DEVELOPMENT OF WIRELESS SENSOR NETWORK SYSTEM FOR INDOOR AIR QUALITY MONITORING

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This thesis describes development of low cost indoor air quality (IAQ) monitoring system for research. It describes data collection of various parameters concentration present in indoor air and sends data back to host PC for further processing. Thesis gives detailed information about hardware and software implementation of IAQ monitoring system. Also discussed are building wireless ZigBee network, creating user friendly graphical user interface (GUI) and analysis of obtained results in comparison with professional benchmark system to check system reliability. Throughputs obtained are efficient enough to use system as a reliable IAQ monitor.

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CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

Pollution from power plants, cars, and other transportation is a well-known contributor to outdoor air pollution, but our indoor air quality is often worse. It can be up to 10 times worse for you than the air outside [2]. Microbial pollutants like mold, pet dander and plant pollen can combine with chemicals like radon and volatile organic compounds (VOCs) to create a pretty toxic environment in your home; since we spend an average of 90% of our time indoors and 65% of our time inside our homes, according to the National Safety Council, that can add up to allergies, asthma and worse. Carbons monoxide (CO), carbon dioxide (CO_2), dust and humidity are the main parameters that harm indoor air quality [2].

Everything that comes in to our homes has the potential to be harmful to our health; that includes things from the building materials and elements that hold homes together to the furniture we sit on and the paint that goes on the walls. Adverse health effects from combustion products range from mild effects to death. Carbon monoxide, a deadly gas, kills over 200 people year in the United States. During power outages, the indoor use of charcoal or gas grills or of gas-powered generators can cause serious carbon monoxide poisoning and possible death to people in the home [2].

With the heightened concern over indoor air quality (IAQ), the interest in monitoring the air quality and the cost of those monitoring systems has drastically increased. The most common types of inside monitoring are done with individually purchased units for the home (i.e. carbon monoxide and smoke detectors). Typically, professional gas sensor units cover a wide variety of gasses and measure them to very sensitive concentrations. The use of these units is constrained by high cost and they are generally used only when a problem has been reported. In order to have a more comprehensive picture of what is happening with IAQ, a more cost effective; early warning system needs to be developed [3].

Enough amount of research is going on in the field of indoor air, to develop new applications and systems, which will help to keep indoor air quality as healthy as possible. But not enough data is available for the development of such system. In order to get availability of more and more data, there is need of more and more people can use such system. Hence there is need of low cost monitoring system, so that enough data available for researchers. Many employees working in offices faced the problem of headache, breathing problem, dry skin, and allergy due to poor indoor environment, so there is need of development of early alarming monitoring system.

Most of the monitoring systems available in market are working on the principle of place-to-place monitoring. So you need to take monitoring system to observation place, collect the data and analyze the results. So there is need of building wireless sensor network for remotely monitor indoor air simultaneously from different places.

The primary professional grade monitoring system researched is the Graywolf Direct Sense IQ 610 monitoring system. This system is also the reference system in this thesis, which was available for comparisons testing with newly build IAQ monitoring system.

This system consists of sensing probe, which contains various sensors that measures various parameters in air. Probe is connected to notebook through USB cable. The entire probe – notebook arrangement is kept inside a box. The IQ610 monitoring system offers several mobile computing platforms making it relatively easy to use. This unit came equipped to measure TVOC, CO2, CO, ozone, temperature, %RH, and dew point for an initial cost of $7449, and the option for adding additional parameters are available [4]. The main concern about this system is its cost. System is very expensive; hence it's not possible for everyone to have this system. Also for measurement we need to carry this system at the particular place, so size of system also matters. This system is very robust and hence very heavy in weight. So if you want to take reading of highly poisonous gases inside air, you have to be very cautious, which is very harmful. We cannot carry this system in hazardous places where concentration of poisonous gases is above risk level.

This system is very accurate in its measurement as it is using very expensive gas sensors. But few applications don't require that much accuracy level. If we can get trend of gaseous parameters, which is consider as enough information in most of the real time applications. So we have tried to develop system, which can be used in such kind of applications.

This thesis deals with building a low cost Indoor Air Quality Monitoring System by using low cost sensors. As we are using low cost system, we have tried to compensate it by processing signal by using various real time algorithms to get values almost similar to that measured with IAQ 610, which we are using as reference benchmark in this thesis. All reading captured automatically with a specific user-defined sampling rate. We have also build wireless ZigBee network, so that we can monitor all gaseous parameters from remote place without actual involvement of any human life.

1.2 Objectives of Research

Indoor air quality monitoring system measured concentration of various gases in air at different locations at the same time. We have used Arduino Uno board as a basic hardware platform for our system. For remote location measurement, we have configured few sensor nodes and connected those in wireless sensor network using XBee module. This thesis deals with the monitoring of indoor air quality by measurement of various gases concentration using different sensors. The key objectives are identified as:

1.2.1. Indoor Air Quality Monitoring System

The primary objective of this thesis is to develop an indoor air quality monitoring system, which effectively monitors air quality. Lowest frequency for measurement is in few seconds, which is almost same as Graywolf sensing system. This provides us real time data capturing system. System captures data according to defined settings and saves them in data files.

1.2.2. Availability of Data

It is important to save this data for further processing as well as for future use apart from its use in real time applications. We mainly are dealing with two kinds of systems, 1. single board wired system, which can save data inside computer and 2. multi boards wireless system that sends data to remote server using ZigBee network.

1.2.3. Remote Monitoring and Management

Indoor air quality monitoring system is sometimes deploying in remote and inaccessible (hazardous) areas such as chemical workshops etc. A remote access to the system is extremely useful to altering variables like sampling rate and mode of operation. It is also important to remotely adjust the system configuration and sensors configuration. Thus, a seamless communication protocol must be established between the system and server.

1.3 Contribution of the Research

Arduino Uno R3 board is used as a basic hardware platform consists of ATMega 328 micro-controller. Various sensors that include temperature and humidity, VOC, CO, CO2, dust sensors were used for measurement of concentration of various gases in air, which are connected to analog and digital pins on Arduino Board. Python based GUI is developed for better user-friendly environment. Main aim of research is to make available the cost effective but reliable system to monitor Indoor air quality. Many people have wrong perception that indoor air quality is better than outside, but as mentioned earlier indoor air is almost 10 times polluted than outside air. This thesis also deals with this miss conception by providing some real life results.

Wireless sensor network helps to monitor air quality inside big buildings or workshops at a very low cost and monitor everything at a remote base station. This system fills the gap between low cost and reliability of any system architecture. As mentioned earlier this system can be used in many applications where accuracy won’t play major role instead trend of parameters is more than enough to get results.

1.4 Organization of the Thesis

Chapter 2 describes main factors that affect indoor air quality. Based on various studies about indoor air quality in past, we have chosen six different parameters that will have adverse effect on human health for system monitoring purpose.

Chapter 3 deals with overall system architecture and top-level description of the working. Detailed description of each block of module is explained in this chapter.

Chapter 4 talks about development of system design and deployment of various sensors. Chapter 4 also mentioned various factors that need to keep in mind while designing system. The chapter includes hardware and software description of components used in the work.

Chapter 5 explains building wireless network for remote monitoring in a more effective way. Detailed procedure is explained that will help to design own wireless network for hobbyist with less efforts.

Chapter 6 deals with the development of communication protocols used in the system. Chapter gives detailed explanation of frame format used for reliable communication to collect data from various routers.

Chapter 7 provides some results along with detailed comparison of our system monitoring results with our benchmark Graywolf system. Chapter also explains some of the experiments results that can lead to various future applications.

Chapter 8 and 9 gives summary of the entire thesis work and potential for future developed respectively.

CHAPTER 2

MAJOR FACTORS AFFECTING INDOOR AIR QUALITY

2.1 Introduction

As mentioned in Chapter 1, various parameters affect quality of indoor air, so it is very important to learn origin of such parameters as well their effects on human health. This information will help to avoid effect of such parameters in future. This chapter gives detailed information of the effect of these parameters.

2.2 Effect of Humidity and Temperature

There is no “ideal” humidity level and temperature suitable for all building occupants. Many factors, such as personal activity and clothing may affect personal comfort. Acceptable relative humidity levels should range from 20% to 60 % year round. Levels less than 20 % in the winter and greater than 60% in the summer should be considered unacceptable. Elevated relative humidity can promote the growth of mold, bacteria, and dust mites, which can aggravate allergies and asthma [5].

As per ASHRAE guideline, indoor temperatures in the winter is to be maintained between 68 °F and 75 °F, with a relative humidity level between 30 % and 60 %. Temperatures in the summer should be maintained between 73 °F and 79 °F, with a relative humidity level between 30 % and 60 % [5]. These ranges should be acceptable for sedentary or slightly active persons.

2.3 Effect of Carbon Dioxide

Carbon dioxide is a normal constituent of exhaled breath and is commonly measured as a screening tool to evaluate whether adequate volumes of fresh outdoor air are being introduced into indoor air. The outdoor level of carbon dioxide is usually from 300 parts per million to 400 parts per million (ppm). The carbon dioxide level is usually greater inside a building than outside, even in buildings with few complaints about indoor air quality. If indoor carbon dioxide levels are more than 1,000 ppm, there is probably inadequate ventilation; and complaints such as headaches, fatigue, and eye and throat irritation may be prevalent [7].

Carbon dioxide itself is not responsible for the complaints; however, a high level of carbon dioxide may indicate that other contaminants in the building also may be present at elevated levels and could be responsible for occupant complaints. Properly ventilated buildings should have carbon dioxide levels between 600 ppm and 1,000 ppm, with a floor or building average of 800 ppm or less. If average carbon dioxide levels within a building are maintained at less than 800 ppm, with appropriate temperature and humidity levels, complaints about indoor air quality should be minimized. Therefore, 1,000 ppm should be used as a guideline for improving ventilation.

If a building exceeds this guideline, it shouldn’t be interpreted as a hazardous or life threatening situation. An elevated carbon dioxide level is only an indication of an inadequate amount of outside air being brought into a building. The level cited in this document should only be used as a guideline to determine the amount of fresh outside air entering a building. In building areas where there are potential sources of carbon dioxide other than exhaled breath, the guidelines above cannot be used. Other sources can include exhaust gas from kilns, internal combustion engines, dry ice, etc. Under these conditions, the Occupational Safety and Health Administration (OSHA) standard for carbon dioxide should be used. The OSHA standard is an eight-hour time-weighted average (TWA) of 5,000 ppm with a short-term 15-minute average limit of 30,000 ppm [2,7].

2.4 Effect of Carbon Monoxide

Carbon monoxide is colorless and odorless and is a normal constituent of exhaust gases from incomplete combustion. Potential sources inside a building that may generate carbon monoxide include gas heating systems, gas stoves, gas hot water heaters, cigarette smoke, and portable kerosene heaters. For office areas, levels of carbon monoxide are normally between 0 ppm and 5 ppm. Levels greater than 5 ppm may indicate the presence of exhaust gases in the indoor environment and should be investigated. Levels of carbon monoxide inside buildings should not exceed 9 ppm [8].

Exposure to carbon monoxide at levels as low as 35 ppm may cause mild fatigue. If levels inside a building are detected greater than 100 ppm, the building should be evacuated until the source is identified and corrected. Adverse health effects such as headache and dizziness may occur after two-hour exposures to carbon monoxide levels as low as 100 ppm [8].

2.5 Effect of Ozone

Ozone is a respiratory irritant produced by equipment that uses high voltage electricity. Photocopiers and ion generator air cleaners can release ozone into the indoor environment. It recommends that ozone levels not exceed 0.08 ppm.

Inhaling fairly low amounts of ozone can result in signs and symptoms such as coughing, congestion, wheezing, shortness of breath, and chest pain in otherwise healthy people. People with already existing asthma, bronchitis, heart disease, and emphysema may find their conditions worsen while inhaling ozone. Although some manufacturers of air cleaning equipment have claimed that ozone generators can decrease volatile organic compounds (VOCs) in the air, research has shown that such devices may, in fact, increase some types of VOCS.

Ozone can be released into the air from some office equipment such as laser printers and copiers, from some types of “air cleaners” such as some electric or ion generators, and from certain industrial processes such as ozone treatment of bottled water [9].

2.6 Effect of VOC

Volatile organic compounds (VOCs) are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects. Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors. VOCs are emitted by a wide array of products numbering in the thousands.

The ability of VOCs to cause health effects varies greatly. As with other chemicals, the effects of VOC exposure depends on several factors including the type of VOC, the amount of VOC and the length of time a person are exposed. Exposure to elevated levels of VOCs may cause irritation to the eyes, nose, and throat. Headaches, nausea, and nerve problems can also occur. Some people do not appear to have any kind of reaction to fairly “low” amounts of VOCs, while other people are fairly sensitive. Studies of animals have shown that breathing some types of VOCs over a long period of time can increase the risk of getting cancer [10].

Although VOCs can be found in both outdoor and indoor settings, the levels of VOCs found indoors can be much higher than those found outdoors. This is because a house or building that doesn't have enough ventilation does not allow potential indoor pollutants to escape. Generally, the air outside naturally dilutes VOCs. Outside exposure to VOCs tends to be more common in urban settings from sources like bus or automobile exhaust [10].

2.7 Effect of Dust

A major man-made type is fumes from combustion processes and products, like tobacco smoke, car exhaust, power plants, wood stoves, oil burners or other heating systems. Even burning candles or oil in lanterns can be sources of particulates. A second major type is dust. This includes dust from mechanical processes like grinding or sweeping and common household dust that may include mold, pollen, and small insect parts. Fibrous building material such as fiberglass may also be a source of particulates.

For people with allergies, certain types and amounts of particulates, such as mold spores, pet dander, pollen, or dust mites, may cause allergic reactions. Some people can be allergic to material in tobacco smoke and other combustion byproducts. Asthmatic episodes can occur in some people. Examples of allergic symptoms and signs include nasal discharge, difficulty breathing, coughing, runny eyes, throat irritation, rashes and headaches. In severe allergic reactions, death can occur [11].

Some particulates such as silica, asbestos fibers, and coal dust can cause permanent lung damage, with symptoms and signs like coughing, chronic shortness of breath and fatigue. When inhaled in high enough doses, lead dust can be a major source of lead poisoning in adults who engage in certain activities such as painting and building renovation. It can cause high blood pressure, decreased hearing, reproductive problems, and even death [11].

CHAPTER 3

OVERALL SYSTEM ARCHITECURE

3.1 Introduction

Indoor air quality monitoring involves measurement of various parameters of air at different location inside any building or house or workplace. This Thesis developed a low cost, reliable system for monitoring indoor air quality in order to pay attention to health problems caused by poor indoor air quality and use this data to avoid such issues in future. The detailed description of system architecture and working principle is given in this chapter.

3.2 Block Diagram of the System

Indoor air quality monitoring involved capturing sensor values of various parameters associated with indoor air quality by using different gas sensors. The system consists of processing unit, which is nothing but Arduino board. We used several motes, which are nothing but sensor boards containing Arduino board and all sensors together with XBee, which is acting as routers. The various blocks of working system are given in Figure 3.1.

