DEVELOPMENT OF WIRELESS SENSOR NETWORK FOR MONITORING INDOOR AIR QUALITY

by

MOHAIYEDIN IDRIS

Thesis submitted in fulfilment of the requirements for the degree of Master of Science

UNIVERSITI SAINS MALAYSIA

OCTOBER 2010

ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratitude to God Almighty for giving me the strength, wisdom and perseverance in accomplishing my research study.

I am extremely grateful to my supervisor, Assc. Prof. Dr. Othman Sidek for giving me the opportunity in doing this masters research under his grant and I am also thankful for his support and supervision. I am obliged to him for his encouragement and understanding throughout my study. I would also like to thank to technicians in helping me in the aspect of test circuitry. I would also like to thank Assc. Prof. Dr. Zailani Abu Bakar and Dr. Ahmad Zuhairi Abdullah for the time spent and for their invaluable ideas, suggestions and limitless information in the field of gas sensors.

I also would like to convey my gratitude to many individuals and member of CEDEC for giving me invaluable ideas and suggestions in the hardware design, to my wife Nur Hidayah Abdul Aziz for her support and encouragement. Special thanks are due to my parents and family, for their moral support and for being patiently there in supporting my career in life.

Last but not least, I would like to express my sincere gratitude to University Technology Mara (UiTM) for the scholarship in pursuing this Master by research degree.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

WSN: Wireless Sensor Network

WSNs: Wireless Sensor Networks

ADC: Analogue Digital Converter

RISC: Reduce Instruction Set Computer

OS: Operating System

VOCs: Volatile Organic Compounds

GC: Gas Chromatography

GC-MS: Gas-Chromatography-Mass Spectrometry

MCU: Micro Controller Unit

GUI: Graphical User Interface

PC: Personal Computer

COTS: Commercial-Off-The-Shelf

CMOS: Complementary-Symmetry Metal-Oxide-Semiconductor

I/O: Input/Output

UART: Universal Asynchronous Receiver/Transmitter

USD: United State Dollar

RAM: Random Access Memory

KB: Kilobyte

mW: Mile Watt

μW: Micro Watt

Kbps: Kilo bits per second

OOK: On Off Keying

DMA: Direct Memory Access

USB: Universal Serial Bus

O-QPSK: Offset Quadrature Phase-Shift Keying

LANs: Local Area Networks

RF: Radio Frequency

WLAN: Wireless Local Area Network

IEEE: Institute of Electrical and Electronics Engineers

ISM: Industrial, Scientific and Medical

U-NII: Unlicensed National Information Infrastructure

UWB: Ultra-Wideband

PHY: Physical Layer

MAC: Media Access Control

PAN: Personal Area Network

BER: Bit Error Rate

TTL: Transistor-transistor Logic

RISC: Reduce Instruction Set Computer

CISC: Complex Instruction Set Computer

PIC: Programmable Interface Controller

EPROM: Erasable Programmable Read-Only Memory

HLL: High-Level Language

IDE: Integrated Development Environment

RH: Relative Humidity

DC: Direct Current

TE: Thermoelectric

MOS: Metal-Oxide-Semiconductor

DPM: Dynamic Power Management

CH: Cluster Head

BS: Base Station

CO: Carbon Monoxide

PEMBANGUNAN JARINGAN PENGESAN TANPA WAYAR BAGI PEMANTAUAN KUALITI UDARA DALAMAN

ABSTRAK

Kualiti udara memainkan peranan penting dalam kehidupan seharian kita. Kesan pencemaran udara di tempat kerja atau di tempat kediaman kita sendiri menarik perhatian ramai ilmuan dan umum sejak beberapa tahun kebelakangan ini. Kebanyakan penyelidikan yang telah dibuat mendapati kesan pencemaran dalaman menyumbang kepada kadar pencemaran yang lebih tinggi jikalau dibandingkan dengan kesan pencemaran luaran. Kesan ini adalah rentetan daripada penggunaan masa hampir 90 % yang diluangkan di dalam bangunan atau rumah. Kualiti udara yang bersih berpotensi untuk memberi keselesaan dan kesihatan yang lebih terjamin serta mewujudkan suasana pekerjaan yang produktif serta boleh menyumbang kepada keselesaan minda. Pendekatan sistem jaringan pengesan tanpa-wayar, diaplikasikan untuk mengesan dan memantau kualiti udara persekitaran, terutamanya kualiti udara dalaman. Parameter-parameter kualiti udara yang telah digunakan adalah seperti suhu udara, kelembapan, dan zat pencemaran udara. LM35DZ, pengesan suhu dan A0545, pengesan kelembapan digunakan untuk mengukur suhu dan peratus kelembapan udara. Berpandukan dua parameter tersebut titik embun dapat diperolehi bagi menunjukkan paras suhu udara yang diperlukan bagi memperolehi kadar kelembapan udara mencapai 100 %. Pengesan gas TGS 2600 digunakan untuk mengesan dan menyukat kepekatan zat pencemaran udara, karbon monoksida dengan keupayaan pengesan memberi bacaan pada 0.0188 punca min ralat kuasa dua. Dalam penyelidikan ini, enam nod pengesan dan satu pengumpul data direkabentuk. Setiap nod pengesan mempunyai mikropengawal PIC16F877, tiga pengesan (suhu, kelembapan, dan gas) dan SWRF-508 modul penghantar-penerima. Kesemua nod pengesan dihubungkan melalui pengumpul data secara jaringan bintang bagi memantau kualiti udara. Sistem yang dibangunkan ini diuji di makmal Mikropengawal, Data Komunikasi, PCB, Enjin, Integrasi, dan Petroleum & Gas, Kampus Kejuruteraan, Universiti Sains Malaysia. Secara keseluruhan, keputusan pemantauan yang dibuat mendapati, secara purata suhu udara bergerak dalam lingkungan 31 °C pada kelembapan udara yang melebihi 55 %. Kesan ini sedikit sebanyak meningkatkan titik embun hampir kepada suhu udara, iaitu pada kadar 24.87 %. Bagi zat pencemaran udara, karbon monoksida dikesan pada kesemua makmal dengan paras yang tidak merbahaya iaitu pada kadar kurang dari 2 ppm dengan taburan secara rawak.

