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HUMIDITY AND GAS SENSOR MONITORING SYSTEM IN AN IDEAL ENVIRONMENT

EZLA NAJWA BTE AHYAT

A report submitted in partial fulfillment of the
Requirements for the award of the degree of
Bachelor of Engineering (Electrical-Telecommunication)

Faculty of Electrical Engineering
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MAY 2010

I declare that this thesis entitled “Humidity and Gas Sensor Monitoring System in an Ideal Environment” is the result of my own research except as cited in the references. This thesis has not been accepted for any degree and is not currently submitted in candidature for any other degree.

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To my beloved father, mother, sister and brothers….

ACKNOWLEGDEMENT

In the Name of ALLAH, the Most Gracious and the Most Merciful

First and foremost, I would like to thank Allah because for His bless and guidance, I finally finished my final year project successfully.

Furthermore, I would like to thank a lot to my dearest family especially my mom and dad who give me a lot of love and spirit to finish this project till the end.

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May Allah bless you all.

ABTRACT

The awareness of air quality control for ideal environment will lessen the risks of increasing environmental threats to public health. The relative humidity and level of contaminants gaseous in the air should be monitored in order to achieve the ideal environment. This project discussed the monitoring control system for sensing humidity and contaminants gaseous in the air. Humidity sensor is a device to detect the percentage of water vapor at a specific temperature in the air which was measured as relative humidity. While, gas sensor is high sensitivity sensor detects low concentrations of gaseous air contaminants. Development in sensor design leads sensor as the main component used to monitor the two factors and microcontroller features as the preferred choice for embedded system which ease the end user to control the system operation. Furthermore, the control system is designed for monitoring and alerting purposes in order to preserve environmental security and condition. Buzzer will produce sounds when relative humidity and level of gaseous are out of the specified range.

ABSTRAK

Kesedaran terhadap kawalan kualiti udara untuk persekitaran ideal dapat membantu mengurangkan risiko dan ancaman persekitaran terhadap kesihatan orang awam. Kelembapan bandingan dan tahap gas-gas beracun di udara perlu dikawal bagi mencapai persekitaran ideal. Projek ini membincangkan tentang sistem pantauan dan kawalan untuk kelembapan dan gas-gas beracun di udara. Sensor kelembapan ialah alat yang digunakan untuk mengesan kandungan wap air di udara pada suhu tertentu. Ia diukur dalam peratus kelembapan bandingan. Sementara itu, sensor gas ialah pengesan yang sensitif bagi mengesan kewujudan gas–gas beracun yang berketumpatan rendah. Kemajuan dalam bidang alat pengesan menyebabkan ia terpilih untuk menjadi komponen utama bagi mengesan kedua–kedua elemen. Ciri-ciri mikropengawal akan memudahkan lagi pengguna untuk mengawal operasi sistem. Selain itu, projek ini dilengkapi oleh sistem kawalan. Penggera akan mengeluarkan bunyi jika elemen di luar julat dalam spesifikasi bagi mengawal keselamatan dan keadaan persekitaran.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION OF THESIS	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	CONTENTS	vii
	LIST OF FIGURES	x
	LIST OF TABLES	xii
1	**INTRODUCTION**	
	1.1 Background of Study	1
	1.2 Problem Statement	3
	1.3 Objective of Project	4
	1.4 Scope of Project	4
	1.5 Outline of Thesis	5
	1.6 Methodology	6
	1.7 Summary of Work	7

2	**LITERATURE REVIEW**	
	2.1 Introduction	8
	2.2 Humidity and Gas Sensor Monitoring System	8
	2.3 Definition of Parameters Humidity	10
	2.4 Humidity	10
	2.5 Contaminants Gaseous	12
	2.6 Ideal Environment Standard	13
	2.7 Sensor and Instrumentation	13
	2.7.1 Humidity Sensor	14
	2.7.2 Gas Sensor	16
	2.7.3 40-pins PIC Start-up Kit	17
	2.8 PIC Microcontroller	18
	2.8.1 PIC18F452	18
	2.9 Programming Tools	20
	2.9.1 MikroC Software	20
	2.9.2 PIC Kit Programmer	22
	2.9.3 Inter-Integrated Circuit Serial Communication	22
	2.10 Indicator	23
	2.11 Components	25
3	**METHODOLOGY**	
	3.1 Introduction	26
	3.2 Research In Phases	27
	3.3 Approches	28
	3.4 Phase 2: Designing Sensor Node	29
	3.4.1 Humidity Sensor (HSM-20G)	29

