-data rate, low-power, and short-range unattended devices that accommodate the global standard. The potential applications of the ZigBee include home automations, smart energy, telecommunication, and healthcare. ZigBee is specified to operate in the industrial, scientific, and medical (ISM) radio bands: 868 MHz with one channel and over-to-air date rate of 20 kbps in Europe, 915 MHz with 10 channels and over-to-air date rate of 40 kbps in North America, and 2.4 GHz with 16 channels and over-to-air date rate of 250 kbps for worldwide coverage. ZigBee allows multi-point networks. The different frequency bands and their characteristics are shown in Table 3.2. ZigBee protocol features include [57]:

- Support for multiple network topologies, such as point-to-point, point-to-multipoint, and mesh networks;
- Low duty cycle – provides long battery life;
- Low latency;
- Direct Sequence Spread Spectrum (DSSS);
- Up to 65,000 nodes per network;
- 128-bit AES encryption for secure data connections; and Collision avoidance, retries, and acknowledgements.

Band	Data rate	Modulator	Channels	Coverage	License required
868 MHz	20 kbps	BPSK	0	Europe	No
915 MHz	40 kbps	BPSK	1-10	North America	No
2.4 GHz	250 kbps	O-QPSK	11-16	Global	No

Table 3.2: The different frequency bands and corresponding characteristics of ZigBee

3.5.1 ZigBee nodes

There are three types of ZigBee nodes: ZigBee coordinator (ZC), ZigBee router (ZR), and ZigBee end device (ZED).

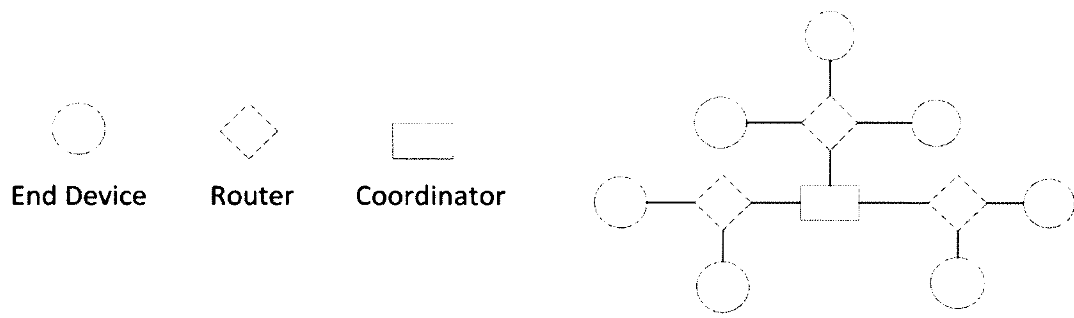


Figure 3.2: Three types of ZigBee nodes: coordinators, routers, and end devices

3.5.2 ZigBee Coordinator (ZC)

The ZigBee network consists of one ZigBee coordinator and one or more end device to form the personnel area network (PAN). The end device has a unique PAN identity (known as PAN ID) to avoid miscommunication between PANs. The coordinator PAN ID is established using the ID (PAN ID) and router commands. The end device associates to a coordinator without knowing the address, PAN ID, or channel of the coordinator. It is the responsibility of the ZigBee coordinator to monitor and control the overall network.

3.5.3 ZigBee Router (ZR)

The ZigBee router establishes a communication link between the coordinator and the end device. Establishing this communication link is very important in situations that require the relay of vital information from several remote stations (end devices) to central unit (ZigBee coordinator). The ZigBee router not only extends network area coverage but also redirects data around obstacles. It also provides up alternative path for data transfer in case of network congestion or device failure.

3.5.4 End Device (ED)

The end device must be connected to the coordinator or router in the network. The end device has limited resources to perform its function. The end device can transmit or receive messages, but cannot relay messages from other ZigBee networks. It is simple and consumes less power.

3.6 ZigBee Topology Network

The three common network topologies supported by ZigBee are star, peer-to-peer (mesh), and cluster tree. The structures of these topologies are shown in Figure 3.3.

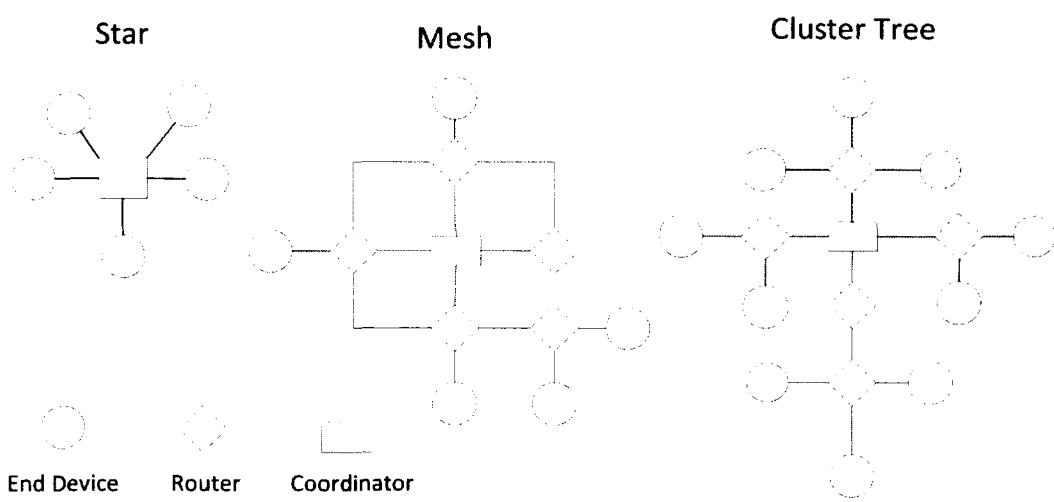


Figure 3.3: Three common ZigBee topologies: Star, Mesh, and Cluster Tree

3.6.1 Star Topology Network

The star topology network consists of one coordinator connected to one or many end devices (ED). The end devices have limited resource to actively transmit data, receive acknowledgement, and return to sleep. They do not relay information from other devices to the coordinator. By spending much time sleeping, the network lowers their duty cycle and extends battery life.

Data in star topology can be transferred in two ways only:

- Data transfer to a coordinator from a device and
- Data transfer from a coordinator to a device.

3.6.2 Mesh or Peer-to-Peer Topology Network

Mesh networking is a powerful way to route data. The peer-to-peer topology network consists of all of the routers. In peer-to-peer, each device can communicate directly with any other device if the devices are placed within the range necessary to establish a successful communication link. Range is extended by allowing data to hop node to node and reliability is increased by "self-healing," the ability to create alternate paths when one node fails or a connection is lost [37].

A mesh network has the following characteristics:

- Every node is capable of connecting directly to all of its neighbouring nodes;
- Every node is capable of routing traffic to and from all of its neighbouring nodes;
- The network is self-forming. This means that new nodes are automatically added to the network without the need for manual configuration; and

- The network is self-healing. This means that the network automatically adjusts the routes to and from nodes.

Data in peer-to peer topology can be transferred in three ways:

- Data transfer to a coordinator from a device;
- Data transfer from a coordinator to a device; and
- Data transfer between two peer devices.

3.6.2.1 Mesh Example

Figure 3.4 (Figure 3.5A) illustrates a typical mesh network, and Figure 3.4 (Figure 3.5B) shows how the mesh network dynamically updates itself when a connection is lost. Node 5 creates an alternative pathway through Node 4 to send collected data to the gateway when the path to the gateway through Node 3 fails for any reason. Node 5 waits for acknowledgement from Node 3. If there is no acknowledgement from Node 3, Node 5 will still attempt to deliver the package to the gateway; however, through the next best path.

In our case, we assumed that the best alternative hop to the gateway is Node 4. Node 5 will dynamically adapt itself by creating an alternative path through Node 4 to send collected data to the gateway.

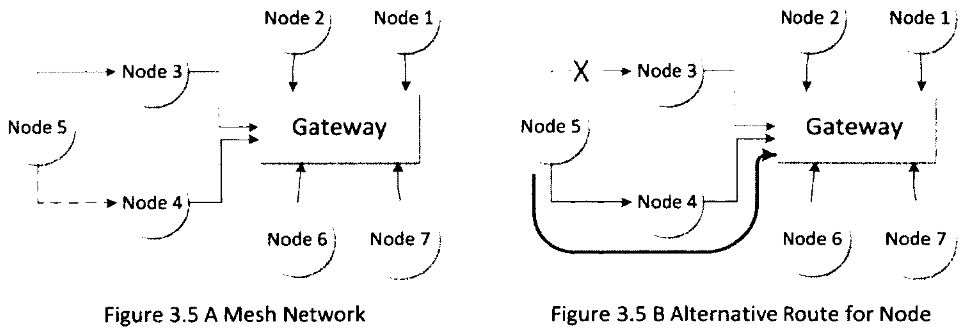


Figure 3.4: Mesh Networking

The collected data is wirelessly transmitted to the gateway. The gateway collects, processes, analyzes, and presents the measurement data using software. The software running on the gateway performs appropriate computation and displays the information on the user screen.

3.6.3 Cluster Tree Topology Network

The cluster tree is a combination of both star and mesh topology. The topology allows for a heterogeneous network in which ZigBee routes and actively and continuously transmits and revives the data that requires a robust power supply, while other nodes respond to stimulus and spend most of their time sleeping. The network is reliable and scalable to extend the range of the network beyond that of a star and mesh. Data in cluster tree topology can be transferred in three ways:

- Data transferred to a coordinator from a device;
- Data transferred from a coordinator to a device; and
- Data transferred between two peer devices.

3.7 ZigBee Protocol Architecture

ZigBee protocol architecture consists of IEEE 802.15.4 and a ZigBee layer, as shown in Figure 3.5.

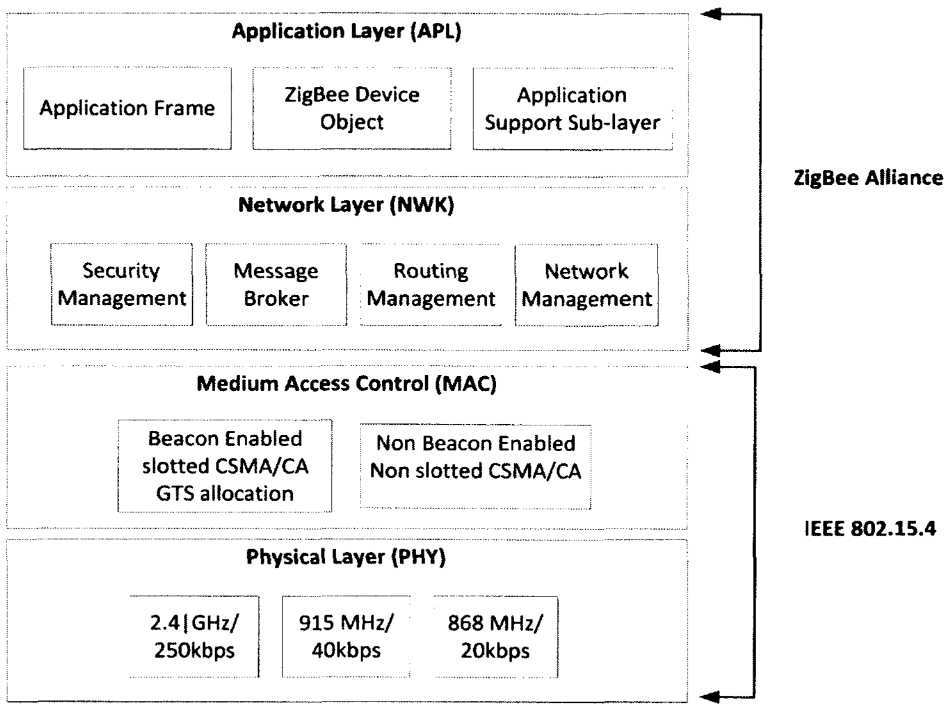


Figure 3.5: ZigBee protocol stack

3.7.1 IEEE 802.15.4

IEEE 802.15.4 consists of a physical (PHY) layer and a Medium Access Control (MAC) layer.

3.7.1.1 Physical (PHY) layer

PHY layer is the lowest layer of the IEEE 802.15.4 protocol. It is the closest layer to the hardware. The layer directly controls and communicates with the radio transceiver. The description of the PHY layer outlines a low-power spread spectrum radio operating at frequency bands such as 2.4 GHz, 915 MHz, and 868MHz. The layer is responsible for the following tasks:

- **Activation and deactivation of the radio transceiver:** The radio transceiver can operate in four different modes: transmitting, receiving, sleeping, and idle.
- **Energy detection (ED):** This layer detects and estimates signal energy (power) level within the bandwidth of an IEEE 812.15.4 channel and determines whether the channel (desired channel) is busy or available (idle) before signal transmission.
- **Link quality indication (LQI):** This layer assesses the quality of signal on a link.
- **Clear channel assessment (CCA):** This operation is responsible for reporting medium activity states (busy or idle). It ensures that the channel is not selected by any other device for a signal to be transmitted. The three following tasks are performed by the CCA:
    - **Energy detection mode:** This mode determines whether the received energy is higher than a given threshold (e.g. energy detection threshold). If the received energy is high it is an indication of the channel being busy.
    - **Carrier sense mode:** This mode is an alternative to the busy or idle mode of a frequency channel.
    - **Carrier sense with energy detection mode:** This mode is the combination of the above methods.
- **Channel frequency selection:** The PHY layer selects the desired channel upon the reception of a request from a higher layer.

3.7.1.2 Medium Access Control (MAC) Layer

The MAC layer provides an interface between the PHY layer and the network layer. The description of the MAC layer explains how multiple 802.15.4 radios operating in the same area can share the airwaves. The MAC layer description also explains different network topologies (e.g. star, peer-to-peer, and Tree cluster). Its responsibilities include the following tasks: generating beacons to enable the network and synchronizing the device in a beacon-enabled network. It is also offers the option for a device to join or leave a network, this option is known as association and disassociation.

3.7.2 ZigBee Layer

The ZigBee description explains application profiles that allow devices from different manufacturers to communicate with each other. ZigBee consists of the network layer and the application layer.

3.7.2.1 Network (NWK) Layer

The NWK layer is the interface between the MAC layer and the application frame. It is responsible for managing the network formation and routing. Routing is the process of selecting paths through which the data will be relayed to its destination.

3.7.2.2 Application (APP) Layer

The application layer is the highest level layer in the ZigBee network and application objects. The application object is developed to customize devices for various applications. It also controls and manages the protocol layer in a ZigBee device. The application layer consists of three parts: the application sub layer (APS), the application framework (AF), and the endpoints.

- **The application sub-layer:** This layer interfaces the ZigBee application layer to the ZigBee networking layer. It also provides a common set of data transport services to all of the endpoints. The endpoints are what most people associate with ZigBee.
- **The application frame (AF):** This is the multiplexes and container that host application objects on a ZigBee device (endpoints). All endpoints are associated with application frames. The application frame gathers data that comes into application layer and sends them into their right destinations, the endpoint associated with the frame.
- **The application object (endpoints):** Endpoints are the numbers (up to 240 endpoints) of container spaces that stores all of application objects. The application object is basically a device profile with whatever extra functionality the user decides to add.
- **ZigBee device object:** This is a protocol within the ZigBee protocol stack that is responsible for overall device management and security keys and policies.

3.7.3 Data Transfer to a Coordinator

There are two methods that data can transfer to a coordinator in IEEE 802.15.4: beacon-enabled and non-beacon-enabled. Figure 3.6 is shown the data transfer to coordinator in IEEE 802.15.4. The two approaches of transferring these data to the coordinator are shown in Figure 3.7.

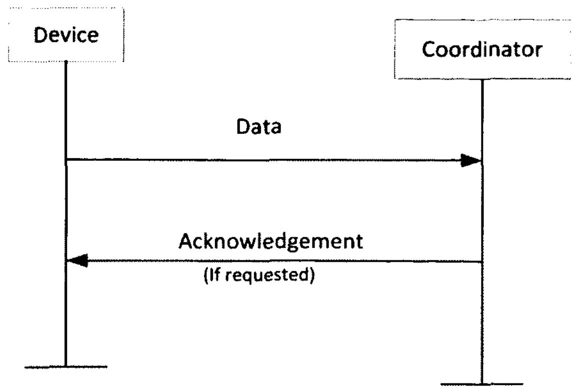


Figure 3.6: Data transfer to a coordinator in IEEE 802.15.4

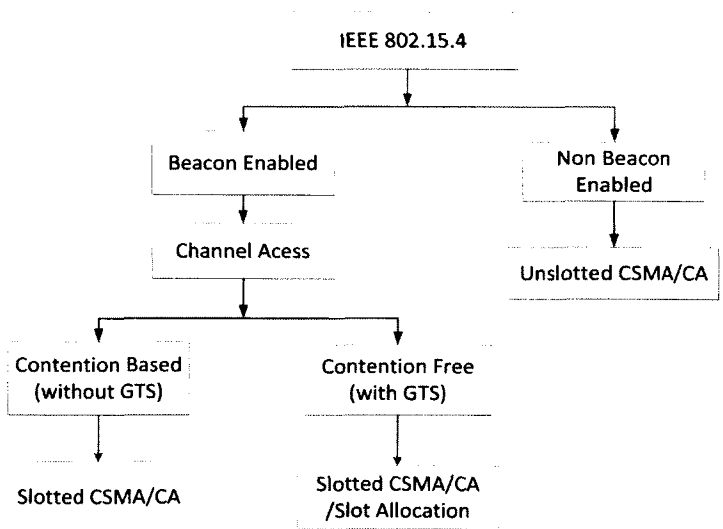


Figure 3.7: IEEE 802.15.4 functioning mode

3.7.3.1 Beacon-enabled

If the PAN coordinator selects the beacon-enabled mode to transmit the signal, there are two ways of transmitting the data: contention-based or contention-free.

In contention-based, IEEE 802.15.4 (PAN coordinator) has implemented Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) method to allow all devices in the network to transmit the signal at the same frequency channel. There are two types of the CSMA-CA mechanisms in describe IEEE 802.15.4: CSMA-CA with slotted and CSMA-CA without slotted. In both circumstances, the algorithm is applied using units of time called back-off periods. When any device decides to transmit a signal, it must first perform clear channel assessment (CCA) to ensure that the desired channel is not in use by any other device.

In contention-free, IEEE 802.15.4 (PAN coordinator) allocates a time slot to a specific device. Without using CSMA-CA mechanism, the device with an allocated guaranteed time slot (GTS) with initially transmits the signal during GTS.

In a beacon-enabled network, the device continuously performs actively and requires a robust battery supply. Beacon-enabled also allows for heterogeneous networks. Some devices are active at all times, while others respond to stimulus and spend most of their time sleeping.

3.7.3.2 Non Beacon-enabled

If the PAN coordinator selects the non-beacon enabled mode, there are no channels to access and non-beacon-enabled the device to use to transmit the data to the PAN coordinator. The device does not use slotted CSMA-CA mechanism to provide medium access control. One of the advantages of the non-beacon enabled network is that the ZigBee device spends much time sleeping, lowering their duty cycle (activity) and extending the battery life, as a result. The devices are active when the beacon transmits data, receives acknowledgement, and returns to sleep mode.

3.7.3.3 Data Verification Method

Data verification method in IEEE 802.15.4 uses a 16-bit frame check sequence (FCS) based on the international Telecommunication Union (ITU) cyclic redundancy check (CRC) to detect possible errors in the data packet [58].

3.8 Overview of the Research Prototype System

In our research, we designed, developed, and implemented a wireless system consisting of several sensors to be used to monitor various Activities of daily living of a user by analyzing different changes in the environmental conditions in a smart home, collect information using microcontroller PIC, and wirelessly transmit the information to a base station using XBee modules. The collected information can be analyzed and displayed to a user's PC screen and simultaneously to a local liquid crystal display (LCD). A buzzer is also included in the prototype system to alert the user of any unacceptable changes in behaviour. The prototype system is cost-effective, has low power consumption, and provides for wireless mesh networking. The prototype system can collect multiple data at the same time. The prototype system is divided into two parts: a remote station and a base station, as shown in the generic diagram of the prototype system in Figure 3.8.

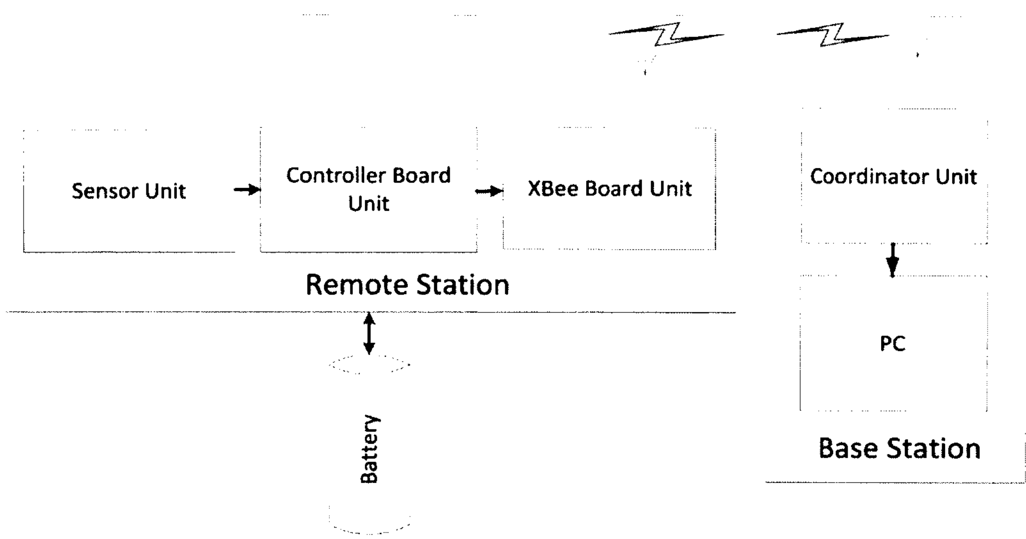


Figure 3.8: Generic figure of base station and remote station of the prototype system

- The remote station is composed of:

  - A sensor unit,

  - A controller board unit,

  - An XBee module board unit, and

  - Power by an energy source (usually a battery or solar energy)

- The base station consists of a coordinator unit connected to a PC.

The prototype system is made up of a set of independent remote stations, the base station as a gateway, and software. The remote station is a self-contained system consisting of several units and powered by an energy source, such as a battery or solar cell. The sensor unit consists of several sensors connected to the controller board unit. The controller board unit consists of a microcontroller PIC 16F876. The main functionality of the microcontroller in the research is to:

- Obtain raw samples of sensor inputs either in analogue or digital form;
- Convert these analog samples to digital binary; and
- Get ASCII code and compile information to be displayed to either on X - CTU terminal or LCD display.

An XBee board unit is an XBee module. Its main functionality is to wirelessly transmit acquired data to the gateway. The gateway is connected to the PC, which is used for collecting, processing, analyzing, and presenting the measurement data using X-CTU software. The software running on the gateway performs the appropriate computation and displays the information on the user screen.

3.9 Components of the Research Prototype System

In this section, we provide the description of each component of the prototype system in more detail. Figure 3.9 illustrates each component in the prototype system. As mentioned above, the prototype system is divided into two parts: a remote station and a base station. The remote station consists of several components, including sensors, a buzzer, a microcontroller, an XBee module, and a power source.

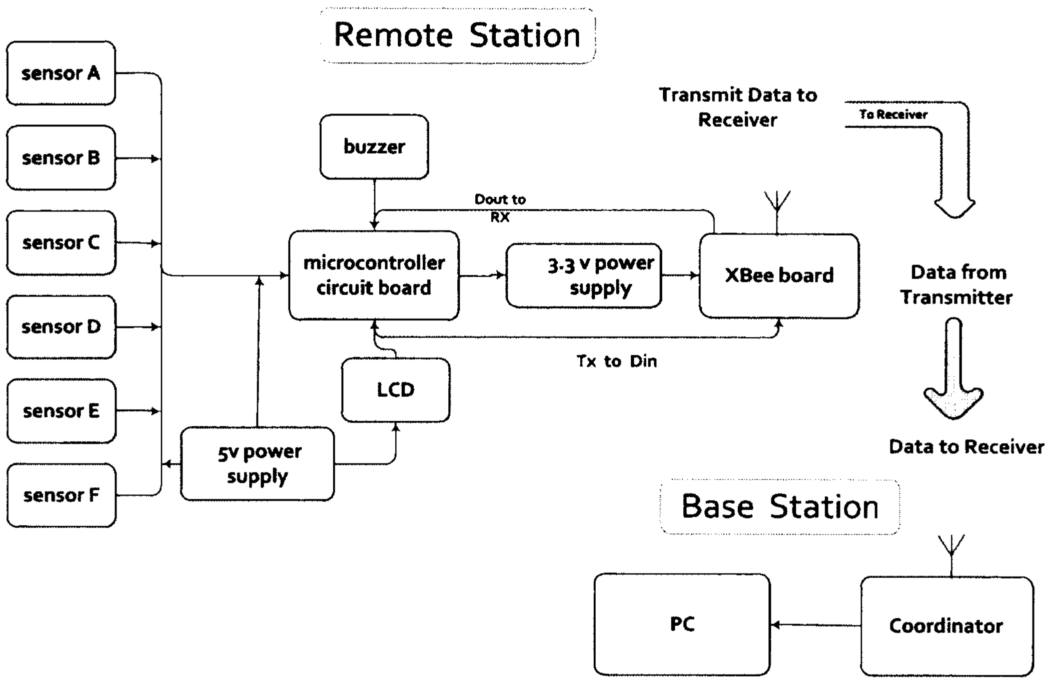


Figure 3.9: Functional block diagram of the system

The base station consists of a coordinator unit. The description of the prototype system is categorized into the following five parts:

(1) Sensors and buzzer;

(2) Microcontroller;

(3) XBee module;

(4) Power supply; and

(5) Coordinator.

3.10 Remote Station Hardware and Specification

The remote station is composed of several sensors, a microcontroller board, an XBee Board, and a power source board. Six non-invasive sensors are composed of temperature, humidity, photocell, ultrasonic, pyroelectric ("passive") Infrared (PIR), Hall Effect, a 5V regulator, and a piezoelectronic buzzer. The microcontroller board contains a microcontroller (PIC 16F876) and XBee Board is composed of an XBee module. Table 3.3 provides a complete list of the components we used for the purpose of this research and their cost.

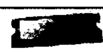
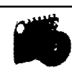
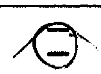
Name	Component Image	Description	Manufacturer	Cost (US Dollar)
XBee Module		XBee 1mW Wire Antenna - Series 1	Digi International	22.95
XBee Adapter		XBee Adapter kit - v1.1	Adafruit Industries	10.00
PIC16F876-20I/SP		Microcontrollers (MCU) 14KB 368 RAM 22 I/O	Microchip Technology	7.84
LCD		16x2 LCD Character Display Modules	Lumex	6.97
Temperature Sensor		TMP36 - Temperature Sensor	Analog Device Inc.	1.50
Ultrasonic sensor		Maxbotix Ultrasonic Rangefinder - LV-EZ1 - EZ-1	MaxBotix Inc.	25.00
Humidity sensor		HUMIDITY SENSOR 5V 5% 3-PIN - CHS-MSS - Sensors, Transducers	TDK	22.62
Light sensor		Photo cell (CdS photoresistor)	Advanced Photonix Inc.	1.00
Hall-Effect sensor		Sensor; Bipolar Hall-Effect; Radio Lead IC Package	Honeywell	0.99
PIR (motion) sensor		Pyroelectric ("Passive") InfraRed sensors	Adafruit shop	10.00
Buzzer		Piezoelectronic Buzzer	TDK	1.50
Total Cost				110.37

Table 3.3: Prototype components used for the study and their cost.

3.11 Hardware and Specifications

The features which are elaborated in the following sections include sensors and buzzers, a microcontroller board, an XBee module, and a 5V power supply to the coordinator at the base station. Table 3.4 illustrates a list of the features of the components of the prototype system.

Components	Features				
	Type	**Objective**	**Range**	**Voltage (V)**	**Manufacturer**
Microcontroller	PIC 16F876	Capture values	-40°C →85°C	2-5.5	Microchip
Temperature Sensor	TMP36	Monitor temperature	-40°C →150°C	2.7-5.5	Analog Devices
Humidity Sensor	CHS- series	Monitor humidity	5% →95%	5	TDK
Light Sensor	PDV-P8001	Detect light	---	2.5-higher	Advanced Photonic, Inc.
Ultrasonic Sensor	LV-maxBotix-EZ0	Detect distance	6 → 254 inch	2.5-5.5	MaxBotix
Motion Sensor	#555-28027	Detect motion	20ft (110°X70°)	3.3-5	Adafruit
Magnetic Sensor	US5881LUA	Detect open/close door	---	3.5-24	Melexis

Table 3.4: Prototype components used for the research

3.11.1 Asynchronous Serial Communication

It is important that different devices communicate with each other whether they are present on the same board or the same device or are on separate individual devices; thus, this communication has to be hardware self-determining. It should not matter what the devices or components are made of; however, there has to be a protocol for communication. There are large numbers of communication protocols available for devices to communicate with each other. The preferable communication system must synchronize its data transmission and receive a clock signal. In certain situations, such as in radio controlled wireless applications, it is difficult or sometimes impossible to establish a separate channel for data and a clock. In these situations, single wire transmission is more effective [59]. USART is the type of serial communication protocol that can establish this kind of transmission.

3.11.2 Universal Asynchronous Receiver and Transmitter (USART) Protocol

This protocol has two terminals: one terminal for receiving data and another for transmitting data. The data is sent and received with no need for clock synchronization. Therefore, it is called asynchronous. The USART protocol is very simple; it requires data composed of either 8 or 9 bits. Furthermore, The USART protocol can be configured as a full duplex asynchronous system that can communicate with peripheral devices, such as cathode-ray tube (CRT) terminals and personal computers, or it can be configured as a half-duplex synchronous system that can communicate with peripheral devices, such as analog-to-digital (A/D), digital-to-analog (D/A) integrated circuits, or serial EEPROM. USART is very commonly used in microcontrollers, because of which most of the microcontrollers provide a built-in hardware module such that this can be enabled. The hardware module has built-in circuitry to handle most of these USART tasks automatically [59], [60]. Microcontroller PIC 16F876 has two external pins (RC6 and RC7) that are necessary to implement the USART protocol, RC6 for the data transmitter (Tx), and RC7 for the data receiver (Rx).

3.12 ZigBee Starter Development Kits

The ZigBee alliance is composed of several associated companies. As of 2007, there were over 200 semiconductor companies that have developed their own ZigBee protocol compatible hardware platforms and corresponding software stack packages, including MICAz from Crossbow, JN5139 from Jennic, CC2430 from Texas Instrument (Chipcon), and XBee from Digi International. In terms of cost, unrestricted development environment, flexibility, and management of advanced nodes with many peripherals, the type of ZigBee that we believe is suitable for this thesis at this stage is XBee, as shown in Table 3.5.

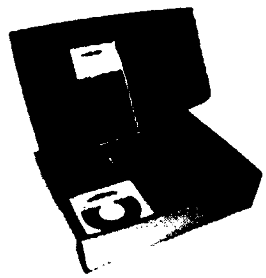
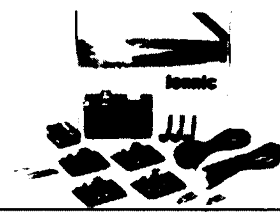
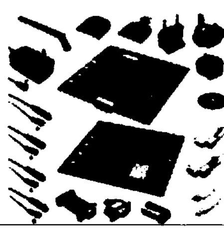
Component	Component Image	Manufacturer	Cost (US Dollar)
Crossbow MICAz Starter Kit		Crossbow	795
JN5139 ZigBee Evaluation Kit		Jennic	499.00
CC2430 ZigBee Development Kit		Taxes Instrument(TI)	1499.00
KIT STARTER XBEE		Digi International	144.81

Table 3.5: ZigBee starter Kits

3.13 XBee Module

The brand of ZigBee module that we used for the research is called XBee. An XBee module is a wireless communication module developed by Digi™ International to meet IEEE 802.15.4 standards that supports the

unique needs of low-cost and low-power wireless sensor networks. The module is relatively small, reliable, and easy to use; requires minimal power; and provides consistently good quality and performance on the delivery of data between devices. The XBee module consists of a microcontroller and a radio frequency integrated circuit (RF IC). The module supports a wide range of communications protocols, such as 802.15.4 and Wi-Fi. The XBee module operates within the Industrial, Scientific, and Medical (ISM)[6] radio band frequency of 868 MHz in Europe, 915 MHz in the North America and Australia, and 2.4 GHz worldwide.