DEVELOPMENT OF WIRELESS SENSOR NETWORK FOR MONITORING INDOOR AIR QUALITY

ABSTRACT

It is an undeniable fact that air quality is vital in our daily lives. The contributing indoor air pollution at the workplace or in our residential areas has caught the attention of scientists and generally, the public in recent years. It is interesting to find that the studies done came up with the discovery that the indoor air pollution contributes higher degree of air contaminants compared to the level of air pollution outdoor. This is probably explained by the fact that people tend to spend 90 % of their time indoor and the rest on outdoor activities. Unpolluted air furnishes us with good, comfortable, and healthy lifestyles which may lead to a productive working environment and at the same time, contribute to a better peace of mind. The approach of wireless sensor network is applied in order to detect and monitor the indoor air pollution. The air quality parameters such as air temperature, percentage of relative humidity, and air contaminants are carried out in this research. LM35DZ temperature sensor and A0545 humidity sensor are employed to measure air temperature and relative humidity in percentage. Based on these two measurements, dew point is obtained to measure the level of air temperature required to produce 100 % relative humidity. The TGS2600 semiconductor gas sensor is employed to detect air contaminants of carbon monoxide with 0.0188 mean square error. In this research, six nodes and a data handler are developed. Each sensor node consists of PIC16F877 microcontroller device with three sensors (temperature, humidity and gas sensors) and SRWF-508 transceiver module. All the sensor nodes are connected to the data handler through the star network to monitor air quality. This system is developed and

has been tested at Microcontroller, Data Communication, PCB, Engine, Integration, Petroleum & Gas laboratories, Engineering Campus, Universiti Sains Malaysia. The monitoring results demonstrate that the air temperatures for all laboratories are moving at the average temperature of 31 ºC with the relative humidity more than 55 %. These effects slightly increase the dew point near to the air temperature at 24.87 %. The air contaminant of carbon monoxide is detected at all laboratories at a non-dangerous level and the concentration is less than 2 ppm with random distribution.

CHAPTER 1 : INTRODUCTION

1.0 Introduction to Wireless Sensor Networks

Communication constitutes one of the most important elements in our daily lives. Communication can be defined as a process of transferring data or information from one destination to another through different media, either wired or wireless. Today, communication based on wireless technology has become one of the most vibrant in the communication field (David and Pramod, 2005). As an advantage, the system can avoid tangled-up connectivity and able to deliver data either for near or otherwise (Shin et al., 2005).

Wireless sensor network (WSN) is one of the most emerging technologies in the wireless communication field. WSNs system seems to be an important technology that will experience major deployment in the next few years for a plethora of applications (Kazem et al., 2007). Typically, wireless sensor network possesses three primary components such as the intelligent sensor network, wireless communication network, and compact intelligent microcontroller - all of which are integrated and adapted into diverse application areas such as real-time monitoring system, indoor or outdoor environments data monitoring, security and surveillance monitoring system, military usage, actuation and maintenance of complex system, continuing data collection system, and hundreds of applications which are able to be realised (Vieira et al., 2003).

1.1 Atmospheric Pollution

Good air quality, or in a simpler term, clean air is the most important element in the human breathing system. A good level of air quality commonly contains 20.95% of oxygen, 78.08% nitrogen, 0.93% argon, 0.038% carbon dioxide, and each gas like neon, helium, krypton, hydrogen, xenon, and other variable gases with the percentages of less than 0.002%. When the amount of oxygen reduces compared to the ordinary value or other variable gases rise, which value is more than ordinary, it shows that the air is polluted and may consequently be dangerous for living beings especially humans.

Obviously, atmospheric pollution mostly relates to the standard regulation of the air quality. The source of pollution can be classified into two kinds that are generated by stationary or mobile sources (Lee and Lee, 2001). Both of them have different nature and means of emitting sources. Atmospheric pollution is defined as a status containing gases, offensive odour, and particles which are harmful to humans, animals, vegetables, or other living entities and environments above the regulation limit in specific regions (Lee and Lee, 2001).

1.2 Indoor Air Pollution

Since early 1980s, there has been an increasingly serious interest in the problem of indoor air pollution (Rafson, 1998). In August 1999, the American Lung Association reported that the indoor air pollution contributed to various lung diseases, including respiratory tract infections, asthma, and lung cancer. Lung disease caused by indoor air pollutions, as claimed by American Lung Association, is close to 335,000 cases in America every year and it is the third leading cause of death in the USA. Over the last decade, the death rates for this disease has risen faster compared with other major diseases (Lungusa.org, 1999).

Contribution of indoor air pollution in the workplace or in residential areas has caught undivided attention of scientists and the public in recent years. Most studies found that the indoor air pollution contributes higher degree of air contaminants compared with outdoor air pollution levels (Montgomery and Kalman, 1989), and this is probably due to the fact that people spend 90% of their time in indoor activities and the rest is spent outdoors (Lee and Chang, 2000).