	3.4.2 Gas Sensor	30
	3.4.3 Hardware of Humidity and Gas Sensor	32
	3.5 Phase 3: Software	33
	3.5.1 Humidity Sensor Programming	33
	3.5.2 Gas Sensor Programming	35
	3.5.3 Programming for I2C	38
	3.6 Component List and Cost	39
4	**RESULT AND DISCUSSION**	
	4.1 Introduction	40
	4.2 Project Description	41
	4.3 Project Result	41
	4.4 Project Discussion	45
5	**CONCLUSION AND RECOMMENDATION**	
	5.1 Introduction	46
	5.2 Conclusion	46
	5.3 Recommendation	47
	REFERENCES	48
	APPENDICES	
	Appendix A -HSM-20G User Manual	50
	Appendix B – TGS 2600 User Manual	52
	Appendix C – PIC18F452 User Manual	54

LIST OF FIGURES

FIGURE NO	TITLE	PAGE
1.1	Block Diagram of Humidity and Gas Sensor Monitoring System in an Ideal Environment	5
1.2	Gantt Chart of the Project Schedule for Semester 1	6
1.3	Gantt Chart of the Project Schedule for Semester 2	6
2.1	Relative Humidity in Percentage	11
2.2	Humidity Sensor Model HSM 20-G	14
2.3	HSM 20-G Connection	14
2.4	TGS 2600-Detection of Contaminants Gaseous	16
2.5	PIC18F452 pins	19
2.6	Programming Diagram Flow	21
2.7	Inter-Integrated Circuit Bus	23
2.8	Light Emitting Diode	23
2.9	16x2 Character LCD Display	24
2.10	Buzzer	24
3.1	The Methodology Approaches	28
3.2	Circuit for Humidity Sensor	29
3.3	Bottom View of Gas Sensor	31
3.4	Gas Sensor Connection	31
3.5	Strip Board Design	32
3.6	Source Code for Humidity Sensor	35
3.7	Gas Sensor Sensitivity Characteristic	37
3.8	Source Code of Gas Sensor	38
3.9	Source Code for I2C Unique Address	38

4.1	**Block Diagram of Whole Project**	**41**
4.2	**The Major Connection of Component**	**42**
4.3	**Complete Hardware of Humidity and Gas Sensor Monitoring System**	**43**
4.4	**Humidity and Gas reading**	**43**
4.5	**Enabled/Disabled Buzzer**	**44**
4.6	**Status of Each Sensor**	**44**

LIST OF TABLES

TABLE NO	TITLE	PAGE
2.1	Parameters specification in Ideal Environment	13
2.2	Humidity Sensor Connection	15
2.3	Extra Features and Applications of HSM20-G	15
2.4	Features and Application for TGS 2600	17
3.1	Humidity Sensor Specification	33
3.2	Gas Sensor Specification	36
3.3	List of Components and Cost	39

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Environment gives significant impact in human daily live. Across the globe, environmental issues are critically discussed due to the increase of awareness and responsibility regarding the threats of environment towards public health [2]. Quality of the air has significant relation with the quality of environment and weather. Since ages, people have blamed bad weather for all type of ailments.

In this project, the objective scope has been focused into two factors that will affect public which are percentage of humidity in the air and level of air contaminants.

Humidity is defined as the amount of water vapor in the air and usually measured in term of Relative Humidity (%RH). Percentage of Relative Humidity is best described as amount of moisture in the air and compared to amount the air can hold at that temperature.

While, air contaminants can be categorized as compounds that may pollute the air. With reasons, some contaminants are group into several specific categories based on the level of contaminants affecting public health. It can be expressed in term of sensor resistance ratio (R_S/R_O).

In accordance with this phenomenon where awareness of the importance of air quality control is increasing, this project encourages public to be alert with the environment they live in. It gives advantage to people who are concern about their health and put efforts in monitoring the environment affected by humidity and contaminants gaseous.

The proper controlled system with continuous and automatic monitoring are the criteria needed to ease the end user. The advantage of this system when it is completed with alarm system is the ability to communicate with multi microcontroller and back-up control system in case of any failure. Besides, this simple system can be applied in various implementations with some alteration especially indoor. Thus, current technologies development and microcontroller may reform the control and operation systems. Development in electronics, the increase reliability of sensor and instrument help monitoring equipment which maintains the parameter.

1.2 Problem Statement

.