3.13.1 XBee Series 1 and XBee Series 2

In our study, we began working with the XBee Series 1 module and then we switched to the XBee Series 2 module. XBee Series 1 and XBee Series 2 are not compatible. They use different chipsets, firmware, and protocol. They cannot be used together at the same time. In addition, XBee Series 1 is designed for point-to-point or point-to-multipoint tasks, while XBee Series 2 is suitable for mesh networks. Figure 3.10 shows an XBee Series 1 with RPSMA connector antenna.

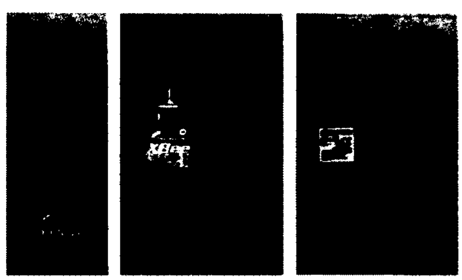


Figure 3.10: XBee Series 1 with RPSMA connector antenna

[6] ISM Band is the frequency band that is set aside to be used for scientific, medical, and industrial purposes.

XBee Series 1 consumes less power compared to other versions of XBee. The typical range for the basic module is up to 100 feet (30 meters) in a normal home or office and 300 feet (100 meters) outside under Line-of-sight conditions.

On the other hand, XBee Series 2 has higher power consumption compared to the XBee Series 1 module. We switched from XBee Series 1 to Series 2[7] because Series 2 has a higher range compared to Series 1, and also Series 2 is suitable for mesh networking. Series 2 is capable of transmitting data to a maximum range of 133 feet (40 meters) indoors and 400 feet (120 meters) outdoors under Line-of-sight conditions. Series 2 can be separated into two sub-series: Znet 2.5 and ZB. The difference between these two series is that Znet can update firmware over-the-air while ZB Series 2 and Series 1 can only upgrade firmware with X-CTU via a serial communication port [61]. The specification of XBee Series 1 and Series 2 are illustrated in Table 3.6.

The XBee Series 2 modules that we used for the study are equipped with a 1/4 wave monopole integrated whip antenna shown in Figure 3.11. The Series 2 module is based on the Ember[8] chipset and is designed to be used in applications that require repeaters or mesh networking. Appendix C provides more information on XBee modules.

---

[7] Series 2 consumes power approximately around 2mW (+3dBm).

[8] Ember is the ZigBee chip family that contains the highest wireless networking performance and application code space within the lowest power-consuming chip set.

Figure 3.11: XBee Series 2 module with an integrated whip antenna

	XBee Series 1	XBee Series 2
Indoor/Urban range	up to 100 ft. (30m)	up to 133 ft. (40m)
Outdoor RF line-of-sight range	up to 300 ft. (100m)	up to 400 ft. (120m)
Transmit Power Output	1 mW (0dbm)	2 mW (+3dbm)
RF Data Rate	250 Kbps	250 Kbps
Receiver Sensitivity	-92dbm (1% PER)	-98dbm (1% PER)
Supply Voltage	2.8 - 3.4 V	2.8 - 3.6 V
Transmit Current (typical)	45 mA (@ 3.3 V)	40 mA (@ 3.3 V)
Idle/Receive Current (typical)	50 mA (@ 3.3 V)	40 mA (@ 3.3 V)
Power-down Current	10 uA	1 uA
Frequency	ISM 2.4 GHz	ISM 2.4 GHz
Dimensions	0.0960" x 1.087"	0.0960" x 1.087"
Operating Temperature	-40 to 85 C	-40 to 85 C
Antenna Options	Chip, Integrated Whip, U.FL	Chip, Integrated Whip, U.FL, RPSMA
Network Topologies	Point to point, Star	Point to point, Star, Mesh
Number of Channels	16 Direct Sequence Channels	16 Direct Sequence Channels
Filtration Options	PAN ID, Channel & Source/Destination	PAN ID, Channel & Source/Destination

Table 3.6: The specification of XBee series 1 and series 2

3.13.2 XBee Development Board

The XBee module cannot function by itself; it needs to be connected to a circuit board to transmit or receive data. There are several XBee development boards that were considered in this research, such as SparkFun XBee Explorer USB board from SparkFun,[9] XBee adapter from Adafruit, and Digi development board from Digi International. However, after investigation, we choose the SparkFun XBee Explorer USB board for the base station and an XBee adapter for the remote station. Appendix C provides more information on the Digi International board.

3.13.3 The XBee Board

The XBee wireless modem adapter seen in Figure 3.12 is the board that we used for the remote station. It is an excellent low-cost adapter board, costing only $10 as shown in Table 3.7. The module is the easiest way to create a wireless point-to-point or mesh network. It has error correction and is configured with AT commands. There are multiple kinds of the unit and it can even be used to create a wireless serial link out of the box. The connection to a computer via USB can be done using an FTDI cable, which means that configuring or upgrading the adapter can be as simple as plugging in a cable. RESET and RX pins are connected into the XBee, passing through a level converter chip that brings the levels to 3.3V; however, voltage between 2.7 to 5.5V can be suitable to communicate with the XBee.

As shown in Figure 3.12, the adapter is very simple, consisting of the following components on board:

---

[9] SparkFun is a well-known online electronic vender that sells bits and pieces to make electronics projects possible, website: www.sparkfun.com

- 3.3V regulator to supply XBee with power, up to 250mA;
- 5V regulator to be used to connect to circuitry, such as the one we are using, without risk of damage;
- Two LEDs, one for activity (RSSI) and the other for power (associate); and
- 10-pin 2mm sockets, included to protect the modem and allow for easy exchange, upgrading, or recycling.

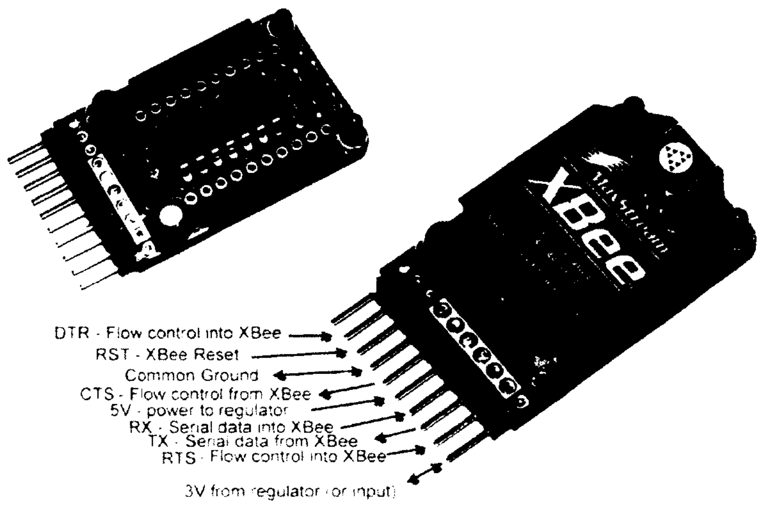


Figure 3.12: XBee Adapter[10]

[10] XBee Adapter from Adafruit, Adafruit website: http://www.adafruit.com

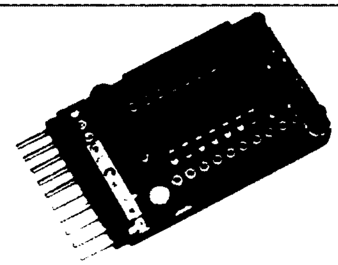
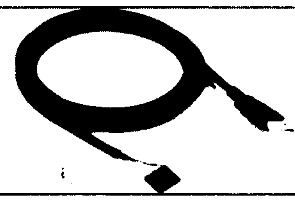
Component	Component Image	Manufacturer	Cost (US Dollar)
XBee Adapter kit - v1.1		Adafruit Industries	10.00
FTDI Cable 5V VCC-3.3V I/O		Adafruit Industries	20.00
Total			30.00

Table 3.7: XBee adapter board

3.14 Base Station – Receiver

The base station consists of the coordinator unit and the PC. The coordinator unit is composed of an XBee module plugged into an XBee explorer USB board from SparkFun Electronics and connected to the PC through a USB Mini-B cable connector, as shown in Figure 3.13.

The main functionalities of the base station are the following:

- To collect, process, analyze, and present the measurement data using X-CTU software. The software running on the gateway performs the appropriate computation and displays the information on the user screen; the software is used for configuring the XBee modules as a coordinator for the base station or routers for the remote station. Further discussion of the X-CTU can be found in section 4.6.4.

- To configure the XBee modules as a coordinator for the base station or routers and end devices for the remote station.
- The coordinator is used to establish the ZigBee network. Only one ZigBee coordinator and one or more end device are needed to form the personnel area network (PAN). The coordinator is configured to synchronize the communication network so that all wireless data received by the antenna are echoed through the USB port to the computer. The end device in the PAN has a unique PAN identity (known as PAN ID) to avoid miscommunication between PANs.
- The coordinator chooses the suitable channel with the appropriate PAN ID (16 and 64 bits) to establish the ZigBee network. The coordinator requests that the end device link to the network without knowing the address, PAN ID, or channel of the coordinator.
- The ZigBee coordinator is responsible for monitoring and controlling the overall network.
- The collected data are displayed on the X-CTU window, as shown in Figure 3.13.

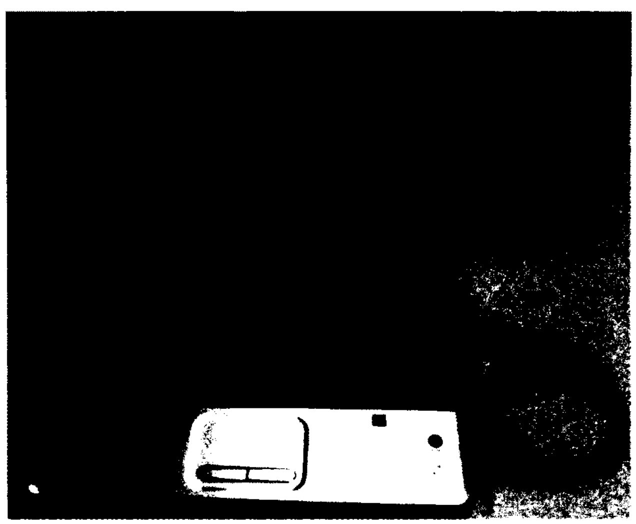


Figure 3.13: Base station of the prototype system

3.14.1 SparkFun XBee Explorer USB

The XBee explorer USB board was selected for the base station. The board was chosen for the following reasons:

(1) It is reasonably small and cost effective;

(2) The board works well with almost all XBee modules, including Series 1, Series 2, Series 2.5, and XBee Pro;

(3) It is very simple to establish a connection with this board. All that is necessary is to plug the module into the XBee Explorer and attach it to a mini USB cable (as shown in Figure 3.14), which allows direct access to the serial and program pins on the XBee module.

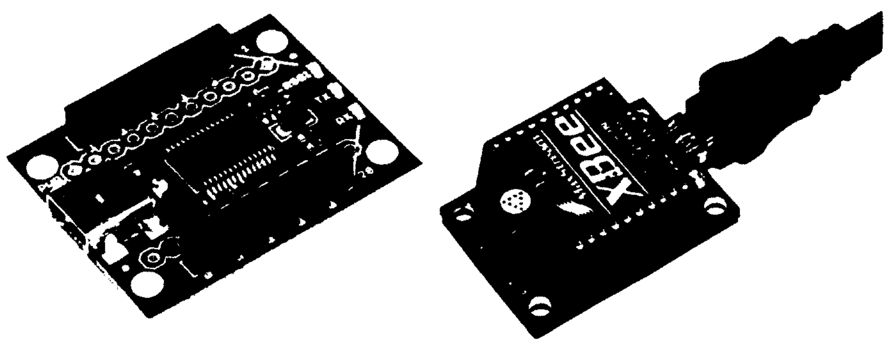


Figure 3.14: SparkFun XBee Explorer USB board[11]

Table 3.8 summarizes the cost of the XBee Explorer USB board.

[11] SparkFun XBee Explorer USB board from SparkFun, website: http://www.sparkfun.com/

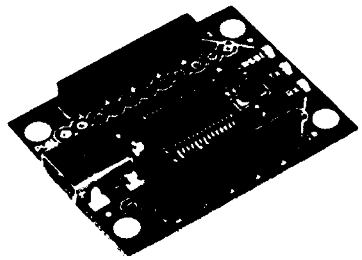
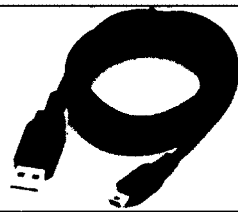
Component	Component Image	Manufacturer	Cost (US Dollar)
XBee Explorer USB		Sparkfun Electronics	24.95
USB Mini-B Cable		Sparkfun Electronics	3.95
Total			28.90

Table 3.8: SparkFun XBee Explorer USB board

CHAPTER 4

DESCRIPTION OF THE HARDWARE AND SOFTWARE

4.1 Introduction

The purpose of this chapter is to provide a detailed description of the hardware and software design of our prototype system. The chapter is divided into four sections: Section 4.2 shows the component images; section 4.3 provides information on the power supply for the prototype system. Section 4.4 contains an explanation of the connection of the components, and, finally, section 4.6 contains information on the software that we used to design and develop the prototype system.

4.2 Component Images

Figure 4.1 shows the actual images of the components we used for the research with arrows pointing to the direction of their connection. The figure consists of the following components:

Sensors: Temperature, Humidity, Light, Ultrasonic, Motion, and Hall Effect

Microcontroller: PIC 16F876

XBee: Series 2

XBee Board

5V regulators: LM 7805

LCD and Buzzer

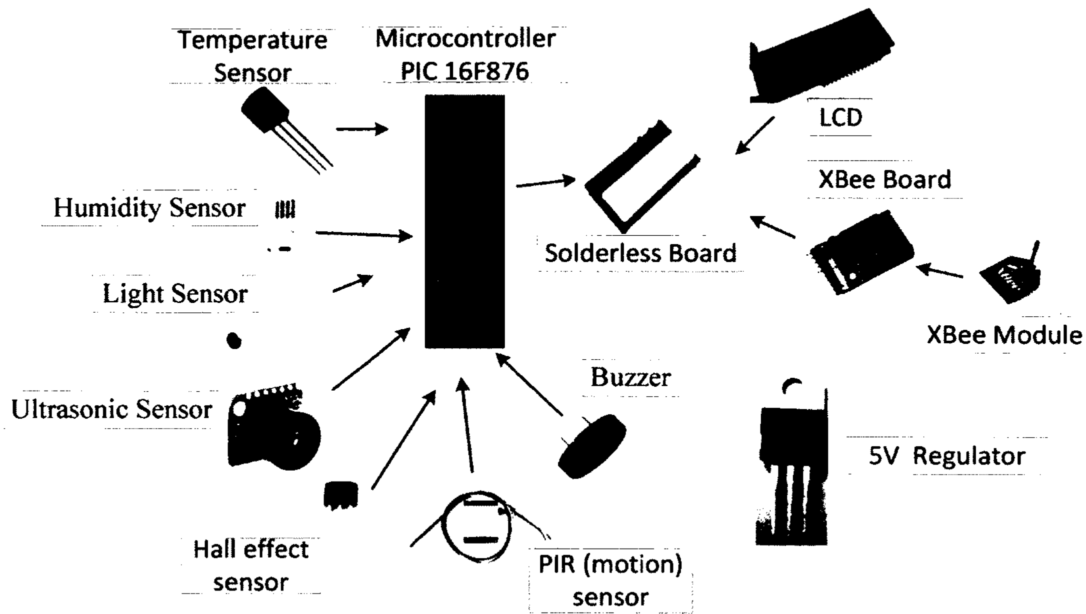


Figure 4.1: Developed remote station with all components

4.3 5V Power Supply Regulator

The first task is to design, develop, and implement a voltage regulator board to generate power to the microcontroller and other components. With the exception of the XBee module, which consumes only 3.3 V DC (Direct Current), the microcontroller PIC 16F876 and other components require 5V DC power supply for their operation. The most common 5V power supply is LM7805. LM7805 has a power supply of 1 AMP and a tolerance of +/- 5 %. In addition, a major concern for the accuracy of the output voltage is the AC noise coming into the input pin. This noise must be reduced. The easiest way to help flatten out ripple is by using filtering capacitors. Electrolytic capacitors and ceramic capacitors were the two types of capacitors chosen for this task. These two types of capacitors and other components in Table 4.1 and Figure 4.2 were used to design the 5V DC power supply for the prototype system.

Component	Voltage (V)
XBee Series 1	2.8 - 3.4
XBee Series 2	2.8 - 3.6
Microcontroller (PIC 16F876)	2 - 5.5
liquid crystal display (LCD)	5
Temperature Sensor	2.7 - 5.5
Humidity Sensor	5
Light Sensor	up to 100
Ultrasonic Sensor	2.5 - 5.5
PIR (Motion) sensors	3.3 - 5
Hall - Effect Sensor	3.5 - 24
Piezo Buzzer	3 - 30

Table 4.1: Components and their voltage ranges

- **Switch:** Use to turn system ON/OFF contains three pins that can easily be snapped into a breadboard to turn the system on or off. The center pin is connected to the power. Sliding forward turns the system off and sliding backward turns the system on.
- **DC jack:** Terminal for power source to the system contains pins that snap into a breadboard.
- **1N4001 protection diode:** Allows the current to flow in one direction, thus blocking the current from flowing in the opposite direction.
- **Two electrolytic capacitors and two 0.1uF ceramic capacitors:** Are used to stabilize the supply output and input.
- **Two LEDs and matching resistors:** The matching resistors are used to oppose an electric current by making a voltage drop between its terminals in proportion to the current.

From Ohm's law (Voltage (V) = current (I) x Resistor (R) → V = IR) with a 5V power supply and a current of 0.005, the matching resistor is 5/0.005 = 1000 Ohm.

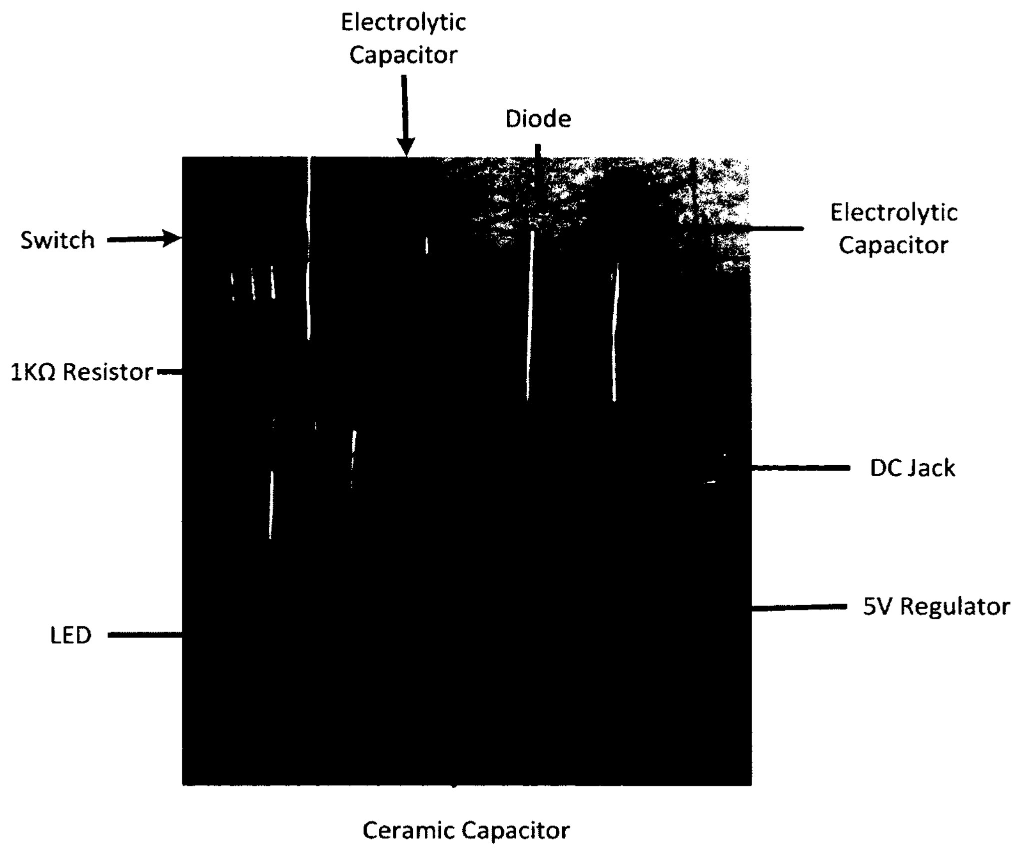


Figure 4.2: 5V power components

Figure 4.3 illustrates the 5V DC power supply that was designed for the study. The figure on the right is when the power switch was turned on, and the figure on the left is when the power switch was turned off. We used a voltmeter to test the power output. Appendix D provides more information related to designing the 5V power supply for the system.

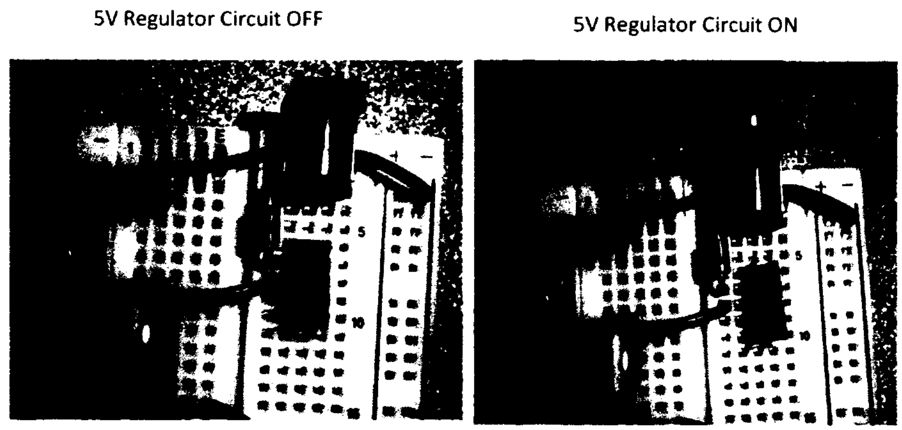


Figure 4.3: 5V regulator circuit designed board when the switch is off and on

4.4 Component Connections

The components and the orders of their interconnections are shown in Figure 4.4. Once the 5V power supply is functioning properly, the next task is to design and develop the microcontroller board. The microcontroller is designed and developed for its functionality by using the LED, buzzer, and LCD, which are programmed to test for the following: LED to test if it's blinking, buzzer to check it's buzzing, and LCD to test if we could display output from it. Once the microcontroller is confirmed to be working well, the sensors are connected one by one and the display of their output on the LCD begins. Then, we connected the XBee module to transmit the collected data to the base station. The components and order of their connections in this system can be described in the four following steps:

(1) Step 1 - microcontroller, PIC 16F876

(2) Step 2 - sensors, LCD, and piezoelectronic buzzer

(3) Step 3 - XBee module

(4) Step 4 - coordinator

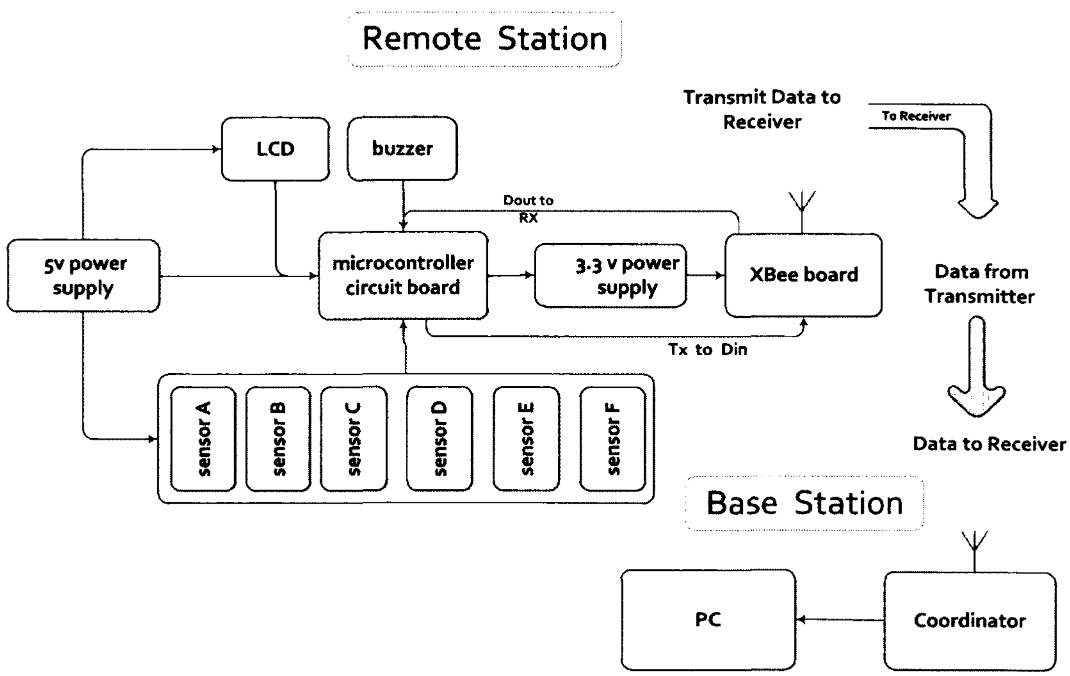


Figure 4.4: Block diagram of the prototype design

4.5 Components Connection Pins

Microcontroller PIC 16F876 is the heart of the remote station. All of the components on the remote station system must be connected to the microcontroller to be programmed to transmit data to the base station via the XBee modules. These components consist of the XBee modules, liquid crystal display (LCD), Hall Effect Sensor, and buzzer and monitor temperature, humidity, photocell, ultrasonic, and Pyroelectric ("passive") Infrared (PIR).

4.5.1 Microcontroller PIC 16F876 Pin Assignments

Microcontroller PIC 16F876 has three input and output (I/O) ports: PORTA, PORTB, and PORTC. These ports are bidirectional, which means the ports can be set as either inputs or outputs. These ports provide the means of communication with the microcontroller. PORTA has six pins, RA0 (least significant bit) to RA5 (most significant bit), as shown in the Figure 4.5 and Table 4.2. PORTB and PORTC have eight pins each, RB0 to RB7 and RC0 to RC7, respectively. Both PORTB and PORTC are 8-bit ports. In this thesis, PORTB is devoted to LCD usage. The LCD is used to display data locally. RC 6 and RC 7 of PORT C are used as the UART PORT to transmit and receive the collected data. Table 4.2 shows the pins of the microcontroller assigned for the function of the components.

IC Pin	PORT A Bit	IC Pin	PORT B Bit	IC Pin	PORT C Bit
Pin 2	RA0	Pin 21	RB0	Pin 11	RC0
Pin 3	RA1	Pin 22	RB1	Pin 12	RC1
Pin 4	RA2	Pin 23	RB2	Pin 13	RC2
Pin 5	RA3	Pin 24	RB3	Pin 14	RC3
Pin 6	RA4	Pin 25	RB4	Pin 15	RC4
Pin 7	RA5	Pin 26	RB5	Pin 16	RC5
		Pin 27	RB6	Pin 17	RC6
		Pin 28	RB7	Pin 18	RC7

Table 4.2: Structure of ports for microcontroller PIC 16F876

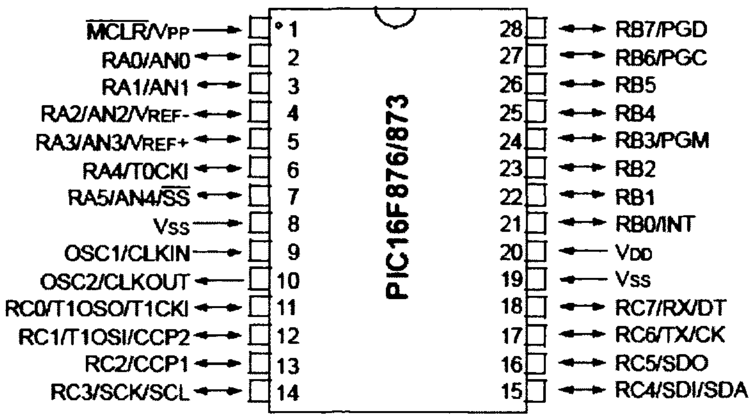


Figure 4.5: Microcontroller PIC 16F876

Appendix B provides more information on the microcontrollers and other components that we considered for the purpose of this research.

4.5.2 Analog to Digital Conversion

Most sensors provide analog voltage readings that must be converted to a digital form using an A/D converter. The digital equivalent to the analog voltage can be determined from Equation 1.

$$output\ voltage^{12} = \left(\frac{raw\ reading}{2^{ADC\ bit} - 1}\right) \text{x refence voltage}(v) \qquad (1)$$

Where:

Raw reading is an incoming raw reading that will contain any reading value from 0 to $2^{ADC\ bit} - 1$.

Reference voltage is 5V power supply; therefore, by default, the reference is set to 5V.

[12] Output voltage is converted into volt by (5/1023)*raw reading. Raw reading contains a value from 0 to 1023.

ADC Bit is the microcontroller PIC resolution. The microcontroller PIC recommends a 10-bit resolution of analog to digital conversion. This indicates that when measuring an arriving voltage, the PIC microcontroller matches up that voltage to a reference voltage and gives the associated representation number from 0 to 1024-1 ($2^{10\ bit\ resolution} - 1$). Therefore, the returned raw reading value is converted into volts by (5/1023)* raw reading. 0 indicates the lowest measurement voltage and 1023 represents the highest measurable voltage. The output will be 0 when the analog input is 0V, and the output will be 1023 when the analog input is 5V, and each step indicates an increment of 5V/1023= 0.00488.

$$output\ voltage = \left(\frac{raw\ reading}{1023}\right) \text{x } 5\text{V} \qquad (2)$$

To get voltage in mV, we multiplied equation (2) by 1000 to get equation (3):

$$output\ voltage = (raw\ reading) \text{x } 4.88 \qquad (3)$$

Equation (3) is used to obtain the digital values of the thesis components.

4.5.3 Temperature Sensor

The TMP36 temperature sensor output voltage is ((output voltage) mV -500) per 10 degrees centigrade (10mV/centigrade). From equation (3), the temperature can be determined as follows:

$$temperature(\text{C}^0) = \left[\frac{raw\ reading 1 \text{x} 4.88 - 500}{10}\right] \qquad (4)$$

Equation (4) can be reduced to equation (5):

$$temperature(\text{C}^0) = \left[\left((raw\ reading 1)\text{x} 0.488\right) - 50\right] \qquad (5)$$

For example, if raw reading1 is equal to number 185, the corresponding temperature it will be

$$temperature(C^0) = [((185)x0.488) - 50]$$

$$temperature(C^0) = [(90.28) - 50]$$

$$temperature(C^0) = 40.28$$

Figure 4.6 shows the voltage output in volts responding to the temperature in centigrade.