The polluted indoor air causes the change of ecosystem and subsequently, the human health. Obviously, four polluted gases emitted indoor and automatically implying hazardous exclusion are radon gases, which are produced from cigarettes, formaldehyde and asbestos. Among these hazardous gases, several components of tobacco smoke as well as formaldehyde can be considered as VOCs (Aguado et al., 2004). The emergence of sensor technology in detecting a variety of hazardous gases through our five senses is another alternative to measure the concentration of gases.

1.3 Research Problem

The key to successful preservation of the environment is monitored through the air quality. Basically the air quality can be divided into two categories, indoor and outdoor. Most research found that the indoor air quality produced lower air quality in comparison to the outdoor air quality. In order to determine the level of indoor air quality, three basic components such as the percentage of relative humidity, air temperature, and Carbon Monoxide (Postolache et al., 2005) concentration are to be monitored.

Generally, the relative humidity level can create a serious problem at any phase of preserving the environment unless it is carefully monitored. Lack of RH with different ranges can be a cause for mould, rot, pests such as termites and cockroaches, and the occurrence of condensation. At this point, the temperature is less of a concern as opposed to the relative humidity or other components. Even though the higher air temperature contains with a higher capacity of RH, when combined they can prove to be detrimental. The air contaminant such as CO concentration is dependent on the volume of indoor rate. CO is odourless, colourless, and the nature is toxic due to incomplete combustion (Dolnick and Anderson, 1998). The person exposed to CO poisoning from inhalation or direct contact, and these exposures depend on the concentration, length of exposure, and the general underlying health status of the exposed individual (Jonathan et al., 2008).

Most commercial systems employ personal, portable, or stationary system to monitor their indoor air quality. Typically these systems possess a few drawbacks such as limited storage capacity, ineffective time usage and problems in maintaining the log report. To add, it is complicated to manage the software or hardware device in IAQ-monitoring since it is operated by inexperienced scientists. Also, some devices do not provide the current time and day of monitoring and thus, these devices need to be manually-reported.

1.4 Research Contribution

The most efficient approach in improving these circumstances is implementing the monitoring technique based on the wireless sensor network (WSN). The WSN can overcome the drawbacks suffered by most commercial systems. The primary components in WSN are sensor node and data handler. The sensor node is located at target places to obtain data of air quality and relay the information to data base. The data base or data handler contains the graphical user interface, GUI to handle, analyse, deposit, and view the data through the PC by an administrator. The GUI is designed using Microsoft Visual C# based on windows application form. One plus point of this is that it is more user-friendly, therefore it may not intimidate inexperienced users. Additionally the system is also designed to monitor IAQ for unlimited time, it is able to store data with unlimited space, to perform parallel monitoring, to report data-monitoring through data view option, other than boasting its printing capabilities.

1.5 Research Objective

There are three main objectives in this research study. The objectives are as follow:

1. To develop WSN to monitor indoor air quality that include sensor node designed to acquire data at different target places and data handler or data base to analyse data from the sensor node.
2. To design six sensor nodes, where each sensor node consists of integration of LM35DZ air temperature sensor, A0545 relative humidity sensor, TGS2600 CO gas sensor, 16F877 microcontroller, and SRWF-508 transceiver module.
3. To design a user-friendly GUI based on Visual C# as a tool to handle, analyse, and store the data of sensor node.

1.6 Research Activities

In order to achieve the mentioned objectives, the following activities were conducted:

1. To calibrate gas sensor - TGS 2600 in clean/fresh air;
2. To analyse LM35DZ temperature sensor and A0545 humidity module;
3. To design electronic circuitry for sensors and interface with PIC16F877 microcontroller and also SRWF-508 transceiver module;
4. To develop software for PIC16F877 MCU to recognise and analyse the sensors' data for each node;

5. To develop Graphical User Interface (GUI) using Object-Oriented Programming in C# Language for analysing, displaying, and storing current sensor node;
6. To calibrate six TGS 2600 gas sensors.
7. To compare the measurement reading of sensors with Direct Sense IAQ (IQ-410) device;
8. To monitor the indoor air quality at target places;
9. To study and analyse the performance of the overall WSN system.

1.7 Thesis Organization

The thesis chapters have been organised into five chapters as follow. The literature review has been provided in Chapter 2. This chapter begins by the representation of reviews of various WSN systems that have been used to monitor applications. In this chapter several common microcontrollers, sensors, transceivers, and network topology that have been used in the development system will also be highlighted. This study moves on to outline their usage and peripherals that have been used in the developed system. The theory chapter covers the basic theory of related hardware and software.

Chapter 3 describes the research methodology used in the study. The hardware and software platforms are described briefly, in terms of the design of electronic circuitry and program flow of sensor node and data handler.

Chapter 4 describes the results and discussion of the preceding in Chapters 3. The calibration of gas sensor, reliability of transmission, sensor response, and data analysis from monitoring result for each sensor are presented and analysed.

Lastly, Chapter 5 outlines the conclusion of the study, some possible suggestions for the future upgrade on the development of the current system.

CHAPTER 2 : LITERATURE REVIEW

2.0 Introduction

This chapter provides an extensive review of literature relevant to the topic of research in question. The fusion of wireless technology and communication, an array of intelligent sensors and network topology have brought about the WSNs system. WSNs promise a significant improvement over the traditional sensors' configuration. A WSN is composed of a large number of integrated sensor nodes that are closely deployed either inside the phenomena or very close to it, and collaboration through wireless network to collect environmental information or react to specific events (Akyildiz et al., 2002). WSN is a new scope that can be applied to a wide range of uses and degrees of monitoring applications' area (Culler et al., 2004).