Arduino board along with XBEE module forms coordinator. Coordinator acts as a base station that receives and transmits information to routers in wireless sensor network. Python based GUI is developed in computer, which is basic tool to operate IAQ monitoring system, by user, which having various

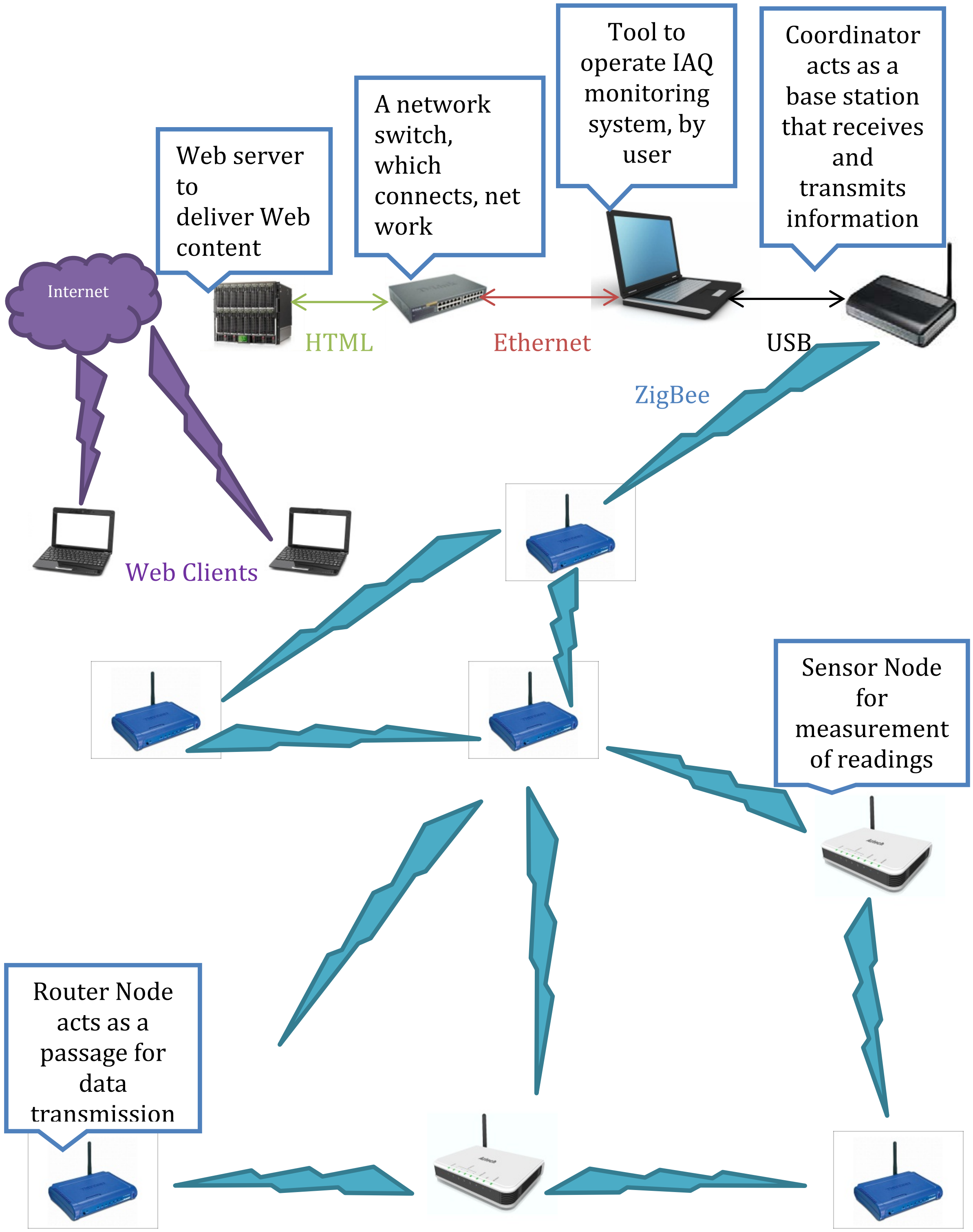

Figure 3.1 IAQ Monitoring System Architecture

network segments or network devices. Web server can either be the hardware or the software that helps to deliver Web content that can be accessed through the Internet. In system architecture Web portal is considered as a future work and is not part of the system in this thesis. Sensor Node is nothing but combination of Arduino, sensor board & XBee module. It is part of wireless network and directly talks with coordinator and also with other routers. Router Node is nothing but a passage for data transmission between coordinator and router, it consist of Arduino board & XBee module.

Graphical user interface (GUI) is developed on computer side for user-friendly environment using wxPython. This GUI is having numerous functions, the detailed description of which is given in coming chapter. Depending upon requested task corresponding command is given to coordinator mote through Universal Serial Bus (USB). We have used high-level data communication protocol and have specific frame structure for reliable inter-communication. Chapter 6 will give brief view of communication protocol.

Coordinator mote consist of Arduino board and XBee module. We have set up XBee module to work as coordinator by using X-CTU software. Detailed description of which is given in Chapter 4. Arduino board is programmed in Arduino programming language (based on wiring). As described in Fig. 3.1 coordinator will broadcast this command packet using ZigBee wireless network. XBee modules are having limitations regarding its range, which is explained in Chapter 5.

Wireless sensor network consist of few sensor nodes, which are nothing but bundle of Arduino board, Sensor shield and XBee module. Sensor shield consists of numerous sensors that measure concentration of various parameters present in air inside house. Design and implementation of sensor board is explained in next Chapter. Each sensor node is having their individual address, depending on address of frame packet corresponding node process the request. Depending upon request sensor node send back requested data to coordinator through ZigBee network. Coordinator forward this data to computer through USB and GUI will either display it or saved it on disc as per user request.

CHAPTER 4

DEVELOPMENT OF SYSTEM

4.1 Introduction

The development of system consist of both hardware and software requirements. The working environment to build the application is setup with all the required hardware components. Software application is then developed which will later tested on hardware platform thoroughly. This chapter explains step-by-step development of hardware system followed by software development and its implementation.

4.2 System Hardware Design

This system is nothing but a stack of several boards starting with Arduino board as a base, sensor board shield on top of it, then XBee shield and XBee module on top level which makes system looks compact in size and very handy to use. This chapter gives detailed review of each of this part along with its working principle.

4.2.1 Arduino Uno R3 Board

As electronic devices got more complicated in the past few decades, it became increasingly difficult and expensive to tinker with hardware. Now the rise of open-source hardware is paving the way for a return of build-it-yourself electronics. Arduino, an inexpensive control board that's easy to program and can hook up to a wide variety of hardware. Figure 4.1 shows Arduino Uno Board hardware.

Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments. Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino Programming Language (based on Wiring) and the Arduino development environment (based on Processing).

Figure 4.1 Arduino Uno R3 Board

The Arduino Uno is a microcontroller board based on the ATmega328 micro-controller. P is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega 328P achieves throughputs approaching 1 MIPS per MHz allowing the system designed to optimize power consumption versus processing speed. The ATMega 328P provides the following features: 32K bytes of In-System Programmable Flash with Read-While-Write capabilities, 1K bytes EEPROM, 2K bytes SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible Timer/Counters with compare modes, internal and external interrupts, a serial programmable USART, a byte-oriented 2-wire Serial Interface, an SPI serial port, a 6-channel 10-bit ADC (8 channels in TQFP and QFN/MLF packages), a programmable Watchdog Timer with internal Oscillator, and five software selectable power saving modes. The Idle mode stops the CPU while allowing the SRAM, Timer/Counters, USART, 2-wire Serial Interface, SPI port, and interrupt system to continue functioning. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button [12].

4.2.2 IAQ Sensor Shield

Size of board and placement of sensors are the two most important things considered while designing sensor shield. Most of the gas sensors available have requirements of preheating of several hours before using it for working applications. As mentioned in earlier chapter, this system uses 6 different gas sensors to measure temperature, humidity, dust, CO, CO2, ozone & VOC. Detailed study of a working principle of these sensors is very important to understand indoor air monitoring system thoroughly. Next sections of this chapter explain detailed study of these sensors.

Main concern of test board design is to accommodate all sensors and try to keep board size as small as possible, in order for convenient use in future development. Apart from this, few sensors need additional supply of heating current along with desired supply voltage; as a result they dissipated more heat. In addition to that three such sensors are having plastic cap and one sensor is having metal cap. So as per simple science metal gives more room to dissipated heat as compared to plastic. So it was challenge to place sensors on a board such that this dissipated heat won’t have effect on other sensors reading, specially temperature sensor.

Another issue needs to be address while design a sensor shield is power consumption of each sensor. As mentioned earlier Arduino can resist up to 500mA of current before overload condition. As many sensors needed extra heating current, it is important to connect limited sensors to Arduino to avoid any damage to board. All gas sensors used in this system requires 5-7 DC voltage and overall current consumption id less than 250 mV that is within the limit [12]. Still it is very important to regular check of leakage of current through any sensor to avoid after effects.

Another important modification in sensor board design is provision of bypassing one or more sensor at any given time as shown in Figure4.3.3. As mentioned earlier, in case of system breakdown, this will help to find out faulty sensor and fast recovery of a system. Also it will help to avoid use of particular sensor, which is not required by application, and hence results in power saving and extended sensor life.

4.2.3 Temperature and Humidity Sensor (RHT-03)

The RHT-03 is a low cost humidity and temperature sensor with a single wire digital interface. The sensor is calibrated and doesn't require extra components so you can get right to measuring relative humidity and temperature. Interface circuit of sensor consists of resistor of 10KOhm as described in Figure 4.2.2.

Figure 4.2.1 Temperature and Humidity Sensor (RHT-03)

RHT-03 output calibrated digital signal. It applies exclusive digital-signal-collecting-technique and humidity sensing technology, assuring its reliability and stability. Its sensing elements are connected with 8-bit single-chip computer. When MCU (Micro-controller unit) send start signal, RHT03 change from standby-status to running-status. When MCU finishes sending the start signal, RHT03 will send response signal of 40-bit data that reflect the relative humidity and temperature to MCU. Without start signal from MCU, RHT03 will not give response signal to MCU. RHT03 will change to standby status when data collecting finished if it don't receive start signal from MCU again [13].

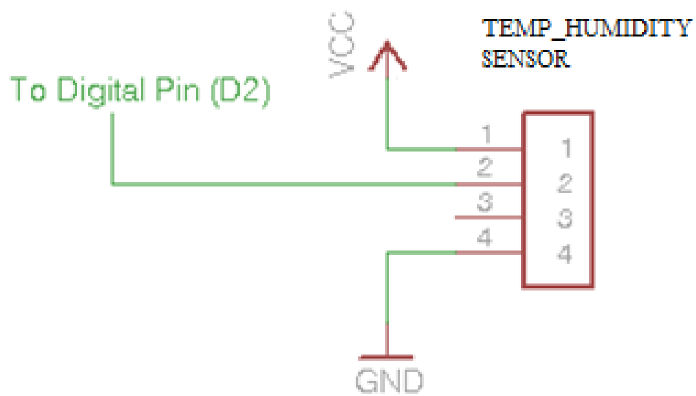

Figure 4.2.2 Measuring Circuit for Temperature and Humidity Sensor RHT03

4.2.4 Dust Sensor (GP2Y1010AU0F)

Sharp's GP2Y1010AU0F is an optical air quality sensor, designed to sense dust particles. An infrared emitting diode and a phototransistor are diagonally arranged into this device, to allow it to detect the reflected light of dust in air. It is especially effective in detecting very fine particles like cigarette smoke, and is commonly used in air purifier systems [14].

Figure 4.2.3 Dust Sensor

An infrared emitting diode (IRED) and a phototransistor are diagonally arranged into this device. It detects the reflected light of dust in air. Interface circuit of Dust sensor consists of a resistor of 150 ohms and 220uF capacitor as shown in Figure 4.2.4.

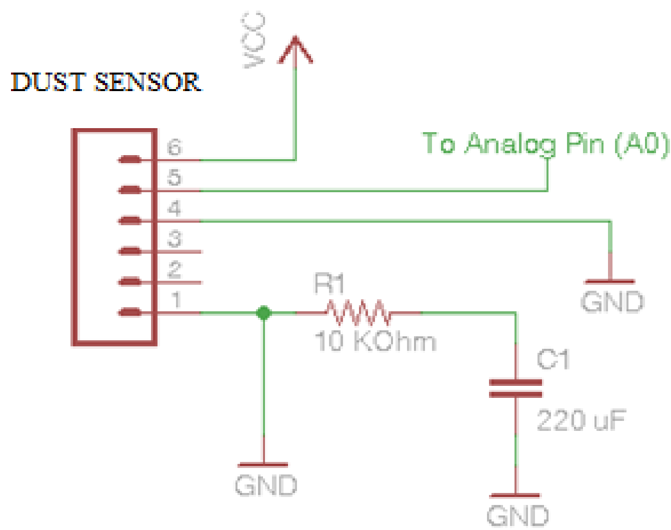

Figure 4.2.4 Measuring Circuit for Dust Sensor

4.2.5 Carbon Monoxide (CO) Sensor (MQ-7)

This is a simple-to use CO sensor, suitable for sensing CO concentrations in the air. The MQ-7 can detect CO-gas concentrations anywhere from 20 to 2000ppm. This sensor has a high sensitivity and fast response time. The sensor's output is an analog resistance. The drive circuit is very simple; consisting of a heater coil with 5V, load resistance, and output connected to an ADC.

Figure 4.2.5 Carbon Monoxide Sensor

Sensor composed by micro AL2O3 ceramic tube, Tin Dioxide (SnO2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-7 has 6 pins, 4 of them are used to fetch signals, and other 2 are used for providing heating current [15].

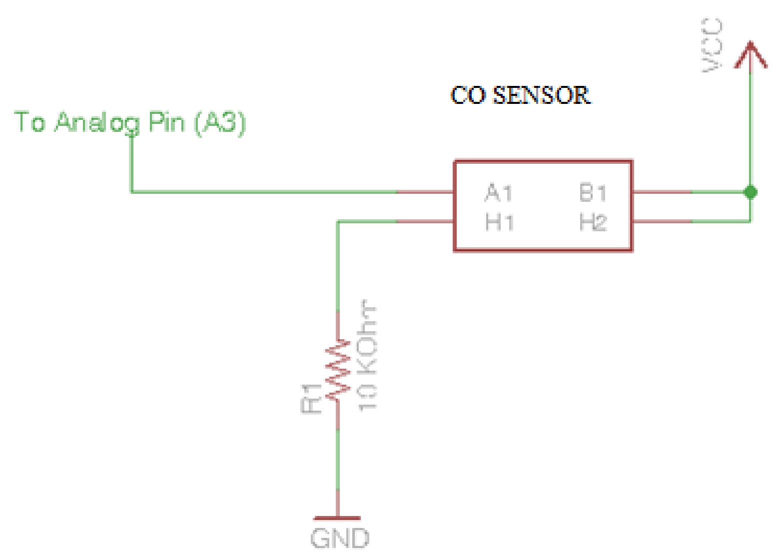

Figure 4.2.6 Measuring Circuit for CO Sensor

As shown in Figure 4.2.6, standard measuring circuit of MQ-7 sensitive components consists of 2 parts. One is heating circuit having time control function (the high voltage and the low voltage work circularly). The second is the signal output circuit; it can accurately respond changes of surface resistance of the sensor.