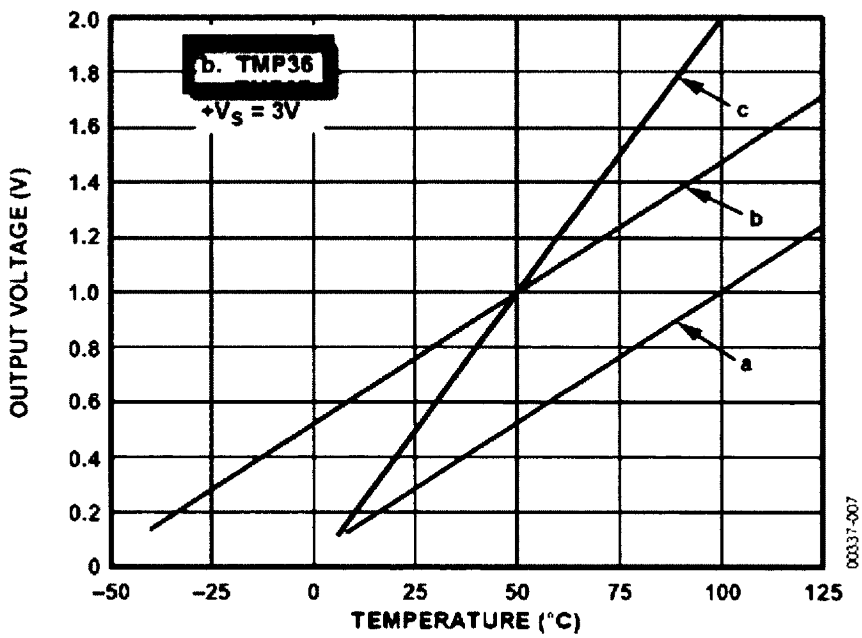
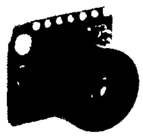


Figure 4.6: Output voltage (V) vs. Temperature (^{0}C)[13]

The TMP36 Temperature sensor is a three pin IC sensor. The sensor should be connected as follows: the left pin is connected to power (5V), the right pin is connected to a ground, and the middle pin (an analogy voltage that is directly proportional (linear) to the temperature) is connected to PIC16F876 at RA0 of PORTA.

[13] Source of this figure: Adafruit, ladyada, http://www.ladyada.net/learn/sensors/tmp36.html

4.5.4 Ultrasonic Sensor



Ultrasonic Sensor provides an output analog voltage with a scaling factor of (Vcc/512) per inch, with a power supply of 5V yields ~9.8mV/in. and 3.3V yields ~6.4mV/in.

From equation 2, the ultrasonic sensor reading can be determined as the following:

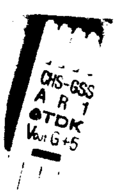
$$raw\ reading2 = \left[\left(\frac{1023}{5\text{V}}\right) \text{x } 9.8\text{mV/distance(inch)}\right] \quad (6)$$

Equation (6) can be reduced to equation (7):

$$distance(inch) = \left[\left(\frac{(raw\ reading2)}{2.00508}\right)\right] \quad (7)$$

The sensor has three pins: pin 3 (right) is connected to 5V power. Pin 2 (middle) is connected to the ground; and pin 1 (left) is connected to the RA 1 of PORTA of the microcontroller.

4.5.5 Humidity Sensor



The relative humidity (RH) can be read directly with a voltmeter; an output DC of 1V can produce 100(%) RH. The sensor is capable of measuring humidity in the range of 5% to 95% relative humidity. Relative humidity can be determined from equation (2) by multiplying equation (2) by 100 to get equation (8):

$$humidity(\%) = \left[\left(\frac{(raw\ reading3)x5V}{1023}\right) \text{x } 100\right] \quad (8)$$

Equation (8) can be reduced to equation (9):

$$humidity(\%) = (\text{raw reading3})\text{x}0.488 \quad (9)$$

The sensor was connected to RA 2 of PORT A of the microcontroller.

4.5.6 Photo Cell Sensor (Light Sensor)

The photocell sensor has two pins. The pins are symmetric. One of the pins is connected to the 5V power supply, and the other pin is connected to RA3 of PORTA of microcontroller PIC 16F876.

The photocell's sensor can be determined from equation 2 above as follows:

$$light = \left(\frac{raw\ reading4}{1023}\right) \text{x } 5\text{V} \qquad (10)$$

Equation (10) can be reduced to equation (11):

$$light = (\text{raw reading3})\text{x } 0.00488 \qquad (11)$$

4.5.7 PIR (Motion) Infrared Sensor

PIR (Motion) Infrared Sensor output provides a binary reading. The sensor has three pins. Pin 3 (right) is connected to 5V power. Pin 2 (middle) is connected to the ground, and pin 1 (left) is connected to the RC 4 of PORTC of microcontroller. The motion is detected when the RC 4 of PORT C output is '1' and motion is not detected when the RC 4 of PORT C output is '0'.

4.5.8 Hall Effect (magnetic) Sensor

The Hall Effect (magnetic) Sensor has three pins, pin 3 (right) is connected to 5V power, pin 2 (middle) is connected to the ground; and pin 1 (left) is connected to the RC3 of PORT C. The sensor operates with a magnet, as shown in Figure 4.6. When the south pole of the magnet is near the front of the sensor, pin 3 will go down to 0V. In our research, this will indicate that the door is closed. Otherwise, it will stay at whatever the pull-up resistor is connected to and display the door being unlocked on the screen. In the north pole of the magnet, nothing occurs if a magnet is placed nearby (unipolar).

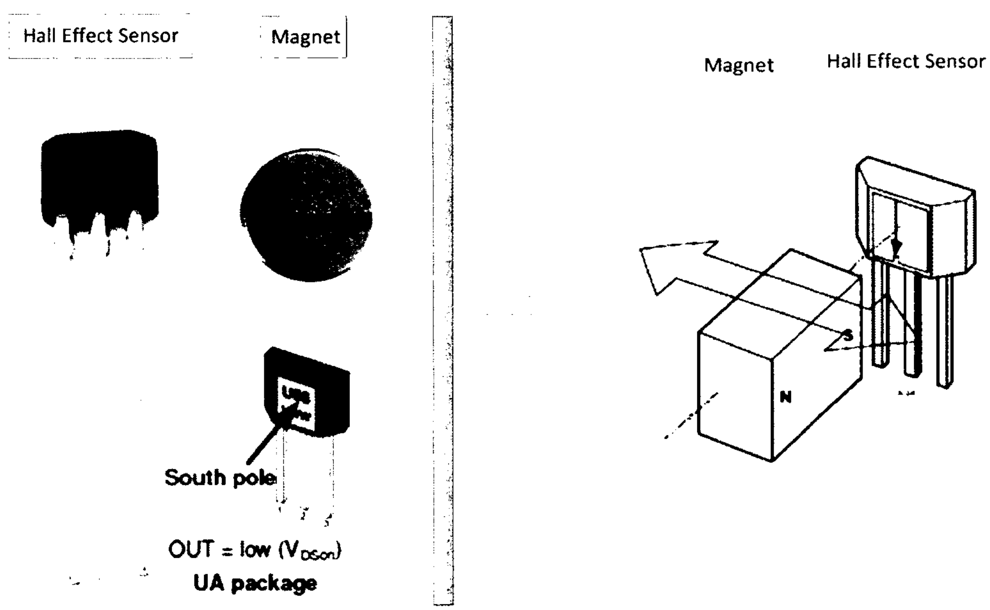


Figure 4.7: Hall Effect sensor with magnet

4.5.9 Piezoelectric Buzzers

Piezoelectric buzzers are used to alert any unacceptable changes in behaviour. It consists of two pins. The pins are connected to RB2 of PORT B and ground of the microcontroller.

4.5.10 Liquid Crystal Display (LCD)

A 16 x 2 backlight liquid crystal display (LCD) is the type of LCD that we used for this thesis. The LCD can display letters, numbers, and a few symbols. All character and letter fonts are developed into the hardware of the LCD device. The LCD is connected to a 5V power supply; the ground; and RB0, RB1, and RB4 of PORT B. The goal of the LCD is to display the data results locally.

4.5.11 XBee Module Communication Protocol

The XBee module communicates with other devices through Universal Asynchronous Receiver and Transmitter (UART) protocol. The UART communication pins of the XBee module are connected directly to the microcontroller's UART, as illustrated in Figure 4.8. The XBee module needs two wires, one for transmitting the data and the other for receiving the data. In our case, these two wires are directly attached to RC6 and RC7 of PORT C of the microcontroller to establish communication with other devices. For serial data, data enters the module UART through the DIN (pin 3) and exits the module UART through the DOUT (pin 2) as an asynchronous serial signal.

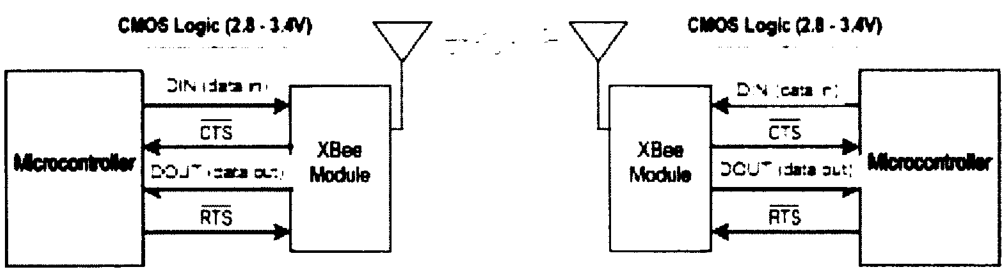


Figure 4.8: System data flow diagram in a UART-interfaced environment[14]

[14] Source Digi International: http://ftp1.digi.com/support/documentation/90000866_C.pdf

4.5.12 XBee Module Pins

Table 4.3 shows pin assignments for the XBee and XBee-Pro modules with brief descriptions of all 20 pins in the modules; however, the pin numbers of significance for the study are the following five pins: pin 1, pin 2, pin 3, pin 5, and pin 10.

Pin	Name	Direction	Description
1	VCC	–	Power supply
2	DOUT	Output	UART data out
3	DIN / $\overline{\text{CONFIG}}$	Input	UART data in
4	DO8	Output	Digital output 8
5	$\overline{\text{RESET}}$	Input	Module reset (at least 200nS)
6	PWM0 / RSSI	Output	PWM output 0 / RX signal strength indicator
7	PWM1	Output	PWM output 1
8	(reserved)		Do not connect
9	$\overline{\text{DTR}}$ / SLEEP_RQ / DI8	Input	Pin sleep control line or digital input 8
10	GND	–	Ground
11	AD4 / DIO4	Either	Analog input 4 or digital I/O 4
12	$\overline{\text{CTS}}$ / DIO7	Either	Clear to send flow control or digital I/O 7
13	ON / $\overline{\text{SLEEP}}$	Output	Module status indicator
14	VREF	Input	Voltage reference for AD inputs
15	Associate / AD5 / DIO5	Either	Associated indicator, analog input 5 or digital I/O 5
16	$\overline{\text{RTS}}$ / AD6 / DIO6	Either	RTS flow control, analog input 6 or digital I/O 6
17	AD3 / DIO3	Either	Analog input 3 or digital I/O 3
18	AD2 / DIO2	Either	Analog input 2 or digital I/O 2
19	AD1 / DIO1	Either	Analog input 1 or digital I/O 1
20	AD0 / DIO0	Either	Analog input 0 or digital I/O 0

Table 4.3: Pin assignment for the XBee and XBee PRO modules [61]

- Pin number 1, Vcc, is a power-supply pin; its practical use is to provide the XBee module with the power it needs to transmit or receive data
- Pin number 2, DOut, is a pin for "UART Data Out"; its purpose in the design of the module is to transmit data to the receiver
- Pin number 3, DIn, is a pin for "UART Data In"; its task is to receive data

- Pin number 5 is an XBee reset pin
- Pin number 10, GND, is ground pin

4.5.13 Remote Station Experimental Prototype

The overall system interconnections are illustrated in Figure 4.9.

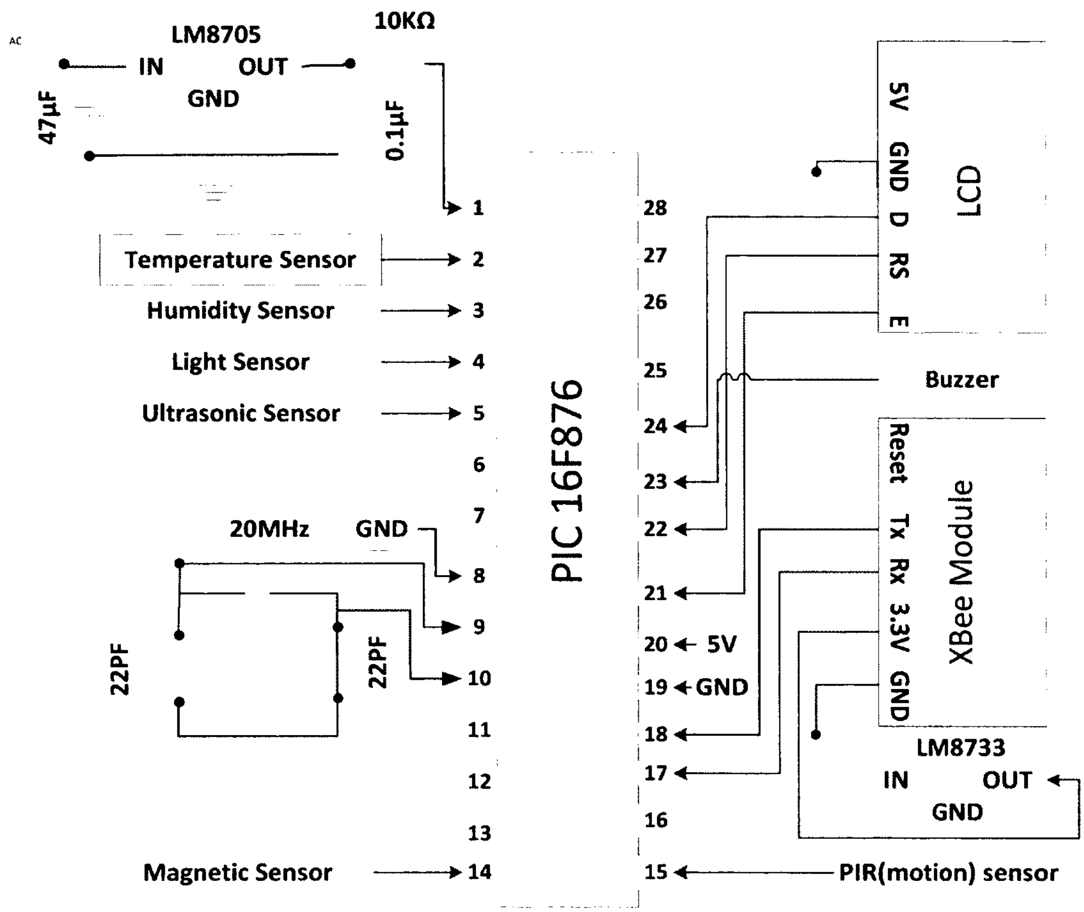


Figure 4.9: Pin details of PIC 16F876 with system components

Figure 4.10 is the actual prototype for the remote station we designed for the study. The remote station is equipped with its own 5V regulated power supply, which can supply up to 1A of load. The power supply to the remote system is given through 9V regulated DC wall-power adapter or 9V battery clip.

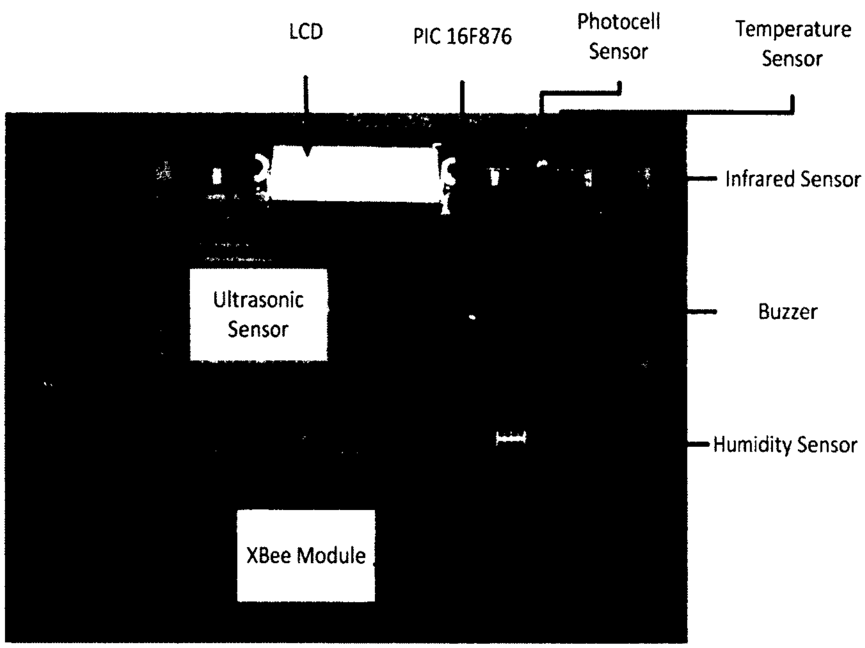


Figure 4.10: Remote station including sensors, LCD, microcontroller, buzzer, and XBee module

4.5.14 The main experimental prototype components

The main experimental prototype components include:

- On board 5V regulated supply;
- Microcontroller PIC 16F876;
- A 16 x 2 backlight liquid crystal display (LCD);
- XBee modules;

- TMP36 temperature sensor;
- CHS – series humidity sensor;
- PDV – P8001 photocell sensor (light sensor);
- US5881LUA hall effect sensor;
- #555 -28027 Infrared (IR) sensor;
- Buzzer;
- 20 MHz oscillator;
- Capacitors;
- Resistors; and
- LED indicators.

4.6 Software

4.6.1 Introduction

The purpose of this subsection is to provide information on Proton IDE, PICKit2, X-CTU, and MATLAB, the software utilized for this thesis. The software were utilized for writing code, compiling and programming the microcontrollers, displaying collected data on the PC screen, and analyzing the data. The section is divided into four subsections. Section 4.6.2 provides step–by–step information on writing and compiling code. Section 4.6.3 provides information on the PICKit2 software used to load programming code into the microcontroller. Section 4.6.4 provides information on the programmer board used to load proton IDE onto the microcontroller. Section 4.6.5 provides information on the X-CTU window. This window is used to display our collected data on the PC screen. Finally, section 4.6.6 provides information on MATLAB. MATLAB was used to analyze our collected data.

Table 4.4 below illustrates a brief description of these software packages.

Software	Feature		
	Version	Objective	Manufacturer
X-CTU	---	Program XBee module and collect data.	Digi International
Proton IDE	Version 3.1	Compile the program code.	Labcenter Electronics
PICKit2	Version 2.61	Download proton software into microcontroller PIC 16F876.	Microchip
Matlab	2007a	Analyse collected data.	The MathWorks

Table 4.4: List of software used for the research

4.6.2 Proton IDE: Compiler

There are several methods of writing programming code onto a PIC microcontroller. These methods can be done through programming languages such as BASIC, C, or Assembly Language. In our study, we chose Proton Basic Integration Development Environment (IDE) because of its features and integration option. The Proton (IDE) is a very popular programming language for microcontrollers. Proton IDE is developed and distributed by Crownhill Associates LTD. The programming language was created as a result of collaboration among three British companies, Crownhill Associates, Mecanique, and Labcenter Electronics. The common goal was to develop a best breed of product that could:

- Provide an affordable, comfortable, and powerful development environment for the most popular microcontrollers: the Microchip PIC® MCU;
- Suit all levels of users from outright beginner to professionals;
- Allow for the development of programming code in a state-of-the-art development environment; and

- Compile the program code and view the resulting assembly language commented with the program code.

After installing the Proton (IDE) software, the window shown in Figures 4.11 and 4.12 was used to write and compile our programming code and save it onto the PC hard drive so that it could be loaded into the microcontroller via software called PICKit2.

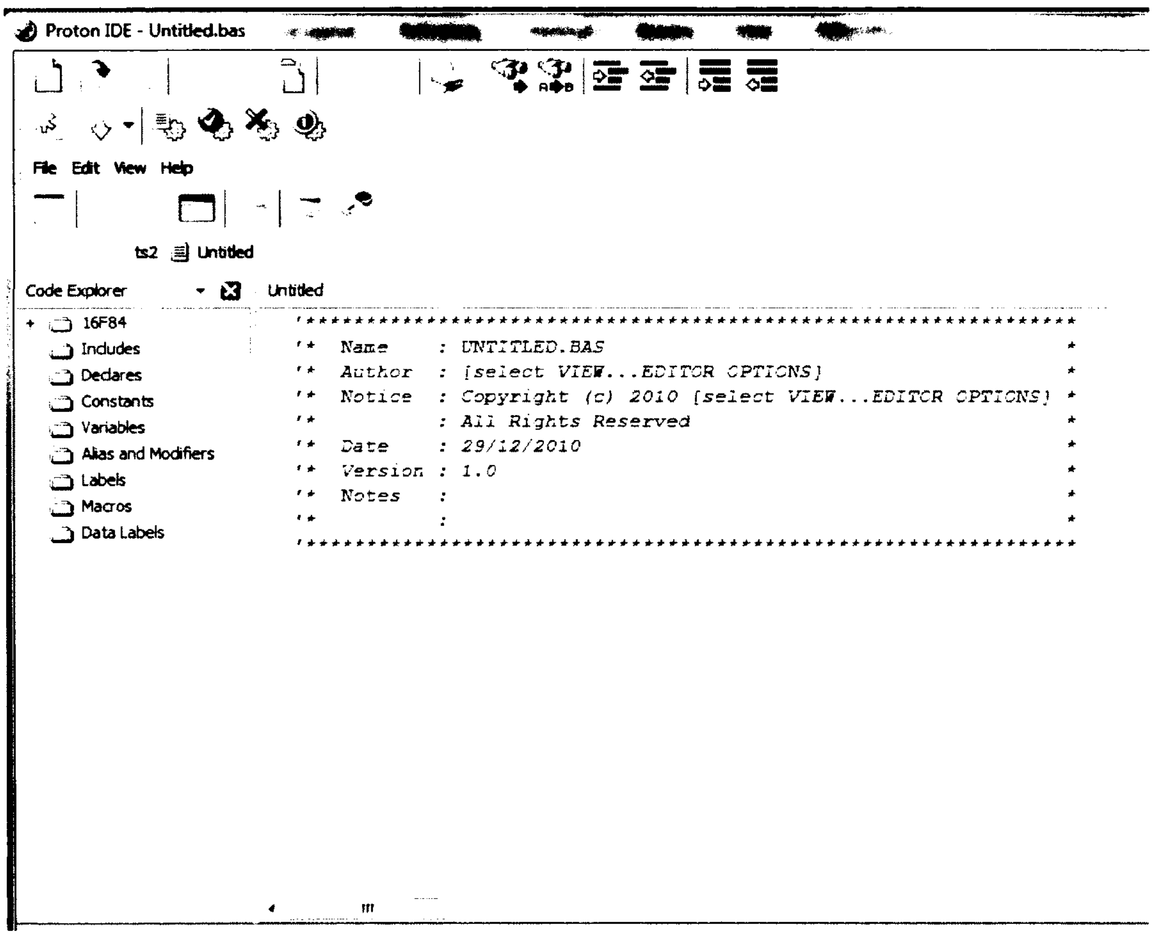


Figure 4.11: Proton IDE

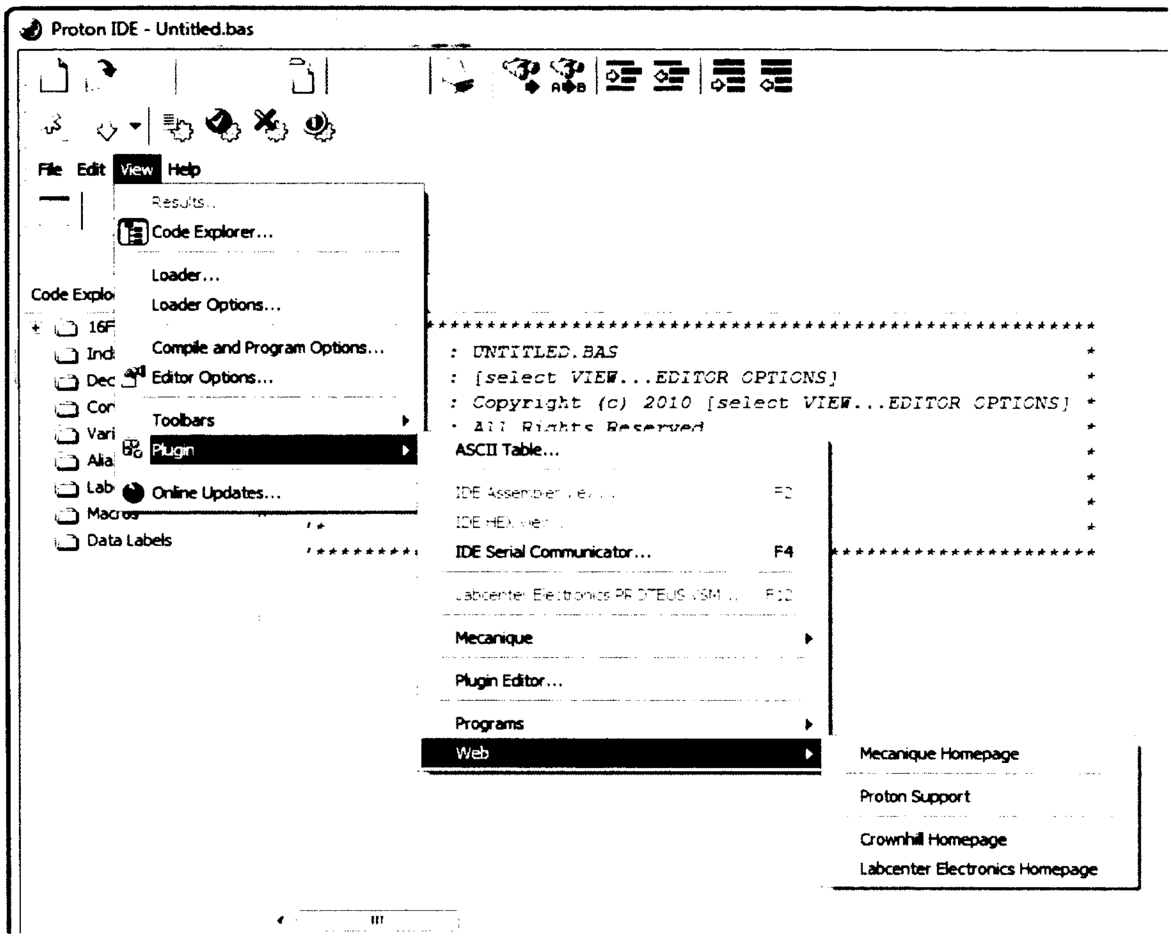


Figure 4.12: Proton IDE with features

4.6.3 PICKit2: Programming Microcontroller

After all of the logical errors were resolved, the programmable tool PICKit2 (shown in Figure 4.13) was used to download the proton IDE programming code into the microcontroller. The hex file was loaded into the microcontroller via the microcontroller programmer hardware as shown in Figure 4.13, Figure 4.14, and Figure 4.15.

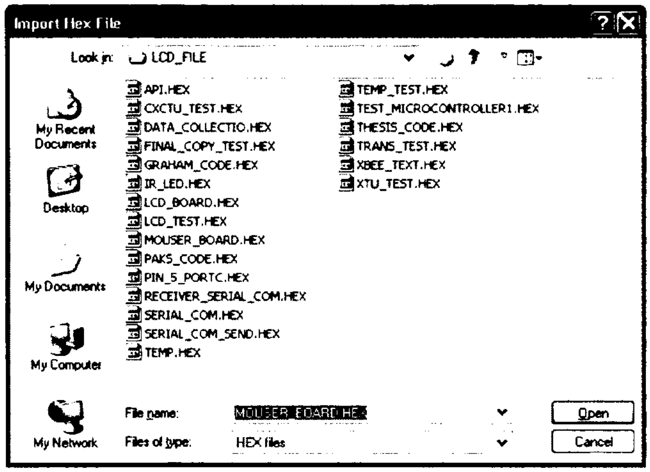


Figure 4.13: HEX file to be loaded into PICKit2

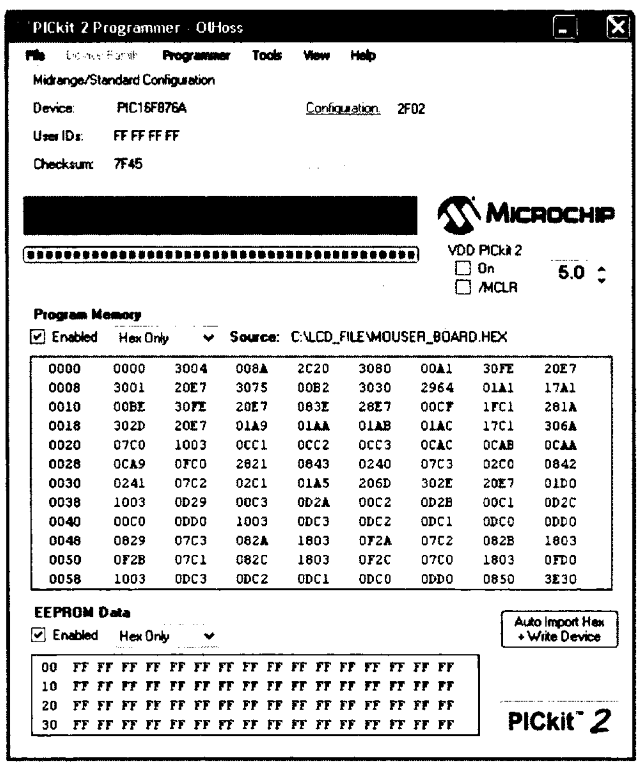


Figure 4.14: PICKit2 is used to load the hex file into the microcontroller via microcontroller programmer hardware

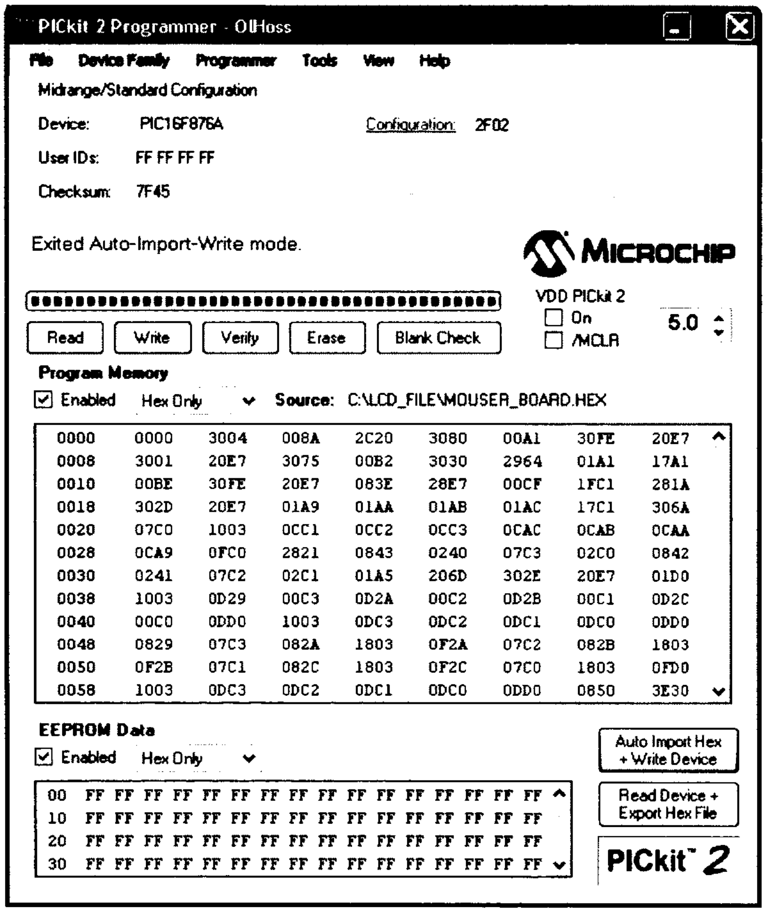


Figure 4.15: PICKit2 is used to load the hex file into the microcontroller via microcontroller programmer hardware

4.6.4 UK1300 USB PIC Programmer

The UK1300 USB PIC Programmer shown in Figure 4.14 is the type of a programmer we used to download proton IDE program into the microcontroller. The programmer board includes ZIF[15] (zero-force-insertion)

[15] ZIF is an acronym for zero insertion force, a concept used in the design of IC sockets, invented to avoid problems caused by applying force upon insertion and extraction.

adapter sockets. The socket board allowed us to remove and insert the PIC 16F876 easily and quickly. The programmer was selected for the thesis because it:

- Supports practically all current pic microcontroller, 8 to 40 PIC pins;
- Does not require a power supply. Power is supplied directly from the USB Port;
- Is 100% compatible with PICKit 2 interfaces; and
- Saves a considerable amount of time and protects microcontroller pins from damage.