Monitoring and controlling air quality is paramount in order to prevent the environment from further deterioration or from affecting the health of human. The impact of air pollution lies in the changes of the ecosystem and dangerous disasters like ozone depletion and its consequences (acid rains, rapid weather change) (Postolache et al., 2002). Indoor air pollution especially produces a tremendous impact on changing the air composition and contributes to a variety of hazardous air contaminants, such as carbon monoxide, nitrogen oxides, tobacco smoke component, suspended particular matters (total suspended particular matter (TSP) and respirable particles (RP)), asbestos, formaldehyde, ozone, radon (Ra-222), carbon dioxide, and organic viable particular matter (Su, 1996). The implementation of monitoring technology via WSN is one of the methods adopted to acquire air quality information for further analysis by researchers.

2.1 WSNs Monitoring Application

WSNs have been involved in many research efforts during the past few years (Liyang et al., 2005). WSN is an emerging technology that enables remote objects and environment monitoring. Recent advances in wireless communications and electronics have enabled the development of low-cost, low-power utilised, multifunctional sensor nodes which are able to communicate unfailingly in short distance. This sensor node has sensing, data processing, and communicating components that are working together as an agent to collect information. WSNs are expected to serve as a key infrastructure for a broad range of applications including precision agriculture, surveillance, intelligent highway system, even in emergency disaster responses and recovery (Hua-Wen et al., 2007).

Tang et al. (2006) had developed an intelligent car park system based on WSNs. The system that they built consists of light, sound, and acoustics sensors to collect the information in the car field, as opposed to some commercial systems which adopted cameras to collect the information. The WSNs are applied to parking lots to monitor and detect occupation status of the parking lots, and to cooperatively process and transmit the information to a management system, enabling them to manage some information about the parking field, including the statistics and real-time information by managers or administrators. A prototype of the system used the crossbow motes products and extended Crossbow XMesh networks' architecture.

Liyang Yu et al. (2005) proposed a real-time forest fire detection method by using WSNs. The detection and prediction on forest fire promptly and accurately are important in order to minimize the loss of forest, wild animals, and people in such unfortunate cases. The proposed system adopted a large number of sensor nodes set up in a forest. This sensor node collected measured data such as air temperature, air relative humidity and is transmitted to their respective cluster nodes that collaboratively process the data by constructing a neural network. The neural network takes the measured data as input to produced weather index, which measured the likelihood for the weather to cause fire. The in-network processing operation proposed by authors based on neural network method in the operation extracts at high-level information from the vast raw data is claimed to be more efficient than other existing in-network processing approaches. The authors also suggested the neural network based in-network processing approach can be applied to other monitoring and detecting sensor networks.

Wireless temperature sensor network for refrigerated vehicles is proposed by Qingshan Shan et al. (2005). The main objective of the system is to keep records of the air temperature in vehicles used in the primary distribution of quick-frozen foodstuff based on wireless sensor network. The authors investigated the potential of the WSN that covers temperature sensor technology, latest communication technology, and mathematical models.

Haowei Bai et al. (2004) proposed a system based on WSN to monitor the health of aircraft engines. The proposed system includes a number of wireless sensor communication nodes and a central engine control unit in operable communication with each other. Each wireless sensor communication node can communicate directly with the engine controller, or through one or more other wireless sensor communication nodes in the network. Each sensor node includes one or more sensors such as temperature sensors, pressure sensors, vibration sensors, proximity sensors, and position sensors, etc., and appropriate signal conditioning circuitry. The sensor node (without sensor and power supply) was fabricated into a single chip and was tested for real world applications.

Wall, J. et al. (2007) had pointed out the used of WSN technology for “tiny agents”, deployed as autonomous controllers for individual pieces of electrical load/generation equipment in a distributed energy system. The novel application that authors proposed based on WSNs as agents for the intelligent control of distributed energy (DE) resources, including heating, ventilation, and air-conditioning (HVAC) systems. It is a common method to conduct the temperature of multiple spaces or rooms with single HVAC system and controller. As it is expensive to connect sensors to the controller using wire, typical installations often have a limited number of sensors located in a subset of the rooms being controlled. This method erroneously assumes every room is at the same temperature as the room containing the temperature sensor. The resulting energy-inefficient control decisions often cause unnecessary heating or cooling, and as a further impact, lead to the occupants’ discomfort. WSN technology alleviates the costs associated with the conventional ‘wired’ sensors and controller hardware, offering an opportunity to install multiple WSN devices serving as autonomous agents for both the sensing of the HVAC system environment and control of HVAC system devices.

2.2 WSNs Architecture

The recent development of wireless networks and inexpensive wireless sensors equipped with radio to perform wireless communication, processing, storage, and battery power, wireless sensor networks have been largely used for different classes of application (Boukerche and Pazzi, 2008). WSNs can analyse a large data collection through its wireless node and are capable of self-organised network for sensing environmental conditions within their range. The development of WSNs architecture is performed in a tiered concept. The lowest level contains a sensor node to compute data from sensors and forward it through the network patch. Data handler (PC) is responsible to collect (database) and analyse data from nodes.