4.2.6 Volatile Organic Component (VOC) Sensor (TGS2602)

The sensing element is comprised of a metal oxide semiconductor layer formed on the alumina substrate of a sensing chip together with an integrated heater. In the presence of detectable gas, sensor conductivity increases depending on gas concentration in the air. A simple electrical circuit can convert the change in conductivity to an output signal, which corresponds to the gas concentration. Figure 4.2.7 shows actual picture of VOC sensor TGS 2602.

Figure 4.2.7 VOC Sensor TGS 2602

The sensor requires two voltage inputs: heater voltage (VH) and circuit voltage (VC). The VH is applied to the integrated heater in order to maintain the sensing element at a specific temperature, which is optimal for sensing. VC is applied to allow measurement of voltage (Vout) across a load resistor (RL), which is connected in series with the sensor. Figure shows interface circuit for VOC sensor [18].

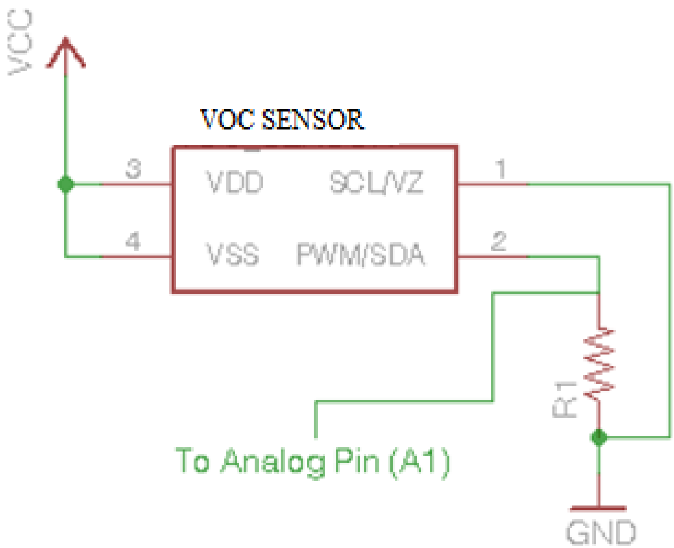

Figure 4.2.8 Measuring Circuit for VOC Sensor

4.2.7 Ozone Sensor (MQ-131)

It detects and measures Ozone (03) Concentration from 10ppb to 2ppm. This sensor is Ideal for monitoring air quality or for use in environment and research experiments. Measuring circuit for this sensor is shown in Figure 4.2.10.

Figure 4.2.9 Ozone Sensor

Sensor composed by micro AL2O3 ceramic tube, Metal-oxide semiconductor sensitive layer, measuring electrode and heater are fixed into a crust made by nylon and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-131 has 6 pins, 4 of them are used to fetch signals, and other 2 are used for providing heating current [17].

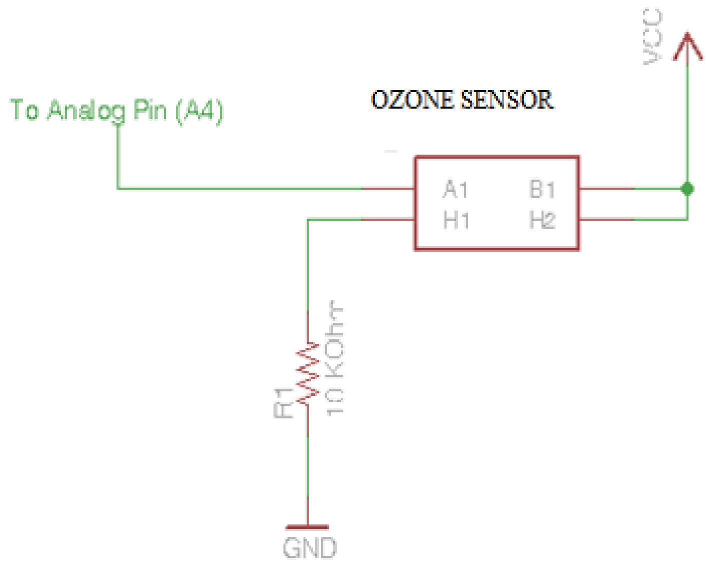

Figure 4.2.10 Measuring Circuit for Ozone Sensor

4.2.8 Carbon Dioxide (CO2) Sensor (MG-811)

It has good sensitivity and selectivity to detect carbon dioxide. Unlike other gas sensors MG-811 has low humidity and temperature dependency that means it gives measurement without much error in much humid condition. It has long stability and reproducibility i.e. no two consecutive readings under same conditions are differing from each other. This sensor works on the principle of solid electrolyte cell [16].

Figure 4.2.11 Carbon Dioxide Sensor

Measurement circuit for CO2 sensor consists of resistor of 10KOhm. As shown in Figure 4.2.11 this sensor also has circular shape with 6 pins. Breakout boards are available for implementation of such sensors if readers want to implement this system on breadboard or prototype board. Figure shows implementation circuit of this sensor.

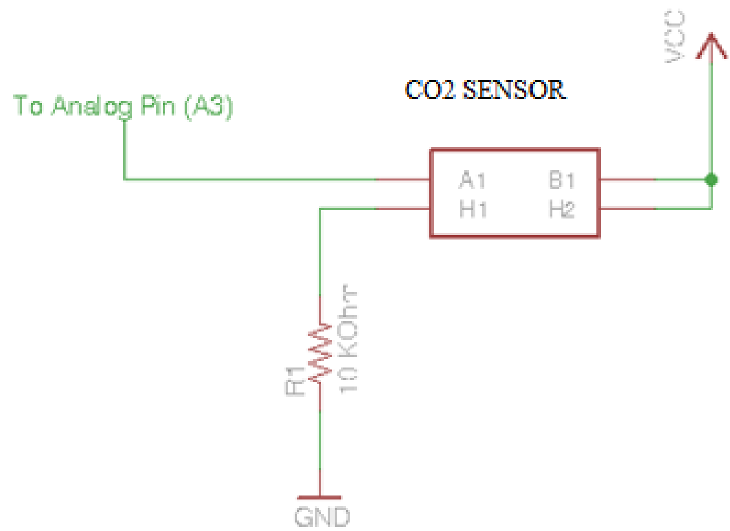

Figure 4.2.12 Measuring Circuit for CO2 Sensor

4.3 System Hardware Implementation

As mentioned earlier, this system consists of 4 different parts. So it is important to implement those in a way to make easy to use, compact and robust system. Next chapter will give thorough knowledge of XBee module and Arduino compatible XBee shield.

As shown in Figure 4.3.1 system consists of Arduino board as a base of stack, on which sensor board is mounted. 6 pin and 8 pin connectors were used in sensor shield to make sure good and robust connection between pins of sensor shield and Arduino board. Please make sure to avoid any short circuit while placing sensor board on Arduino board at USB connection and external power supply connection on Arduino board.

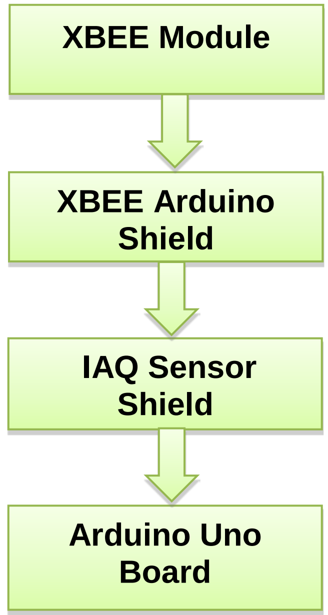

Figure 4.3.1 Different Levels of System Hardware

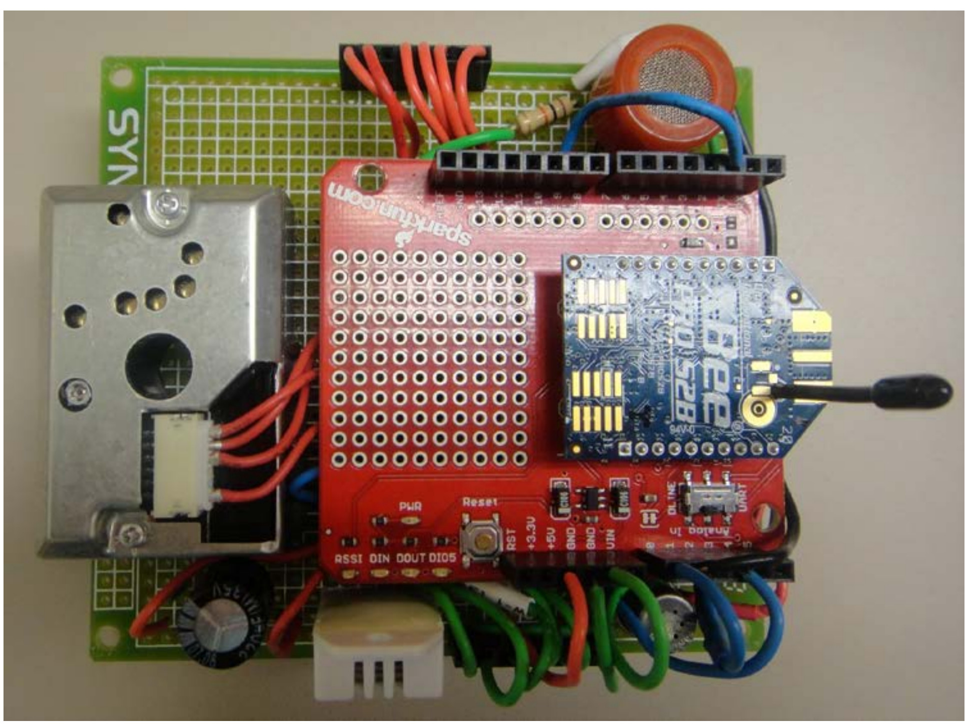

Figure 4.3.2 Sensor Node

Next layer of stack is XBEE shield. It is Arduino compatible XBee shield powered by 3.3V from Arduino board power pin of 3.3V. As shown in figure XBee module is mounted on this XBee shield in a slot provided. This design implementation makes system looks compact at the same time space efficient. Figure 4.3.2 shows actual implemented sensor node and Figure 4.3.3 shows circuit diagram of system board designed using Eagle PCB Design software.