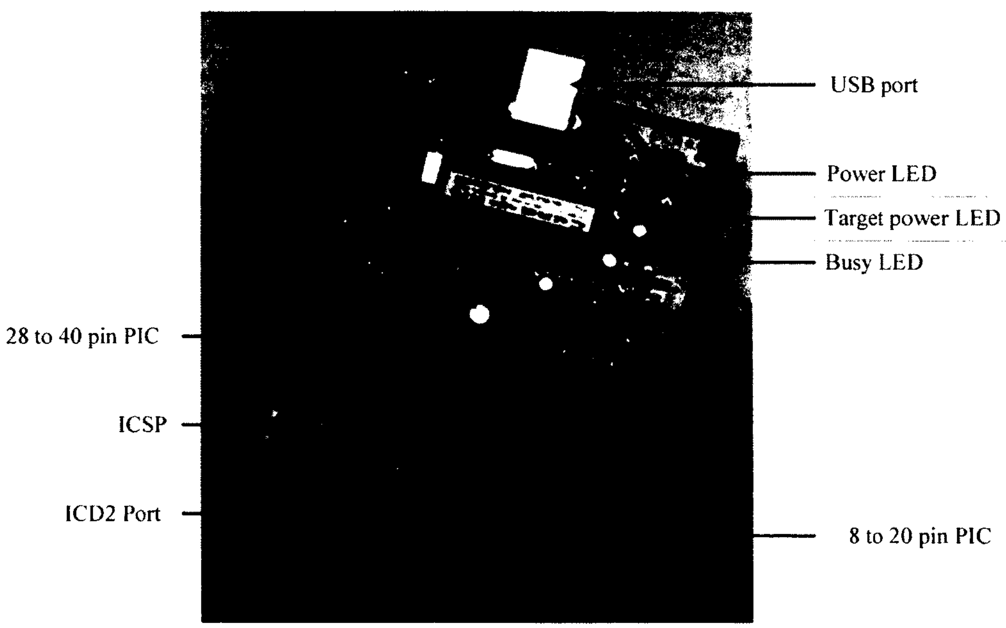


Figure 4.16: UK1300 – USB PIC Programmer for programming microcontroller

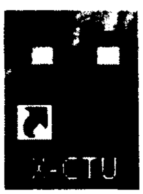
Programmer	UK1300-USB PIC Programmer
Support	8 to 40 PIC pins
Manufacturer	Cana-Kit Corporation

Table 4.5: UK1300 – USB PIC Programmer

The device was connected to the computer to program our microcontroller, as shown in Figure 4.15.

Figure 4.17: USB PIC Programmer connected to computer to program microcontroller

4.6.5 X – CTU



X-CTU is a Windows-based application for XBee software for configuration and test utility. The software is provided by Digi and designed to interact with the firmware files found on Digi's RF products and to provide a simple-to-use graphical user interface [62]. We used the software to configure the XBee radio and also to collect the data to be analysed. Figure 4.16 depicts X-CTU window. The "Terminal" tab is where collected data is displayed. "Select Com Port" is where the information on the type of XBee module connected to the Com Port is displayed. There is no XBee module connected in the Figure 4.16 to be displayed into the Com port. The "Modern Configuration" button is where the XBee module is configured. Firmware needs to be loaded to all ZigBee modules to form the network. X-CTU software is used configured ZigBee modules. X-CTU software program and installation instruction are available at http://ftp1.digi.com/support/documentation/90001003_A.pdf. In addition to X-CTU software, the appropriate driver for the XBee adapter board is also available at http://www.digi.com/support/productdetail?pid=3352.

Here are the basic steps that must be followed to load firmware properly into the ZigBee module.

- Download and install the X-CTU software, and make sure the right version of the X-CTU software is installed.
- Connect the XBee board to computer Com Port via the USB adapter. This procedure will prompt the connected Com Port to appear on the X-CTU screen.
- Click the "New version" button to download the new version of the X-CTU software.
- After the new version is installed, click "Configure tab." This will load settings for the install module. In "Function Set" select the type of modern from the list.
- Once the firmware update is completed, click on the "Read" button to change a few parameters.
  - To set ZigBee device as "Coordinator," the following parameters need to be changed:
    - PAN ID = 234 (actual any PAIN ID number between 0x0 and 0xFFFFFFFFFFFFFFFF)
    - Destination Address Low = FFFF
    - Node Identifier = COORDINATOR
    - Packetization Timeout = 25
- The coordinator was programmed as a coordinator to synchronize the communication networks so that all of the wireless messages received by the antenna were echoed through the USB port to the computer.
  - To set ZigBee device as "router," the following parameters need to be changed:
    - PAN ID = 234 (PAIN ID selected should be the same as in Coordinator)
    - Destination Address Low = FFFF
    - Node Identifier = R1 ...Rn

- Packetization Timeout = 25

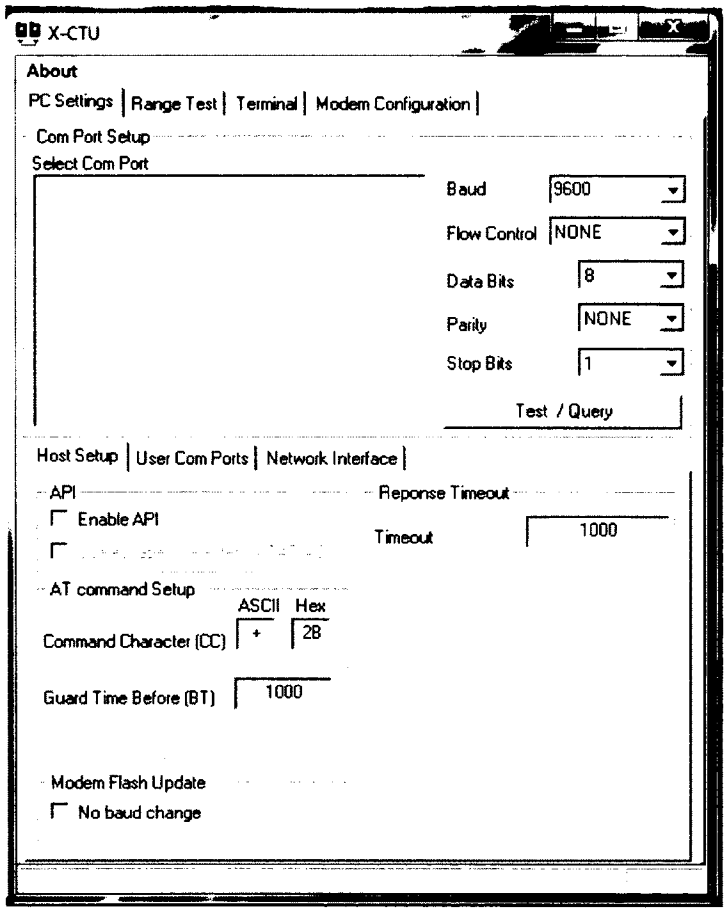


Figure 4.18: X-CTU Windows graphical user interface (GUI) for configuration and testing

X-CTU is designed to operate strictly for the Windows platform. Windows 98, 2000, ME, XP, and Windows 7 are versions of Windows that are compatible with X-CTU. Window 95, NT, UNIX, or Linux are not compatible with X-CTU. However, there is other software that can be used for the following operating systems, such as Coolterm, HyperTerminal, TeraTerm, Zterm, or Screen.

- **CoolTerm:** Is an open source serial terminal program created by Roger Meier[16] that runs well on both Windows and Macintosh.
- **HyperTerminal:** Is a serial terminal program that can be found in Windows XP and other older versions of Windows operating systems.
- **Tera Term:** Is a free open source window that has many functions, including a serial communication terminal.
- **Zterm:** Is a Macintosh serial terminal program.
- **Screen:** Is suitable for UNIX and Macintosh serial terminal programs.

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[16] Roger Meier is a person who began writing his own program as a hobby when he could not find any decent firewall or shareware for certain tasks he wanted to use on a computer.

CHAPTER 5

TESTING AND RESULT

5.1 Introduction

This chapter is organized into three sections: Section 5.1 provides an introduction to the chapter. Section 5.2 presents information on the testing of the prototype system at different locations. Finally, section 5.3 focuses on the results of collected data in the prototype apartment.

5.2 Testing the Prototype system at Different Locations

This section explains the testing process of the indoor and outdoor range of the prototype system, which was done to determine the accuracy and functionality of the system indifferent environments. Appendix E provides information related to the testing of each sensor for their functionality prior to their usage for the research.

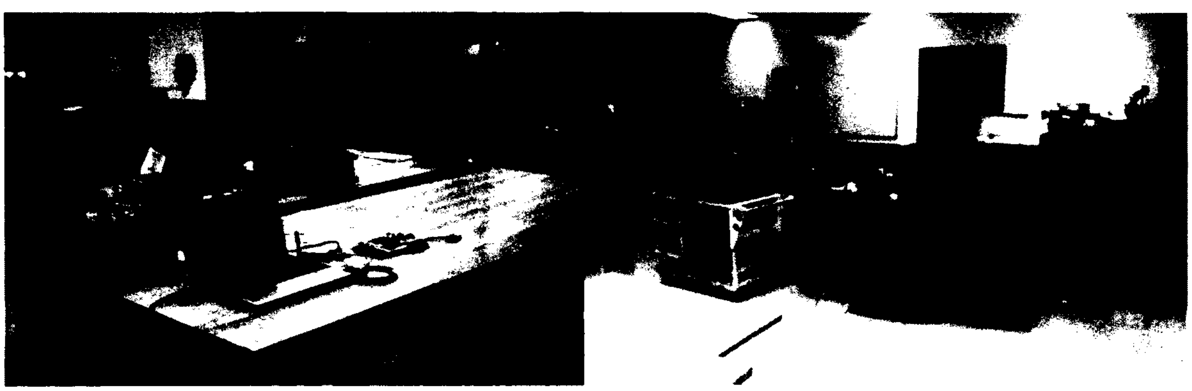
The section is divided into five subsections: section 5.2.1 provides a brief description of the Portable Radio Communication Lab. Section 5.2.2 discusses the indoor testing of the system. Section 5.2.3 reflects on the data collected at the Portable Radio Communication Lab (4050MC). Section 5.2.4 focuses on the outdoor testing of the system for accuracy and functionality in different environment. Finally, section 5.2.5 focuses on the comparison of the outside collected weather data of the prototype system to an Ottawa weather report from Google and Yahoo websites

5.2.1 Laboratory Portable Radio Communication

The experiment was conducted at the Portable Radio Communication Lab (4050MC) in the Minto Building. The Lab is located on the 4th floor of the Minto Building, 4050 MC. The lab is about 40 feet by 40 feet and equipped with all of the necessary tools for the research.

5.2.2 Indoor Test Case

Test purpose: To test the range of the prototype system. The field testing for the range of the prototype system was tested at different locations of the Minto Building (MC), both inside and outside of the building. Figure 5.1 illustrates indoor testing range of the system at different locations of the 4th floor of the MC Building.



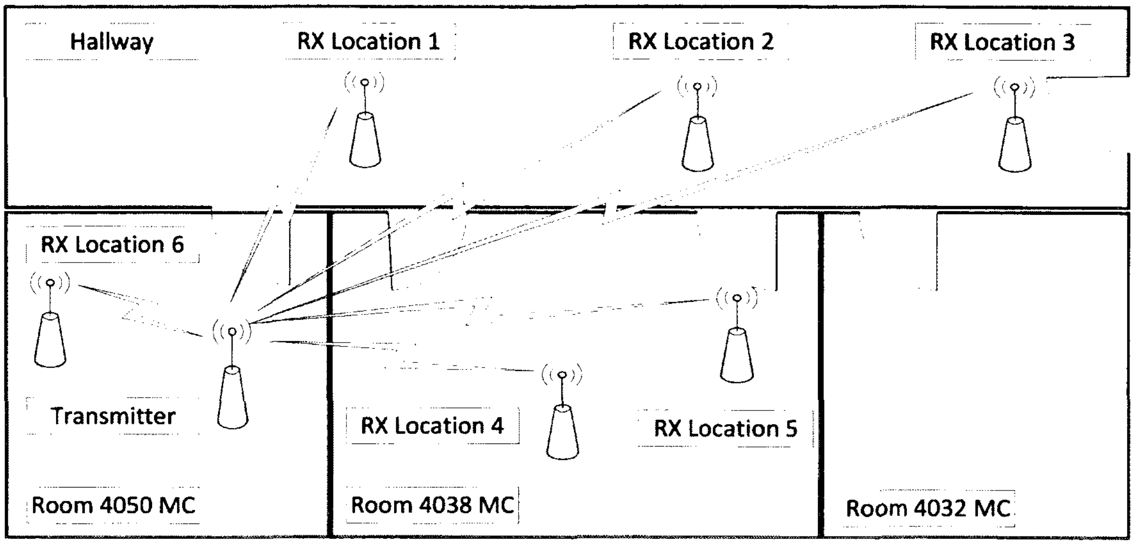


Figure 5.1: Prototype system testing locations at 4th floor of the Minto Building

Expected result: The prototype system was expected to transmit data every two seconds within the XBee transmitter range. We also anticipated that fading, reflection, or interference would degrade the indoor performance of the prototype system. We also expected the throughput would decrease considerably when the distance between the transmitter and receiver reached a particular distance.

Test procedure: The transmitter (base) and receiver (remote) were set at distances of 10-100 feet from each other. The base station was positioned at different locations to test the range of the prototype systems, as shown in Figure 5.1. The station was then moved further and further away from the transmitter station until we reached at a distance that could no longer receive any data. The maximum distance at which XBee Series 1 can transmit data is 100 feet and the maximum distance at which XBee Series 2 can transmit data is 133 feet. As we were approaching this maximum distance, the throughput began to fail.

Tested result: The results we obtained were as we had anticipated. As soon the XBee Series 2 was positioned at distance of the base station at location 3 and the XBee Series 1 was positioned at distance of the base station at location 5 (as illustrated in Figure 5.1), the prototype system performance degraded. Theoretical range as indicated by the product manufacturer data sheet for the XBee Series 1 is 100 feet and 133 feet for XBee Series 2; however, our experimental result showed that when the distance between transmitter and receiver range was 80 feet for XBee Series 1 and 100 feet for XBee Series 2 the performance of the prototype system dropped dramatically, as illustrated in Figure 5.2.

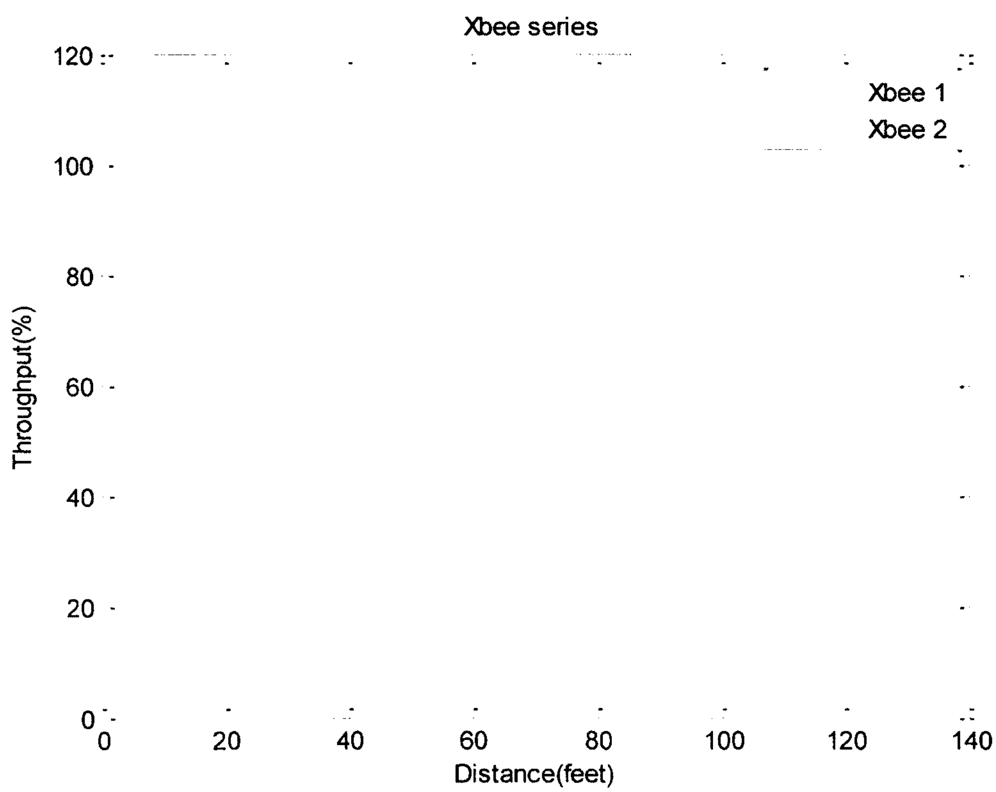


Figure 5.2: Range of XBee Series on 4th floor of the Minto Building

5.2.3 Collected Data at the Portable Radio Communication Lab

The collected data at the Portable Radio Communication Lab 4050 MC consists of the room temperature, ultrasound distance, light, and humidity. The collected data at the Portable Radio Communication Lab is shown in Figure 5.3.

- **Light:** 4.154 was indicated as the level of light in the room at the time (2:00 PM). The data was collected using the light sensor. A value of 5 is the maximum level of brightness to which the light can be turned on and 0 is the minimum value of darkness when the light is turned off.
- **Temperature:** 24.780 was the temperature of the lab in Celsius.
- **Ultrasound:** 63.837 was the distance from the workbench of the research to the ceiling of the lab in inches.
- **Humidity:** 29.325% was the humidity of the lab at time that the data was obtained as determined by the humidity sensor.

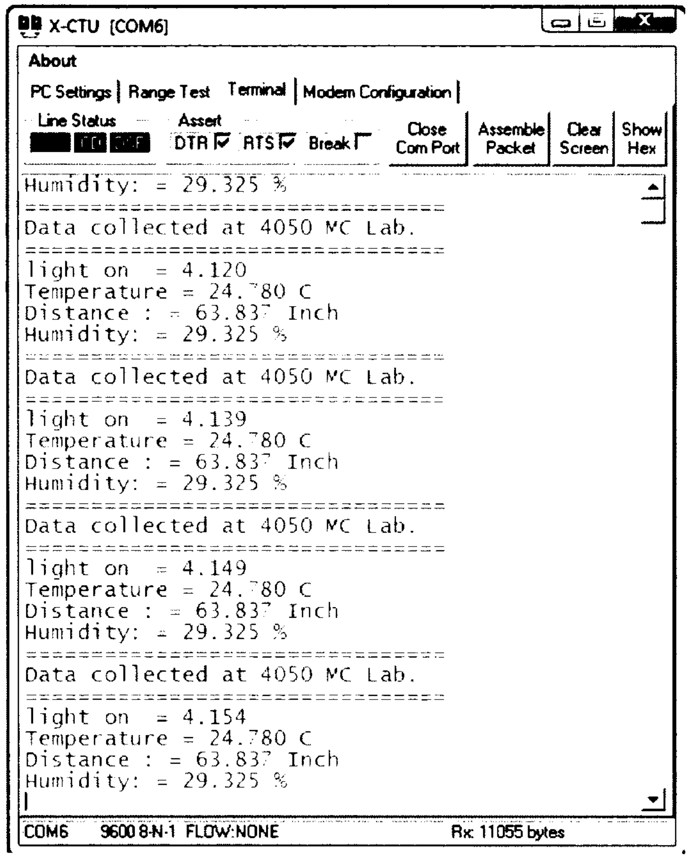


Figure 5.3: 4050 MC laboratory collected data

5.2.4 Outdoor Test Case

Test purpose: The purpose of the outdoor test was to determine the accuracy and functionality of the system in different environments.

Expected result: The device was expected to transmit data every two seconds and operate at any condition.

Test procedure: The transmitter station was placed outside of the Minto Building at below zero temperatures for 20-30 minutes to transmit data within the system transmission range to the receiver station. The receiver station was placed inside the Minto Building at a distance of about 30 feet from the transmitter.

Tested result: The result we received was as we had anticipated. This result is shown in Figure 5.4, which consists of outside temperature and humidity values at the particular time of day that the data was gathered

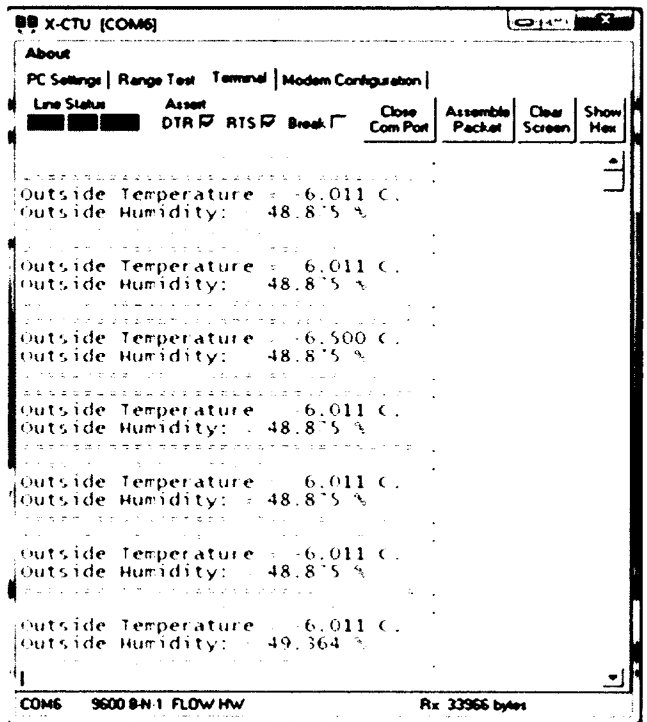


Figure 5.4: Outside temperature and humidity results

- **Temperature sensor:** - 6.011 was the outside temperature in Celsius.
- **Humidity sensor:** 48.875% was the outside relative humidity.

5.2.5 Ottawa Weather Report

The collected data in Figure 5.4 were compared with the weather report of the city obtained from Google and Yahoo sites in Figure 5.5 to determine the accuracy and functionality of the prototype system. Based on the results, we conclude that our results in Figure 5.4 are very close to the results in Figure 5.5. A comparison of the results is shown in Table 5.1.

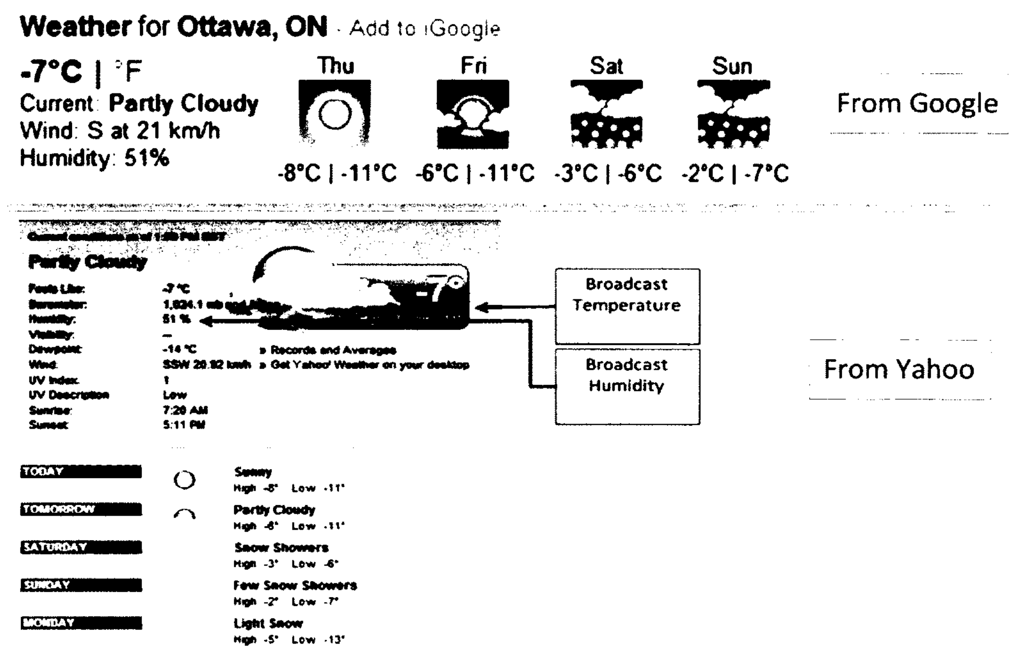


Figure 5.5: Ottawa weather report from Google and Yahoo websites

Type	Research Result	Google	Yahoo
Temperature (°C)	-6.011	-7	-7
Humidity (%)	48.875	51	51

Table 5.1: Comparison of our research values with Google and yahoo websites weather report

5.3 Prototype Apartment Results

5.3.1 Introduction

The purpose of this section is to analyze our collected data from the different locations of the prototype apartment and various appliances in the apartment. The main goal of the section is to potentially identify an assortment of various Activities of daily living (ADL) such that a user can be alerted of any unacceptable change in behaviour of the occupant in the apartment.

The section is organized into seven subsections. Section 5.4.1 is the introduction; section 5.4.2 provides brief information on the data collection. Section 5.4.3 provides brief discuss on the locations in the prototype apartment of the collected data. Section 5.4.3 discusses the data analysis. Section 5.4.3 deliberates on the results of the data collected in the bathroom. Section 5.4.4 discusses the results of the kitchen collected data. Section 5.4.5 reflects on results of the refrigerator collected data. Section 5.4.6 deliberates on the results of the living room collected data, and finally section 5.4.7 describes the results for the balcony collected data. Section 5.4.8 discusses the Activities of daily living and the actual data interpretations of events of these the activities of daily living.

5.3.2 Data Collection

The data collection occurred through a laptop computer and sometimes through a desktop computer. The collection of the data can be divided into two parts: hardware and software.

- **Hardware:** The hardware consisted of a remote station and the base station, as shown in Figure 5.6.
- **Remote station:** The remote station consisted of three major components: six non-invasive sensors, LCDs to display data locally, and an XBee module to transmit data to the base station wirelessly. In our case, since line power was available where the remote station was placed in the apartment, the remote

station was plugged into electrical outlets via a DC adapter (wall wart), as shown in Figure 5.7. Even though the station was not portable in this situation, data transmission still occurred in a wireless manner.

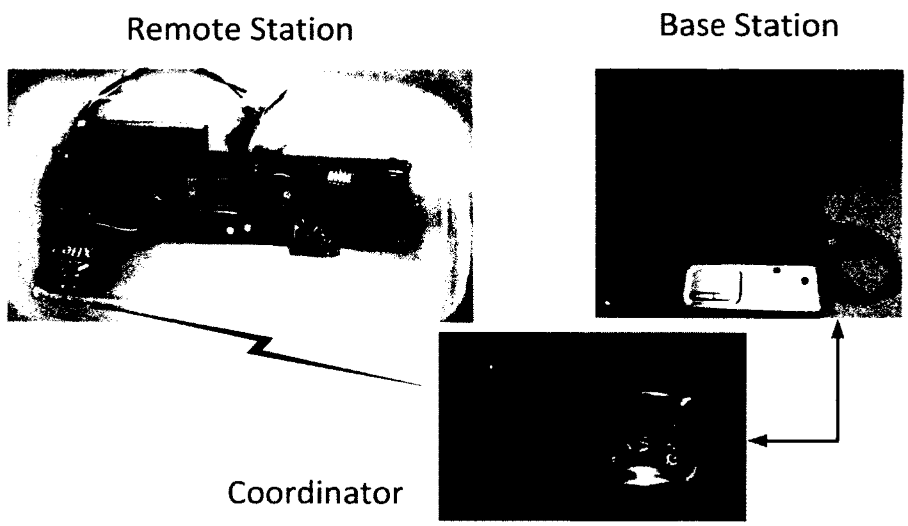


Figure 5.6: The system hardware consisted of a remote station and a base station

Figure 5.7: The remote station connected to the electrical outlet

- **Base station:** The base station consisted of a coordinator connected to a desktop computer or laptop. The coordinator was connected to a computer through a USB connector. The coordinator collected data from the remote station and relayed it to the computer where the data were stored. The sensors data fusion were recorded according to changes in events (such as active or inactive), physical characteristics, moisture content of the environment, or speed or vector of an object or objects in the field of view.
- **Sensors**: The following six non-invasive sensors were used to collect data for analyses:
  - **Infrared Sensor**
    - To target mobility of humans in specific apartment areas, such as kitchen, washroom, living, and bedroom.
  - **Light Sensor**
    - To detect the switching on/off of lights.
    - To detect lightness and darkness.
    - To determine use of appliances, such as the refrigerator.
  - **Temperature Sensor**
    - To measure ambient temperature.
    - To detect use of the shower and toilet.
    - To detect use of the electrical appliances.
  - **HumiditySensor**
    - To measure ambient humidity.
    - To detect use of the shower and toilet.
    - To detect use of the electrical appliances.

- **Magnetic Sensor**
  - To identify the opening and closing of doors.
  - To identify use of major appliances, such as the refrigerator.
- **Ultrasound**
  - To measure the distance between objects.

5.3.3 Data Collection Locations

This section focuses on the results of the data collected at the following locations of the prototype apartment: kitchen, living room, washroom, and balcony, as shown in Figure 5.8. The data for the apartment appliances, such as the fridge and stove, were also collected and analysed.

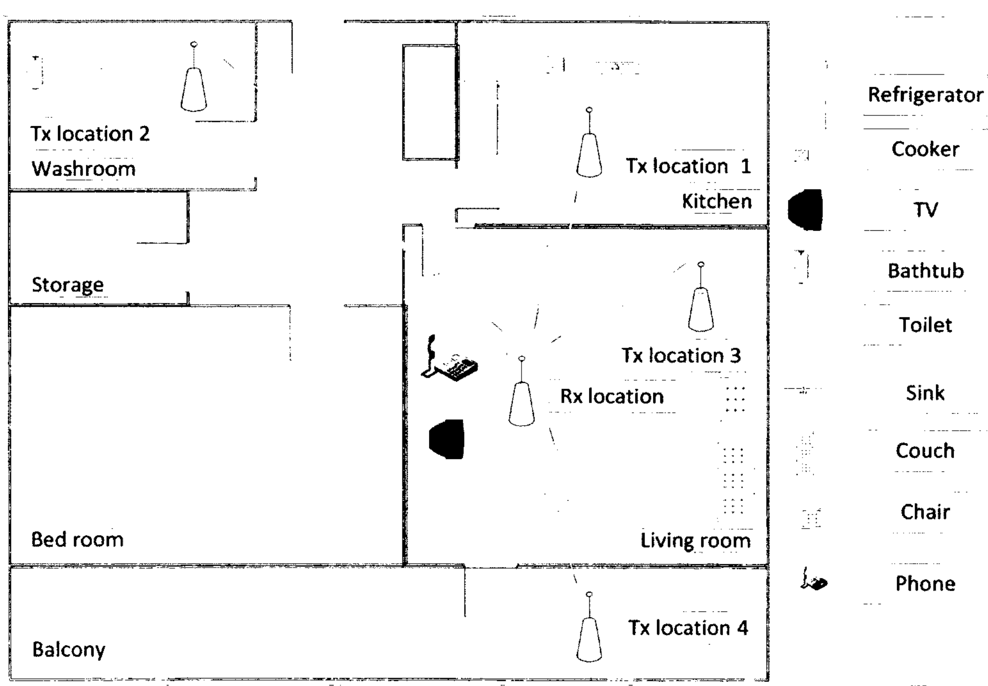


Figure 5.8: The prototype apartment

Table 5.3 shows the types of sensors used to collect data at different locations in the prototype apartment.