Akyildiz et al. (2002) noted the architecture of sensor node consists of four basic components such as the sensing element, a processing unit, a transceiver unit, and a power unit. The sensing element usually converts type of energy element such as the analog signals produced by sensors based on the observed phenomena, into a reading or electrical signal. This valuable signal feeds into a processing unit, ADC part, by converting the analog signal from sensor into the digital signal. The processing unit manages the procedures of sensor that have been made and are fed into the transceiver system, making it able for the data to be transmitted. The important element of sensor node is power supply. Power unit may be supported by battery, solar panel or fixed power sources which rely on the desired application.

2.3 Sensor Node

The terms like *sensor node, wireless node, smart dust, mote,* and *COTS mote* are used somewhat interchangeably in industries (Sohraby et al., 2007). Generally, sensor node consists of four components such as controller, sensors, communication, and power supply. Each of these components has to cooperate, balancing between the small of energy consumption as possible on the one hand and need to fulfil their tasks on the other hand (Holger and Andreas, 2005). For example, the communication and controller part should be turned off/sleep as long as possible and turned up again by using a pre-programmed timer to be reactivated after some time. The interconnection between the individual components required both control and data information to be exchanged, such as a sensor could simply report an analog valued to the microcontroller and only goes off when the actual time has been detected. The pre-processing can be highly customized to the specific sensor yet remain simple enough to run continuously, resulting in improved energy efficiency (Asada et al., 1998).

2.3.1 Controller

The controller is the core of wireless sensor node. The principle of controller operation in sensor node is to collect data from sensors, process this data, decide when and where it is sent, and to receive from other sensor nodes. The controller also executes a series of programs ranging from sensor data fusion and communication protocols.

Ciaran and Fergus (2004) set up a PIC microcontroller as a CPU in the sensor node design. The sensor node architecture equipped with low-power, high-performance RISC CPU, PIC16F877, external memory EEPROM running on 256kb capacity with serial interface over I^2C communication protocol and external Nordic nRF903 with free ISM band GFSK transceiver module (Nordic VLSI ASA, 2002) with the capability of operating at up to 76.8kbit/s. The controlling software for this microcontroller based on PIC C with is similar to C object-oriented language for embedded use.

Ferrigno and Pietrosanto (2004) reported the application of wireless sensor network as visualization monitoring. The hardware of sensor node designed focuses on the implementation of low-cost gray scale camera as a sensing component, the low power PIC16F877 microcontroller as a processor part, and medium range (300m) Bluetooth as the transmission part. The PIC16F877 processor is used in the design to process the image data that is captured from a digital camera and stored in the external memory which constituted of a 256 kB FIFO flash RAM device, and finally fed into the transceiver module. Alongside the useful feature of the microcontroller is the capability to operate in a low power consumption mode (Sleep mode). During the phase, the normal I/O processor activities are stopped and automatically the longevity of the power usage is observed.

Virk and Madsen (2007) developed a Hogthrob sensor node platform controlled by an ATMega128L microcontroller. This sensor node encompasses four primary blocks function such as sensor, computing, radio, and power supply sub-system. The controller part operates with low clock cycle, 8MHz at 3.0V and is supported with a basic communication interface.

2.3.2 Sensing

Haowei Bai et al. (2004) developed a wireless sensor network for the purpose of monitoring the health of aircraft engines. The authors designed a single-chip solution which was equipped with all the components of sensor node such as the sensor, processing, communication, and power supply section. The sensor node is mounted on the engine or inside the engine to monitor or sense various physical parameters associated with the engine operation. The low-power sensors include one or more sensors (e.g. temperature, pressure, proximity, and position sensor) and an appropriate signal conditioning circuitry. This sensing part contained the sensing and signal conditioning parts that collaborate into a single-element layer and it fed the analysed data into communication stage for further process.

Morreale, P. et al. (2009) addressed the development of real-time contextual representation of sensor network data for environmental trend identification. The street CORNERS (Correction of Networked Environmental Sensors) is the application based on wireless sensor network which supports contextual presentation of data gathered from an urban setting. The sensor node kit from Crossbow Technology was selected by the authors to examine the urban ecosystem and its environmental sustainability. Seven sensor nodes are utilised by authors and each sensor node is attached with the temperature, light, and humidity sensors. The sensor node is also set to report new readings every three minutes at approximately 2 Kbps of the data rate.

Kewei Sha et al. (2006) implemented the wireless sensor network platform for the fire rescue application. In this application, the authors set up the Crossbow mote module as a sensor node to make environmental monitoring possible. In the sensor node, the primary sensing components in this application which the authors proposed are to detect any information pertinent to the environment surrounding the fire field, including the humidity, temperature, wind speed, and density of the smoke.

Berglund et at. (2006) designed a voice user interface for understanding wireless networks by integrating the voice recognition features of the Center for Spoken Language Understanding (CSLU) toolkit with wireless sensor nodes, allowing a wireless interaction with a wireless sensor network through voice input. The authors used Tmote Sky mote platform that include four sensor nodes, one base node, and three slave nodes. Each monitoring sensor node is attached with three sensors such as light, humidity, and temperature sensors. With the voice recognition technology that authors adopted, the user is able to select/set a sensor node, and is also able to choose/set the reading of sensor based on voice input.

The Discovery Channel (2003) reported an application of a wireless sensor network in a vineyard in BC, Canada. In the application of weather monitoring, sixty-five sensor nodes were installed in a 1-acre land. Each sensor node is integrated with the temperature, moisture, and the sun light intensity sensors. The sensor nodes reported the weather information every 5 minutes to the database.