The awareness of air quality control for ideal environment will lessen the risks of increasing environmental threats to public health. The relative humidity and level of contaminants gaseous in the air should be monitored in order to maintain an ideal environment. The common problem results by humidity such as dampness, dryness and condensation in surroundings cause discomfort and various problems to public. While, for contaminants gaseous the effect of it existence is obviously gives severe pollution and adverse consequences to public.

A recent development in automated control system has increase the demand of various kinds of sensors. Humidity and contaminants gaseous are very common in the environment. Control and measurement of these elements is important not only to avoid discomfort but for broad range of industries.

Maintaining good environment quality is essential to closed space system as poor air quality will rapidly reduce health, fitness, living quality and productivity. Hence, monitoring on continuous basis is a must because it tends to significantly give huge effect when readings are out of specified range.

In order to ensure energy efficient and optimized results, proper controlled system need to be designed. The intelligence of current technologies is applied to revolutionize the system. Development in sensor design lead sensor as main component used to monitor some of the parameters and microcontroller features make it preferred choice for embedded control to ease the end user to control the parameters, control devices and system operation.

1.3 Objectives of Project

The objectives of the project are to:

1. Receive sensing data (physical condition) from analog sensor.
2. Able the communication between microcontroller via inter- integrated circuit (I2C).
3. Activate alert system when result is out of specification.

1.4 Scope of Project

The scope of this project is to study, investigate and understand humidity and gas sensor monitoring system in an ideal environment. The scope involved:

1. Review on sensor node study for monitoring system and comparison study.
2. Designing sensor node
   a. Component needed
   b. Arrangement of component on the strip board
3. Designing programming for microcontroller
   a. Controlling data acquisition in microcontroller
   b. Programming for interfacing the module and sensor
4. Microcontroller communication set up.
5. Alerting system when the parameter is out specification.

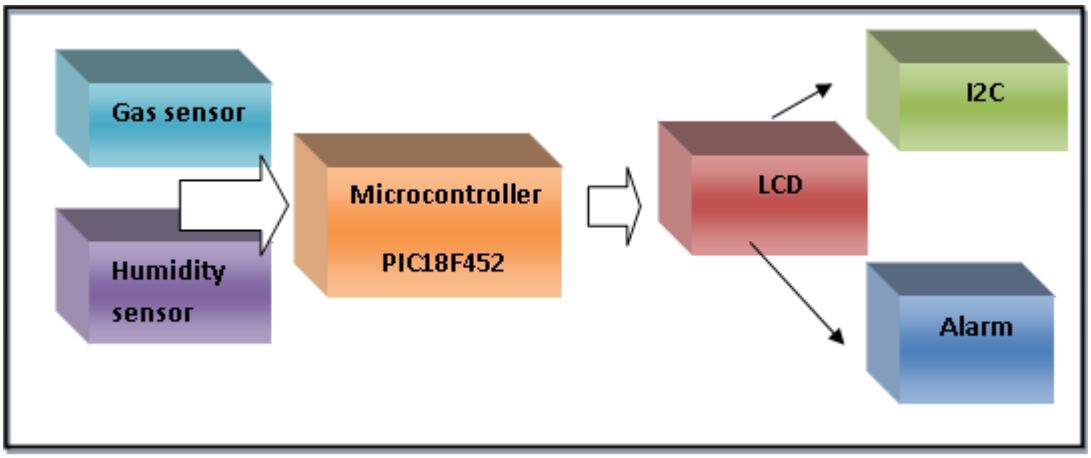


Figure 1.1: Block Diagram of Humidity and Gas Sensor Monitoring System in an Ideal Environment

1.5 Outline of Thesis

CHAPTER 1.0: This chapter commences with an introduction of humidity and gas sensor monitoring system and automated control system.

CHAPTER 2.0: This chapter focused on literature review presenting up to data findings and useful theoretical definitions and conventions. Besides, research related to project is reviewed.

CHAPTER 3.0: This chapter focuses on the exact steps to be undertaken to complete the project. Hardware design and the development of operating system will be examined.

CHAPTER 4.0: Full system and the results from the performed project will be discussed in detail.

CHAPTER 5.0: Finally, review and summary of project's findings will be concluded in the thesis. Recommendation for future development will be included.