Locations	Sensor	Monitoring
Bathroom	thermistor, humidity, Photocell, PIR motion	temperature, humidity, light, bathroom motion
Kitchen		temperature, humidity, light, kitchen motion
Living room		temperature, humidity, light, living room motion
Refrigerator	thermistor, humidity, Photocell, hall effect	temperature, humidity, light, refrigerator door
Balcony	thermistor, humidity, Photocell	temperature, humidity, light

Table 5.2: Location and sensor used to collect data in the apartment

5.3.4 Data Analysis

This subsection discusses the detection of events from different sensors. Each event was given a symbol to identify it, as shown in Table 5.3. The goal of this subsection is to investigate events that occurred as a result of changes in the environment. The purpose of this subsection is to analyze our collected data of events of daily living of an occupant in the different locations of the prototype apartment that pertain to the usage of various appliances in the apartment. The analysis part is done using MATLAB. Figures 5.9, 5.11, 5.13, 5.15, and 5.17 illustrate the results of the data analysis. Table 5.3 illustrates the transition states of the sensors.

Sensors	Transition state	Actions
Motion	On - Off	A
	Off - On	B
Light	On - Off	C
	Off - On	D
Temperature	Rise - Fall	E

	Fall - Rise	F
Humidity	Rise - Fall	G
	Fall - Rise	H
Magnetic	On - Off	I
	Off - On	J

Table 5.3: Transition states of sensors

5.3.5 Bathroom Results

Test purpose: The purpose of this section is to collect data about the changing events in the bathroom.

Expected result: The result was expected to indicate that temperature and humidity sensors detected an increase in temperature and humidity in the washroom when the bathtub was filling with hot water. Furthermore, we expected motion sensor to detect human motion in the washroom while the occupant was in the washroom filling the bathtub with the hot water.

Test procedure: The remote station was placed in the bathroom to transmit data every two seconds.

Tested result: The results we received were as we had expected.

Figure 5.9 illustrates the real-time monitoring of the physical activities of a user inside a bathroom.

- Before the user took a shower, Figure 5.9 indicates that:
    - The temperature sensor detected that the temperature was at room temperature of approximately 23.8 degrees Celsius.
    - The humidity sensor detected that the humidity reading was low; it was at approximately 28% relative humidity at 23.8 degrees Celsius.

- The light sensor spotted no indication that the light was turned on (event ('D')) and no human motion (event ('B')) or activities in the bathroom prior to the user taking a shower were identified by the motion sensor.

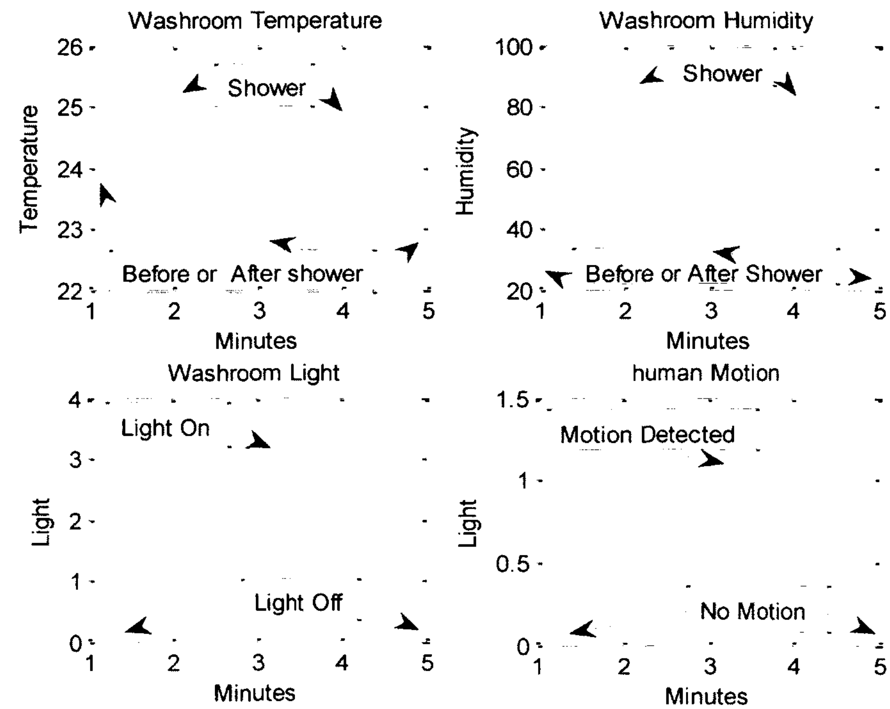


Figure 5.9: Graph of the data collected in the bathroom

- However, during the shower (as shown in the Figure 5.9), the prototype system temperature and humidity readings in the washroom indicated that:
    - The temperature sensor detected an increase in the washroom temperature to 25.4 degrees Celsius (event ('E')).

- ❖ The humidity sensor noticed the humidity increased to approximately 88% of relative humidity at 25.4 degrees Celsius (event ('G')).
- ❖ The motion sensor also showed that there was an indication of human motion (event ('B')) in the bathroom during the shower period.
- ❖ The light sensor indicated that the bathroom light was turned on (event ('C')) during the shower period.

- A few minutes after the user left the washroom, the temperature and humidity sensors showed the temperature and humidity dropped to its original level before the user had entered the washroom to take the shower.
  - ❖ The temperature sensor detected the washroom temperature dropped to approximately 22.8 degrees Celsius (event ('F')).
  - ❖ The humidity sensor noticed the washroom humidity also dropped to approximately 30% relative humidity at 22.8 degrees Celsius (event ('H')).
  - ❖ The motion sensor detected no human motion was present in the bathroom after the shower (event ('B')).
  - ❖ The light sensor spotted no light present in the bathroom after the shower (event ('D')).

We noticed that the temperature and humidity of the bathroom increased when the user was taking a shower. The figure also shows that the light in the bathroom was turned on and there was indication of the motion of a person in the washroom. These results indicate that during the collection of the data, there were some events going on in the washroom.

Figure 5.10: Remote station in bathroom collecting data

5.3.6 Kitchen Result

The kitchen is an area in house composed of various appliances, such as the refrigerator, dishwasher, oven, cook top, microwave, toaster, etc.

Figure 5.11: Prototype apartment's kitchen

Test purpose: The purpose of this section is to collect data of the events when kitchen appliances were used in the kitchen.

Expected result: The results were expected to show that the temperature and humidity sensors detected an increase in temperature and humidity when oven was switched on to cook in the kitchen. Furthermore, we also expected that the motion sensor would detect human motion in the kitchen.

Test procedure: The remote station was placed in the kitchen to transmit data every two seconds.

Tested result: The results we received were as we had expected. Figure 5.11 illustrates the data of the events in a kitchen in real time monitoring when a kitchen appliance, such as the stove, was used. Figure 5.11 shows the results of the data in the kitchen before, during, and after the kitchen appliances were used.

- Before any detected of events in kitchen of appliances been used:
    - ❖ The temperature sensor detected that the kitchen temperature was approximately 22.8 degrees Celsius.
    - ❖ The humidity sensor identified that the kitchen humidity was at approximately 23.2% relative humidity at 22.8 degrees Celsius.
    - ❖ The motion sensor showed no detection of human motion (event ('B')) inside the kitchen before the stove was turned on.
    - ❖ The light sensor detected that there is no light (event ('C')) present in the kitchen before any activities occurred.

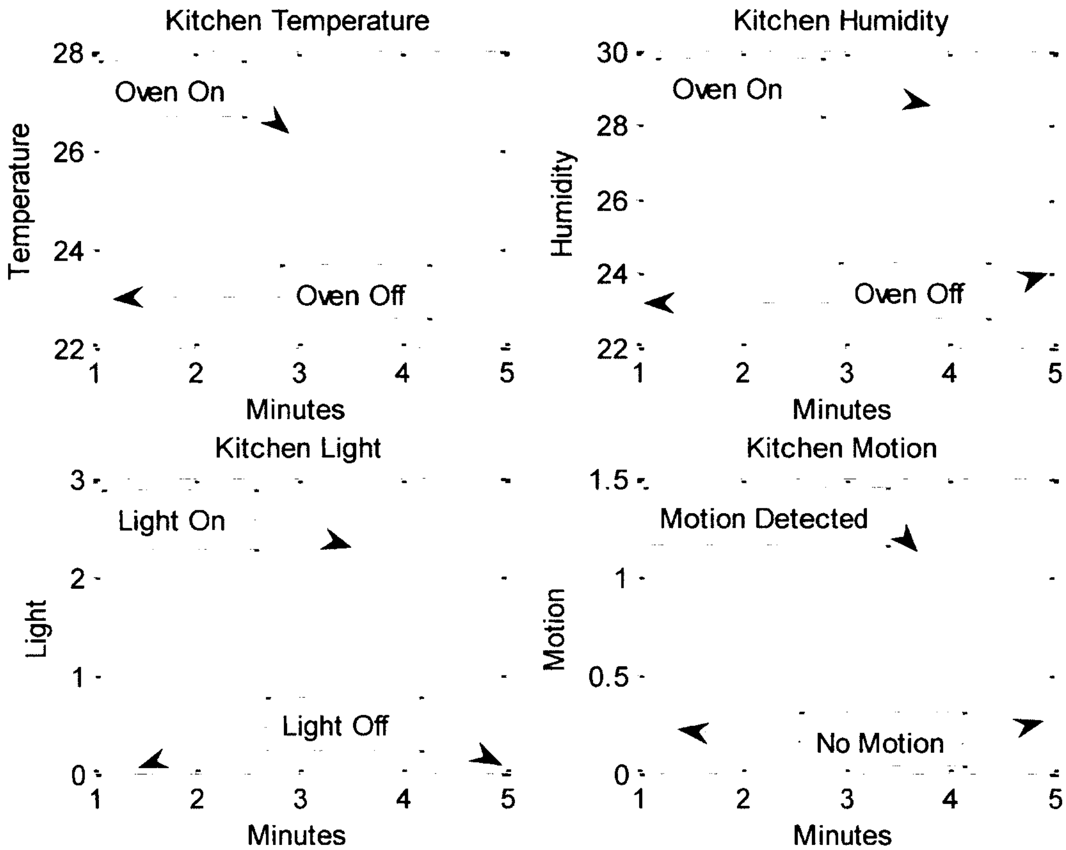


Figure 5.12: Graph of the data collected in the kitchen

- During the events in the kitchen - Figure 5.11 shows that when the stove was turned on to cook or boil water for tea or coffee, the temperature and humidity sensors detected that the kitchen temperature and humidity increased.
    - The temperature sensor detected that the kitchen temperature increased to about 26.8 degrees Celsius (event ('E')).

- The humidity sensor spotted that the kitchen humidity also increased to approximately 30% relative humidity at 26.8 degrees Celsius (event ('G')).
- The motion sensor detected human motion (event ('A')) inside the kitchen when the stove was turned on.
- The temperature sensor detected that the temperature of the kitchen increased when the stove was switched on (event ('E')).
- The light sensor identified that there was also light present in the kitchen (event ('C')).

- After the event in the kitchen stopped:
  - The temperature sensor detected that the kitchen temperature dropped to approximately 23.8 degrees Celsius (event ('F')).
  - The humidity sensor noticed that the kitchen humidity also dropped to approximately 23% relative humidity at 23.8 degrees Celsius (event ('H')).
  - The motion sensor detected that no human motion (event ('B')) was present in the kitchen after the stove was turned off.
  - The temperature sensor detected that the temperature of the kitchen dropped after the stove was turned off (event ('F')).
  - The light sensor indicated that the kitchen light was turned off (event ('D')).

Figure 5.13: Remote station located in the kitchen collecting data

5.3.7 Refrigerator Result

Test purpose: The purpose of this subsection is to explain the procedure used to collect the refrigerator data in the kitchen.

Expected result: The results were expected to show that the temperature and humidity sensors would detect a decrease in temperature and humidity when the prototype system was placed inside the refrigerator for a few minutes. Furthermore, we expected that the motion would to show human motion present in the kitchen.

Test procedure: The remote station was placed inside the refrigerator to transmit data every two seconds.

Tested result: The results we received were as we had expected.

Figure 5.13 illustrates the results of the collected data from the refrigerator in real time monitoring.

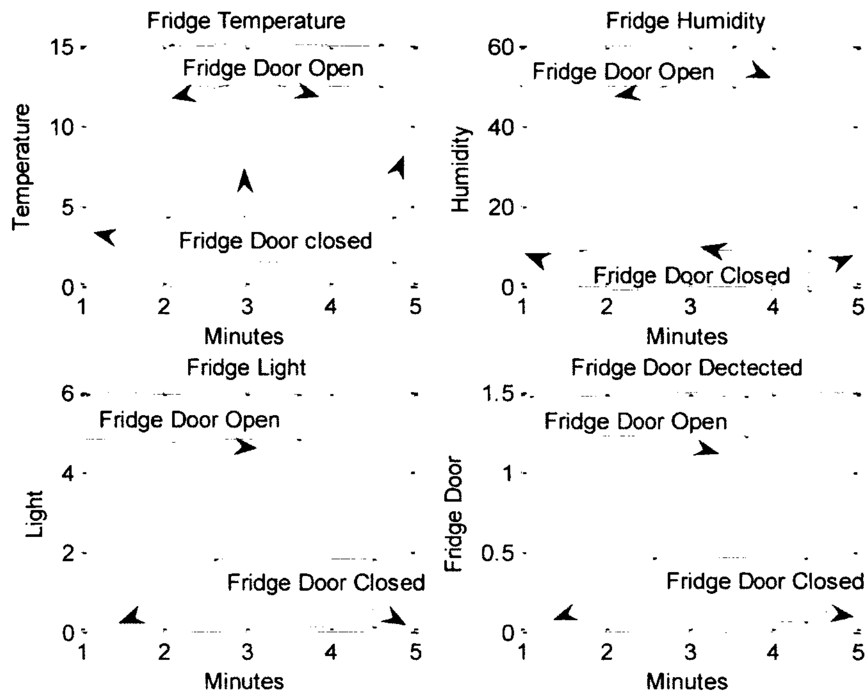


Figure 5.14: Graph of the data collected in the fridge

- When the remote station was positioned inside the fridge for few minutes and the fridge door was closed:
  - ❖ The temperature sensor showed that the fridge temperature was set to 4 degrees Celsius.
  - ❖ The humidity sensor showed that the fridge humidity was at 8% relative humidity at 4 degrees Celsius.
  - ❖ The light sensor indicated that the fridge light automatically turned off (event ('D')) whenever the fridge door was closed.
- As soon as the fridge door was opened:

- The figure indicates that the temperature sensor detected that the temperature of the fridge increased to 12 degrees Celsius (event ('E')).
- The humidity sensor also detected that the fridge humidity increased from 8% when the fridge door was closed to 42% relative humidity at 12 degrees Celsius (event ('G')).
- At the same time, the light sensor showed that the fridge light turned on automatically (event ('C')) whenever the fridge door was opened.
- The magnetic switch sensor also showed that the fridge door was opened (event ('I')).

Figure 5.15: Remote station inside fridge collecting data

5.3.8 Living Room Result

Test purpose: The purpose of this section is to collect data of events in the living room.

Expected result: The result was expected to indicate events of daily living in the living room.

Test procedure: The remote station was placed in the living room to transmit data every two seconds.

Tested result: The results we received were as we had expected.

Figure 5.15 illustrates the collected data in real time in the living room of the apartment.

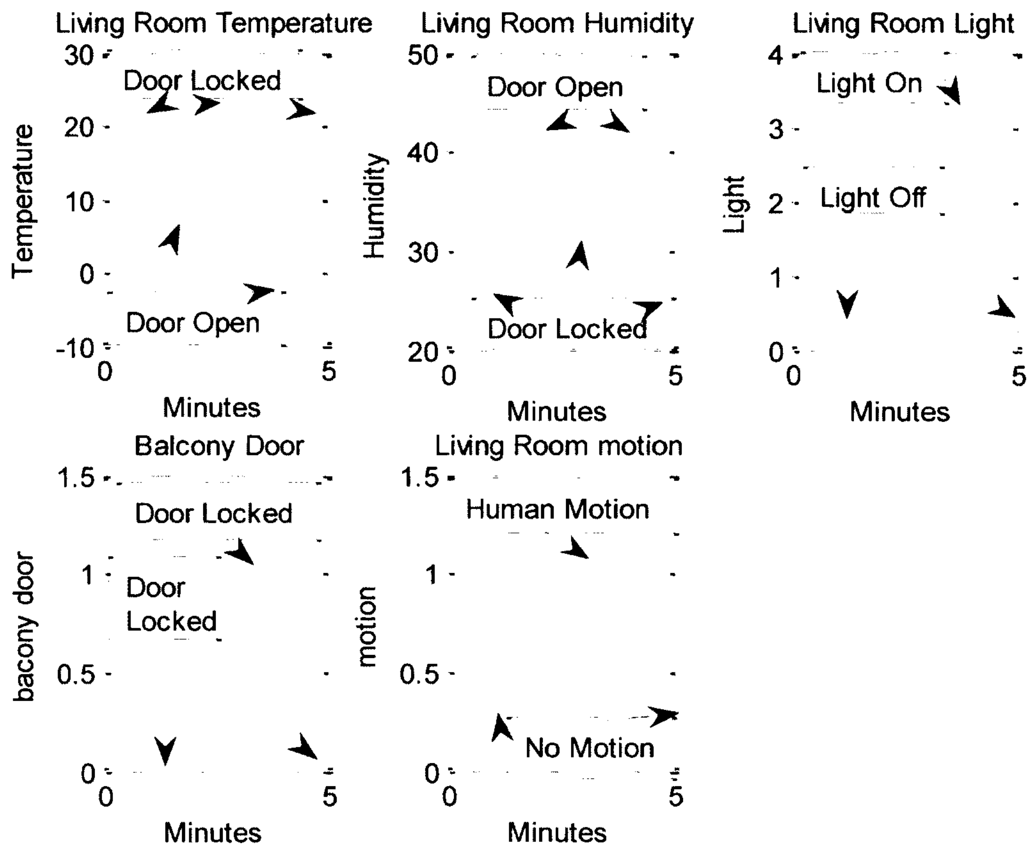


Figure 5.16: Graph of data collected from the living room of the apartment

As can be seen in the Figure 5.15:

- The temperature sensor detected that the living room temperature was at 22 degrees Celsius.
- The humidity sensor detected that the living room humidity was at 25% relative humidity at 22 degrees Celsius.
- There was also the detection of human motion in the living room (event ('A')) by the motion sensor.

- There was also the sensor detection of light present inside the living room (event ('C')).

As soon as the balcony door was opened as shown in Figure 5.16:

- The Figure 5.15 indicates showed the temperature sensor detected the temperature of the living room dropped to 4 degrees Celsius when the balcony door was opened for few minutes (event ('F')).
- The humidity sensor detected the living room relative humidityalso increased to 42% relative humidity at 4 degrees Celsius (event ('G')).
- At the same time, the light sensor indicated that the living room light was turned on, (event ('C')).
- The magnetic switch sensor also showed that the balcony door was opened (event ('I')).

Figure 5.17: Living room when balcony door was opened

5.3.9 Outside Results

Test purpose: The purpose of the section is to collect data from the balcony of the apartment.

Expected result: The results were expected to indicate a decrease in temperature and an increase in humidity during the wintertime.

Test procedure: The transmitter station was placed on the balcony of the apartment to transmit data every two seconds.

Tested result: The results we received were as we had expected, the prototype system indicated a drop in temperature outside and an increase in humidity.

Figure 5.17 illustrates the data collected outside the apartment (balcony) during the wintertime.

- Outside - As can be seen in Figure 5.17, the temperature and humidity sensors detected dropped in temperature and increased in relative humidity when the remote station was placed outside.
  - ❖ The outside temperature dropped to -4 degrees Celsius when the developed system was placed outside to collect data.
  - ❖ The outside humidity increased to 77 % relative humidity at -4 degrees Celsius (event ('G')).
  - ❖ It was pitch black, there was no light (event ('D')) present outside at the time of collecting the data.
- Inside (living room) – As can be seen in Figure 5.17, as soon the remote station was brought inside the apartment, the temperature and humidity sensors showed the temperature increased gradually while the humidity reading decreased simultaneously. Furthermore, there was an indication of the presence of light in the living room.
  - ❖ The temperature increased to 4 degrees Celsius when the system was placed inside the apartment (event ('E')).
  - ❖ The humidity sensor detected dropped of 52% relative humidity at 4 degrees Celsius (event ('H')).

- There was light (event ('C')) present inside the apartment at the time of collecting the data for the Figure 5.17.

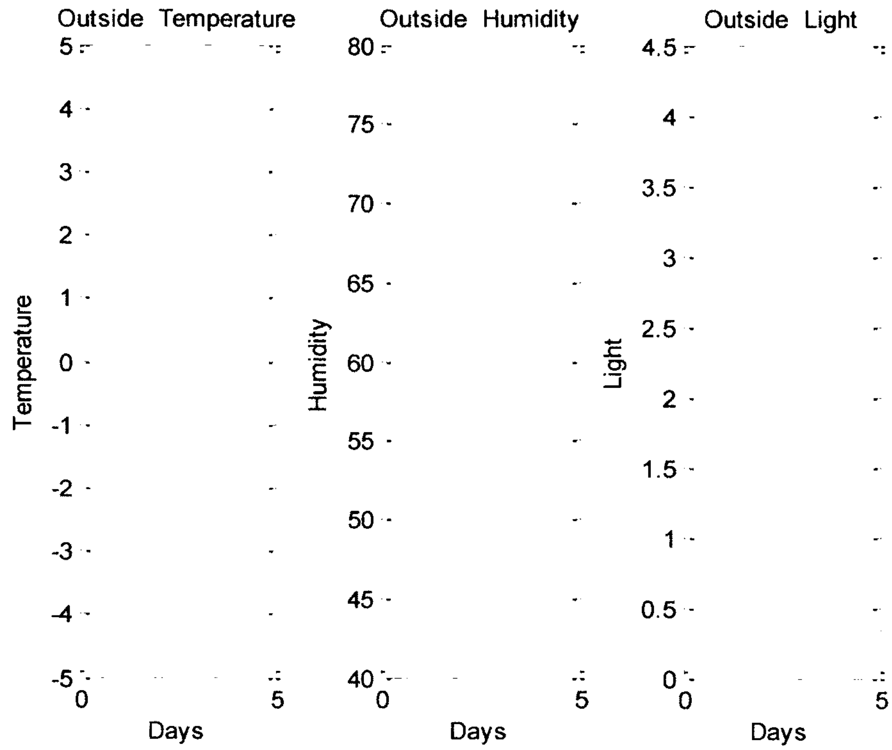


Figure 5.18: Graph of data collected from outside of the apartment

5.4 Data Interpretations

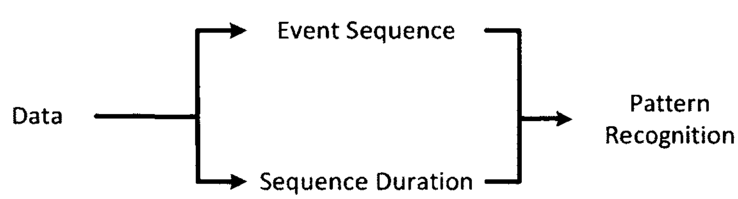


Figure 5.19: Sequence of data interpretations

Data interpretation is important to identify common patterns such that meaning can be derived. In the data analysis subsection, we assigned a symbol to each event. In this subsection, we will show how to derive meaning from the sequence of these symbols and duration of the events, as shown in Table 5.4. The goal is to potentially identify various Activities of daily living of an occupant from the sequence of the symbols. The Activities of daily living in which we are interested are activities such as bathing, toileting, eating, sleeping, and cooking, as shown in Table 5.4 and Figure 5.19.

Activities of daily living (ADL)	**Transition state (sequence)**	**Events**
Bathing	A,C,E,G,D,B	Motion on, light on, temperature on, humidity on, light off, motion off
Toileting	A,C,B,A,E,G,D,B	Motion on, light on, motion off, motion on, temperature on, humidity on, light off, motion off
Cooking	A,C,I, E,G,J,E,D,B	Motion on, light on, magnetic on, temperature on, humidity on, light on, magnetic off, temperature on, light off, motion off
Eating	D, B, A,C,D, B A,C	Light off, motion off, motion on, light on, light off, motion off, motion on, light on
Sleeping	A,C,D,B, A,C	Motion on, light on, light off, motion off, motion on, light on

Table 5.4: Sequence of events of Activities of daily living of an occupant

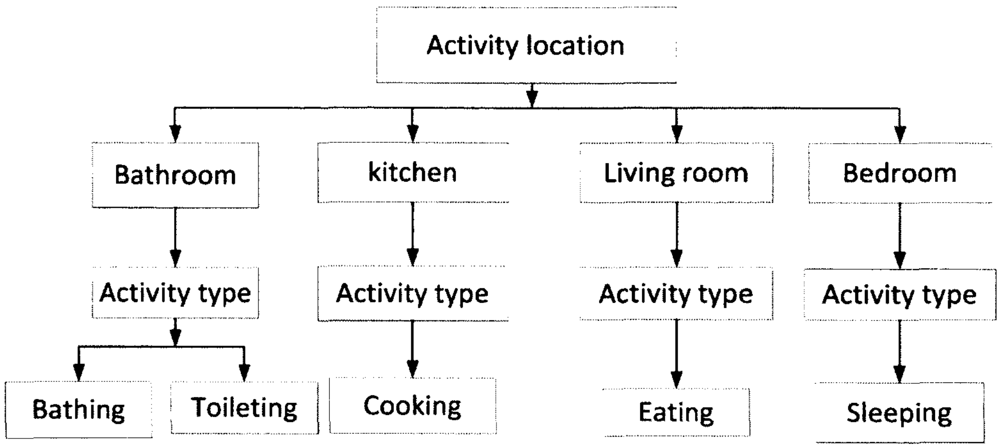


Figure 5.20: Activities of daily living of an occupant

- **Possible scenario for bathing activity is as shown in Figure 5.20:** An occupant enters the washroom, triggering the motion sensor (event ('A')); turns on the light, which activates the light sensor (event ('C')); and proceeds to taking a shower, turning on the hot water tap, which triggers the temperature and humidity to rise (event ('E') and event ('G'), respectively). After the shower, the occupant gets out of the bathtub, takes a towel to rub water off her/his body, puts on some body lotion, dresses, and then moves toward the door to exit the washroom; these activities continue to generate motion (event ('A')). The occupant then turns the light off (event ('D')) and departs the washroom (event ('B')). The expected duration of the activity is 10-15 minutes as shown in Figure 5.20.

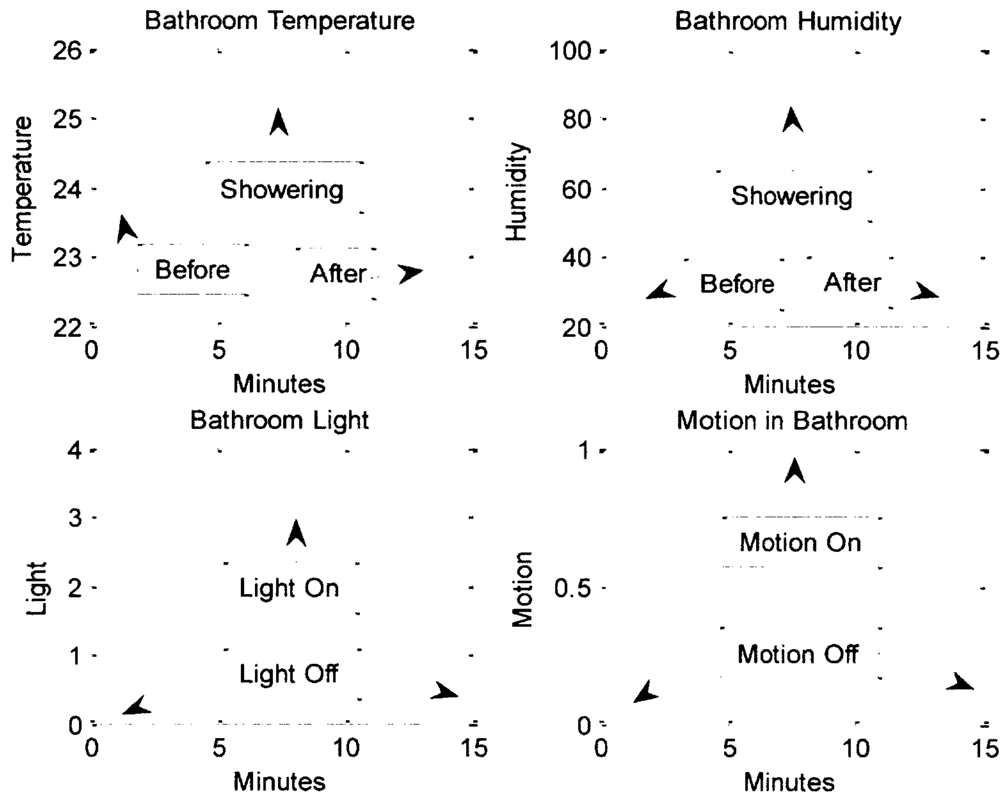


Figure 5.21: Bathroom results

- **Possible scenario for toileting activity is as shown in Figure 5.21: :** An occupant enters the washroom, triggering the motion sensor (event ('A')); turns on the light (event ('C'); and sits down on toilet seat, where they make no movement at all and therefore trigger the motion off (event ('B')). The occupant moves to stand up, triggering the motion sensor on (event ('A')); flushes the toilet; and turns on the tap to wash their hands, triggering the temperature and humidity to rise (event ('E') and event ('G'), respectively). The occupant then moves toward the door and turns off the light (event ('D')) and departs (event ('B')). The expected duration of the event is 5-10 minutes as shown in Figure 5.21.

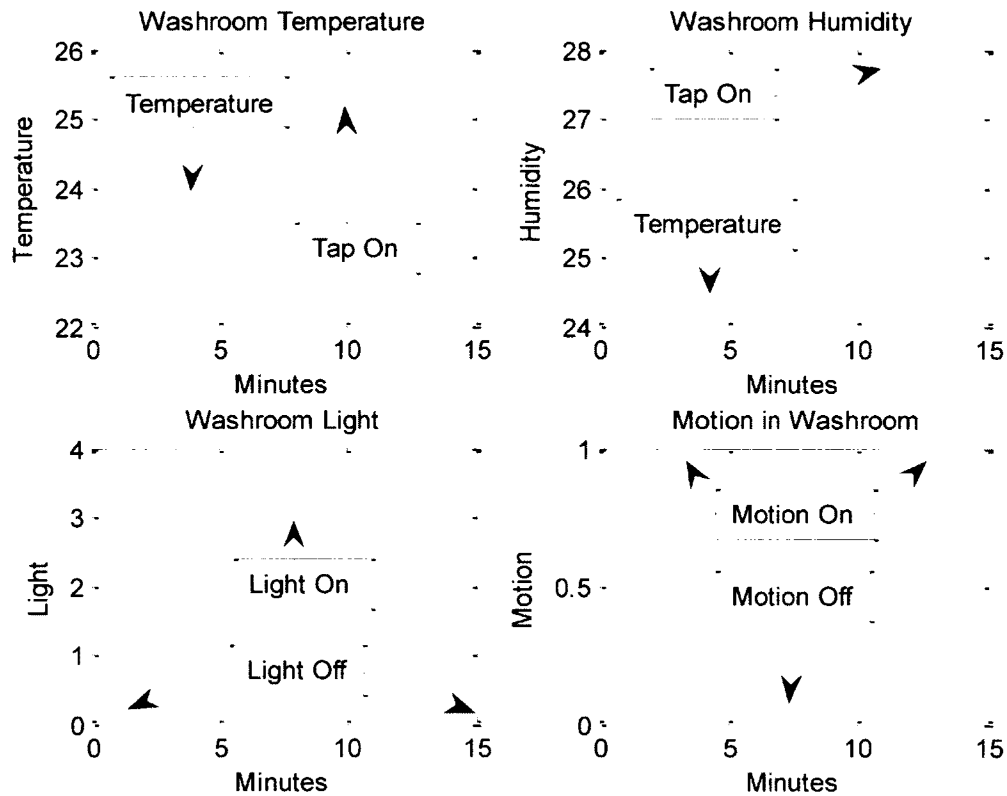


Figure 5.22: Washroom results

- **Possible scenario for cooking activity is as shown in Figure 5.22:** An occupant enters the kitchen, triggering the motion sensor (event ('A')), and switches on the light (event ('C')). The occupant then moves toward the refrigerator and opens the refrigerator door, triggering the magnetic sensor on (event ('I')). The refrigerator's light turns on, as it does automatically whenever the refrigerator door is opened (event ('C')), and the temperature and humidity rise (event ('E') and event ('G'), respectively) as shown in Figure 5.13. The occupant then closes the fridge door, triggering the magnetic sensor off, (event ('J')) and refrigerator's light turns off, as it does automatically whenever the refrigerator door is closed (event ('D')). The occupant switches the stove on, prompting the temperature sensor to go up (event ('E')). The occupant's movement and activity around the kitchen continues to trigger the motion sensor on (event ('A')) in the kitchen. Upon completion of food preparation, the occupant turns off the light (event ('D')) and departs from the kitchen, triggering the motion sensor to not detect any motion (event ('B')) in the kitchen. The expected duration of the cooking event is 10-30 minutes as shown in Figure 5.22.