2.3.3 Communication

Akyildiz et al., (2007) made some observation on the wireless sensor multimedia sensor network. The authors divided the framework of wireless sensor multimedia into two parts, which are the sensor node and the base station. In the sensor node, three hierarchy structures were designed by authors and the lowest tier consisted of MICA2 sensor nodes. The MICA2 used low power CC2420 RF transceiver. The MICA2 Motes were also equipped with 900 MHz radios interfaced with scalar sensor such as vibration sensors.

Carlo et al. (2007) reported the TinyLime middleware mobile data collection in a sensory network-based wireless sensor network architecture. This novel TinyLime makes sensor data available through a tuple space interface, providing the illusion of shared memory between the applications and sensors. The authors had implemented the model and application programming interface of TinyLime in MICA2 sensor node platform. The Crossbow MICA2 mote sensor board supports several environment readings including those on light, acceleration, humidity, magnetic field, or sound. The MICA2 runs the TinyOS operating system and has 32 kB RAM, 5 Mbit of EEPROM flash memory. This MICA2 sensor node module works in ISM band frequency and is supported by the CC2420 multichannel selection.

Mahlknecht and Bock (2004) addressed the used of the transceiver in the WSNs' applications. The authors also noted the use of commercial high-bit rate transceiver for a low-duty cycle established in WSNs such as the Chipcon CC1000/CC2400, Nordic nRF2401/nRF905, RF Waves RFW302, RFM TR1001/TR1100, TI TRF-9600A, and Xemis XM1203 .

2.3.4 Power Management

The power source is the main criteria when it comes to enabling sensor node's functionality. The sources can be obtained from main sources, batteries or solar cells. These sources hinge on the application areas where the main sources can be used for indoor applications and alternative sources are required for outdoor application areas (Edgar and Callaway 2004).

2.3.5 Data Handler

WSNs provide the means for gathering vast amounts of data from physical phenomena and as such, they are being used for applications such as habitat monitoring, environmental monitoring, and others. The data base or data handler in WSNs functioned to collect vast information relayed from sensor nodes. In this part, a high-level processing unit is required to receive, analyse, and store data from each sensor node. The GUI designed is necessary to enable activities of gathering data from the sensor node.

Brian and Rammohan (2006) adopted Microsoft C#.Net version 2 as GUI design at the target platform to enable the application of data handler or base station in WSNs' application. The authors designed the base station to send and receive message packets from a variety of sensor network platforms and protocols. This implementation allows the ability to interact with the sensor at the lower levels, and further leads to a tighter control of integration.

2.4 Literature Review Conclusion

The monitoring system addressed in (Fuch et al., 2007), (Lodhi and Zain-al-Abdin, 1999), (Keller, 1995), (Morsi, 2008), (Zampolli et al., 2004), (Jae et al., 2008), and (Anuj et al., 2009) used portable and sensor array methods to acquire information on indoor air quality. These methods consist of a few drawbacks such as their demonstration of limited data storage of air pollutant - a weakness so observable especially when data needs to be accumulated for a long period of time, the fact that they are costly, the ineffective time usage, their debility in reporting measurement data, and last but not least, the fact that these methods tend to be less accepted.

Most of the applications that have been reviewed for monitoring application deployed WSNs as a framework to aggregate the physical phenomena. The WSN consists of larger number of sensor nodes to collect information and convey this information to the data handler or database for further analysis. In the sensor node, four primary elements such as the controller, sensors, communication, and power supply are furnished. The database is equipped with the transceiver and data management which operate via the computer. All the primary components that have been reviewed were deployed in the design of WSN in order to monitor the indoor air quality.

In the sensor node design, each node is furnished with the PIC16F877 microcontroller as a controller element, a sensing element consisting of temperature, relative humidity, and semiconductor gas sensor used to measure the indoor air quality parameters, communication part using the data transceiver module, and the power element employing the fixed power source since the measurement is applied indoor. The smart admin GUI was designed based on the windows platform and adopted in the data handler/database.

2.5 Research Background

In this part, the theoretical part relevant to the research is addressed extensively. WSNs can be seen a large data collection through wireless nodes and are capable to function as a self-organised network able to sense environmental conditions within their range. The development of WSNs architecture is performed in a tiered concept as shown on Figure 2.1. Obviously, the WSNs structure can be divided into two parts- the sensor node and database or data handler architecture. The lowest level contains sensor node to compute data from sensors and forward it through the network patch. A sensor node device makes wireless communication possible, enables data storage, and is able to bring about limited amount of computation and signal processing. This sensor node is equipped with four primary components such as the processor, sensor, transceiver, and power supply as shown in Figure 2.2.The data handler (PC) is responsible for collecting (database) and analysing data from nodes.