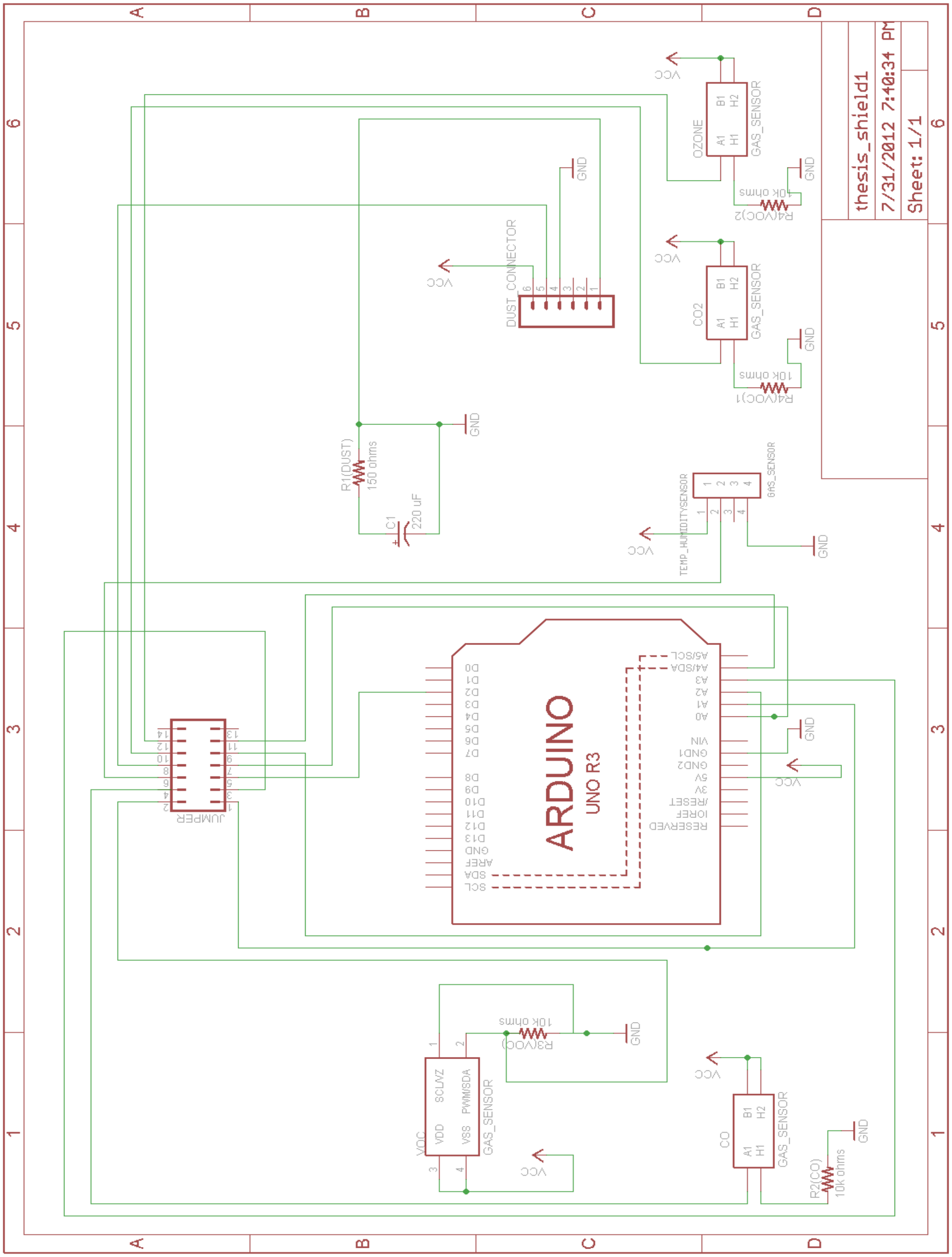

Figure 4.3.3 Circuit Diagram for IAQ Sensor Shield

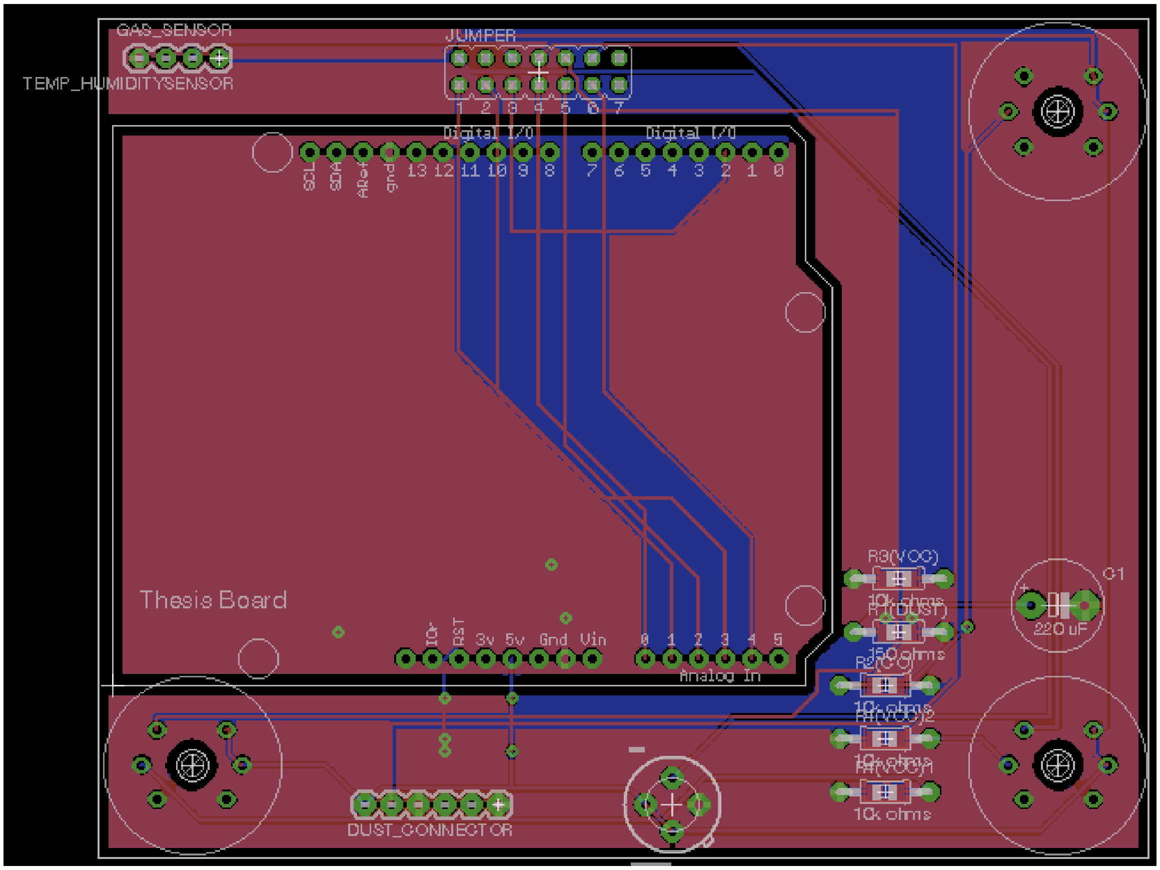

Figure 4.3.4 PCB Layout for IAQ Sensor Shield

4.4 System Software Design

Software design of this system is having mainly two parts. Arduino boards need to be programmed in order to measure sensor readings and forward it whenever ordered. As discussed earlier computer side GUI is developed for user-friendly environment. Arduino boards are programmed using Arduino programming language while GUI is developed in python programming. Next section will describe detailed functionality of both programming.

4.4.1 Arduino Board Programming

Very simple approach is used while developing program for Arduino board. Basic function of Arduino board in this system is logging of sensor data and processing according to user request. As different sensors are implemented in system, they all have different sensor reading techniques. Detailed study of working of this entire sensor is must while programming board. This chapter already mentioned necessary information regarding all these sensors. Apart from temperature and humidity sensor all others are having analog output, so special attention need to be given while programming RHT-22 sensor.

Apart from data logging, Arduino boards programmed to send status of each sensor i.e. number of readings logged, time interval and unit using to log sensor readings. As mentioned earlier Arduino Uno board is having 2K byte of EEPROM, which is used for temporary storage of data. In case of loss of data packet from router to coordinator, router always has back up data to send again on request. This makes this system more reliable [12].

4.4.2 Computer Side Programming

In order to create a system which will have global exposure it was very important to have user friendly usage that means user who knows nothing about technical aspects of the system can able to operate it without any trouble just like any cell phone. Main reason for selecting python to create GUI is it has optimum scope to improve GUI design in the sense of implementing text monitor window, buttons that will perform specific task, graph window that will display live graph of sensor readings etc.

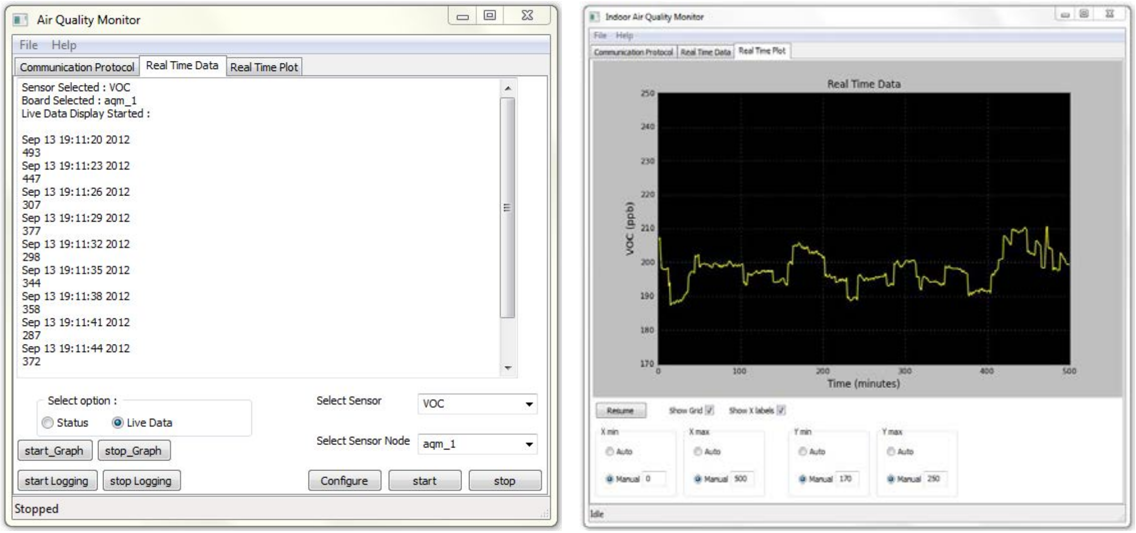

Figure 4.4.1 System GUI Showing 'Real Time Data' Tab and 'Real Time Plot' Tab Windows

As mentioned initially, Graywolf system is considered a benchmark system in development of this system; this GUI mentioned in Figure 4.4.1 is having very much resemblance with its GUI. As shown in figure GUI is very simple and performs several additional tasks which are missing from Graywolf such as monitoring various sensor nodes using wireless network instead of wired sensor node. Following table explain working of few selected functions.

This GUI is having three tabs namely Communication, Live Data and Live Graph. Real time graph of live data gives easy idea to user to understand basic trend of particular element in air. User having options of changing axes parameters if needed. As shown in Figure 4.4.1 'Real Time data' window of IAQ monitor system consists of few functions logging data, live graph, live data, status and sensor configuration which are explained in following sections.

As the name suggests, monitoring continuous data is the main function of IAQ monitor system. Live data function continuously displays live data for a selected sensor of a selected sensor node.

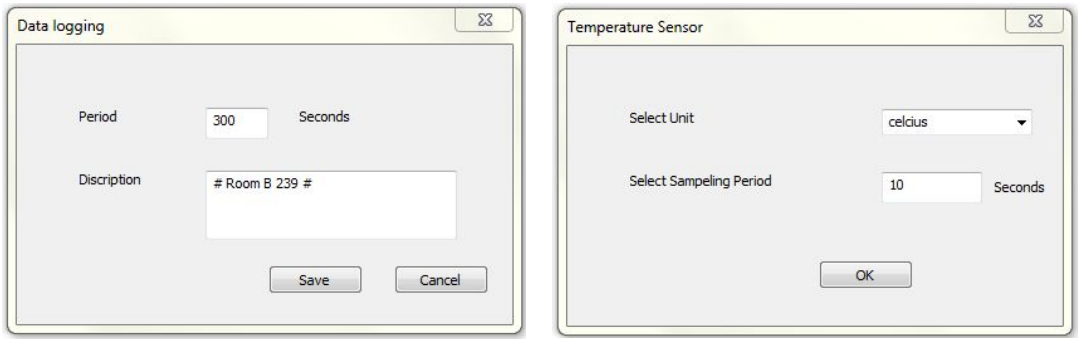

Figure 4.4.2 Popup Windows of GUI Used to Set Different Parameters

CHAPTER 5

BUILDING WIRELESS NETWORK

5.1 Introduction

To build a reliable and robust system to monitor air quality in big buildings, workshops or green house, it is very important to have robust wireless sensor network that will cover all parts of building or green house. So while choosing components for such network cost and distance covered are the main factors need to be consider. XBee is such module having highly reliable data transmission and receiver modes. This chapter will give brief view of XBee module, ZigBee network and procedure to build highly reliable mesh loop network using coordinator and routers.

5.2 XBee PRO S2B Module

The XBee RF Modules interface to a host device through a logic-level asynchronous serial port. Through its serial port, the module can communicate with any logic and voltage compatible UART; or through a level translator to any serial device through RS 232 or USB interface board. Next section will describe these two data modes briefly.

Figure 5.2.1 XBee Module

5.2.1 UART Data Flow

Devices that have a UART interface can connect directly to the pins of the RF module as shown in the figure below.

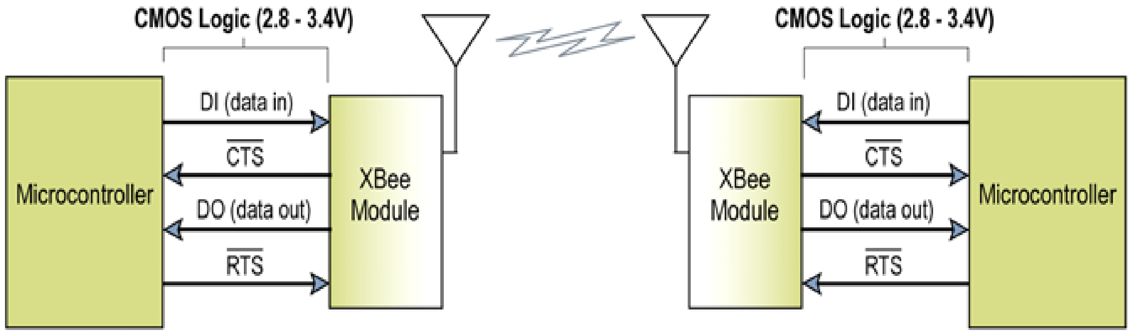

Figure 5.2.2 system Dataflow Environment in a UART Interface Environment [1]

5.2.2 Serial Data

Data enters the module UART through the DIN (pin 3) as an asynchronous serial signal. The signal should idle high when no data is being transmitted.

Each data byte consists of a start bit (low), 8 data bits (least significant bit first) and a stop bit (high).

Serial communications depend on the two UARTs (the microcontroller's and the RF module's) to be configured with compatible settings (baud rate, parity, start bits, stop bits, data bits). The UART baud rate, parity, and stop bits settings on the XBee module can be configured with the BD, NB, and SB commands respectively [19].

5.2.3 Modes of Operation

XBee module works in three different modes, which are, explained as follows.

5.2.3.1 Idle Mode

When not receiving or transmitting data, the RF module is in Idle Mode. The module shifts into the other modes of operation under the following conditions:

- Transmit Mode (Serial data in the serial receive buffer is ready to be packetized)
- Receive Mode (Valid RF data is received through the antenna)
- Sleep Mode (End Devices only)
- Command Mode (Command Mode Sequence is issued)

5.2.3.2 Transmit Mode

When serial data is received and is ready for packetization, the RF module will exit Idle Mode and attempt to transmit the data. The destination address determines which node(s) will receive the data. Prior to transmitting the data, the module ensures that a 16-bit network address and route to the destination node have been established [1].

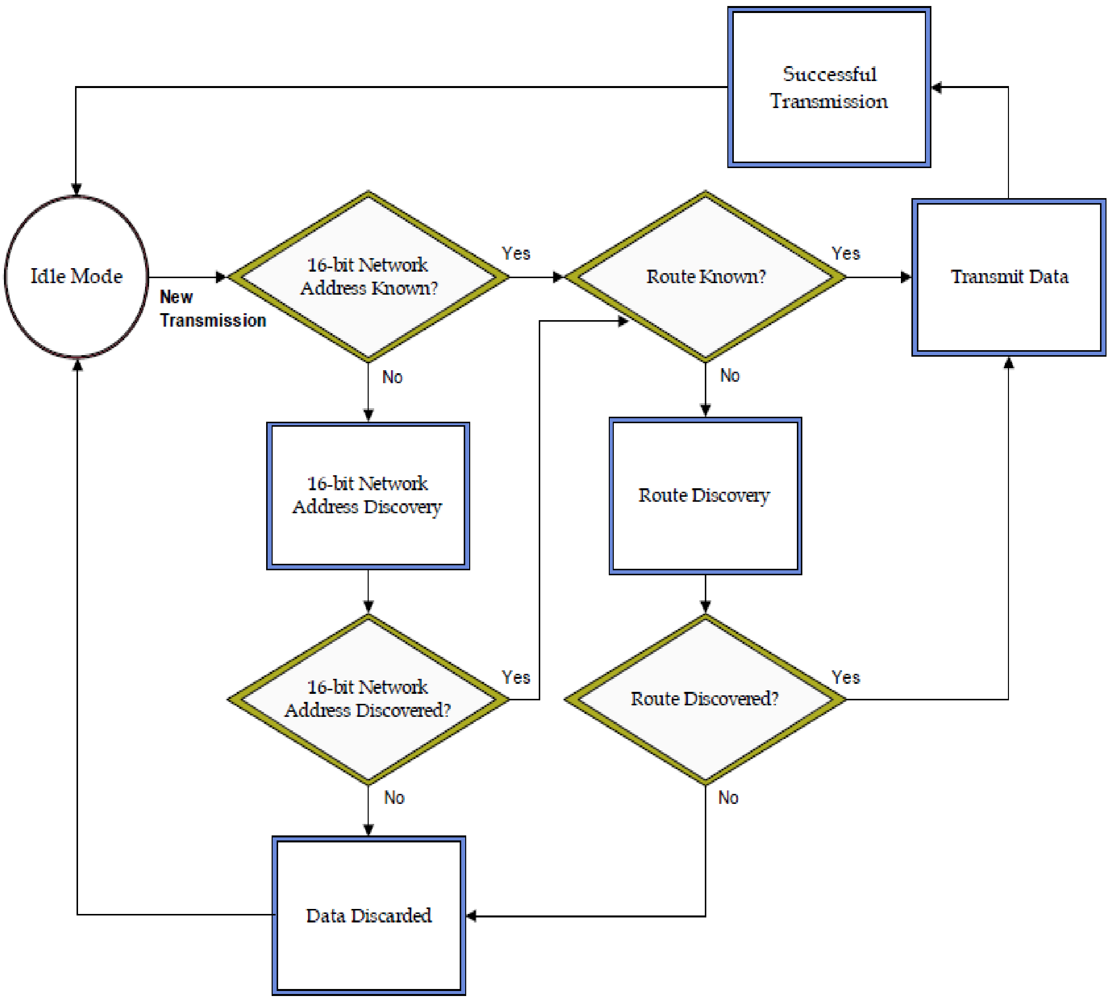

Figure 5.2.3 Flow Chat for Transmit Mode [1]

If the destination 16-bit network address is not known, network address discovery will take place. If a route is not known, route discovery will take place for the purpose of establishing a route to the destination node. If a module with a matching network address is not discovered, the packet is discarded. The data will be transmitted once a route is established. If route discovery fails to establish a route, the packet will be discarded. 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 that the destination node received the data packet. If a network acknowledgement is not received, the source node will re-transmit the data [19].

It is possible in rare circumstances for the destination to receive a data packet, but for the source to not receive the network acknowledgment. In this case, the source will retransmit the data, which could cause the destination to receive the same data packet multiple times. The XBee modules do not filter out duplicate packets.