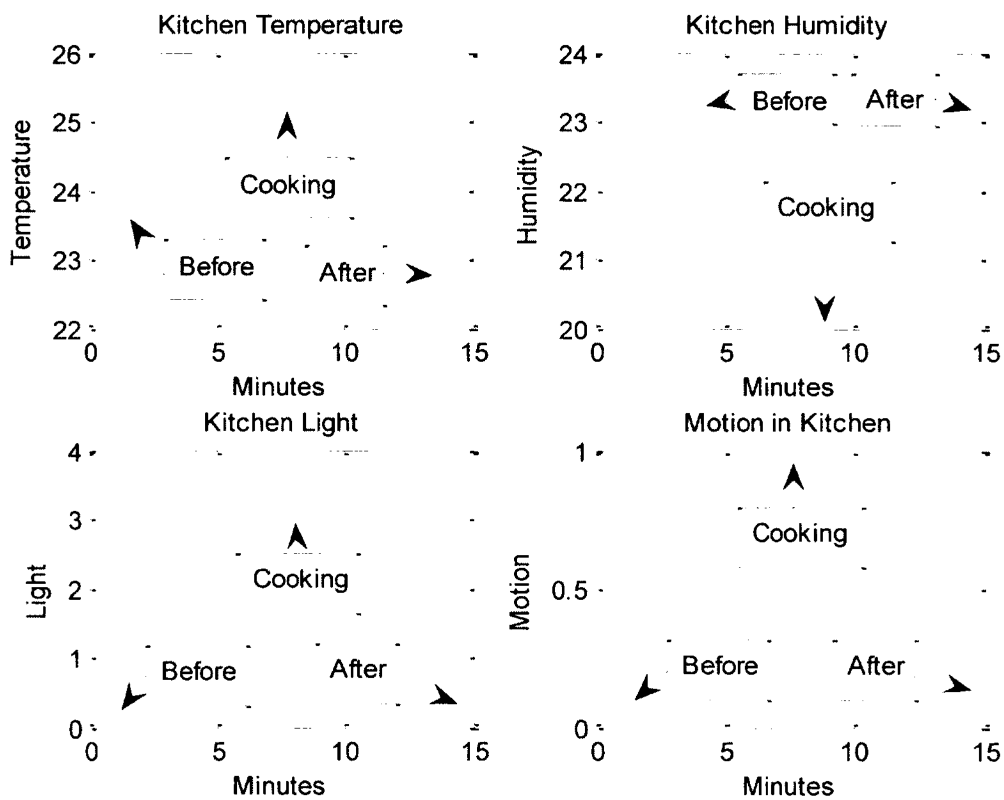


Figure 5.23: Kitchen results

- **Possible scenario eating activity is as shown in Figure 5.23:** The activity starts in the kitchen, moves to the living room, and then back to the kitchen again. Upon completion of food preparation, the occupant turns off the kitchen light (event ('D')) and departs from the kitchen, triggering the motion sensor to off (event ('B')). The occupant then enters the living room, triggering the motion sensor (event ('A')), turns on the light, (event ('C')), and sits down to eat. After the meal the occupant goes back to kitchen, triggering the motion sensor on, (event ('A')), and switches the kitchen light on again (event ('C')). The expected duration for the eating events is 10-30 minutes as shown in Figure 5.23.

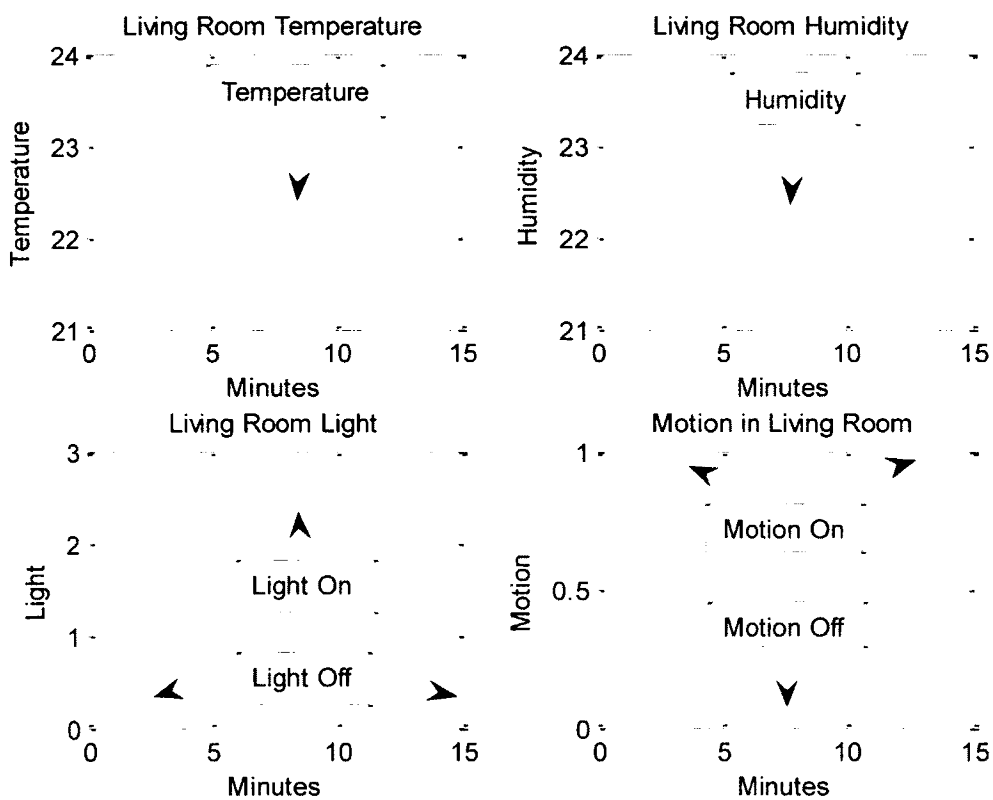


Figure 5.24: Living Room results

- **Possible scenario for sleeping activity is as shown in Figure 5.24:** The activity starts at the time that the occupant goes to bed and ends at the time that the occupant wakes up. The occupant enters the bedroom, triggering the motion sensor (event ('A')); turns on the lamp (event ('C')); and proceeds to the bed to lay down on it. The occupant then turns the lamp off (event ('D')) and lays down on bed to sleep, triggering the motion sensor off (event ('B')). The occupant wakes up in the morning, triggering the motion sensor on (event ('A')). The expected duration of sleep is 6-8 hours as shown in Figure 5.24.

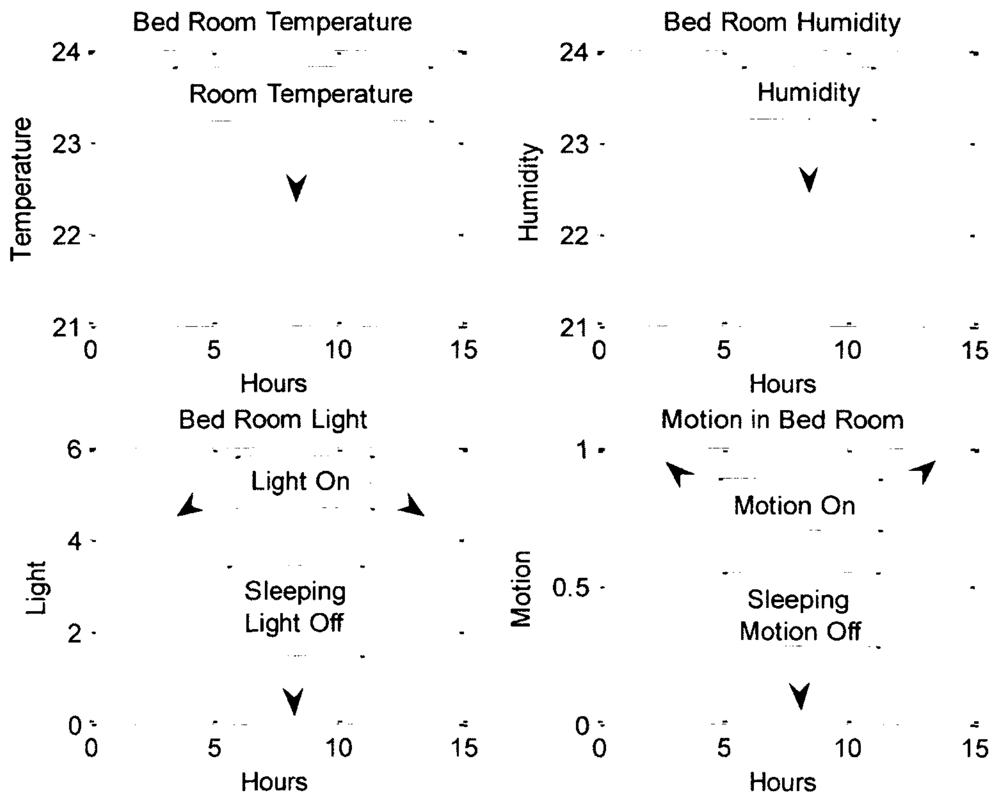


Figure 5.25: Bed Room results

5.5 Potential Benefits of the Research

As we have seen, the monitoring system can automatically detect the Activities of daily living (ADL) of elderly populations in their home to improve the occupant's health and well-being, and the safety of their living conditions. This section will describe some of the potential benefits of our developed system.

- **Health and well-being**: Health and well-being can be determined through the level of mobility and the performance of ADL of the occupant. Early signs of health problems of the occupant can be identified from abnormal patterns in their ADL. Moreover, knowing if sleeping, eating, or bathing times change day after day is also a good indication of health problem. The objective here is early recognition of abnormal conditions and prompt, appropriate, and cost-effective interventions of medical and welfare professionals to help reduce morbidity and maintain independent lifestyle of the elderly in their own home.
- **Food spoilage:** The refrigerator is one of most important appliances in the kitchen in regards to keeping food safe. It helps protect food from spoiling by slowing bacterial growth. Bacteria grow rapidly at temperatures between 4°C and 60°C. This temperature range is commonly referred to as the "Danger Zone." The refrigerator temperature should be 4°C or lower. This temperature level and refrigerator door should always be monitored to prevent food from spoiling.
- **Well-cooked food**: It is important to cook food thoroughly to kill harmful bacteria that might contaminate food, especially meat. Sometimes meats are contaminated with pathogens[17]; to kill these germs, meat must be cooked thoroughly at a temperature of at least 77°C. However, high temperatures destroy certain vitamins and minerals in food, so food must be cooked at the temperature range that is

[17] Pathogens are germs that cause serious illness.

suitable for each type of food. Our designed prototype system is suitable for monitoring food temperature levels to ensure safety.

- **Negligence:** Caregiver negligence is one of the problems facing the elderly population. One example of negligence is the well-known story in June 2010 of the elderly person in Toronto who was neglected for several months in a makeshift bedroom setup inside an uninsulated and inadequately heated garage. She was left there with only a bucket of water, very little food, and a port-a-potty that was not properly maintained [63]. She was found unconscious, starving, and suffering from frostbite. Monitoring systems such as ours that can automatically detect the daily living activities of elderly populations in their home can lead to the improvement of their health and well-being, and the safety of their living conditions and could have made a difference in this situation. Another story of neglect is that of an elderly couple in the UK, Mr. Randall, 76, and his wife Mrs. Jean, 79 [64]. The couple was left to die in their freezing home after neighbours' pleas for help to the authorities were ignored. The system that can monitor room temperature and make sure it does not drop below ambient temperature, especially in the winter, could have saved the couple.
- **Intruders**: Another issue facing elderly people is that of intruders. There are frequently reports of break-ins into the homes of the elderly and assaults of elderly people that could be avoided. One way of preventing these crimes is by continuously monitoring windows and main entrances of buildings to ensure they are locked at all times as well as putting in place a system with a buzzer that would send out an alert if doors and windows are open for a long period.
- **Water leakage:** There are so many headline news stories of water leakage problem facing elderly. The stories such as "Water heater's monoxide leak kills elderly couple." Taipei City police found the bodies of

an elderly couple living in the Shizhi District who had reportedly died from carbon monoxide poisoning resulting from an overheated water heater in a tightly sealed home [65]. A continually monitoring of home temperature and humidity levels to avoid water leakage or water damage restoration.

- **Energy consumption:** Energy consumption is one of the most pressing issues facing the elderly population. Sometime elderly people forget to switch off the stove or turn off the lights, faucets, or tap after usage, which leads to heat loss and energy waste. One way of controlling this is through continuously monitoring the major domestic equipment: the hot water heater, stove, refrigerator, and light switches. This can detect the usage pattern and the impact of seasonal difference on energy usage and help identify when a particular appliance is ON and the length of time that it has been ON.

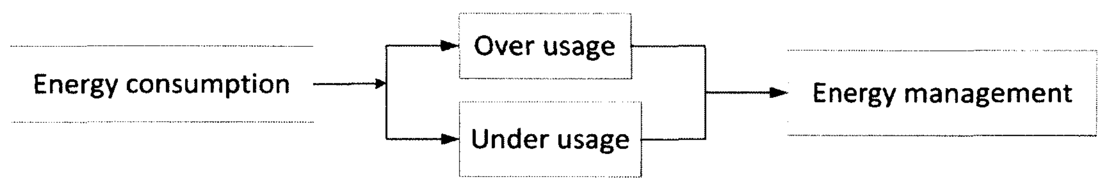


Figure 5.26: Energy consumption due to activities of daily living of an occupant

5.6 Potential Benefits of Sensors

The experimental results for our collected data at different locations and environments clearly show that our prototype system can achieve high levels of accuracy. Each sensor in the prototype system has the potential of benefitting the occupant in the smart apartment. The potential goals are discussed as follows.

- **Temperature sensor:** The goal of the temperature sensor is to monitor environmental temperature to ensure appropriate heating and cooling of the apartment. Also, the aim of the temperature sensor is to monitor the condition of appliances in the apartment, such as the refrigerator or stove, to ensure they are operating at an acceptable temperature range. The designed system also includes a buzzer to alert the user of any change in the normally required range of temperature in the apartment or appliances.

- **Photocell sensor:** The goal of the photocell sensor is to monitor the presence of light in the apartment. This information could potential help an occupant turn the light off when light is not supposed to be on. Another goal of the light sensor is to monitor the condition of appliances, such as the fridge. From the experimental results of the fridge, we have learned that whenever the fridge door is open, the fridge light turns on automatically. As soon as the door is closed, the fridge light turns off. With this information, it can be easily recognized when the fridge door is open or closed; this can lead to ensuring that the fridge door is closed to prevent food from spoiling.

- **Pyroelectric Infrared (PIR) Motion Sensor:** The goal of the sensor is to monitor the presence and motion of the resident throughout the apartment. Information about the occupant's health, hygiene, and eating patterns can be determined from the motion sensor. For example,

  (1) Concerns about the occupant's hygiene can be determined from motion in the bathroom.

  (2) Concerns about the eating behaviour of the occupant can be determined from motion in the kitchen and living room.

  (3) Health concerns about the occupant can be determined from prolonged presence of motion in one place or room and no motion throughout the entire apartment. The information here can indicate that occupant might be too ill to move around the apartment. Also, irrational

wondering or random changes of motion in the apartment could indicate mental anxiety or confusion.

- **Humidity sensor**: The aim of the humidity sensor is to monitor environmental relative humidity of the apartment or appliances to enable the observer to determine the Activities of daily living of the user and the condition of their appliances in the apartment. From the experimental results of the fridge, we have detected that when the fridge door is open, the relative humidity of the fridge increases. We also observed an increase in relative humidity when the bathtub is filled with water and when windows or the balcony door is open. With this information, the following information can be determined:

  (1) The occupant taking a shower can be determined from changing levels of relative humidity in the bathroom.

  (2) The fridge functionality can be determined from the relative humidity of the fridge.

  (3) An open balcony door or window can be determined by changes in the relative humidity of the apartment.

- **Ultrasonic sensor**: The objective of the ultrasonic sensor is to detect an object and measure the discrete distances between objects in the apartment. For example, it can be used to measure a distance between an object in the kitchen or bathroom of the apartment; this information can identify the exact location of an occupant in the apartment.

- **Hall Effect (magnetic) sensor**: The purpose of the Hall Effect sensor is to detect whether a door is open or closed. It is convenient for the monitoring of the entry and exit from various rooms or the apartment.

It is also useful for monitoring windows or kitchen appliances, such as the refrigerator, dishwasher, or stove.

- **Piezoelectronic buzzers**: There are also buzzers that will alert the users of any unacceptable changes in behaviour. An example of an unacceptable change in behaviour would be when the temperature of the apartment or appliances, such as fridge, is lower or higher than the acceptable range.

The primary goal of the research is the early recognition of abnormal conditions such that automatic, prompt, appropriate, and cost–effective interventions can be implemented by medical and welfare professionals to help reduce the morbidity of elderly people and maintain independent lifestyles of this population in their own homes. The target intervention will potentially help reduce requests for expensive medical services and reduce elderly demands in emergency.

CHAPTER 6

CONCLUSION, LIMITATIONS, AND SUGGESTIONS FOR FUTURE RESEARCH

This chapter is organized into two sections: section 6.1 focuses on the conclusions of the research and section 6.2 emphasizes limitations and suggestions for future research.

6.1 Conclusions

The objective of the research was achieved. We designed, developed, and implemented an ultra-safe and reliable wireless sensor network system with multiple functions that functions trouble-free in different environments and require minimal maintenance. The system is cost-effective, easy to use, portable, and consumes less power than other wireless sensor networks, such as Wi-Fi, Bluetooth, wireless USB, Ultra wideband (UWB), or IR wireless. Nowadays, with busy lifestyles, a wireless sensor network is an excellent device to monitor vulnerable, isolated, or neglected people in society, such as the many senior citizens who are left alone in their homes with little or no supervision. With this contribution, this research could potentially lead to major cost savings in regards to the monitoring of the elderly population in that they can maintain an independent, healthy lifestyle in their own home rather than relocate to more expensive and isolated care facilities. However, it is up to the users to decide whether to accept this wireless device as an integral part of their life.

6.2 Limitations and Future Research

6.2.1 Limitations

Although the research has reached its objectives, there were some limitations to the research. Some of these limitations will be discussed in this section.

Data retrieval: The developed system only collects data and does not store it for future research. We suggest that future research further develop this system to include storage features that store data for future studies.

Design and implement control features: The developed system we proposed monitors the activities of daily living but does not control the activities. For future research, we recommend that the design system include control features.

Multiple remote stations: Although the developed system we proposed can be used for collecting data from multiple remote stations, we were unable to receive data from multiple remote stations simultaneously, instead we used pair form. Pair form is the simplest network with just two radios, a coordinator, and one remote station. To further the impact of this research, we suggest future research look into these issues.

Algorithm and implementations: The developed system we proposed for monitoring does not include algorithms for pattern recognition; we suggest this be included in future research. Some of the most common machine learning algorithmic models used in this area are Bayesian Network, Logic Models, Decision Tree, Artificial Networks, and Dynamic Bayesian models.

6.2.2 Suggestion for Future Research

Although we have reached our goals, there are ways that the research can be improved. Some recommendations that we suggest for future research are described in this section.

Extend the range of data transmissions: The developed system we proposed transmits data up to the range of 133 feet (40 meters) indoors and 400 feet (120 meters) outdoors at Line-of-sight. We suggest the range of transmission should be extended for future research such that data can be collected at as great a distance as possible.

Power consumption: We used electric outlets as the power source for our system since it was readily available at the area of data collection, as such, we do not know the exact life expectancy of the system when using batteries. For future research, if the system is going to be used with batteries as the power source to collect data indoors or outdoors, then the life expectancy of the battery should be determined.

Incorporate new type of sensors in the environment: New type of sensors may help to recognize sets of more complex activities, or activities not detected before. For example, a sensor which is able to monitor current consumption of electric/electronic appliances is likely to provide powerful hints about device usability [66]. Other sensors that can be considered such as a water-flow sensor to monitor water flow and a force sensor which can be installed in the bed, chair, couch, or mat to pinpoint the exact location of the occupant when the occupant is cooking, eating, or sleeping.

Publication of the research: One of the most important parts of the research that is not yet completed is publication of the results of the research. It will be ideal to consider the research for publication in future.

Cellular, WiMAX, Wi-Fi, or Ethernet connection: For future research, we recommend the use of ConnectPort X shown in Figure 6.1. ConnectPort X is a gateway that provides PC or IP Network connectivity for end point devices in XBee WPANs, allowing data to be collected anywhere in the world. Gateways collect end node data, aggregate it, and send it to a parent application using cellular, WiMAX, Wi-Fi, or Ethernet connections. ConnectPort X gateway can extend wireless connectivity to other devices such as Smart mobile phones.

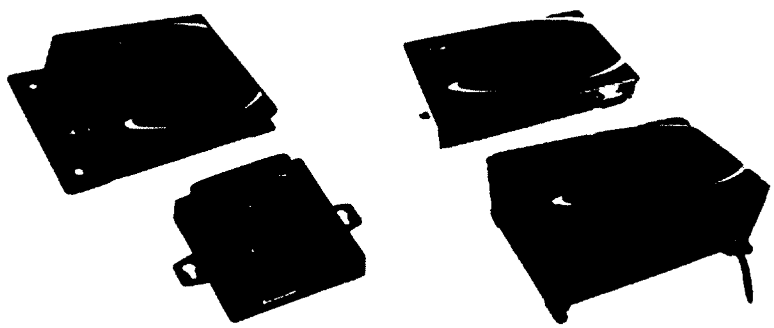


Figure 6.1: Different types of ConnectPort X gateway

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APPENDIX

Appendix A: Wireless Technologies

The advantages and disadvantages of the potential wireless technologies are following:

Advantages of Wi-Fi are summarized below:

- Good for moving large amounts of data (1Mb+);
- Employs unlicensed radio spectrum and does not need regulatory approval for individual launch;
- Has a set of global standards, which means it can operate in different countries around the world at all times; and
- Supports roaming: it allows mobile users with devices such as laptop computers to be able to move from one access point to another.

Disadvantages of Wi-Fi are summarized below:

- Consumes larger amounts of power compared to some other standards such as XBee, Wireless USB, or Bluetooth. Wi-Fi requires approximately 100mA to handle 802.11 stacks, making the battery life and heat a major concern to some users; and
- Wi-Fi networks have limited range depending on the physics of the radio wave propagation with the frequency band. A typical range is about 45 m (150 ft.) indoors and 90 m (300 ft.) outdoors.

The advantages of Bluetooth are summarized as follows:

- Can be used in both fixed devices, such as telephones, computers, printers and other devices, in mobile devices, such as cell phones, laptops, and other devices, and also for creating personal area network (PANs);
- Is easy to use;
- Certified interoperability: it has the capability for diverse systems and organizations to work together;
- The range is between 50–100 meters, suitable for Bluetooth applications; and
- Also supports audio links.

The disadvantages of Bluetooth are the following:

- Uses the same frequency as the WaveLAN[18] standard, which may cause interference; and
- Is omni-directional; it encounters problems in determining the intended recipient device.

Ultra wide band (UWB)

These applications are summarized below. Ultra wide band applications can be divided into two forms: communications and radars.

(1) Ultra wide band can be used for the following applications in communications:

- High-speed, multi-user wireless networks;
- Wireless personal area networks (PAN)/local area networks (LAN);

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[18] WaveLAN is a trade name that describes two completely different families of wireless network solutions:

- Pre-IEEE 802.11 WaveLAN, also called Classic WaveLAN
- IEEE 802.11-compliant WaveLAN, also known as WaveLAN IEEE or ORiNOCO

Source: en.wikipedia.org/wiki/WaveLAN

- Indoor video/data/voice distribution; and
- Military applications.

(2) Ultra wide band can be used for the following applications in radars:

- Through-wall imaging and motion sensing radar;
- Security systems for alarming and tracking movement;
- Underground imaging;
- Vehicular radar: collision avoidance/detection, road conditions sensing; and
- Military applications (intrusion detection radars, proximity fuses, unmanned ground and aerial vehicles).

Advantages of the Ultra wide band (UWB) are summarized below:

- One of the most significant of these advantages is its capability to relatively easily share spectrum space with other devices. Since their frequencies are so adaptive, the devices can easily change to locate an open range in which to transmit;
- UWB communications transmit in a way that does not interfere largely with other more traditional narrowband and continuous carrier wave uses in the same frequency band;
- High capacity for frequency band;
- Multipath robustness;
- Position location capability;
- Low transmission power;
- Low implementation cost; and
- Multi-access capability.

Disadvantages of the Ultra wide band (UWB) are summarized below:

- Power limitation; and
- Synchronization.

Advantages of the Infrared (IR) are summarized below:

- Consumes low power: ideal for devices such as laptops, telephones, personal digital assistants'
- Inexpensive: costs around $2-5 for the entire coding/decoding circuitry;
- IR circuitry is very simple. No special or proprietary hardware is necessary and it can be incorporated into the integrated circuit of a product;
- XBee has higher security compared to other wireless technologies because of the directionality of the beam, which helps ensure that data is not leaked or spilled to nearby devices as it is transmitted;
- It is portable;
- No restrictions by international regulations for devices to be functional, and can be used by anyone especially by international travelers, no matter where they may are with no restrictions; and
- No interference from signals from other devices.

Disadvantages of the Infrared (IR) are summarized below:

- The technology is not like radio-frequency (RF) wireless links in that IR wireless cannot penetrate through walls. IR wireless communications or control is generally not possible between different rooms in a house or between different houses in a neighbourhood except when they are facing windows. Any blockage by common objects, such as people, animal, walls, plants, can obstruct the transmission of data;

- It must be almost directly in the line of sight for devices to transmit and receive data;
- Performs well for short range; however, the range drops off with longer distance;
- Transmission can be affected by elements such as light, weather, sunlight, rain, fog, dust, or pollution; and
- Data rate transmission is slower than typical wired transmission.

Radio Frequency Identification (RFID)

Advantages of the Radio frequency identification (RIFD) are summarized below:

- Non-line-of-sight operation;
- Higher inventory rates; and
- Rewritable product IDs.

Table 7.1 provides a summary of the potential wireless technologies, including Wi-Fi, Bluetooth, Ultra wide band (UWB), Wireless Universal Serial Bus (USB), Infrared (IR) wireless, and ZigBee.

	ZigBee	802.11 (Wi-Fi)	Bluetooth	UWB (Ultra Wide Band)	Wireless USB	IR Wireless
Data Rate	*20, 40, and 250 Kbits/s*	11 & 54 Mbits/sec	1 Mbits/s	100-500 Mbits/s	62.5 Kbits/s	20-40 Kbits/s 115 Kbits/s 4 & 16 Mbits/s
Range	*10-100 meters*	50-100 meters	10 meters	<10 meters	10 meters	<10 meters (line of sight)
Networking Topology	*Ad-hoc, peer to peer, star, or mesh*	Point to hub	Ad-hoc, very small networks	Point to point	Point to point	Point to point
Operating Frequency	*868 MHz (Europe) 900-928 MHz (NA), 2.4 GHz (worldwide)*	2.4 and 5 GHz	2.4 GHz	3.1-10.6 GHz	2.4 GHz	800-900 nm
Complexity (Device and application impact)	*Low*	High	High	Medium	Low	Low
Power Consumption (Battery option and life)	*Very low (low power is a design goal)*	High	Medium	Low	Low	Low
Security	*128 AES plus application layer security*		64 and 128 bit encyption			
Other Information	*Devices can join an existing network in under 30ms*	Device connection requires 3-5 seconds	Device connection requires up to 10 seconds			
Typical Applications	*Industrial control and monitoring, sensor networks, building automation, home control and automation, toys, games*	Wireless LAN connectivity, broadband Internet access	Wireless connectivity between devices such as phones, PDA, laptops, headsets	Streaming video, home entertainment applications	PC peripheral connections	Remote controls, PC, PDA, phone, laptop links

Table 7.1: Comparison of ZigBee with other wireless technologies [67]

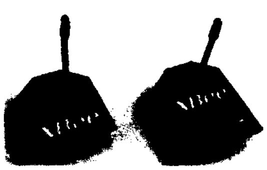
Appendix B: XBee Module

Communication is easy to establish with the XBee module because the interface used for sending and receiving data is UART (TTL). All it needs is to connect the UART communication pins of the XBee module directly to the microcontroller's UART. The XBee module is a half-duplex (HDX) module that provides information in both directions, but only one direction at a time (not simultaneously). Usually, when an XBee module begins receiving a signal, it must wait for the transmitter to stop transmitting before replying to the transmitter. Table 7.2 illustrates the basic feature of XBee modules.

Wireless Type	ZigBee (XBee)
Wireless Size	0.962" x 1.2972" (2.438cm x 3.294cm)
Transmission	250 kbps
Frequency Band	2.4 GHz
Communication distance	• Indoor/Urban: up to 100' (30 m) • Outdoor line-of-sight: up to 300' (100 m)
Network Topology	• Point to point • Peer to peer • Point to multipoint
Supply Voltage	2.8-3.3V
Manufacturer	Digi International

Table 7.2: Features of XBee

XBee and XBee-PRO RF Modules



The component is available in both a low-power XBee and XBee-PRO RF version. The XBee-PRO RF has an extra amplifier for higher ranges; nevertheless, the power required to run The XBee-PRO RF is also a lot higher. Choosing the best or most suitable modules depends on the application (e.g., the purpose, or situation, of the research) and the users' request. Both the XBee and XBee-PRO RF modules are bidirectional bands and are pin-for-pin compatible with each other. The one to the right is of XBee Series 2 and the one to the left is XBee Pro Series 2; both modules are equipped with whip antennae. Table 7.3 is the comparison of the specifications of XBee and XBee Pro, including brief descriptions of their ranges, transmitter and receiver power, and sequence channels.

Item	XBee	XBee Pro
Range, Indoor/Urban	100 Feet (30 meters)	300 feet (90 meters), 200 feet (60 meters) for International variant
Range, Outdoor line-of-sight	300 feet (90 meters)	1 mile (1600 meters), 2500 feet (750 meters) for International variant
Transmit Power	1 mW (0 dBm)	63mW (18dBm), 10mW (10dBm) for International variant
Receiver Sensitivity	-92 dBm	-100 dBm
TX Peak Current	45 mA (@3.3 V)	250mA (150mA for international variant) 340mA (180mA for international variant
RX Current	50 mA (@3.3 V)	55 mA (@3.3 V)
Power-down Current	< 10 µA	< 10 µA
RF Data Rate		250,000 bps
Sequence Channels	16	12

Table 7.3: Different between XBee and XBee Pro [61]

Types of Antennae

There are the following different types of antenna choices available for the XBee modules that allow for connection to a dipole or other external antennae.

(1) Wire

(2) Chip

(3) UFL

(4) PCB

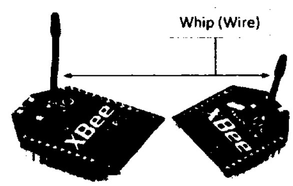
(5) RP-SMA

The applications of XBee with these types of antennae depend on the users' application, for example:

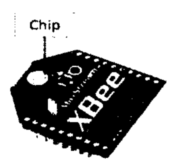
(1) The integrated whip or wire antenna and the chip antenna

These kinds of antennae work well with any application but they are especially useful in embedded applications. They have no problem transmitting or receiving signals through plastic cases or housings; they can, therefore, be completely enclosed.