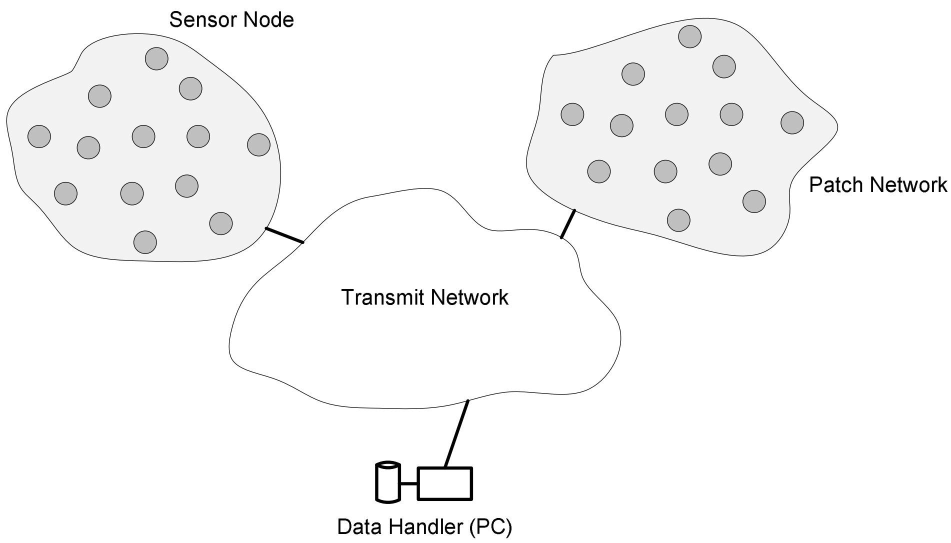

Figure 2.1: WSNs architecture system.

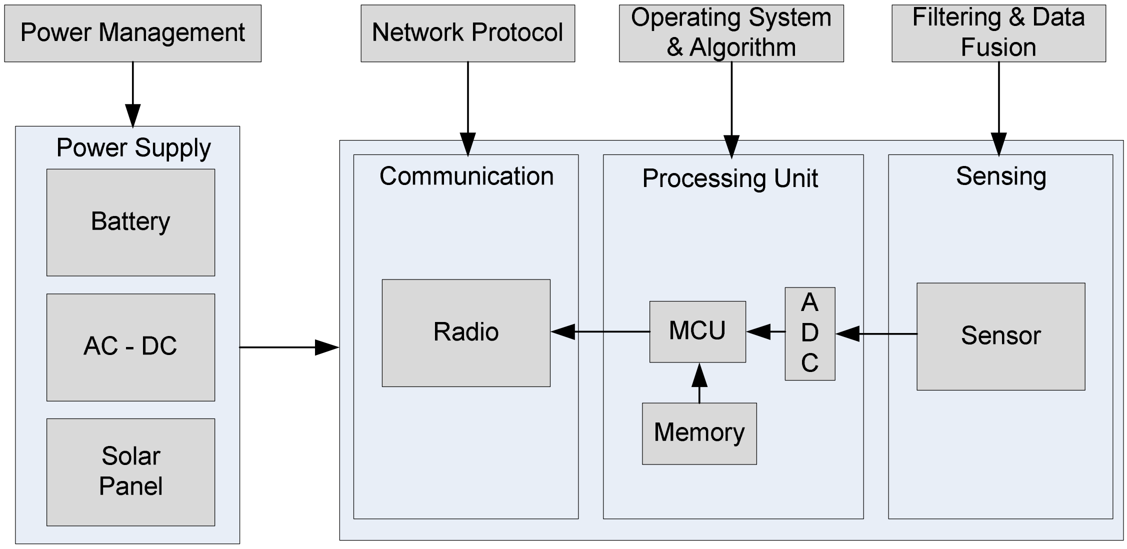

Figure 2.2: Basic sensor node architecture.

2.5.1 PIC16F877 Microcontroller Unit

Modern microcontroller constitutes a system-on-a-chip. It is a type of microprocessor emphasizing high integration, low power consumption, self-sufficiency and cost-effectiveness, in contrast to a general-purpose microprocessor. Generally MCU possesses an integration of CPU as computing, memory, a clock oscillator, ROM and RAM memories, general purpose I/O ports and special hardware features (Hamad et al., 2006).

The general purpose of CPU architecture is categorised into two common groups of microprocessors, the RISC and CISC. The major contrast between RISC and CISC processors is that RISC uses a set of simple instructions to execute and to achieve higher clock frequencies and also to process more instructions per clock than CISC processors (Tolley, 1991). Typically, the CISC processor consists of a larger density of transistors and a more complex set of instructions compared to the RISC architecture. The RISC's CPU is installed using a hard-wire processor and software, fast processor and fast cache for instructions (these instructions take one cycle to execute), and also using a simple pipeline. Therefore, a processor based on RISC concept will use a few instruction sets, which use a few transistors as opposed to the CISC processor, hence the reduction in cost and manufacturing process. Furthermore, the RISC processor is readily employed with internal integration peripheral already equipped with all the necessary features to support communication to the outside world. The influence of advanced technology in semiconductor fields lay on Moore and Bell Law has rapidly turned electronic devices, especially the microcontroller device to small, compact and higher-performance gadgets.

In wireless sensor network application, the microcontroller becomes one of the main devices used to control and compute data from sensors and all in all, manage the communication. Therefore, PIC microcontroller is selected to meet the specifications needed to enable WSN as a monitoring application. A PIC is a family of microcontrollers made by Microchip Technology. The first invention of PIC family is PIC1650 developed by General Instruments. The acronym of PIC stands for Programmable Intelligent Computer and now it is associated with the Programmable Interface Controller. The basic idea of PIC is intended to take over the I/O tasks for the CPU, or rather, to improve performance. Since 1985, PIC was upgraded with EPROM to produce programmable controller (Julio and Maria, 2007). Today, huge varieties are available with the growth of many different types of PIC families, and gradually these new machines take over many better-established competitors. In many cases, PIC microcontrollers can run faster with a simple chip-set using the Harvard Architecture. Even some microcontrollers use the Von Neumann Architecture. The most prominent difference is that, in the Von Neumann architecture program and data are stored in the same memory and managed by the same information-handling subsystem, whilst in Harvard architecture the program memory and data memory are accessed from separated buses as shown in Figure 2.3. Both the architectures have their own capabilities- the Harvard architecture provides easier pipeline, preventing memory alignment to occur, while the Von Neumann architecture is more flexible and it allows self-modifying codes (Wilmshurst, 2007).