1.6 Methodology

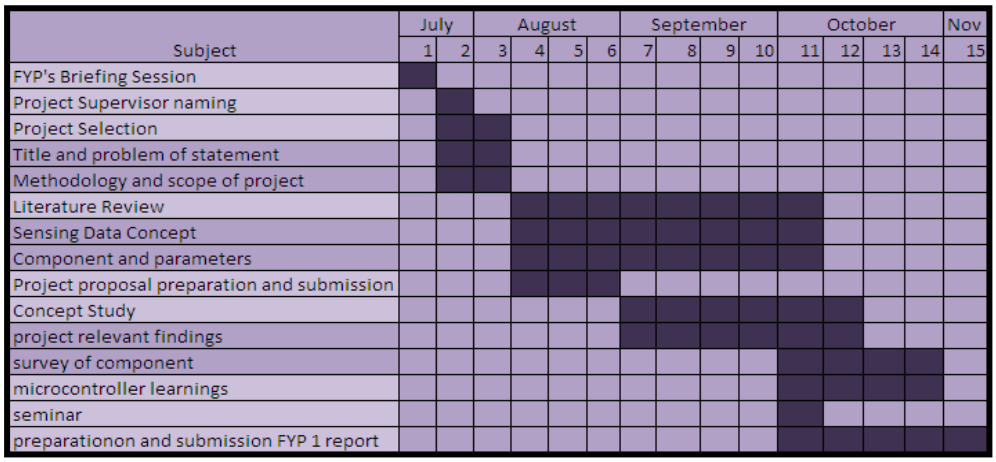


Figure 1.2: Gantt Chart of the Project Schedule for Semester 1

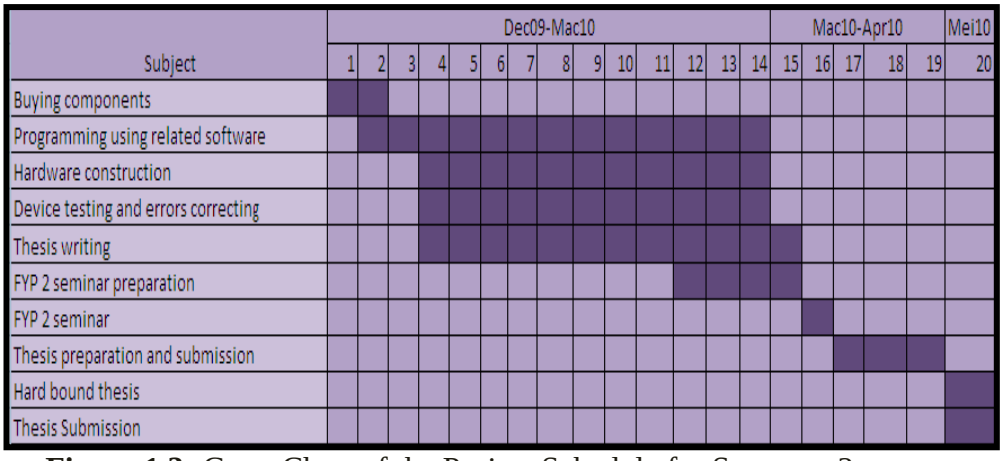


Figure 1.3: Gantt Chart of the Project Schedule for Semester 2

1.7 Summary of Work

This project flows from the sensing data of humidity and gas sensor. Analog sensor is used and will indicate as voltage in output. Both sensors are interfaced to microcontroller (PIC18f452) and sensing data is displayed in LCD (2x 16 characters). The sensors will work based on the programming in the microcontroller and able to communicate with master controller as the backup monitoring system if any failure happens. Alert system is designed and will produce alarm when sensing data out of the specified range.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will focused on the definition of whole concept of monitoring control system and further details regarding it. Explanation on microcontroller, sensor and other instrumentation were discussed. Related software was determined.

2.2 Humidity and Gas Sensor Monitoring System

Nowadays, the environment is polluted with so many elements which are hazardous to human. The most significant pollution is air pollution where the air that human breathes will directly affect the health and living condition. Hence, drastic action needs to be taken in order to resolve and prevent this problem.

Two most major elements which give significant effect towards environment are air contaminants gaseous and humidity. There are many solutions created to keep the right level of humidity and to detect the existence of contaminants gaseous. However, alternative system can be design to solve or regulate the value as to minimize the effect of these two elements. The automated monitoring control system was designed to overcome this problem and this system will ease the end user.

Furthermore, the project was designed with alert system where alarm was produced when sensing data are out of the required specification range. Communication between microcontrollers was set up via inter-integrated circuit (I2C). Slave mode was activated only if its internal address matches the value sent by the master controller. The transferred sensing data is depending on the master acknowledgement.