5.2.3.3 Receive Mode

If a valid RF packet is received, the data is transferred to the serial transmit buffer.

5.3 Description of XBee Shield

The XBee shield allows an Arduino board to communicate wirelessly using ZigBee. It is based on the XBee module from MaxStream. The module can communicate up to 100 feet indoor or 300 feet outdoors (with line-of-sight). It can be used as a serial/USB replacement or you can put it into a command mode and configure it for a variety of broadcast and mesh networking options. The shields breaks out each of the XBee's pins to a through-hole solder pad. It also provides female pin headers for use of digital pins 2 to 7 and the analog inputs, which are covered by the shield (digital pins 8 to 13 are not obstructed by the shield, so you can use the headers on the board itself).

5.4 Description of ZigBee Network

ZigBee is a standard that defines a set of communication protocols for low-data-rate short-range wireless networking. ZigBee-based wireless devices operate in 868 MHz, 915 MHz or 2.4GHz frequency bands. The maximum data rate is 250 kbps. ZigBee uses DSSS (Direct Sequence Spread Spectrum) which divides the 2.402 to 2.480 GHz spectrum into 16 channels or 10 channels in the 915 MHz spectrum and 1 channel in the European 868 MHz spectrum.

ZigBee is targeted for low-data-rate, low-cost, and battery-powered applications [2]. In many ZigBee applications, the total time that the wireless device is engaged in any type of activity is very limited; the device spends most of its time in a power-saving mode, called ”sleep mode”. As a result, ZigBee-enabled devices are capable of being operational for several years before their batteries need to be replaced. ZigBee defines three different device types, which are coordinator, router and end device:

1. Coordinator: Start a new PAN by selecting the channel and PAN ID, allow routers and end devices to join the PAN, transmit and receive RF data transmission, and route the data through the mesh network.

2. Router - Transmit and receive RF data transmission, and route data packets through the network, which is nothing but sensor node in this system.

3. End Device - Cannot assist in routing the data transmission but transmit or receive RF data transmission, and intended to be battery-powered devices.

5.5 Wireless Mesh Network

In general, ZigBee mesh topology consists of a coordinator and a set of routers and end devices. We have used one coordinator and several routers to build up our Mesh Network. A router can be linked to one or more routers and end devices. The communication rules of mesh topology are flexible because the routers that are located within range of each other can communicate directly. An advantage of mesh network is that there is likely another alternative route in case an existing link fails. Hence, this type of network topology is very reliable. Also this concept is applicable to wireless networks, wired networks, and software interaction.

5.6 Building Wireless Mesh Network

XBee devices do building an XBee network automatically. We have assigned specific PAN ID to our coordinator mote; the Coordinator then starts a ZigBee network by scanning available channels. From now on, a router can join a Coordinator or another router that has already joined the same PAN. If the router is not being a part of the network, it performs a PAN scan of the SC channels and looks for the coordinator or router operating with the valid PAN ID.

The router scans the SC channel until the valid device is discovered. Then, it sends an association request frame to associate device and receives an association response to verify the allowance into the network. The joining router then sends a broadcast discovery frame to discover 64-bit address of the Coordinator. Each router and Coordinator parents can allow up to 8 end device children to join their own device.

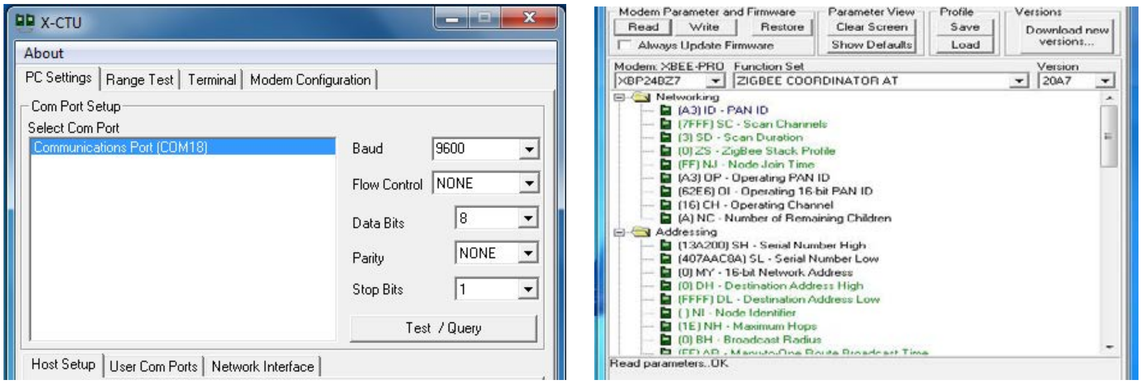

Figure 5.3.1 Screen Shots of X-CTU Software

CHAPTER 6

COMMUNICATION PROTOCOL

6.1 Communication Protocol Design

IAQ system is connected to computer through USB, which use one of the available COM port for communication. At competitive level we have to match our system with available professional systems. Communication protocol plays vital role in raising standard of our system. So we have defined our communication protocol by taking 'High Level Data Link Control' as a reference protocol**.** High-Level Data Link Control (HDLC) is a bit-oriented HDLC provides both connection-oriented and connectionless service.

This system used byte oriented data packets transmission by assigning Start flag, address, control byte, information and End flag. Flags are used to indicate start of packet and end of packet. In this communication, user can send command as a command frame structure from computer side in python to Arduino to start any new task such as to start takes readings or to send reading stored in its EEPROM or to read current sensor value and send it back. Once Arduino receives this command data packet it checks address of this data packet, id it matches with pre-defined address then it will do the ordered operation else it will just discard that data packet. Arduino sends similar data packet with information to computer. On computer side, python code checks data packets for authenticity of sender.

6.2 Description of Frame Format

This system used frame format structure as explain in figure. It contains starting flag as a start of packet and another flag to indicate end of packet. These frame used single bytes for start and stop flag. Address is very important for authentication of communication.

FLAG	ADDRESS	INFORMATION	FCS	FLAG
1 byte	1 or more byte	0 or more bits	2 bytes	1 byte

Figure 6.2 Frame Structure of Data Packet

The frame check sequence (FCS) is a 16-bit CRC-CCITT or a 32-bit CRC-32 computed over the Address, Control, and Information fields. It provides a means by which the receiver can detect errors that may have been induced during the transmission of the frame, such as lost bits, flipped bits, and extraneous bits. If the receiver's calculation of the FCS does not match that of the sender's, indicating that the frame contains errors, the receiver can send nothing. After timing out waiting for a positive acknowledge packet, the sender can retransmit the failed frame.

6.3 Design and Implementation of Commands

IAQ monitor system used many different commands to perform various operations. It is very important to design such command in such way that system will perform reliable operations. This section, chapter will explain descriptions of various commands in a brief manner.

In this system, for a command like ‘to change sampling period’ of individual sensor, command consist of sampling period as an additional field apart from flags and address. So as per sampling rate entered by user, packet consists of same value and sends it to sensor node to make corresponding modifications. Other command which are having additional fields of special values includes ‘Change of unit’, ‘sampling period of data logging’, ‘Description of data logging’.

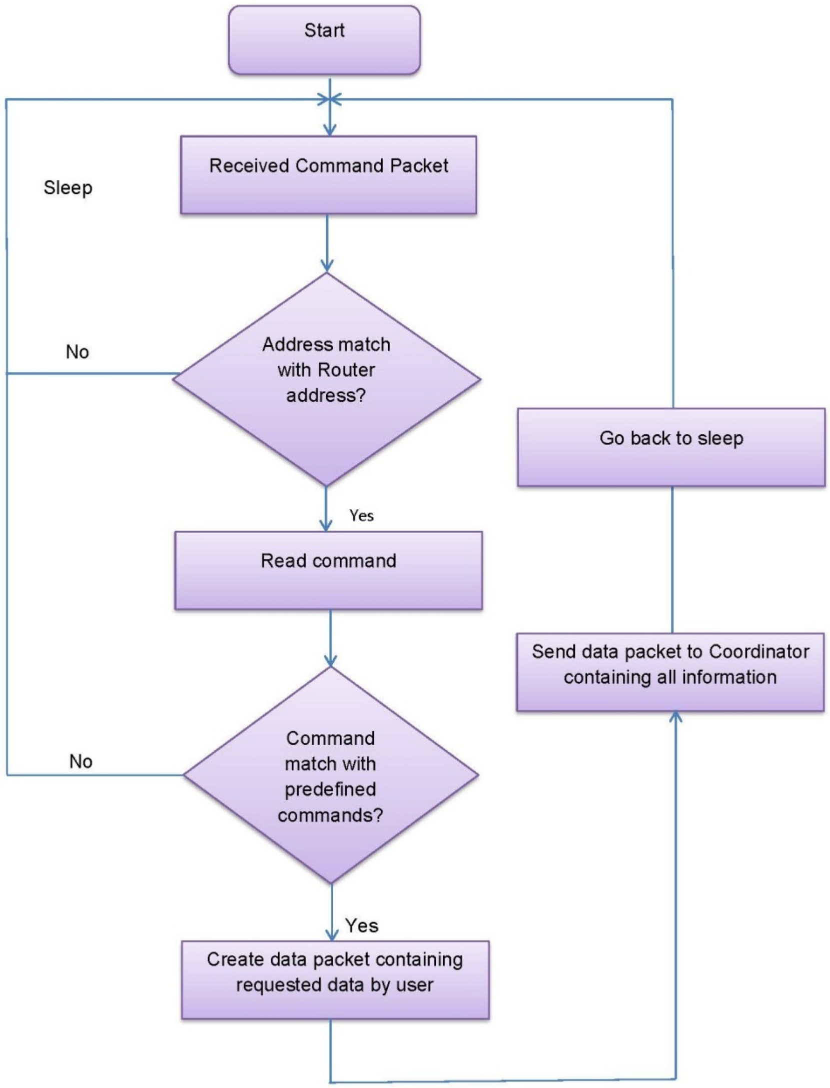

Figure 6.1 Flowchart Showing Behavior of Each Sensor Node

As shown in figure 6.1, whenever any command approaches Sensor node, number of operations performed at sensor node. First, it will check for address, as there are number of Sensor nodes present in wireless network so it is very important to get response from correct Sensor node. Once, address verified, it checks for next command packet field. If address doesn’t match with Sensor node address, it just discards command. Depending upon nature of command mentioned in command field, Sensor node performs respective operation. Once it finished with operation, then it will create information packet containing all information and send it back to coordinator and go back to sleep mode.

CHAPTER 7

EXPERIMENTAL STUDIES AND RESULTS

7.1 Introduction

This chapter will give detailed review of various experiments conducted with this system. First section will explain reliability of the system by showing actual working of the system. Also it gives comparison results between this system and professional Graywolf system for the sake of checking reliability and accuracy of newly developed system. This chapter also features some of the experiments result that will lead to develop few new applications in the field of indoor air quality monitoring.

7.2 Testing IAQ Monitor System

For any system it is very important to be work properly as desired. In this case also, IAQ monitor need to be pass this hurdle by giving good results during its testing period. Experimental set up for testing is shown in figure, followed by test results. Two rooms were chosen in Electrical Engineering department at University of North Texas (UNT) for testing purpose and routers were places in those two rooms. Coordinator is placed in base station which is nothing but monitor room.

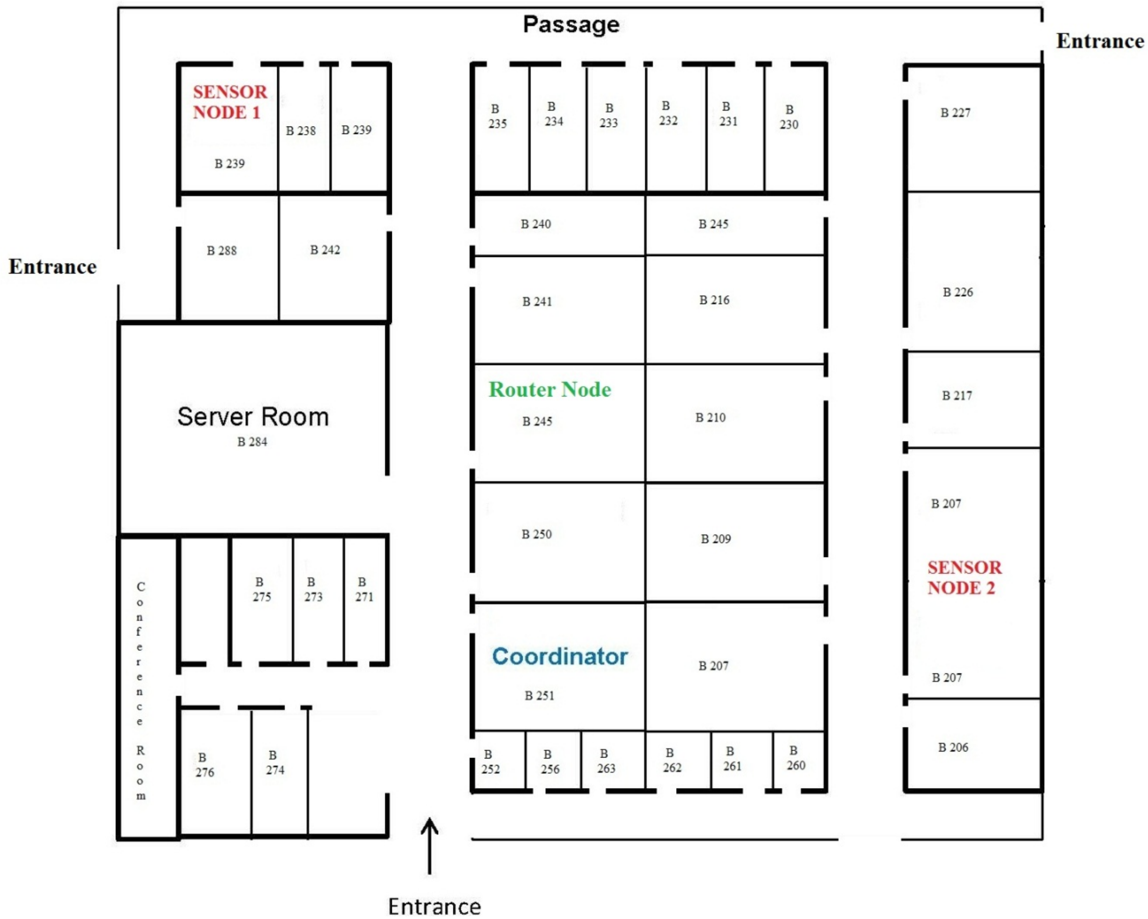

Figure 7.1 Experimental Set Up (Electrical Engineering Department at UNT)

Experimental set up for the IAQ monitor is shown in figure 7.1. Coordinator, sensor nodes and router were deployed in Electrical Engineering department of University of North Texas (UNT). Sensor nodes were placed in two different labs, which are at a distance of 80-100 meter from coordinator lab and having few obstacles like classroom walls and open passage. Router node is placed in lab B 245 which acted as a passage for routing the data packets. Base station consists of coordinator that will monitor all readings coming from routers and saved it in .txt files on computer.