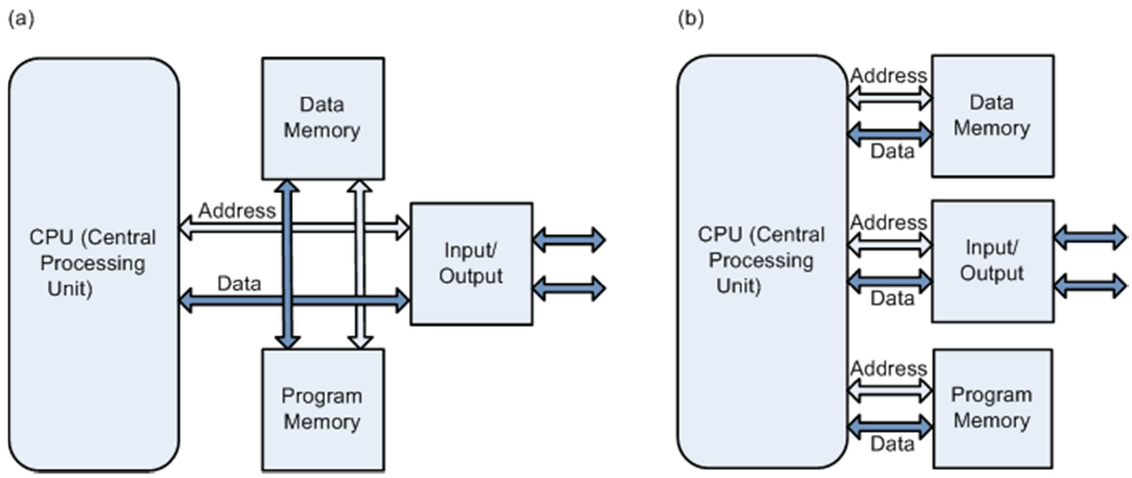

Figure 2.3: Organizing memory access. (a) The Von Neumann architecture. (b) The Harvard architecture.

Today, a huge range of PICs microcontroller is expanding and is available sporting many different on-board peripherals and program memories ranging from a few hundred words to 32K. Generally, Microchip (manufacturer of PIC microcontrollers) offers five main families of PIC microcontroller as shown in Table 2.1. Other than establishing the basic idea such as wearable computing in these microcontrollers (Henriksen and Gallagher, 2004), each family in PIC microcontroller also shares the same core architecture and instruction set. Thus, Microchip categorises each PIC microcontroller into three ranges namely the Base-Line, Mid-Range, and High-End (Rizk and Eltelety, 1998), as shown in Figure 2.4.

Table 2.1: Comparison of PIC families.

PIC family	Stack size (word)	Instruction word size (bit)	Number of instructions	Interrupt vectors
12CXXX/ 12FXXX	2	12 or 14	33	none
16C5XX/ 16F5XX	2	12	33	none
16CXXX/ 16FXXX	8	14	35	1
17CXXX	16	16	58 including hardware multiply	4
18CXXX/ 18FXXX	32	16	75 including hardware multiply	2 (prioritised)

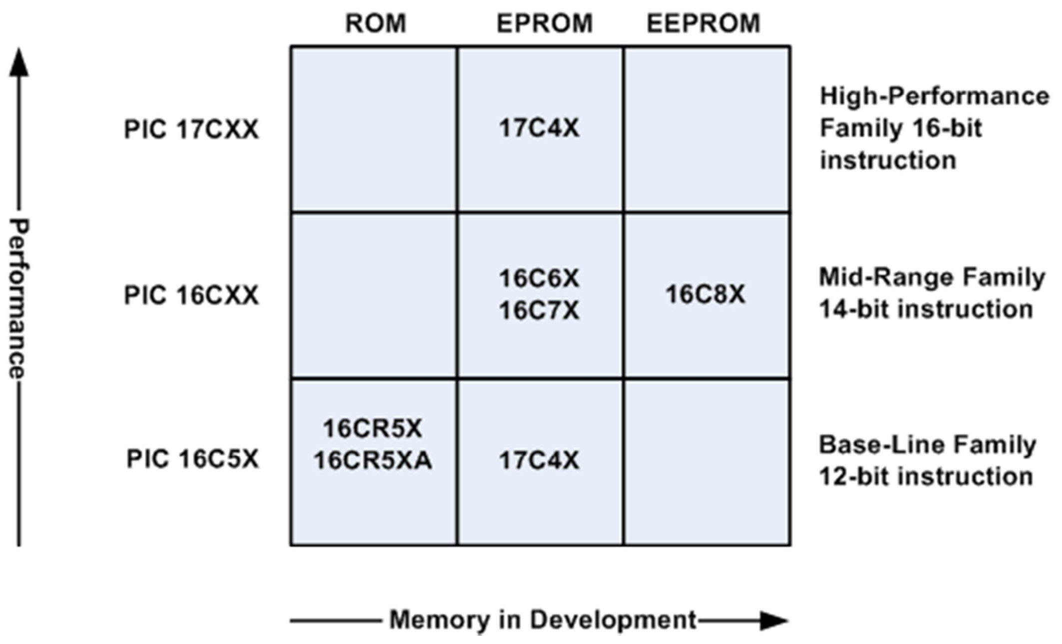

Figure 2.4: PIC microcontroller family ranges.