In conjunction with that, the main key for closed system aquaculture in this thesis is the control system which monitors and regulates the entire main environment discussed.

2.3 Definition of Parameters

Humidity: The concentration of water vapor in the air. It can be expressed by relative humidity, absolute humidity and specific humidity. This element depends on the temperature and it gives adverse effect not only towards human health in fact all life aspect.

Contaminants Gaseous: Undesired compound that consist of acid gaseous which may cause or contribute to an increase in deaths or in serious illness, or which may pose a present or potential hazard to human health.

2.4 Humidity

Malaysia is an equatorial country which experience uniform temperature and high humidity level. Since ages, weather has been blamed for most types of ailment experienced by human. Unfortunately, most of the public has neglected humidity as one factor contributed to the scenario and worst, humidity actually can influence human physically and mentally.

Based on Argentina study, high humidity plays a key-role in human health life. High humidity contributed to some serious disease as listed below [4]

1) Osteoarthritis and Rheumatoid Arthritis
2) Asthma
3) Fatigue

Researchers concluded that it is difficult to draw definitive conclusions between arthritis and humidity. However, some clear up has been made and declared as true which is arthritis patients might be more physically sensitive to humidity changes. It affects arthritis symptoms rather than cause of arthritis.

Nevertheless, researches have strong agreement towards the reason why hot, humid days cause fatigue. Likewise daily activities like washing, steaming, and drying wet clothes can also contribute to high moisture levels in homes. Normally, body perspires to cool down when temperatures are high. But if the humidity is also high, body are trapped in a moist environment where sweat cannot evaporate and escape from skin. These causes expend extra energy, which can leave the body feeling sluggish or fatigued. Furthermore, alertness and mental capacity may also be affected.

In this thesis, humidity will be expressed as relative humidity (RH) which is determined as ratio of the current vapor pressure of water in air to the equilibrium vapor pressure, where the gas are saturated at certain temperature. It is represented as a percentage. Equivalently, it is the ratio of the current mass of water per volume of gas and the mass per volume of a saturated gas.

$$Relative\ Humidity\ (RH) = \frac{actual\ vapor\ pressure}{saturation\ vapor\ pressure}\ x\ 100$$

Figure 2.1: Relative Humidity in Percentage

2.5 Contaminants Gaseous

Air contaminants give huge impact to the level of human health and directly affected human through the mixture of gaseous that human breath in. air contaminants including gaseous, liquid or solid state which emitted from many sources in industry, mining, transportation, electricity generation and agriculture.

Examples of contaminant gaseous are Methane, Carbon Monoxide, Iso-butane, Ethanol and Hydrogen. However, in daily routines human are always exposed and poisoned by Methane and Carbon Monoxide resulting from cigarette smoke and fuel combustion of vehicle. These results the suffering respiratory system, hospitalization for heart and lung disease, asthma, and even premature death.

However, this thesis focused on indoor contaminant gaseous as these gaseous are two to five times polluted than outdoor. This phenomenon happen when outdoor air contaminants is allowed to bypass filters(indoor area), potentially disrupt the balance and permit the introduction of excess moisture if access is not controlled. It can be monitored by using monitoring control and solved by proper design of Heating, Ventilation and Air-Conditioning (HVAC) Systems [10].

Air Contaminants will be determined as sensor resistance ratio (Rs/Ro) which indicates as:

Rs: Sensor resistance in displayed gaseous at various concentrations

Ro: Sensor Resistance in fresh air

2.6 Ideal Environment Standard

Table 2.1 shows the specified range for these two elements. All the parameters should follow this specification in order to maintain air quality in a closed system.

Table 2.1: Parameters Specification in Ideal Environment

Parameters	**Specification**
Humidity	65-85 (%RH)
Gas	0.3-0.6 (Rs/Ro)

2.7 Sensors and Instrumentation

To design reliable control system for Humidity and Gas Senor Monitoring System in an ideal environment suitable components, instrument, sensors programming design are needed. Presently, there are many new developments in electronics that have lead success in designing monitoring system [5].

2.7.1 Humidity Sensor

Humidity sensor is a devise consisting of a special plastic material whose electrical characteristic change according to the amount of humidity in the air. Basically, this sensor senses the amount of water vapor in air. For this project, analog input sensor was used. HSM 20-G is essential for the objectives and applications where the reading in terms of Relative Humidity was converted into standard voltage output.