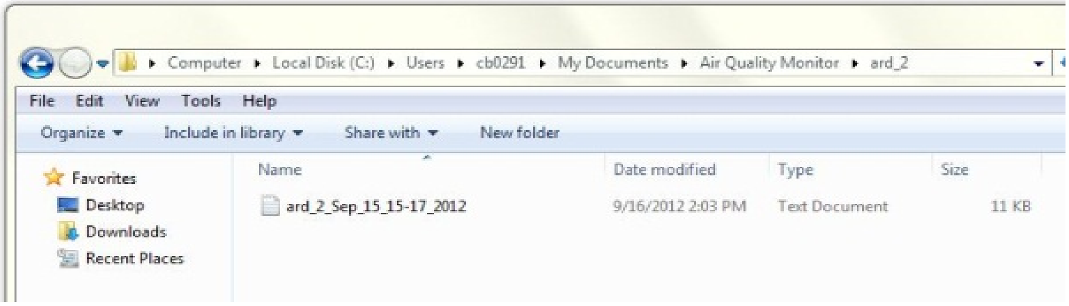

Figure 7.2 Screenshot Showing Saved Data Log File in Computer

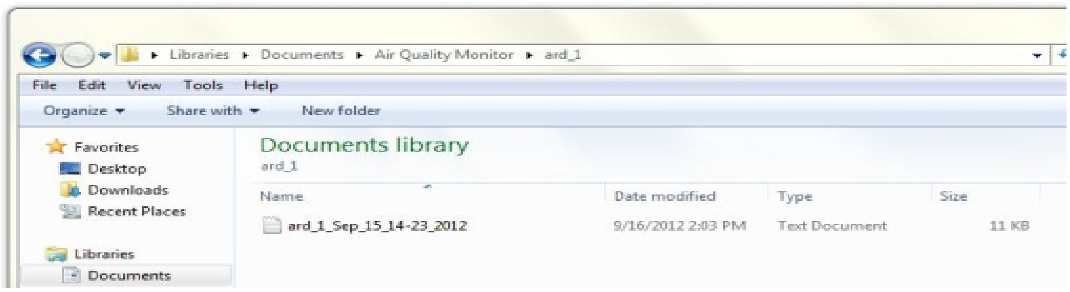

Figure 7.3 Screenshot Showing Saved Data Log File in Computer

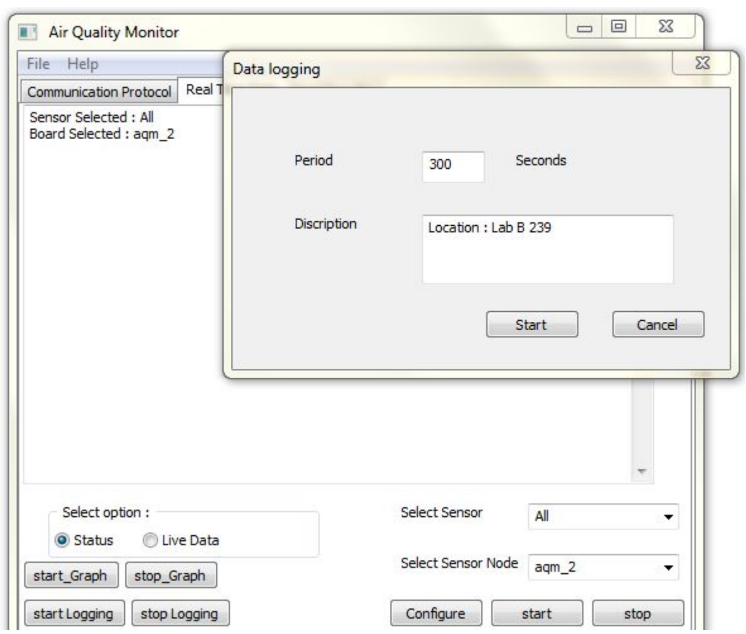

Figure 7.4 Screenshots of GUI and Popup Windows

Data logging started in those two rooms by using GUI. Figure 7.2 shows screenshots of GUI showing parameters selection prior logging started. Sampling period is set to 300 seconds and logging took for 24 hours to have large data to see clear trend of sensor readings. Program will create .txt files for individual sensor node and saved them at desired location set by user in program.

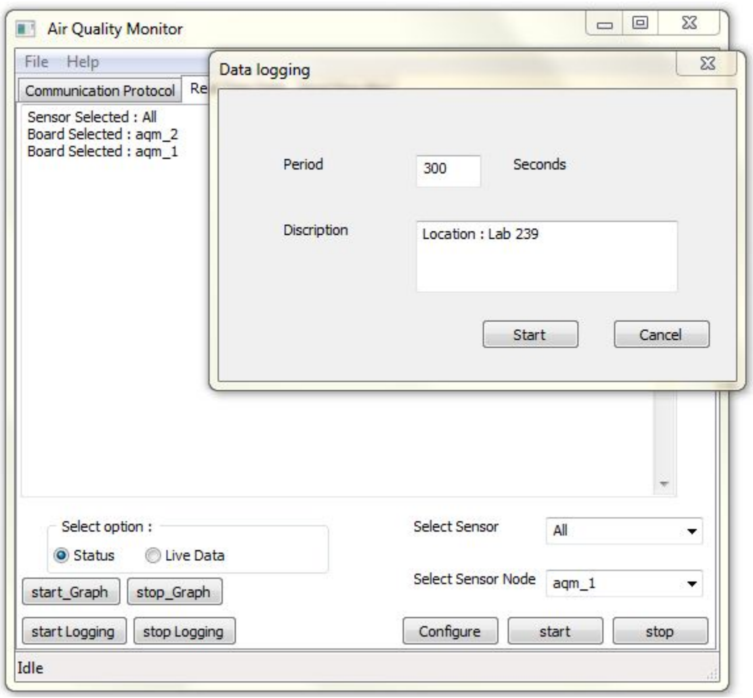

Figure 7.5 Screenshots of GUI and Popup Windows

7.3 Comparison Between IAQ Monitor System with Graywolf System

To prove reliability of IAQ monitoring system, it is very important to test accuracy of data. Few experiments were conducted by using both systems and compare their readings. Readings of gas sensors were taken from 5 different locations at Discover Park building in University of North Texas campus, which are as follows:

Location 1: B242 Lecture Room

Location 2: B239 Teacher Lab

Location 3: Copy Room

Location 4: Staff Kitchen

Location 5: Terrarium

Using these two systems monitors each of this location. To have access to large amount data as well as to capture more detailed trend of each of the sensor value, Sampling period of both system for each of the sensor has set to 5 minute and readings were taken at each location for 24 hours. Following section will give brief review of each sensor measurement using two different systems at different locations.

Figure 7.2.1 Work Room

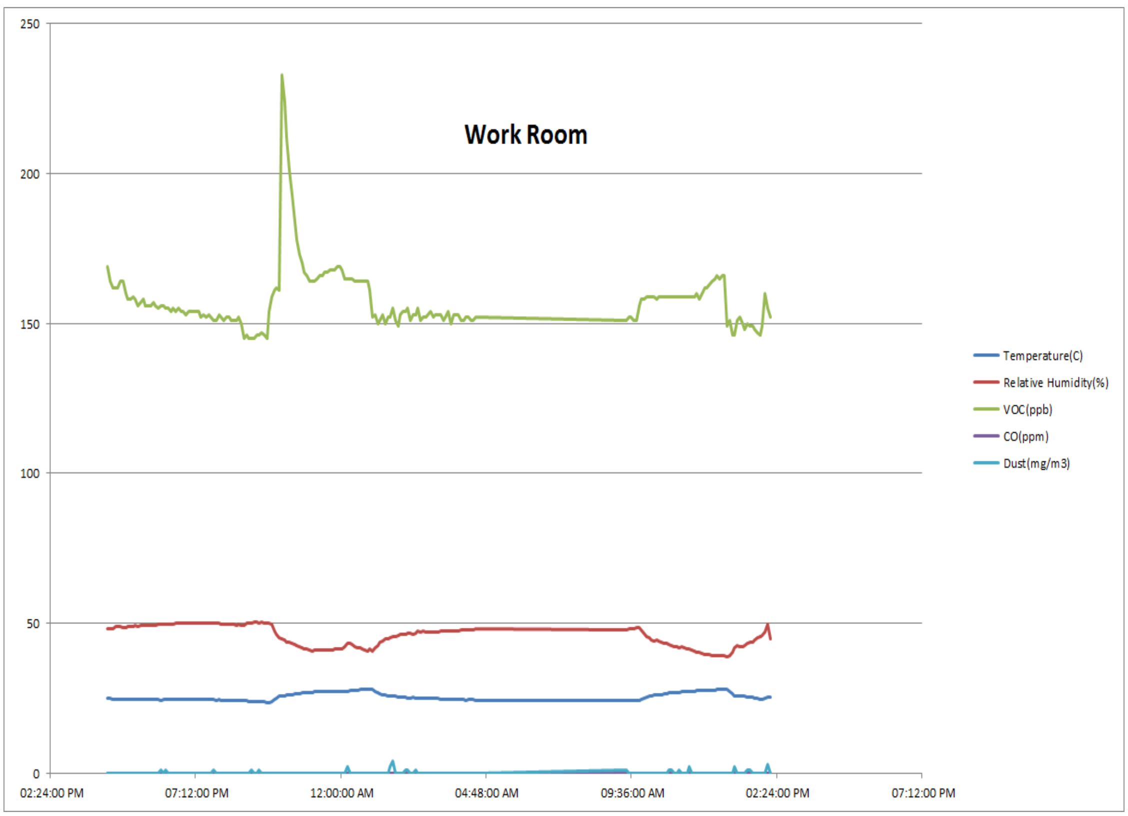

Figure 7.2.2 2 Graph of Sensor Values Using IAQ Monitoring System

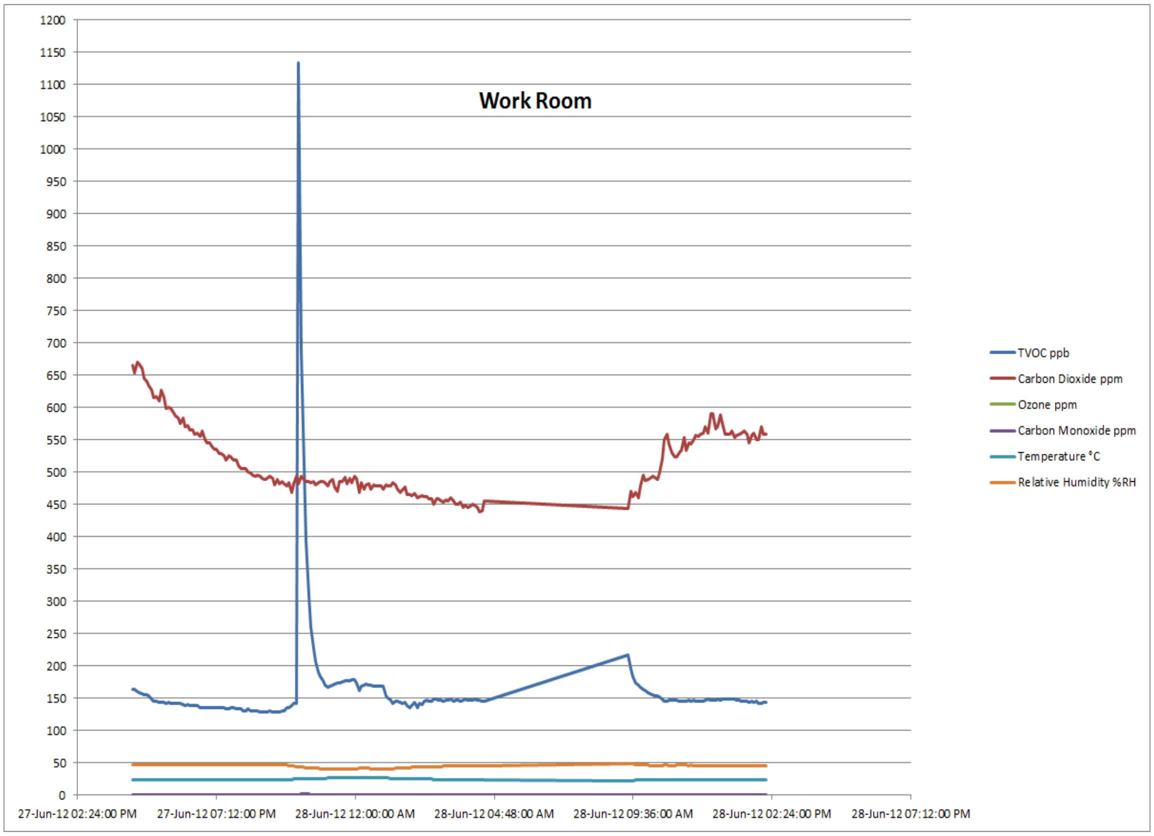

Figure 7.2.3 Graph of Sensor Values Using Graywolf System

As shown in graph, trends for each of the sensors are similar to that of Graywolf system. Graph for VOC in IAQ monitor system is represented by green color while that in Graywolf is represented by blue color. But at the same time IAQ monitor has difference of about several parts per billions (ppb) as compared to Graywolf system for VOC sensor. As mentioned earlier IAQ monitoring system using very low cost sensors, and hence is not accurate as Graywolf system, but giving the same trends of sensor values which is useful in many applications where accuracy is not a prime concern. Trends for rest of the sensor values are almost similar. Sudden change in VOC is assumed to be due to use of copier machine for a longer time during that period.