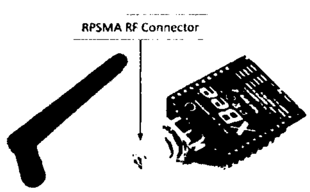
(i) **Integrated whip or wire antenna** uses Omni-directional radiation. This means that the antenna is capable of transmitting or receiving signals in all directions, especially when the whip or wire is straight and perpendicular to the module as shown to the right.



(ii) **Chip antennae** have a triangle-shaped radiation pattern that allows the signal to attenuate in many directions. The chip antenna is suitable for a device where mechanical stress to the wire antenna might break it or the module needs to be put in a very small space, such as anything wearable. The figure to the right shows the type of this chip antenna.



(2) The U.FL connector is used in conjunction with an adapter cable that can allow connection to a dipole or gain antenna as shown at Figure 7.1. The antenna is suitable for an XBee module that is embedded in metal or a solution that is more desirable mechanically. However, the antenna is to be left outside if the XBee module is going to be left on the inside of a metal box to avoid



transmitting or receiving signals that should not be attenuated by the enclosure. In addition, it is sometimes beneficial to orient an external antenna differently than the XBee itself or to use a special-purpose antenna with a precise radiation pattern, such as a high-gain antenna that passes signals in a single direction over a broader distance. The U.FL connector is small, fairly fragile, and most of time used with a short connecting cable that carries the signal from a remotely mounted antenna.

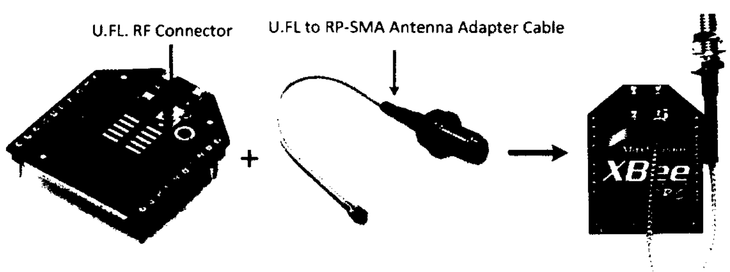


Figure 7.1: XBee module with type U.FL connector

(3) **PCB antenna**, which was established with the XBee-PRO S2B, is printed directly on the circuit board of the XBee. It is composed of a series of conducting traces set out in a fractal pattern. The PCB antenna offers many of the same benefits as the chip antenna and has a much lower manufacturing cost.

(4) **RPSMA connector** is just a different type of socket from the U.FL connector. It's known for its typically inconvenient size and for taking up a lot of space. It is large and unwieldy, but it can be used with an external antenna mounted directly to the XBee without a connecting cable. For most studies, it is still better off with the simple wire antenna that is smaller, cheaper, and generally just as good. That is why we used wire antennae for our study.

Although the 2.4 GHz XBee module has a maximum over-the-air date rate of 250000 bps due to the overhead of the protocol, the actual theoretical maximum data rate is approximately half of that at

15200 bps. The possible values are shown in Table 7.4. The Baud rate is managed by the BD setting, with standard Baud rates defined as the codes 0 to 7 [68]. 3(9600 bps) is set by factory default. The XBee module has low baud rates of between 1,200 and 115,200 bps.

BD	Baud Rates
0	1200 bps
1	2400 bps
2	4800 bps
3	9600 bps
4	19200 bps
5	38400 bps
6	57600 bps
7	115200 bps

Table 7.4: Baud rates and parameter (BD) defined as the codes 0 to 7.

Digi Development Board

The Digi development board was also considered for the research. The board was included with a starter kit that we bought from Digi International for our research; however, for reasons of cost, size, and flexibility, we decided not to use it. The two types of these boards, USB and RS 232 Digi Development Boards, are shown at Figure 7.2. The boards are composed of a power supply source, USB or RS 232 connector, switch button, reset button, and lights. Although the boards are suitable for our base station, we decided to use the XBee adapter from SparkFun for our base station and Adafruit XBee adapter for our remote stations instead.

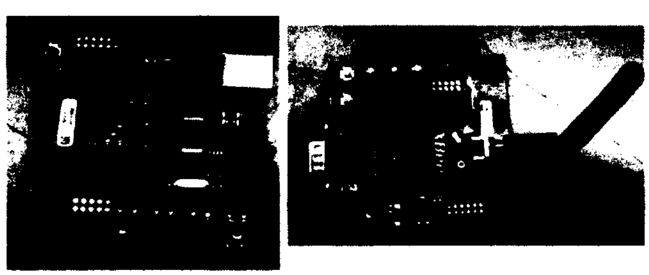


Figure 7.2: Digi International Development Boards for XBee

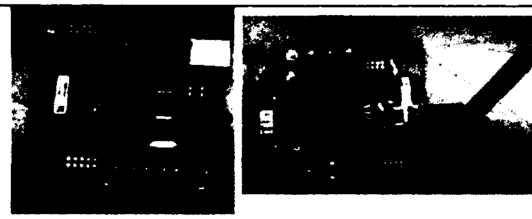
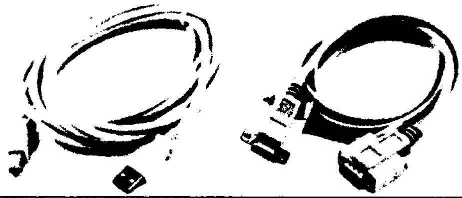
Component	Component Image	Manufacturer	Cost (US Dollar)
Zigbee / 802.15.4 Modules RS-232 XBee-PRO pro onal interface board		Digi International	79.90
USB Mini-B Cable - 6 Foot		Sparkfun Electronics	4.95
Total			84.85

Table 7.5: USB and RS 232 XBee Development Board

Appendix C: Microcontroller

The main purposes of the microcontroller in our research are as follows:

- Obtain raw samples of sensor inputs either in analogue or digital form;
- Convert these samples to digital binary;
- Convert these binary samples to binary-coded decimal (BCD); and
- Get ASCII code and compile information to be displayed at X - CTU Terminal.

PIC 16F876

The brand of microcontroller that we used in our research is a series of microcontrollers called Peripheral Interface Controller (PIC) from Microchip manufacturer. Microcontroller PIC comes in different varieties, some with a basic low memory type, going all the way through analog-to-digital converters (ADC) and to the even pulse-width modulation (PWM) built in.

The type of Microcontroller PIC that we used to capture the sensor's collected data is PIC 16F876, which is a microcontroller with 28 pins. It has an 8-Bit processor with a high-performance FLASH microcontroller, which means it can be erased and reprogrammed without having to use a UV light source. This allows the same device to be used for prototype development as well as production. The chip has 8k of code space and 22 I/O lines (5 of which are a 10 bit analogy to the digital converter capable), 368 bytes of RAM, and 256 bytes of EEPROM. This microcontroller can run up to 20 MHz with external crystal, and a package can be programmed in a circuit. It has a universal asynchronous serial transport (UART) for asynchronous serial communication, and a microchip family that is the synchronous serial port (MSSP) for Serial Peripheral Interface (SPI™) and Inter-Integrated Circuit (I^2C™).

The synchronous serial port can be configured as either 3-wire SPI™ or the 2-wire I²C™ bus. Table 7.6 and Figure 7.3 illustrate the key features of this microcontroller.

Parameter Name	Value
Program Memory Type	Flash
Program Memory (KB)	14
CPU Speed (MIPS)	5
RAM Bytes	368
Data EEPROM (bytes)	256 bytes
Digital Communication Peripherals	1-A/E/USART, 1-MSSP(SPI/I2C)
Capture/Compare/PWM Peripherals	2 CCP
Timers	2 x 8-bit, 1 x 16-bit
ADC	5 channels, 10-bit
Temperature Range	-40 to 85
Operating Voltage Range (V)	2 to 5.5 V
Pin Count	28 pin
Manufacturer	Microchip

Table 7.6: Characteristics of microcontroller PIC 16F876

Before we can begin discussing the other components, we would like to describe asynchronous serial communication.

- **RA4/TOCK1**, pin 6 can be used as input or output (**RA4**), or can be used for a clock (**TOCK1**) input that operates an internal timer. It operates in isolation to the main clock. The same was also true in this thesis; once the pin was selected for one function, it was not available for any other function. For example, if the pin is used at input or output (**RA4**) then it is unavailable for the interruption monitoring (TOCK1).
- **RBO/INT**, pin 21 can be used for an input or output (**RBO**), or it can be used for interruption (**INT**) monitoring. For example, if the pin goes high, it can cause the program to restart, stop, or any other single function desired. Once the pin is selected for one function, it is not available for any other function. In other words, if the pin is used at input or output (**RBO**) then the pin is unavailable for the interruption monitoring (INT).

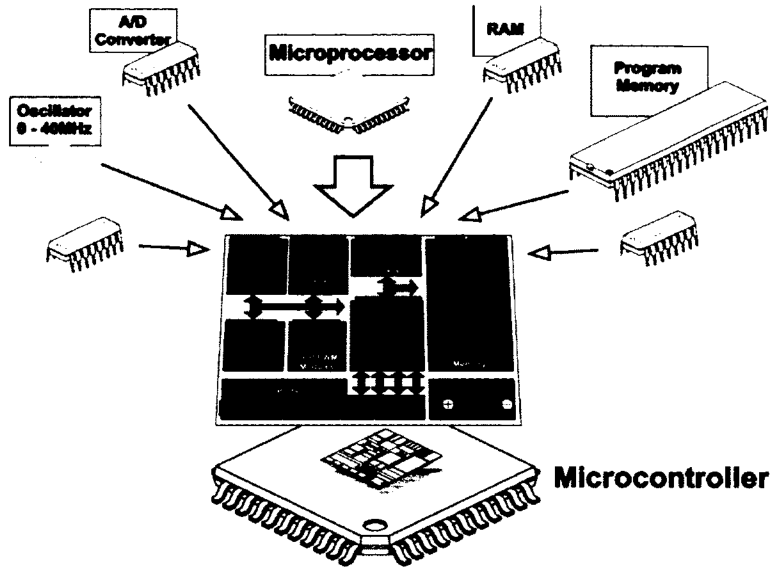


Figure 7.3: Microcontroller [69].

The brand of microcontroller that we used in this thesis is a series of microcontrollers called Peripheral Interface Controller (PIC) from Microchip manufacturer. This PIC microcontroller chip comes in different varieties, some with a basic low memory type, going all the way through analogue-to-digital converters and to even pulse-width modulation (PWM) built in. In this study, we started working with different PICs including: PIC 16F628, PIC 18F2520, PIC 16F876, and PIC 16F877, as illustrated in Figure 7.4.

- **PIC 18F2520** is the newest part of the series of PICs we used. PIC 18F2520 is the chip with prefix 18 and is for 16–bit core chips. It has an improved instruction set, peripherals, and twice the code and the speed compared to 14-bit (16F) PICs. However, the price is slightly higher.
- **PIC 16F628** is quite cheaper compared to the old 16F84; however, it has twice the code size, much more RAM, a UART and some more instruction sets. The chip is suitable to simple applications and learning.

- **PIC 16F876** is the microcontroller we chose for the study because of its size, memory, features of the chip, ease of use, quality, and cost. However, the chip has less code size, RAM, and I/O compared to the 16F877. The price is the same as the PIC 16F877.
- **PIC 16F877** is the largest chip of the 16F87X family and a little bit expensive compared to PIC 16F628 or 18F2520; however, it has eight times the code size, much more RAM and much more I/O pin, a UART, A/D converter, and a lot more.

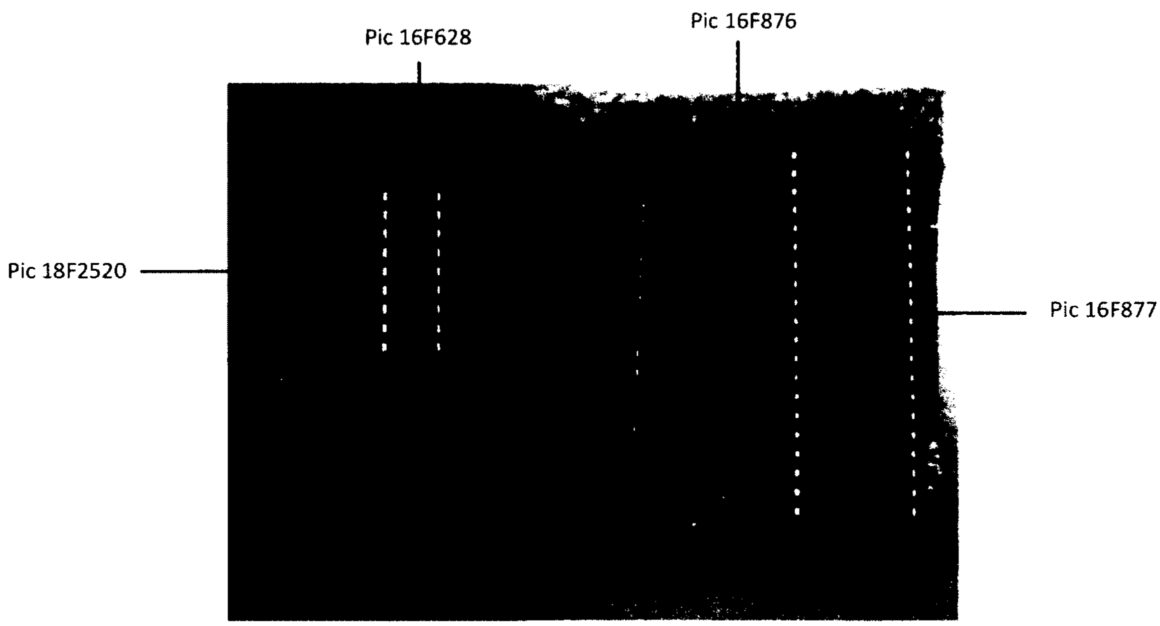


Figure 7.4: PIC 18F2520, PIC 16F628, PIC 16F876, and PIC 16F877

Appendix D: Components

This section provides a description of each component in detail. These components include sensors, 5V regulator, and a buzzer. The sensors non-invasive consist of temperature, humidity, photocell, ultrasonic, pyroelectric ("passive"), Infrared (PIR), and Hall Effect. A more detailed explanation of each component is in the following subsections.

5V DC voltage regulator

The most common 5V DC voltage regulator is called LM 7805. LM 7805 provides circuit designers with a simple way to regulate DC voltages to 5V. Summarized in a single chip/package (IC), the LM 7805 is a positive voltage DC regulator that has only 3 terminals: Input voltage, Ground, and Output Voltage. LM 7805 has a power supply of 1 AMP and tolerates +/- 5%, which means that the voltage of 5V with a toleration of +/- 5% can yield result of between 5.25 V to 4.75 V; this is a major concern for the accuracy of output for the sensors.

Type	LM 7805CT-ND
Voltage output	5V @ 1A
Operating Temperature	−40°C ~125°C
Manufacturer	Fairchild Semiconductor

Table 7.7: Characteristics of LM7805CT

Piezoelectronic Buzzer

The type of buzzer that was chosen for the research is called the piezoelectronic buzzer. The characteristics of the piezoelectronic buzzer are shown in Table 7.8. The device is used for many applications, including for making beeps, tones, and alerts. A piezoelectronic buzzer is small but loud. It operates with 3-30V peak-to-peak square waves. It has two pins; one pin can be connected as a ground and the other pin to a square wave out from a timer or microcontroller. The loudest tones can be achieved at a frequency around 4 KHz; however, a piezoelectronic buzzer operates quite well from 2 KHz to 10 KHz. To get extra volume, both pins can be connected to a microcontroller and swapped to determine which of the pins is high or low for double the volume.

Component type	PS1240P02BT
Component size	12.2mm x 6.5mm x 5mm
Sound pressure	70dBA
Operating temperature range	−10 to 70°C
Storage condition	5 to 40°C
Maximum input voltage	30V
Minimum input voltage	3V
Manufacturer	TDK

Table 7.8: Characteristics of the piezoelectronic buzzer

TMP36 Temperature Sensor

The TMP36 temperature sensor is the type of sensor that was used for our research. The reason for choosing this temperature sensor is that this sensor has a very wide range. It produces temperature readings in Celsius and does not require a negative voltage to read sub-zero temperatures. It is inexpensive, small, and can take up very little space in our circuit board. The characteristics of the TMP36 temperature sensor are shown in Table 7.9. The temperature sensor is of an analog type. The sensor is an integrated circuit (IC) and does not require external calibration or trimming. Temperature is a low-voltage operation between 2.7V to 5.5 V that calibrates directly in °C and 10 mV/°C scale factor. It has a ±2°C accuracy over temperature and ±0.5°C linearity. The sensor is stable with large capacitive loads, specified at −40°C to +125°C, and operating to up +150°C.

Sensor type	Analog Devices TMP36
Sensor size	0.2" x 0.2" x 0.2"
Temperature range	−40°C to 150°C /−40°F to 302°F
Output voltage range	0.1V (−40°C) to 2.0V(150°C)
Power supply	2.7V to 5.5V only, 0.05 mA current draw
Manufacturer	Analog Devices

Table 7.9: Characteristics of TMP36 temperature sensor

Humidity Sensor

The humidity sensor that we used for the research is the CHS-GSS brand. The relative humidity (RH) for the sensor can be read directly with a voltmeter; output DC of 1V can produce 100(%) RH. The sensor is capable of measuring humidity in the relative humidity range of 5% to 95%. It operates at a temperature range of 0°C to 50°C, and requires a 5V power supply. In addition, the sensor has low current consumption, only 0.6 mA. Table 7.10 provides a brief description of the features for the humidity sensor that was used for the research.

Sensor type	CHS-series
Sensor size	27mm x 11.5mm
Measuring range	5% to 95% (RH)
Operating condition	$0\ to\ 50°C$
Storage condition	-20 to 60°C
Power supply	5V
Manufacturer	TDK

Table 7.10: Characteristics of humidity sensor

Photocell sensor - light sensor

The photocell sensor that we used for our research is also known as a cadmium-sulfide (Cds) cell. The sensor is made of cadmium-sulfide; it is small, inexpensive, low-power, easy to use, and does not wear easily. It can be found in toys, gadgets, and appliances. However, in our research, we used the sensor to detect lightness and darkness in a room. Table 7.11 provides specifications of the photocell (light) sensor that was used for the purpose of this research.

Sensor type	PDV-P8001
Sensor size	5mm (0.2") diameter.
Operation temperature range	-20°C to 75°C
Resistance range	200K Ω (dark) to 10KΩ (10 lux brightness)
Sensitivity range	Cds cells respond to light between 400nm (violet) and 600nm (orange) wavelengths, peaking at about 520nm (green).
Power supply	Almost anything up to 100V, uses less than 1mA of current on average (depends on power supply voltage)

Manufacturer	Advanced Photonix, Inc.

Table 7.11: Characteristics of the photocell sensor

Hall Effect Sensor – US5881LUA

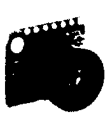
The type of magnetic sensor that we used for the research is the Hall Effect. The sensor has discs with an approximate 1/2" diameter and 3/16" thickness. This type of sensor is useful for non-contact/waterproof type switches, position sensors, and rotary/shaft encoders. The sensor operates at 3.5V to 24V and it has three terminals: pin 1 is the input voltage pin (left pin), which is used to connect to the power; pin 2 is the ground pin (the middle pin); and pin 3 is the output voltage pin, which requires a 10K pull up resistor and is connected to power. The Hall Effect (magnetic) sensor was used to detect whether a door was open or closed. The characteristics of Hall Effect sensor are shown in Table 7.12.

Component type	Unipolar switch-US5881LUA
Component size	$\frac{1}{2}$diameterX3/16" thick discs
Operating temperature range	-50 to $150°C$
Maximum input voltage	24V
Minimum input voltage	3.5V
Output type	Digital
Manufacturer	Melexis Inc.

Table 7.12: Characteristics of the Hall Effect sensor

Ultrasonic Sensor

The LV-EZ1 Maxbotix Ultrasonic Rangefinder was the type of ultrasonic sensor that we used for the



purpose of our research. The sensor provides very short- to long-range detection. It can detect objects from 0-inches to 254-inches (6.45-meters) and provides sonar range information from 6-inches out to 254-inches with 1-inch resolution. The interface output formats included pulse width output (PWM), analog voltage output (Vcc/512 volts per inch), and serial digital output (9600 baud) [48]. The analog output is used to determine the distance of the object. An output analog voltage with a scaling factor of (Vcc/512) per inch and a supply of 5V yields ~9.8mV/in. The output is buffered and corresponds to the most-recent range data.

The benefits of the LV-EZ1 Maxbotix Ultrasonic Rangefinder include, but are not limited to, the following [70]:

- Acoustic and electrical noise resistance;
- Reliable and stable range data;
- Sensor dead zone virtually gone;
- Low cost;
- Quality controlled beam characteristics;
- Very low power range, excellent for multiple sensor or battery based systems;
- Can be triggered externally or internally;
- Sensor reports the range reading directly, frees up user processor;
- Fast measurement cycle;
- User can choose any of the sensor outputs;
- No calibration requirement, which is perfect for when objects may be directly in front of the sensor during power up; and
- Small size allows for easy mounting.

Table 7.13 provides a brief description of specifications for the ultrasonic sensor used for this research.

Sensor type	LV - MaxBotix – EZ0
Sensor size	0.645" x 0.610"
RS232 serial output	9600 pbs
Analog output	10mV/inch
PWM output	147 µs /inch
Power supply	2.5V – 5.5V
Manufacturer	MaxBotix

Table 7.13: Characteristics of ultrasonic sensor

Appendix E: Power Supply

In many countries, the house outlet operates at a power of 220V AC (Alternating Current), while in North America or in Canada the house outlet operates at a power of 110V AC. Alternating current is very bad for 5V DC components. Therefore, the 110V AC or 220 AC must be converted from a house outlet to a useable 5V DC. In order to convert the alternating current from the house outlet to a useable 5V DC, voltage regulators are required. The most common 5V DC voltage regulators are called LM 7805 with a power supply of 1 AMP with a toleration level of +/- 5%, which means the voltage of 5V with a toleration level of +/- 5% can yield results between 5.25 V to 4.75 V, which is a major concern for the accuracy of the output for the sensors. LM 8705 is illustrated in Figure 7.8. LM 7805 provides circuit designers with a simple way to regulate DC voltages to 5V. Summarized in a single chip/package (IC), the LM 7805 is a positive voltage DC regulator that has only 3 terminals: input voltage, ground, and output voltage.

Even though the LM 7805s were mainly designed for a fixed-voltage output (5V), it is in fact possible to use external components in order to obtain DC output voltages of: 5V, 6V, 8V, 9V, 10V, 12V, 15V, 18V, 20V, and 24V. Note that the input voltage must, of course, be greater than the mandatory output voltage, so that it can be regulated downwards.

General Features:

- Output current up to 1A
- Output voltages of 5V or higher
- Thermal overload protection
- Short circuit protection
- Output transistor safe operating area protection

For the accuracy of the output voltage, the noise coming in the input pin must be reduced. The easiest way to help smooth out ripples is by using filtering capacitors. Electrolytic capacitors and ceramic capacitors are the two types of capacitors we used to build the voltage regulator circuit.

Electrolytic capacitors: The two examples of electrolytic capacitors are illustrated in Figure 7.5. The capacitors have storage of 10μF/50V, which means it can withstand up to 50V. The capacitors with storage of 100μF/16 can withstand up to 16V. They are polarized with a positive pin and a negative pin. The positive pin is a little bit longer than the negative pin. The positive pin is connected to the input and 10μF/16V is connected to the output. The negative pin is connected to ground.

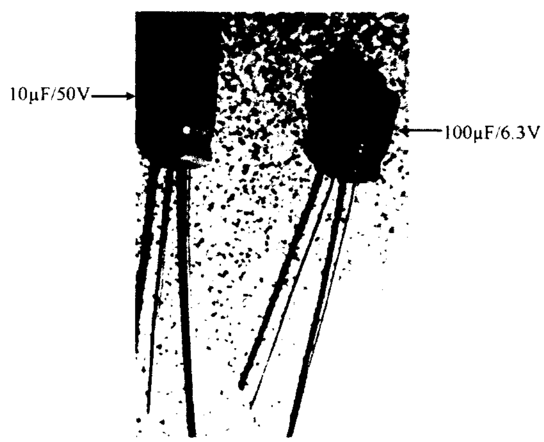


Figure 7.5: Electrolytic capacitors (10μF/50V) and ceramic capacitor (100μF/6.3V)

Ceramic capacitors: are non-polarized capacitors operating at a value of 100μF/6.3V. It has 2 pins and is not positive or negative. Therefore, the pins can be connected in the breadboard in any way.

Both capacitors are required to build the 5V power supply because electrolytic capacitors are larger capacitors and are very slow in releasing their stored energy, while ceramic capacitors are small and very fast in the delivery of their stored energy. So electrolytic capacitors can help maintain a declining voltage while ceramic capacitors can help contain higher frequency noise and shorter power dips.

Capacitors cannot deliver their stored energy instantaneously. Larger caps (10uF and 100uF) store more energy, but they react more slowly. The smaller the capacitor, the faster it can deliver its stored energy. If you have a large power outage (power dips for 10-100ms), a big cap (100uF to 1000uF) will help 'hold up' the falling voltage. A smaller cap (0.1uF) will help suppress higher frequency noise and shorter power dips (noise in the 1us to 100us range). Therefore, 0.1uF caps are located near the microcontroller to help with short bursts, where 100uF and 10uF caps are used on the power rails [71].

Battery

The battery supplies power to the remote station. It is a 5 voltage power source for the circuit. The power can be supplied to the remote system through 9V regulated DC wall-power adapter or 9V battery.

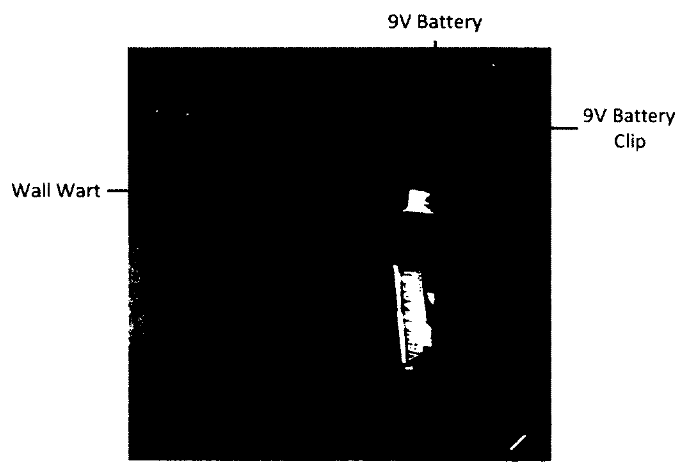


Figure 7.6: Battery with 9V regulated DC wall-power adapter and 9V battery clip

Appendix F: Testing

The testing sensors steps are as follows:

- **Testing Temperature Sensor**: The temperature sensor that we used for the study comes in a "TO-92" package, which means that the chip is housed in a plastic hemi-cylinder with three pin terminals: input, output, and ground. The pins can be bent easily to allow the sensor to be plugged into a breadboard or can also be soldered to the pins to connect long wires. Figure 7.7 (Figure 8.3 A) illustrates the temperature sensor that was used for the study.

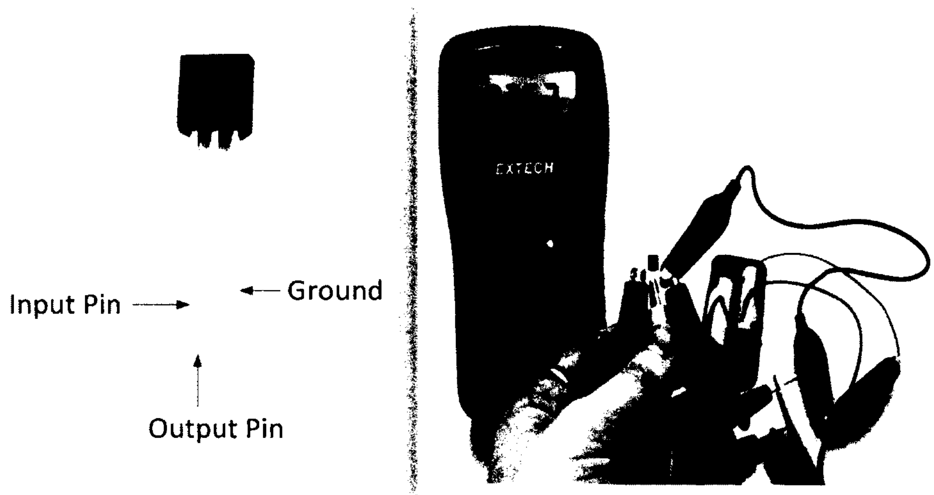


Figure 8.3 A: TMP36 Temperature

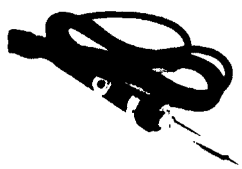
Figure 8.3 B: TMP36 Temperature connected to Multi-meter

Figure 7.7: TMP36 Temperature[19]

We tested the temperature sensor using different techniques and tools such as a soldering iron, air conditioner, and an ice cube.

[19] Figure 8.3B is from Adafruit website, source: http://www.ladyada.net/learn/sensors/tmp36.html

- **Testing Temperature sensor using soldering iron:** The soldering iron that we used to test



temperature level of the sensor is a "pen-style" soldering iron; this soldering iron is shown to the right of the text. The plug for the iron is 110 US-style and can only be used in 110V countries, such as USA and Canada. The iron also comes with a very simple flip-up stand, which is only marginally useful.

- **Testing the functionality of Temperature sensor:** Once the soldering iron was plugged in and heated up, it was placed close to but not as close to touch the sensor, so that it could not cause the sensor to melt. The heating soldering iron allows the temperature to increase gradually; through multi-meter and LCD we observed that the temperature reading was increasing gradually. However, we stopped raising the temperature when it reached 30 degrees Celsius because we set a buzzer to go off at that temperature.
- In addition to using a soldering iron to test the functionality of the sensor, we also held the sensor using our fingers as shown on figure 7.8 (Figure 8.5A) to observe any change in the temperature.
- We also used a piezo buzzer set to go off when the temperature reading reached 30 degrees Celsius or higher and also when the temperature reading dropped below 15 degrees Celsius.
- **Testing Temperature sensor using an ice cube**: The other testing we used was an ice cube, as illustrated in figure 7.8 (Figure 8.5B). We pressed the ice cube against the sensor. The ice cube was carefully covered by a plastic bag to prevent water from getting on the circuits. We observed over the multi-meter that the temperature was dropping gradually.