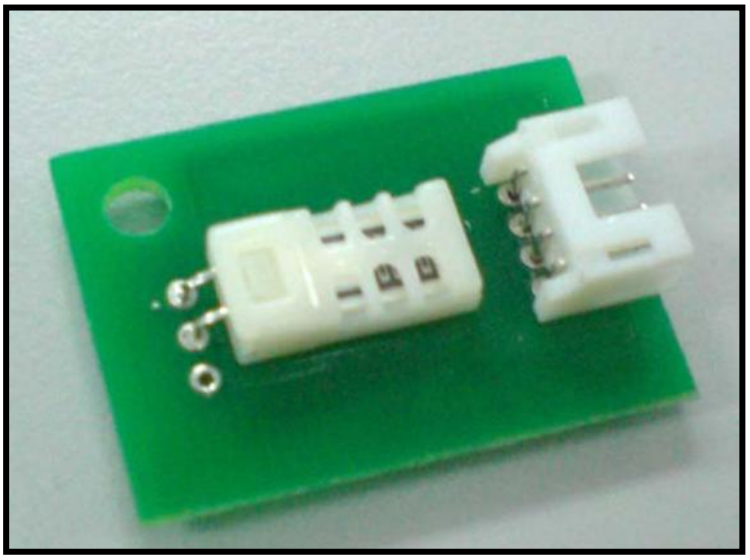


Figure 2.2: Humidity Sensor Model HSM 20-G

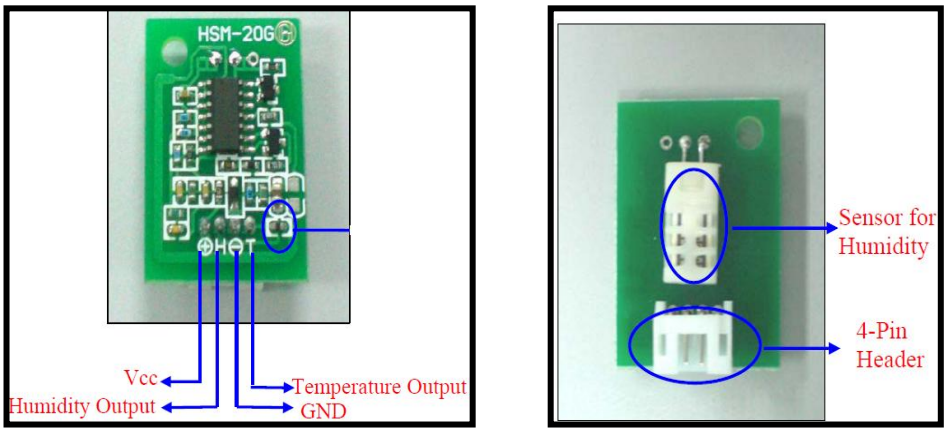


Figure 2.3: HSM 20-G Connection

Based on Figure 2.2 the connection of HSM 20-G is defined as:

Table 2.2: Humidity Sensor Connection

Label	Description
VCC	Power supply to the sensor
GND	The Ground of the sensor.
Humidity Output	The analog output for sensor(humidity)
Sensor For Humidity	The sensor to sense humidity
4-pin Header	The connector to the cable which connect to microcontroller circuit.

HSM20-G is complete with extra features and applications included as below:

Table 2.3: Extra Features and Applications of HSM20-G

Applications	Extra Features
1. Humidifiers and Dehumidifiers	1. Small size makes it easy to conceal and suit current miniaturization product.
2. Air-conditioner	2. Compatible with all types of microcontroller makes it reduces the complexity of interfacing
3. Humidity data loggers	3. Very high sensitivity to humidity in the air and makes it reliable.
4. Automotive climate control	4. Voltage analog output

2.7.2 Gas Sensor

The sensing element compromised of a metal oxide semiconductor formed on an alumina substrate of a sensing chip together with an integrated heater. In the presence of detectable contaminant gas, the sensor's conductivity increases depending on the 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.

The TGS 2600 has high sensitivity to low concentrations of gaseous air contaminants such as hydrogen and carbon monoxide which exist in cigarette smoke. The sensor can detect hydrogen at a level of several parts per million (ppm). Due to miniaturization of the sensing chip, TGS 2600 requires a heater current of only 42mA and the device is housed in a standard TO-5 package.