Figure 7.3.1 Classroom B242

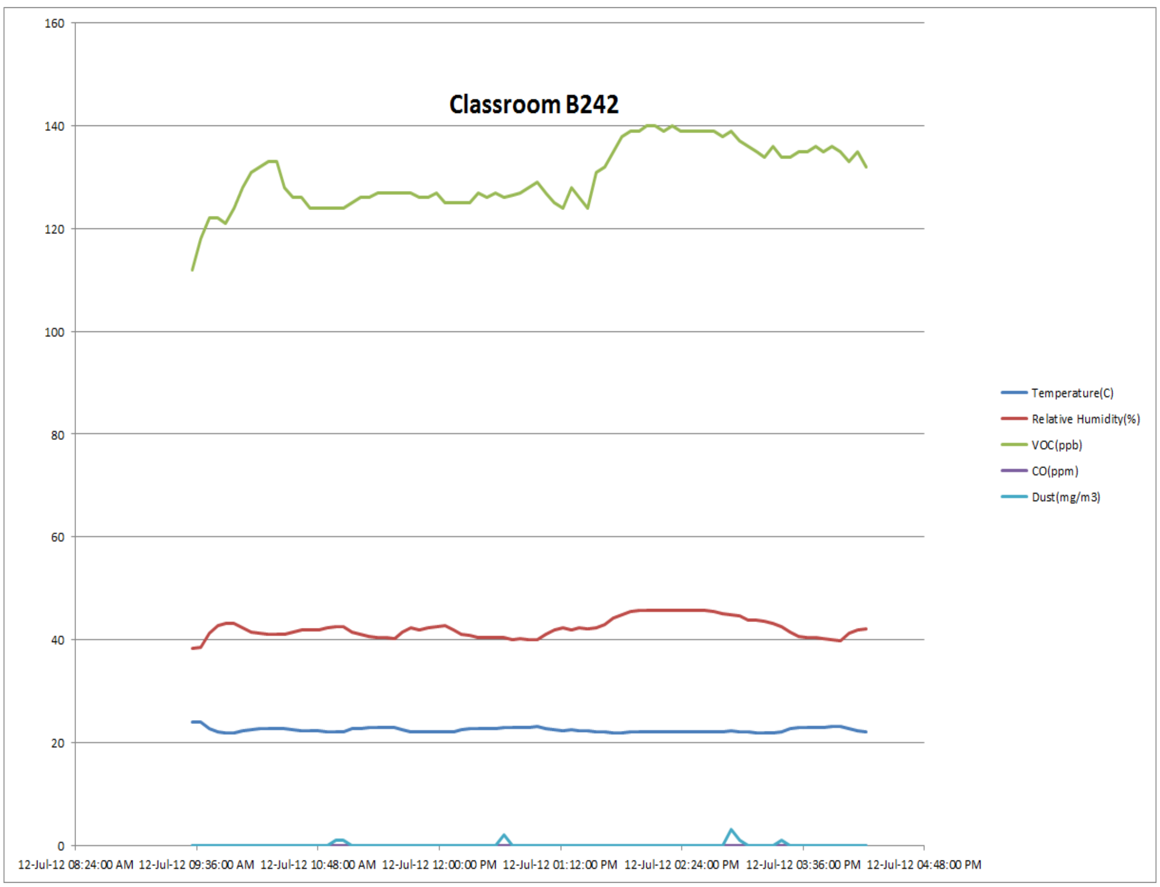

Figure 7.3.2 Graph of Sensor Values Using IAQ Monitoring System

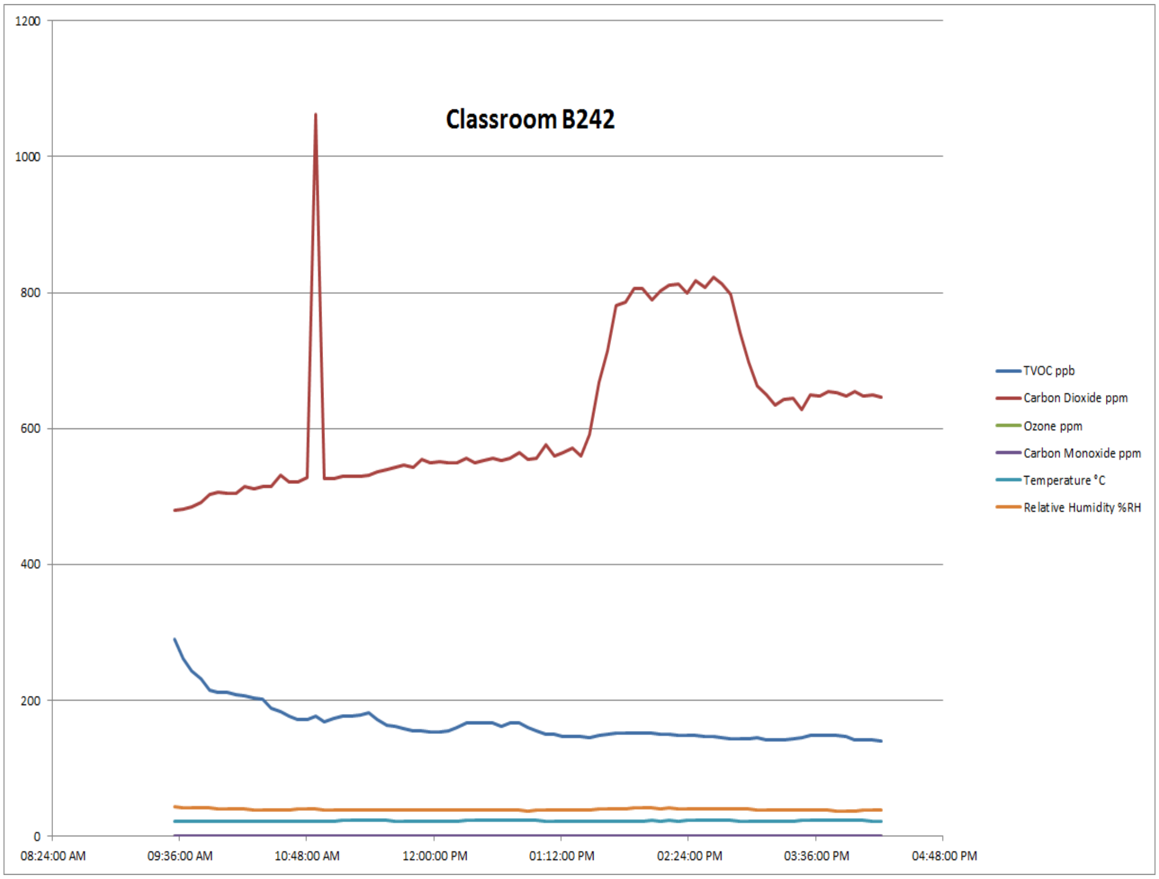

Figure 7.3.3 Graph of Sensor Values Using Graywolf System

Temperature and humidity values are observed to be exactly same as that of Graywolf system. It has been observed from graph, dust values are increased for some time, this may due to cleaning of that particular classroom. From the graph, it is clear that increased in carbon di oxide is during classroom time and it come back to normal when all students left classroom.

Figure 7.4.1 Electrical department Break room

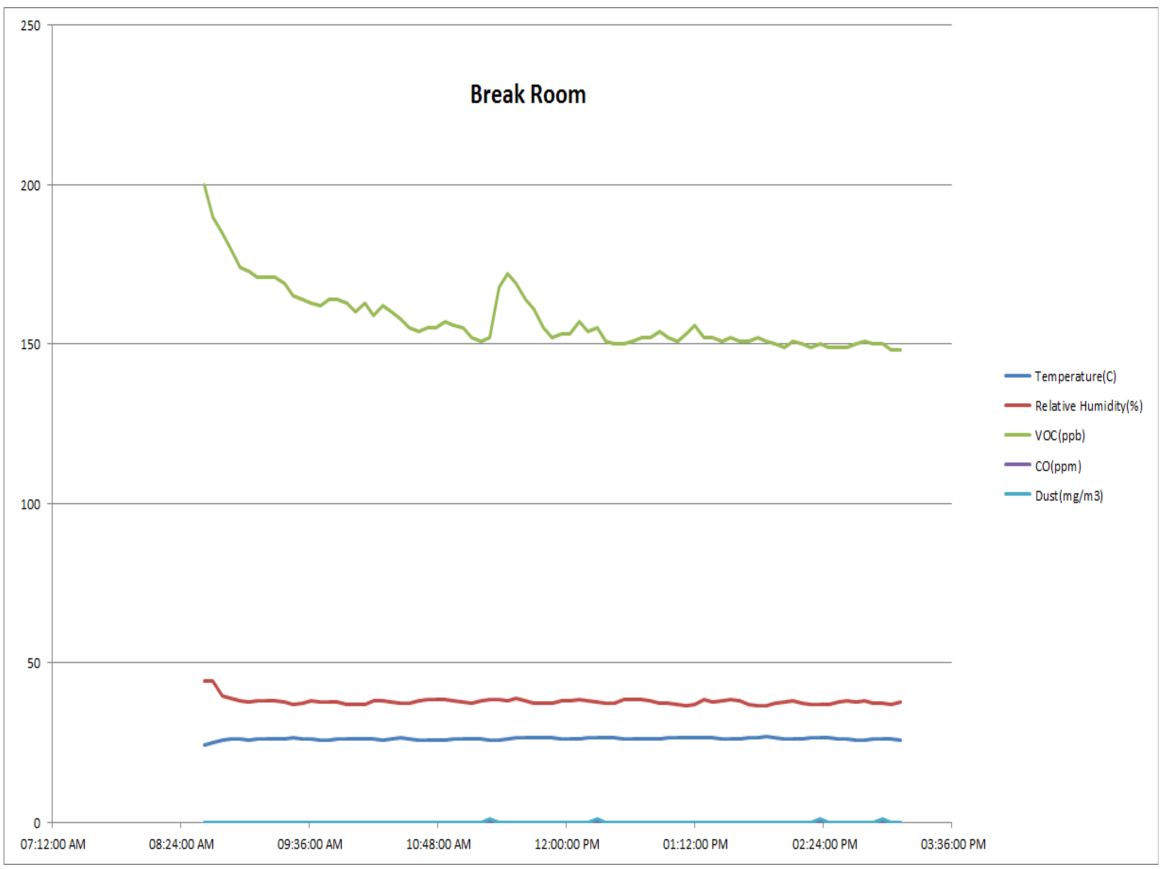

Figure 7.4.2 2 Graph of Sensor Values Using IAQ Monitoring System

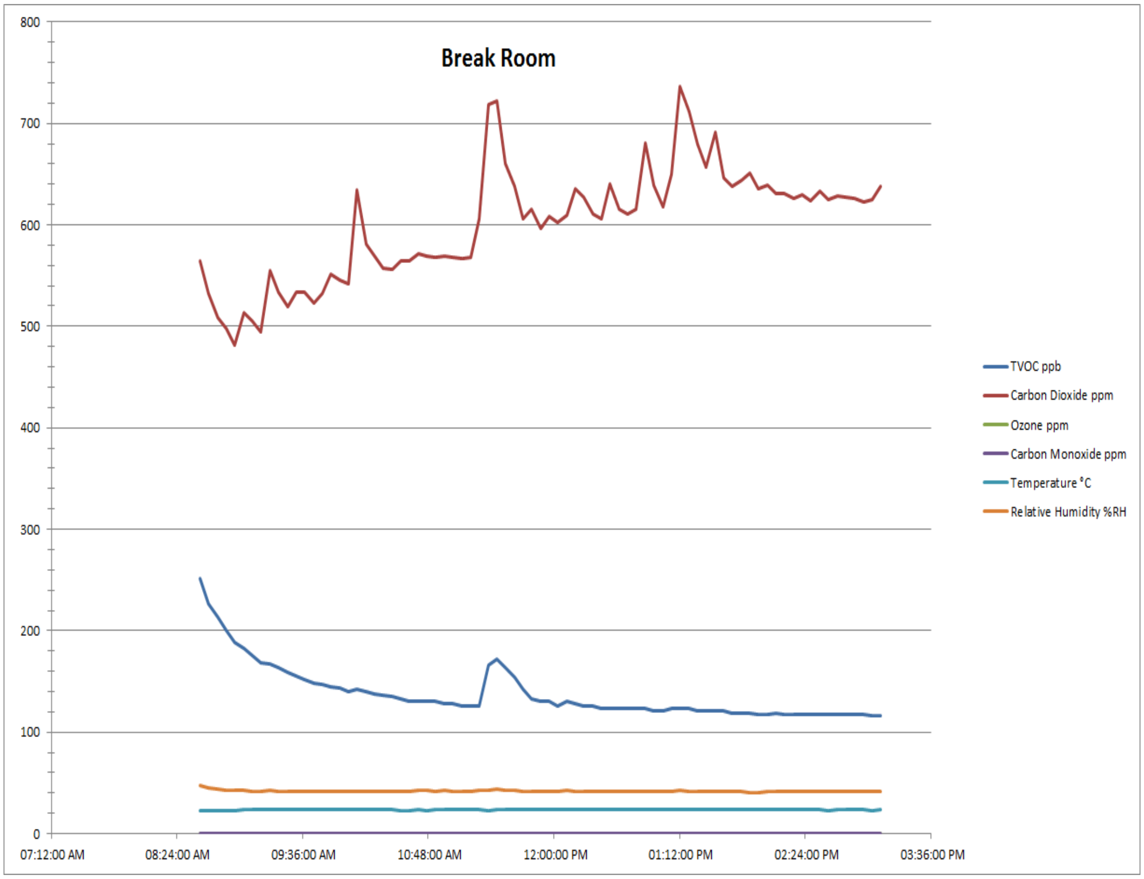

Figure 7.4.3 Graph of Sensor Values Using Graywolf System

In kitchen, the only important parameter to be observed is VOC. As mentioned earlier in Chapter 2, VOC sensor is very sensitive to different smells like food, smell from copier machine or hand sanitizer. It can be easily observed from the graph, VOC values varies at certain points and then drop back to normal values and trends for it for both system is same.