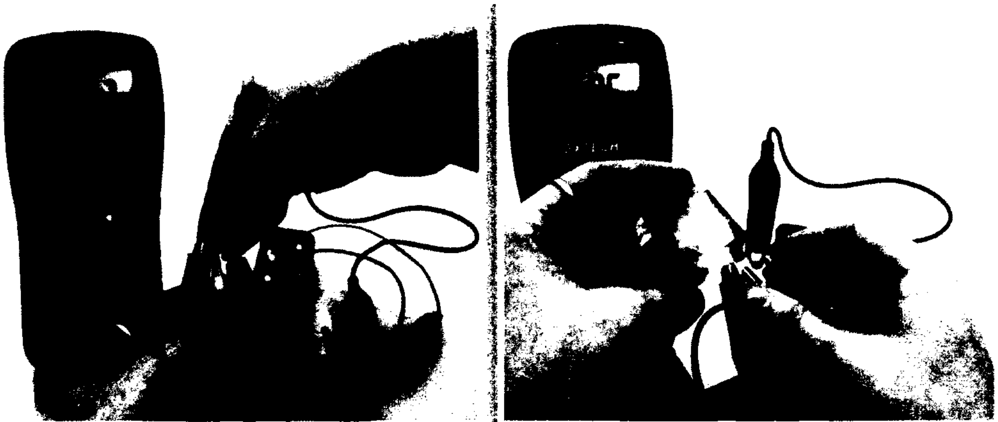


Figure 8.5A - Temperature Sensor connected to multi-meter to test temperature level when temperature sensor covered by figures

Figure 8.5B - Temperature Sensor connected to multi-meter to test dropping in temperature using an ice cube

Figure 7.8: Testing Temperature Sensor using an ice cube[20]

- **Testing temperature sensor after connection:** After connecting the component, we applied the same above testing to the sensor to determine its functionality. Not only were we able gather data using the multi-meter, but we were also able to use LCD and X-CTU software to test the sensor this time.
- **Testing Photocell (Light) Sensor:** The sensor we used for the research is non-polarized just like basic resistors. It has a two-pin terminal that can be connected in measurement mode to the two leads up in "either way" of pins to a multi-meter in resistance, as illustrated in Figure 7.9 (Figure 8.7A). We then observed on the multi-meter how the resistance changes when shading the sensor with our hand or turning on/off lights of the room. This light sensor test indicated the functionality level of the sensor.
- **Testing Photocell (black object) Sensor:**

[20] The images of the Figure 7.8 is from Adafruit website: http://www.ladyada.net/learn/sensors/tmp36.html

- The test was also done by covering the sensor with a black object, such as shown in Figure 7.9 (Figure 8.7B). Since the multi-meter resistance changes a lot, we used an auto-ranging meter. It worked well here. Different ranges of resistances between 1MΩ and 1KΩ were also used to test the functionality of the sensor.
- **Testing Photo cell (Light) sensor after connection**
- **The rest of the sensors:** The remaining sensors are Ultrasound, Hall Effect, (Magnetic) motion, and humidity sensor and were tested by the connection of the System. Once connected, the same testing was done to the sensor to determine its functionality.

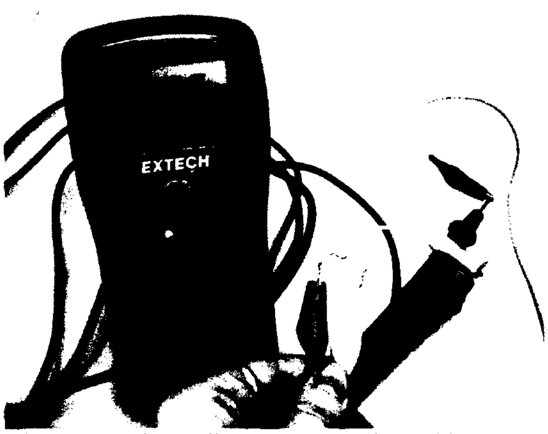


Figure 8.7A: Photo cell sensor connected to multi-meter to detect light

Figure 8.7B: Photo cell sensor covered with black object to test the functionality of the sensor

Figure 7.9: Detecting light using multi-meter[21]

[21] Source of the Figure 7.9 is from Adafruit website: http://www.ladyada.net/learn/sensors/tmp36.html

Appendix G: Proton IDE

```
'*************************************************************************************
* Name    : Thesis Proton Code
*
* Author: Rudhwan Issa
*
'* Notice: Copyright (c) 2012
*
'*          : All Rights Reserved
'*
'* Date    : 30/03/2012
'*
'* Version: 1.0
'*
'* Notes   :
'*
'* purpose: the purpose of this code that can display sensors values on LCD
'*
'*         and PC Screen. The temperature sensor buzzer the temperature drop
'*
'*      to 15 or increases above 30 C degrees. The sensors are consisting of
*
'*    temperature, humidity, light, ultrasonic, motion, magnetic, and buzzer
*
'*                                                                              *
'*
*
'* Connection: the connection of the sensors to the PIC 16F876 is as follow:
*
'*
*
'*             Temperature connects to pin 2:
*
'*             ultrasonic connect to pin 3:
*
'*             humidity connects to pin 4:
*
'*             light connect to pin 5:
*
'*             magnetic connect to pin 14:
*
'*             motion connects to pin 15:
*
'*             buzzer connects to pin 24:
*
'*             LCD connects to pin 22, 23, and 24:
*
'*
*
'*************************************************************************************
*****
' BUTTON Command for the PROTON board
' Demonstrates multiple BUTTON commands. Each of 3 buttons toggles an LED.
```

```
' Hold a button for 1 second and the LED will flicker (auto-repeat).

    Device = 16F876            'Select Microcontroller
    XTAL = 20                  'Select Clock frequency 20MHz
    ALL_DIGITAL = TRUE         'Make All lines digital as we are not
                               'going to use Analog
    TRISC = %11111110
    TRISB = %00001000
    TRISA = %11111111
    ADCON1 = %10000010
    ADIN_RES 10
    ADIN_TAD FRC
    ADIN_STIME 100

    Print Cls

'*****************************************************************
'*               Variable declaration                            *
'*****************************************************************
        Symbol led = PORTC.0

        Dim raw As Word         ' create an 32-bit unsigned variable
                                '(0 to 65535)
        Dim raw1 As Word        ' create an 32-bit unsigned variable
                                '(0 to 65535)
        Dim raw2 As Word        ' create an 32-bit unsigned variable
                                '(0 to 65535)
        Dim raw4 As Word        ' create an 32-bit unsigned variable
                                '(0 to 65535)
        Dim v As Float          ' create an 32-bit floating point variable
        Dim light As Float      ' create an 32-bit floating point variable
        Dim RH As Float         ' create an 32-bit floating point variable
        Dim distance As Float ' create an 32-bit floating point variable

        PORTB_PULLUPS = Off           '

'*****************************************************************
'*            LCD declaration to PORTB of PIC 16F876             *
'*****************************************************************
        Declare LCD_DTPIN PORTB.4     '
        Declare LCD_ENPIN PORTB.0     '
        Declare LCD_RSPIN PORTB.1     '
        Declare LCD_INTERFACE 4       '
        Declare LCD_LINES 2           '
        Print $FE,1                   '
        Print $FE,2                   '

        Symbol Pizo = PORTB.2         ' defined Pizo and equate to PORTB.2
        Output Pizo                   ' make Pizo output

        DelayMS 1000                  ' delay for 1 second

        Cls                           ' Clears the text

'*****************************************************************
```

```
'*                         initializing asynchronous           *
'**************************************************************

       HSERIAL_BAUD = 9600           ' Set baud rate to 9600
       HSERIAL_RCSTA = %10010000     ' Enable serial port and
                                     'Continuous receive
       'HSERIAL_TXSTA = %00110000 ' Enable transmit and asynchronous mode
       HSERIAL_TXSTA = %00100000     ' Enable transmit and asynchronous mode
       HSERIAL_CLEAR = On            ' Optionally clear the buffer
                                     'Before receiving
       'HSERIAL_PARITY = ODD         ' Use if odd parity desired

'**************************************************************
'*       :                                                  *
'**************************************************************

loop:

    HRSOut "================================ ", 13 '* display the
                                                   'Statement on PC screen
    HRSOut " Data collected " , 13                 '* display the
                                                    'Statement on PC screen
    HRSOut "================================ ", 13 '* display the
                                                    'Statement on PC screen


'**************************************************************
'*                    temp sensor   calculation               *
'**************************************************************

      raw = ADIn 0          '  // assign pin 2 of PIC 16F876 to output
                            'Voltage (raw)
      v= (5*raw)*1000        ''//
      v=v/1023
      v=v-500
      v=v/10

      If v >= 30 Then        ' if the temperature is 30 or greater buzzer
         Sound Pizo, [100, 50, 110, 50, 90,100]
         DelayMS 50
      End If

      If v <= 15 Then        'If the temperature is 15 or less buzzer
        Sound Pizo, [100, 50, 110, 50, 90,100]
        DelayMS 50
      End If
   DelayMS 500                       ' delay for 0.5 second


    Print At 2,1, "Temp = " , Dec v , " C "
    HRSOut "Temperature = " , Dec v , " C", 13

      DelayMS 1000              ' delay for 1 second
```

```
'****************************************************************
'*       'Ultrasonic sensor calculation                         *
'****************************************************************

        raw1 = ADIn 1        'assign pin 3 of PIC 16F876 to Output
                               'Voltage (raw1)
                               'Ultrasonic sensor calculation

        distance = raw1/1.998

        Print At 1,1,"Distance: ", Dec distance,  "Inch"
        HRSOut "Distance: = ", Dec distance, "Inch", 13

        DelayMS 1000                ' delay for 1 second

        Print $FE,1
        Print $FE,2

'****************************************************************
'*             humidity sensor calculation                      *
'****************************************************************

        raw2 = ADIn 2                ' assign pin 3 of PIC 16F876 to
                                     'Output voltage (raw2)
        RH = (5/1023)*raw2           'RH = 5*raw/1023
        RH = RH*100                  'RH = RH*100 multiply by 100 to get
                                     'in percent

        Print At 2, 1,"Humidity: ", DEC2 RH, "%" ' display humidity on
                                               'message on
                                               'LCD screen
        HRSOut "Humidity: = ", Dec RH, "%", 13 ' display light on
                                                   'message on
                                               'PC screen
        DelayMS 1000                           ' delay for 1 second

'****************************************************************
'*               light sensor calculation                       *
'****************************************************************
 raw3 = ADIn 3       ' assign pin 4 of PIC 16F876 To Output voltage (raw3)
 light=(5/1023)*raw3

   If light >=3 Then
      Print At 1,1,"Light on: ", DEC2 light   ' display light on message on
                                              'LCD screen if the light value
                                              'is 3 or greater
    HRSOut "light on = " , Dec light , 13 ' display light on message on
                                          'PC screen if the light value
                                          'is 3 or greater
    DelayMS 500
```

```
 Else If light >=2 Then
 Print At 1, 1,"Dim Light: ", DEC2 light ' display Dim light on message on
                                          'LCD screen if the light value
                                          'is 2 or greater
HRSOut "Dim Light = " , Dec light, 13   ' display Dim light on message on
                                        'PC screen if the light value
                                        'is 2 or greater
DelayMS 500                             ' delay for 0.5 second

    Else
          Print At 1,1,"Light off: ", DEC2 light
            HRSOut "Light off = " , Dec light , 13
    EndIf

  DelayMS 1000                 ' delay for 1 second


'***********************************************************************
**
'*            magnetic sensor calculation
*
'***********************************************************************
**


      DelayMS 1000                                'delay for 1 second

       If PORTC.3= 0 Then
          Print At 1, 1," Door is Locked.."   ' display "door is locked"
                                              'message on LCD screen
          HRSOut "Door is Locked.." , 13      ' display "Door is locked
                                              'message on PC screen
          DelayMS 500
       Else
          Print At 1,1," Door is unlocked.."   'display "door is unlocked"
                                               'message on LCD screen
          HRSOut "Door is unlocked.. " , 13   ' display "Door is unlocked"
                                               'message on PC screen
          DelayMS 500                          'delay for 0.5 second

          Print $FE,1
          Print $FE,2
       EndIf


'*************************************************************
'*      motion sensor calculation                            *
'*************************************************************

        If PORTC.4=1 Then
          Print At 1,1,"Motion detected.."    '* Display motion detected
                                              '* message on LCD screen
          HRSOut "Motion detected .. " , 13   '* display motion detected
                                              '* message on PC screen
```

```
        Print $FE,1
        Print $FE,2

    EndIf


GoTo loop
End
```

Appendix H: Matlab

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Title      :   Thesis Matlab Code to analyses collected data at      %
%            :   prototype apartment                                   %
%            :                                                         %
% Author     :   Rudhwan Issa                                  %
%            :                                                         %
% University :   Carleton University                                   %
%            :                                                         %
% Notice     :   Copyright (c) 2012 Rudhwan                            %
%            :   All right reserved                                    %
%            :                                                         %
% Date       :   30 February 2012                                      %
%            :                                                         %
% Notes      :  The goal of the Thesis Matlab code is to analyses our  %
%            :  collected at different locations (washroom, kitchen,   %
%            :  living room, and balcony) and appliances (fridge,      %
%            :  stove, and other appliances) of our prototype apartment %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Duration for the collecting the data                                 %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
Number = [1:1:5];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Temperature Data for washroom, fridge, kitchen, living room, and     %
% outside at balcony of the apartment                                  %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Temperature = [23.802, 25.268, 22.825, 24.780, 22.825];  % washroom Temp
Temperature1 = [3.274, 11.584, 7.673, 11.584, 8.651];    % fridge Temp
Temperature2 = [22.825, 24.780, 26.246, 25.757, 26.409]; % kitchen Temp
Temperature3 = [23.313, 6.695, 23.802, -3.567, 22.825];  % living room
Temperature4 = [-2.101, -4.545, 4.740, 4.578, -4.545];   % outside Temp

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Humidity Data for washroom, fridge, kitchen, living room, and outside%
% at balcony of the apartment                                          %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Humidity = [26.392, 86.532, 32.258, 80.156, 22.482];     % shower Humidity
Humidity1 = [8.797, 46.432, 10.263, 52.785 8.388];       % fridge Humidity
Humidity2 = [23.460, 23.949, 25.904, 28.572, 23.949];    % kitchen Humidity
Humidity3 = [25.904, 43.010, 31.280, 41.544, 24.926];    % living room
Humidity4 = [76.246, 51.808, 67.937, 44.477, 43.988];    % outside Humid

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Light Data for washroom, fridge, kitchen, living room, and outside at%
% balcony of the apartment                                              %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Light = [0.03, 0.03, 3.07, 3.07, 0.02];      % Light data at washroom
Light1 = [0.06, 0.06, 4.46, 4.48, 0.06];     % Light data at fridge
```

```
Light2 = [0.02, 0.02, 2.27, 2.27, 0.03];      % Light data at kitchen
Light3 = [0.29, 0.29, 3.22, 3.22, 0.22];      % Light data at living room
Light4 = [0.16, 0.16, 4.31, 4.31, 0.16];      % Light data at outside

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Occupant motion detect data at washroom, kitchen, and living room    %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
motion = [0.03, 0.03, 1.07, 1.07, 0.02];      % Data for the washroom
motion1 = [0.02, 0.02, 1.07, 1.07, 0.03];     % Data for the kitchen
motion2 = [0.29, 0.29, 1.08, 1.08, 0.29];     % Data for the living room

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% collected data for the door of the fridge, main, and balcony of the  %
% apartment                                                            %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
door1 = [0.06, 0.06, 1.08, 1.08, 0.06];      % Data for the fridge
door2 = [0.02, 0.02, 1.0, 1.01, 0.03];       % Data for the main door
door3 = [0.03, 0.03, 1.04, 1.04, 0.02];      % Data for the balcony door

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Name       :  Code for washroom data before, during, and after       %
%            :   shower                                                %
%            :                                                         %
% Purpose    :  The goal of the code is to analyze data collect at     %
%            :  washroom                                               %
%            :                                                         %
% Return     :  The code returns graphs for light, temperature,        %
%            :  humidity, and motion of the user in the washroom       %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Figure 1 washroom
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for temperature of washroom                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
figure                              % display figure on the window
subplot(2,2,1)                      % position plot to 2,2,1, of the window
plot(Number, Temperature)            % output the temperature graph
ylabel ('Temperature')              % y - axis
xlabel('Minutes')                   % x - axis
title ('Washroom Temperature')      % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for humidity of washroom                                        %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,2,2)                     % position plot to 2,2,2, of the window
plot(Number,Humidity,'green')      % output the humidity graph
ylabel ('Humidity')                % y - axis
xlabel('Minutes')                  % x - axis
title ('Washroom Humidity')        % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for light of washroom                                           %
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,2,3)                    % position plot to 2,2,3, of the window
plot(Number, Light, 'red')         % output the light graph
ylabel ('Light')                  % y - axis
xlabel('Minutes')                 % x - axis
title ('Washroom Light')          % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for motion in washroom                                            %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,2,4)                    % position plot to 2,2,4, of the window
plot(Number, motion, 'red')        % output the motion graph
ylabel ('Light')                  % y - axis
xlabel('Minutes')                 % x - axis
title ('human Motion')            % title of the figure
hold on
%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Name         :  Code for fridge data before, during, and after the   %
%              :  fridge door was closed                                 %
%              :                                                         %
% Purpose      :  The goal of the this code is to analyze the data       %
%              :  collect at the fridge                                  %
%              :                                                         %
% Return       :  The code returns graphs for light, temperature, and    %
%              :  humidity of the fridge                                 %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Figure 2 Fridge
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for temperature of the fridge                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
figure                           % display figure on window
subplot(2,2,1)                   % position plot to 2,2,1, of the window
plot(Number,Temperature1)        % output the temperature graph
ylabel ('Temperature')           % y - axis
xlabel('Minutes')                % x - axis
title ('Fridge Temperature')     % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for humidity of fridge                                            %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,2,2)                    % position plot to 2,2,2, of the window
plot(Number,Humidity1, 'green') % output the humidity graph
ylabel ('Humidity')               % y - axis
xlabel('Minutes')                 % x - axis
title ('Fridge Humidity')         % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for light of fridge                                               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
subplot(2,2,3)                    % position plot to 2,2,3, of the window
plot(Number,Light1, 'red')        % output the light graph
ylabel ('Light')                  % y - axis
xlabel('Minutes')                 % x - axis
title ('Fridge Light')            % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for magnetic sensor fridge door                               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,2,4)                     % position plot to 2,2,4, of the window
plot(Number,door1, 'red')          % output the fridge door graph
ylabel ('Fridge Door')             % y - axis
xlabel('Minutes')                  % x - axis
title ('Fridge Door Detected') % title of the figure
hold on
%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Name       :  Code for kitchen data before, during, and after the   %
%            :  activities of the occupant in kitchen                 %
%            :                                                        %
% Purpose    :  The goal of the code is to analyze data collect at    %
%            :  kitchen                                               %
%            :                                                        %
% Return     :  The code returns graphs for light, temperature,       %
%            :  humidity, and motion of the user in the kitchen       %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Figure 3 Kitchen Graph
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for temperature of kitchen                                    %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
figure                             % Display figure on window
subplot(2,2,1)                     % position plot to 2,2,1, of the window
plot(Number,Temperature2)          % output the temperature graph
ylabel ('Temperature')             % y - axis
xlabel('Minutes')                  % x - axis
title ('Kitchen Temperature')      % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for humidity of kitchen                                       %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,2,2)                     % position plot to 2,2,2, of the window
plot(Number,Humidity2, 'green') % output the humidity graph
ylabel ('Humidity')                % y - axis
xlabel('Minutes')                  % x - axis
title ('Kitchen Humidity')         % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for light of kitchen                                          %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,2,3)                     % position plot to 2,2,3, of the window
```

```
plot(Number,Light2, 'red')       % output the light graph
ylabel ('Light')                 % y - axis
xlabel('Minutes')                % x - axis
title ('Kitchen Light')          % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for motion in kitchen                                          %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,2,4)                   % position plot to 2,2,4, of the window
plot(Number,motion2,'magenta')   % output the motion graph
ylabel ('Motion')                % y - axis
xlabel('Minutes')                % x - axis
title ('Kitchen Motion')         % title of the figure
hold on
%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Name        :  Code for data collected at the living room           %
%             :                                                       %
% Purpose     :  The goal of the code is to analyze data collect at   %
%             :  living room                                          %
%             :                                                       %
% Return      :  The code returns graphs for light, temperature,      %
%             :  humidity, and motion of the user in the living room  %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Figure 4 living room graph
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for temperature of living room                                 %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
figure                             % Display figure on window
subplot(2,3,1)                     % position plot to 2,3,1, of the window
plot(Number,Temperature3)          % output the temperature graph
ylabel ('Temperature')             % y - axis
xlabel('Minutes')                  % x - axis
title ('Living Room Temperature')% title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for humidity of living room                                    %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,3,2)                   % position plot to 2,3,2, of the window
plot(Number,Humidity3, 'green') % output the humidity graph
ylabel ('Humidity')              % y - axis
xlabel('Minutes')                % x - axis
title ('Living Room Humidity')  % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for light of the living room                                   %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,3,3)                   % position plot to 2,3,3, of the window
plot(Number,Light3, 'red')       % output the light graph
ylabel ('Light')                 % y - axis
```

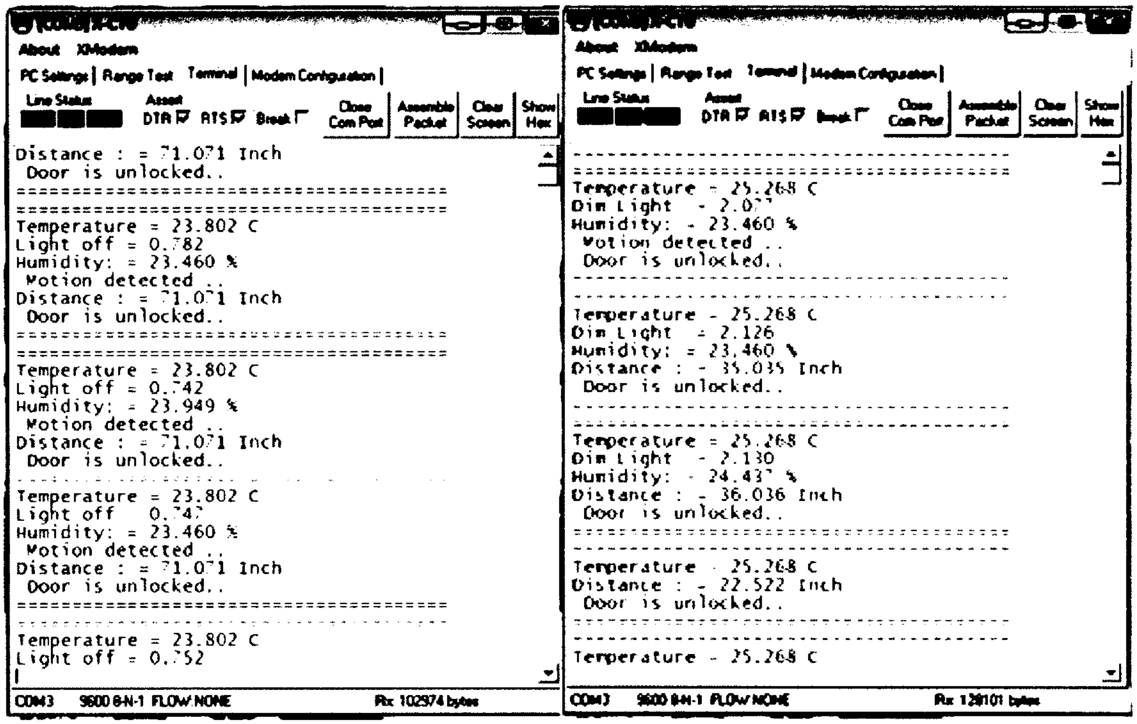
```
xlabel('Minutes')                   % x - axis
title ('Living Room Light')         % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for magnetic sensor data balcony was open                        %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,3,4)                      % position plot to 2,3,4, of the window
plot(Number,door2, 'red')           % output the balcony door graph
ylabel ('balcony door')              % y - axis
xlabel('Minutes')                   % x - axis
title ('Living Room Balcony')        % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for motion in living room                                         %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(2,3,5)                     % position plot to 2,3,5, of the window
plot(Number,motion2, 'red')        % output the motion graph
ylabel ('motion')                  % y - axis
xlabel('Minutes')                  % x - axis
title ('Living Room motion')       % title of the figure
hold on


%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Name        :  Code for outside data                                  %
%             :                                                         %
% Purpose     :  The goal of the this code is to analyze the data       %
%             :  collect outside                                        %
%             :                                                         %
% Return      :  The code returns graphs for light, temperature, and    %
%             :  humidity of outside data                               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Figure 5 outside data
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot for outside temperature                                          %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
figure                              % Display figure on window
subplot(1,3,1)                      % position plot to 1,3,1, of the window
plot(Number,Temperature4)           % output the temperature graph
ylabel ('Temperature')              % y - axis
xlabel('Minutes')                   % x - axis
title ('Outside  Temperature')      % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot of outside humidity                                              %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(1,3,2)                      % position plot to 1,3,2, of the window
plot(Number,Humidity4, 'green')     % output the humidity graph
ylabel ('Humidity')                 % y - axis
```

```
xlabel('Minutes')                  % x - axis
title ('Outside  Humidity')        % title of the figure
hold on

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot outside light                                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
subplot(1,3,3)                     % position plot to 1,3,3, of the window
plot(Number,Light4, 'red')         % output the light graph
ylabel ('Light')                   % y - axis
xlabel('Minutes')                  % x - axis
title ('Outside  Light')           % title of the figure
hold on


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Title      :   Thesis matlab code to plot ranges of XBee series 1     %
%                and 2 types.                                            %
%                                                                        %
% Name       :   Rudhwan Issa                                            %
%                                                                        %
% Date       :   30 March 2012                                           %
%            :                                                           %
% University :   Carleton University                                     %
%                                                                        %
% Notice     :   Copyright (c) 2012 Rudhwan                              %
%            :   All right reserved                                      %
%                                                                        %
% Notes      :  The goal of the thesis matlab code is to determine    %
%               the range of XBee module of series 1 and series 2 types. %
%               and the plot of the XBee series result                 %
%               series 1 consists of range and through put             %
%                                                                        %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Duration for the collecting the data                                   %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% the range of the XBee series 1                                         %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Distance = [0, 0, 0, 1:5:105];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Through put of the XBee series 1                                       %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Through_Put=[120,100,100,100,100,100,100,100,100,100,100,100,100,100,100,100,
98,97,93,90,80,65,40,0];


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot of Through put vs. range of XBee series 1                         %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
figure                                % display figure on the window
plot(Distance, Through_Put)            % output the XBee series 1 graph
hold on

%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  The range of the XBee series 2                                       %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Distance2 = [0,0,0,1:5:135];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Through put of the XBee series 2                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Through_Put2  =  [120,100,  100,  100,  100,  100,  100,  100,  100,100,100,
100,100,100,100,100,100,100,100,100,100,100,98,97,93,90,80,65,40,0];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% plot of Through put vs. range of XBee series 2                       %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
plot(Distance2,Through_Put2, '--rs')  % output the XBee series 2 graph
ylabel ('Throughput(%)')              % y - axis
xlabel('Distance(feet)')              % x - axis
title ('XBee series')                 % title of the figure
legend('XBee 1','Xbee 2')
```

Appendix I: Prototype Apartment Sample Data

Kitchen Data



(a) (b)

Figure 7.10: Kitchen Data Figure (a) before cooking and Figure (b) during cooking

Living Room

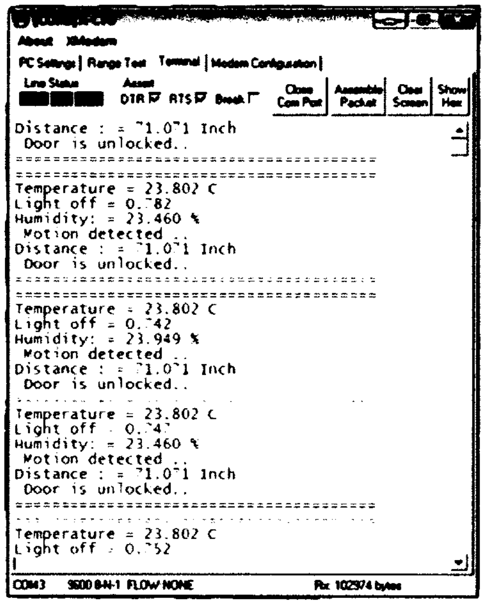
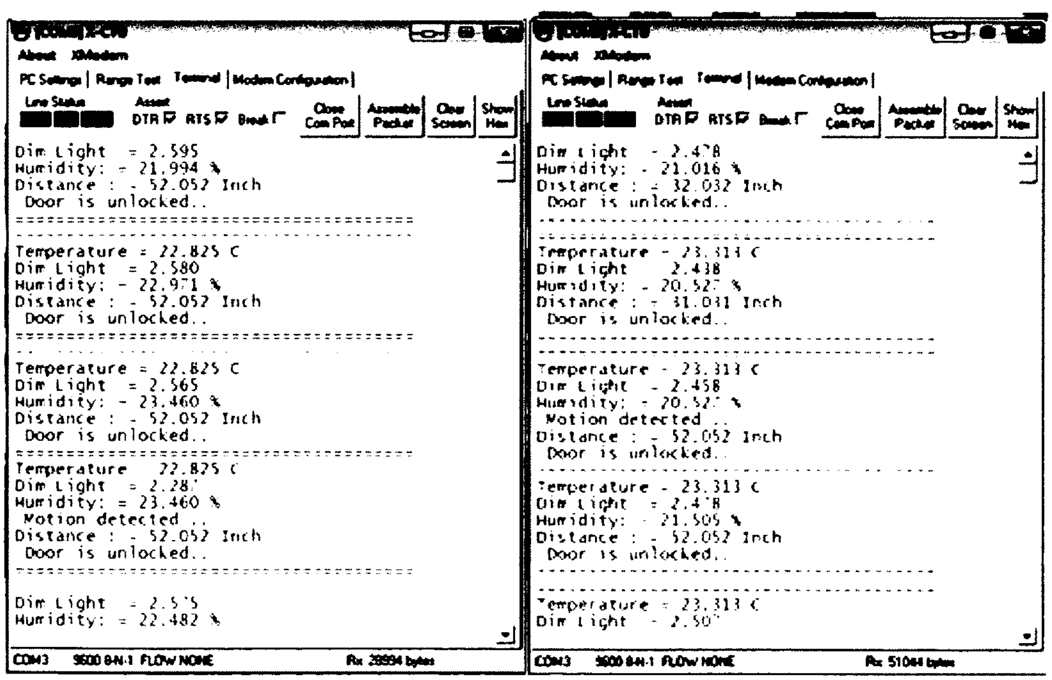


Figure 7.11: Living room Data

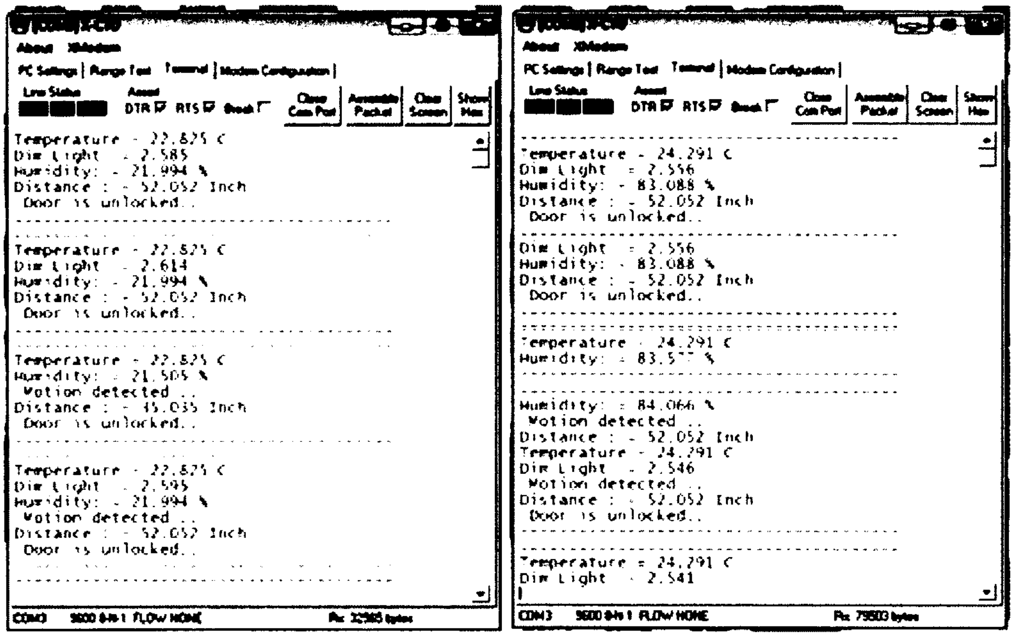
Toileting data



(a) (b)

Figure 7.12: Washroom data, Figure (a) shows data before toilet and Figure (b) after toilet

Bathroom data



(a) (b)

Figure 7.13: Bathroom data, Figure (a) data before shower and Figure (b) data during