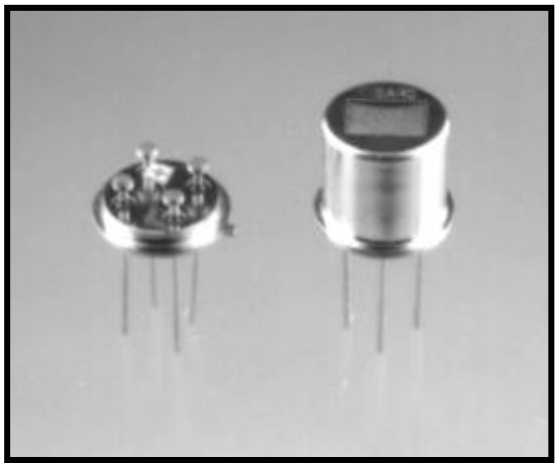


Figure 2.4: TGS 2600-Detection of Contaminants Gaseous

There are few extra features and application of TGS 2600 shown in Table 2.4.

Table 2.4: Features and Application for TGS 2600

Features	**Applications**
Low power consumption	Air cleaners
High sensitivity to gaseous air contaminants	Ventilation control
Long life and low cost	Air quality monitors
Small size	
Uses simple electrical circuit	

2.7.3 40 pins PIC Start-Up Kit

A low cost and yet enhanced technology for save development and soldering time. It is designed to offer an easy to start board for PIC MCU user. This board comes with basic element for user to begin project development. It is compact, powerful, flexible and robust start-up platform.

2.8 PIC Microcontroller

Many related computer systems especially in engineering field used microcontroller. The design learning process for beginner can be discovered in many reliable resources making a user friendly component. By using microcontroller, different methods can be implemented in order to find a solution depending on user's creativity [3].

Generally there are many reasons microcontroller is chosen as the brain of the system. It is due to the low cost, small packaging, low power consumption, reprogrammable, easy integration with custom circuits and compatible to software development and debugging tools.

In this project, microcontroller will act as the main component in embedded system because of it multi-tasking capabilities, processing data and the ability to control the functionality of other device.

2.8.1 PIC18F452

PIC18F452 is chosen due to it characteristic that is suitable to this project application. Based on the data sheet, this microcontroller has 32kb internal flash program memory which is reprogrammable and suitable for prototyping. Besides that, it compatibility to use the same source code with the PIC16 and PIC17 instruction sets makes the references broaden. This PIC included with internal 10 bit Analog-Digital converter that allows the converting process of analog data from sensors into digital signal.

Other brilliant features of PIC18F452 have 75 instruction sets need to be learn and low power, high speed FLASH/EEPROM technology. This chosen PIC consist of up to 33 general purpose I/O pins with port A,B,C,D,E that will reduce the complexity of the system which is suitable for the beginner.

There are also peripheral features that enable the communication between PIC and other devices including Synchronous Serial Port (SSP) with SPI(Master mode) and I2C(Master/Slave) and Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI). Furthermore, PIC18F452 is compatible 10-bit Analog-to-Digital Converter module (A/D) with fast sampling rate and conversion available during SLEEP suits the demand of this project [14].