Figure 7.5.1 Lab B239

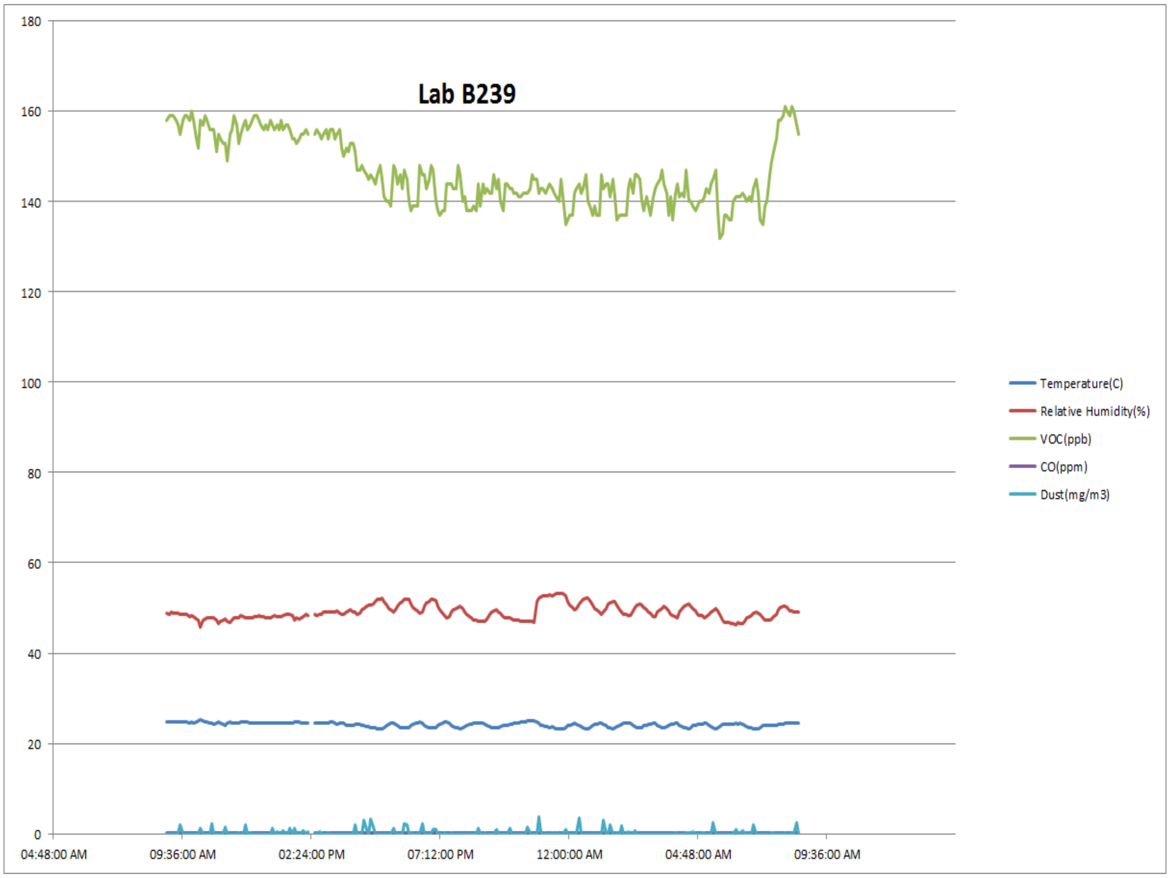

Figure 7.5.2 2 Graph of Sensor Values Using IAQ Monitoring System

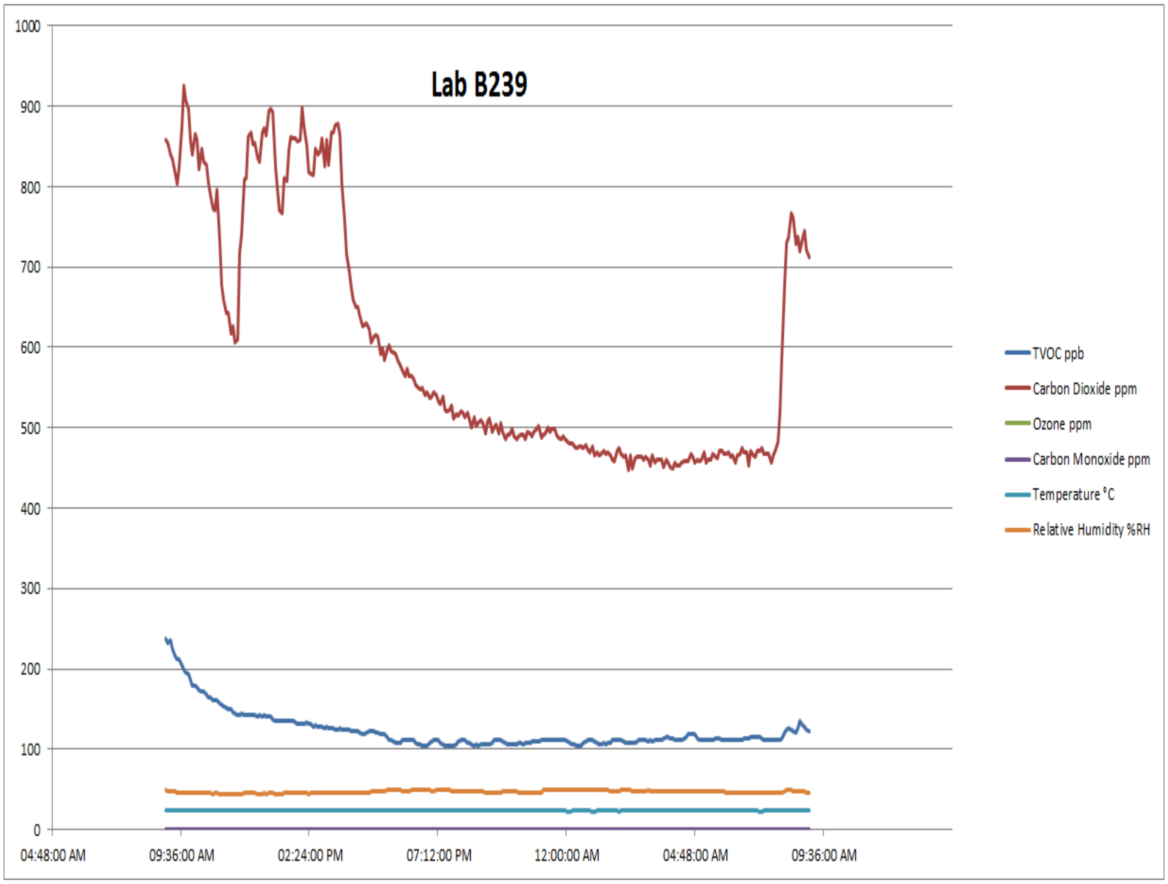

Figure 7.5. Graph of Sensor Values Using Graywolf System

When we took readings, different teachers used lab B239 for their summer projects. As shown, VOC values vary quite often. This may due to perfumes used by different teachers. Also growth in carbon dioxide is observed during day time, when number of people was present inside lab.

Figure 7.6.1 Terrarium

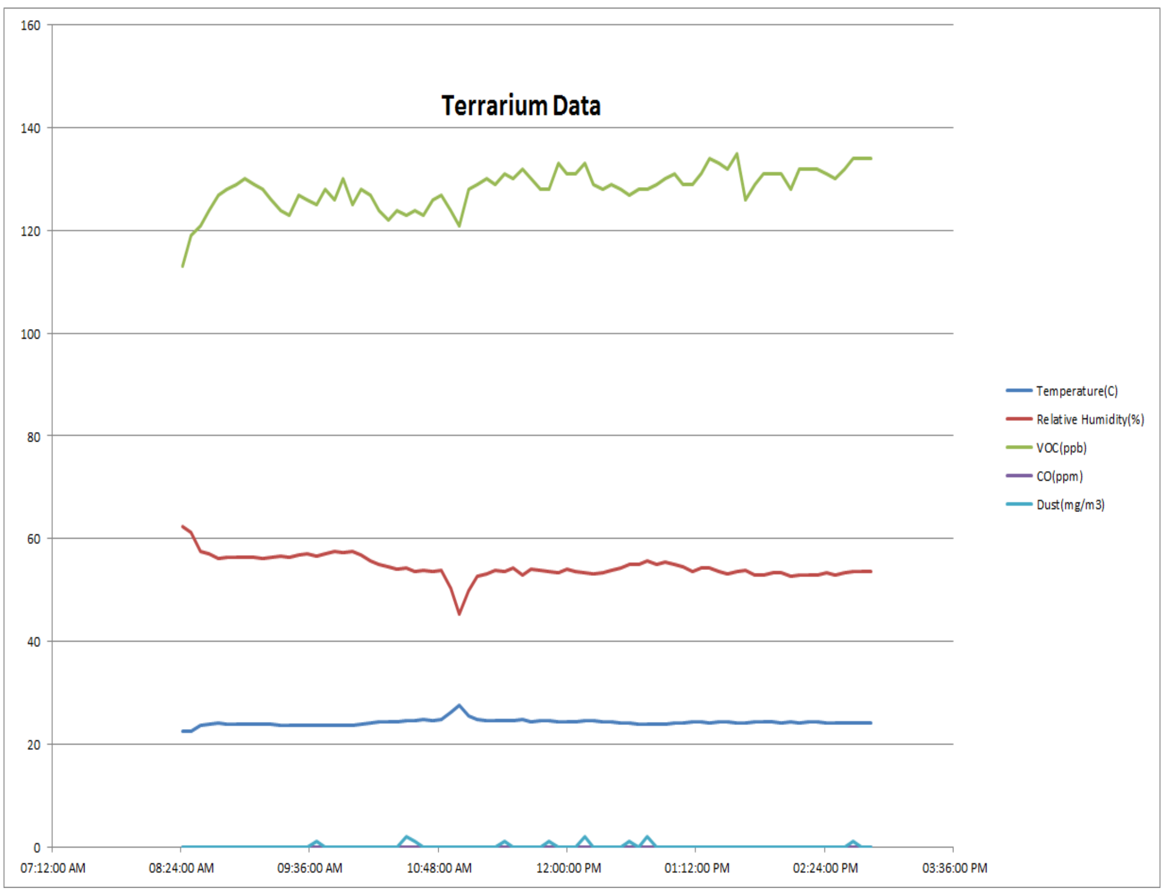

Figure 7.6.2 Graph of Sensor Values Using IAQ Monitoring System

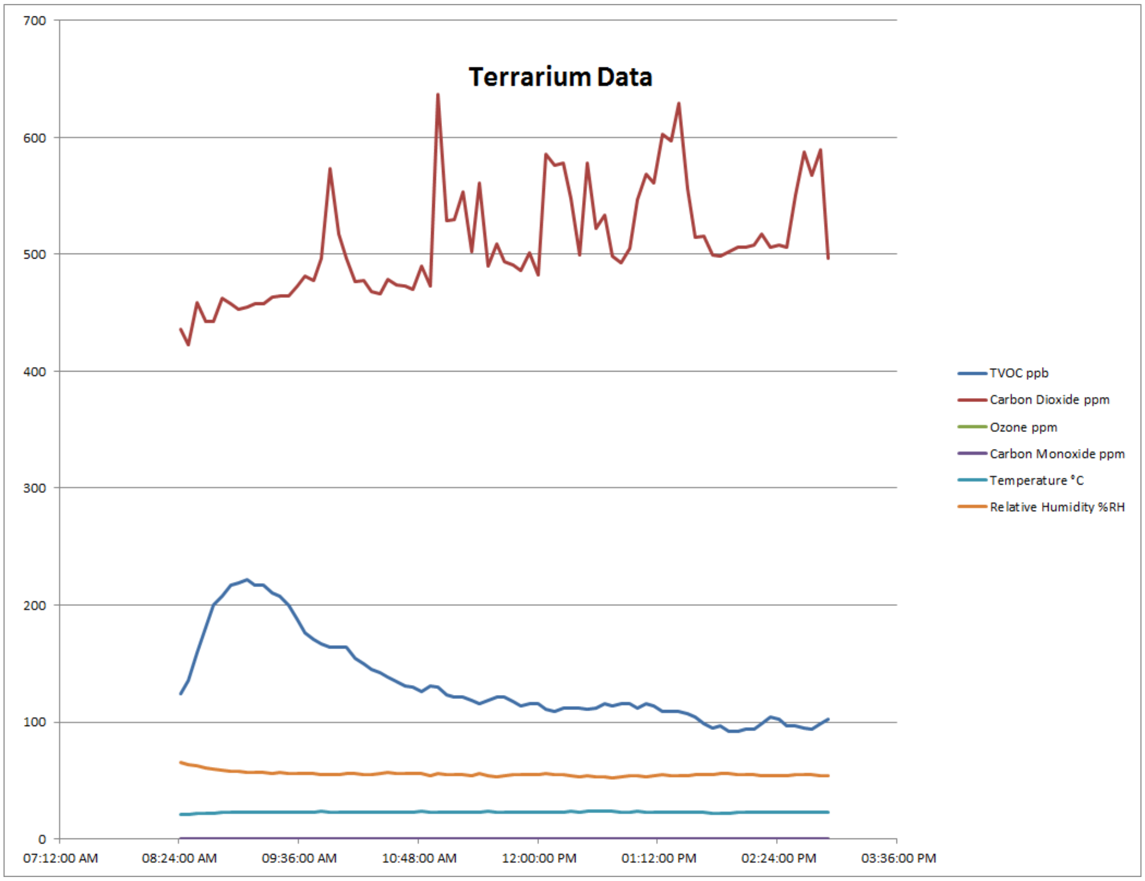

Figure 7.6.3 Graph of Sensor Values Using Graywolf System

At terrarium, VOC and carbon monoxide values found to be lowest as it is full of green plants. Dust values shows increment some times, as it is open area inside building and having much access for dust to interfere. Also, carbon dioxide is observed to be lowest obviously due to presence of plants. Effect of plants on carbon dioxide is mentioned in detail in next section.

By thoroughly observing all this results, thesis comes up with conclusion for each of the air quality parameter. The following section will review behavior of sensor readings in different environment and explained few observations that will help for future development of indoor air quality applications.

7.4 Comparison of Temperature and Humidity Readings in Both Systems

Both of these are related to the comfort of the individuals inside of the building, but can also be related to the levels of biological contaminants in the building. The warmer a building is and the higher the relative humidity, the more conducive it is to the growth of biological factors. We found that the building is maintained at 22.8 degrees Celsius with a relative humidity of 47.8%. During weekends and holidays the buildings average temperature and relative humidity remained the same.

7.5 Comparison of VOC (Volatile Organic Compounds) Readings in Both Systems

The kitchen location gave the best representation of VOC data. When the sensor was set up in the morning, the aroma of coffee was noticeable in the air. This was supported in the data by a high VOC reading in the morning that slowly decreased until 11:30. At 11:30 the readings spiked again, which can be explained by building occupants preparing their lunch that once again produced an aroma. After lunch the readings dropped and leveled out with no significant events.

7.6 Comparison of Carbon Monoxide Readings in Both Systems

Carbon Monoxide is produced mainly by the incomplete combustion of fuel, such as coal or gas. Low levels of carbon monoxide found inside can most likely be attributed to air entering from outside the building through fresh air intakes. Looking through our data we found that the buildings CO levels are well within acceptable IAQ levels.

7.7 Dust Readings Behavior

Dust concentration remains constant at most of the places except few incidents where it increased for some time interval. By general observation sudden increased of dust parameter happened when cleaning crew came to locations for cleaning purpose and came back to normal level when cleaning is over.

7.8 Carbon Dioxide Readings Behavior

Carbon Dioxide levels are an excellent indicator of how adequate the buildings ventilation rates are. Looking at the data we found that the levels are typically below 800 ppm, with levels only exceeding that threshold when labs are at their full capacity. For example, with the teacher lab at full capacity the CO2 levels reached a maximum of 900ppm but when occupants took a break for lunch the levels dropped back below the threshold of 800 ppm. In the terrarium sample we saw levels drop below 550 ppm and reach a max of only 650ppm. This was expected due to the low population, openness of the area, and the reduced population of occupants.

After tested system thoroughly we came to conclusion that system is much more reliable for use in continuous monitoring data as well as it is more efficient in its working when compared with Graywolf system results as described in Section 7.3. IAQ monitoring system provides some additional features like remote configuration and data monitoring, which are absent in Graywolf system. System can collect data over a larger area by implementing several sensor nodes and end devices and monitor it over a wireless ZigBee network without any interruptions.

CHAPTER 8

SUMMARY AND CONCLUSION

A low cost IAQ monitoring system is developed to give clearer and more detailed view of indoor air quality and will be beneficial in many low cost applications. Also such system is in reach of all individuals irrespective of economical class. This system is extension for all available IAQ monitoring system, which are working on the principle of place-to-place gas detection i.e. without using wireless network to monitor gas detection over a larger area. In addition to that, this system provides some additional features like continuous data monitoring from more than one place, gas detection in hazardous areas, monitoring at different parts of the building at the same etc. than available IAQ monitoring systems.

The overall cost of this system is around 370-400 $ when using 2 sensor nodes and 150$ extra for each additional sensor node. This is price is much cheaper as compared to existing systems in market and provides much more additional functions in terms of more sensors, more functionality for data processing and availability of data in public.

Sensor nodes can reconfigure remotely over a wireless network and most of the processing done in software on computer side in order to reduce memory space at sensor nodes, so sensor nodes only saved sensor reading for a backup purpose in a buffer in case of loss of data packets. This process also reduces communication load as reduction in packet size.

CHAPTER 9

FUTURE WORK

Web portal creation will be the primary development in this system in order to make all data to be available in public domain. This will be a reference database for researchers who are working in the field of indoor air quality and also help to increase awareness about indoor air quality among people. A self-computer Linux board can be very useful for implementation of this application.

Wireless network can be make more robust and fast by making use of Wi-Fi or GSM mode of communication. Many more sensors can be added which will give more detailed information about indoor air. Also addition of few sensors like H_2S, NO, HCl, NO_2 etc. will make the product useful in many industries for gas detection. GUI can be modified by addition of few more useful functions and can be implemented with powerful interrupts handler.

One more very important issue where system can be improved is calibration of sensors. As mesh topology is using in this wireless network, calibration can be carried out remotely over a wireless network by taking readings from the neighboring sensor nodes in the network as a reference. This will help in monitoring air without any interrupts due to sensor failure.

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