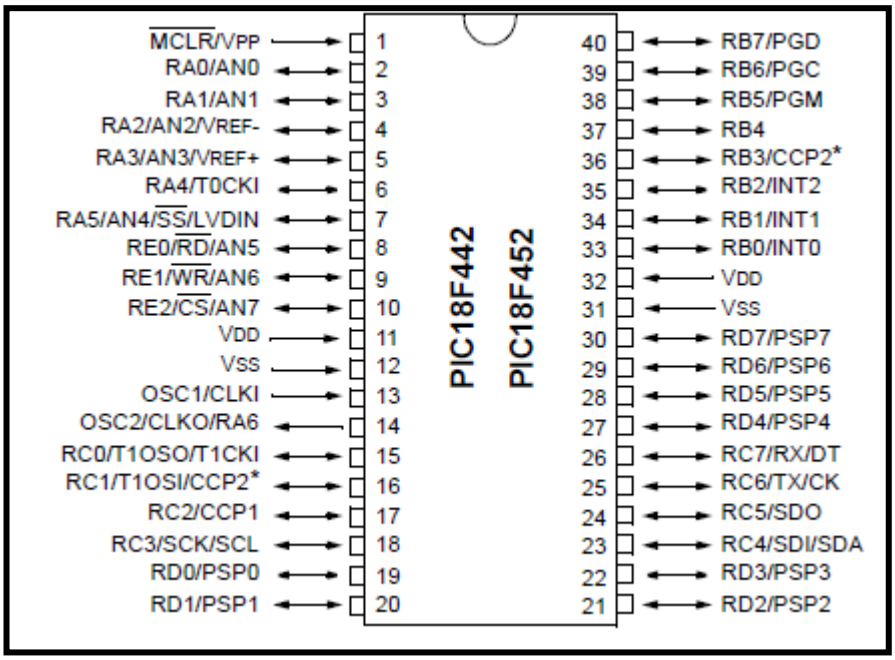


Figure 2.5: PIC18F452 Pins

2.9 Programming Tools

I. PIC is programmed by using MikroC software.
II. Program written and convert into machine code.
III. PIC is placed in special program a unit which is attached to the host computer.
IV. Program downloaded via PIC kit.
V. PIC is placed in the application circuit.

2.9.1 MikroC Software

MikroC is powerful and user friendly C compiler for PIC microcontroller form Mikroelektonika. This software program runs on a PC to build up applications for PIC microcontroller families. It is called an Integrated Development Environment, or IDE, because it provides a single integrated “environment” to develop code for embedded microcontrollers [13].

Furthermore, highly sophisticated IDE provides the power you need with the simplicity of a Windows based point-and-click environment. MikroC is a powerful, feature rich development tool for PICmicros. It is designed to provide the users with the easiest possible solution for developing applications for embedded systems, without compromising performance or control.

PIC and C fit together well because PICs are used widely over the world with wide variety of applications while C, credited for its efficiency, is a natural choice for developing microcontroller applications. MikroC provides a successful match featuring highly advanced IDE, ANSI compliant compiler, broad set of hardware

libraries, comprehensive documentation, and plenty of ready to run example programs. MikroC allows you to quickly develop and deploy complex applications:

I. Write C source code using the built-in Code Editor.
II. Use the included MikroC libraries to dramatically speed up the development: data acquisition, memory, displays, conversions, and communication.
III. Monitor your program structure, variables, and functions in Code Explorer.
IV. Generate commented, human-readable assembly, and standard HEX compatible with all programmers.
V. Inspect program flow and debug executable logic with integrated Debugger.
VI. Get detailed reports and graphs on code statistics, and assembly listing.
VII. Debugger.

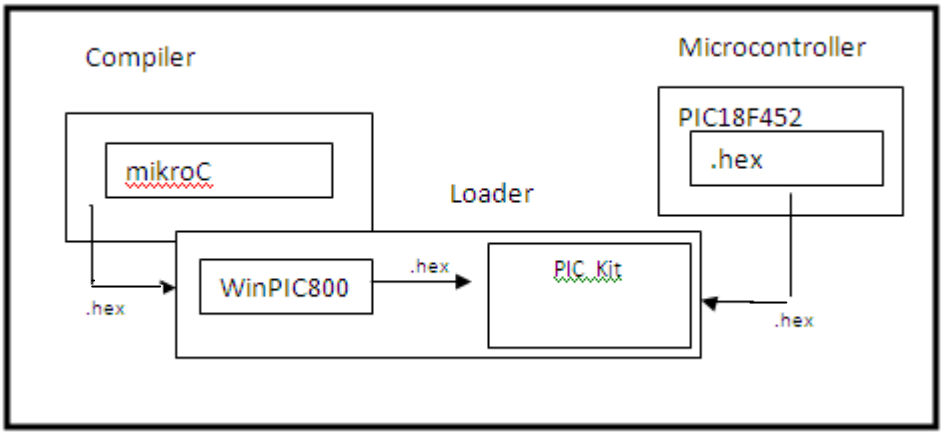


Figure 2.6: Programming Diagram Flow

2.9.2 PIC Kit Programmer

In order to load the program in the microcontroller, this software was used. This software will load all program made into internal memory of PIC18F452. Once the HEX file was created in MikroC, this file will then be loaded into PIC18F452 using PIC Kit2.

2.9.3 Inter-Integrated Circuit (I2C) Serial Communication

I2C interface one or more microcontroller and peripherals in embedded system for example exchanging data with master controllers via single connection (10). It has two active wires which are serial data line (SDA) and serial clock line (SCL). These two buses will synchronize mater/slave communication by using software.

I2C is suitable for communication between separate microcontroller boards and provide simple hardware design but more complex in the software. Every devices have it own unique address and can act as a receiver or transmitter depending on the function. I2C is a multi master bus which indicates that more than one ICs can initiate data transfer and called as Bus Master while other ICs as Bus Slaves.

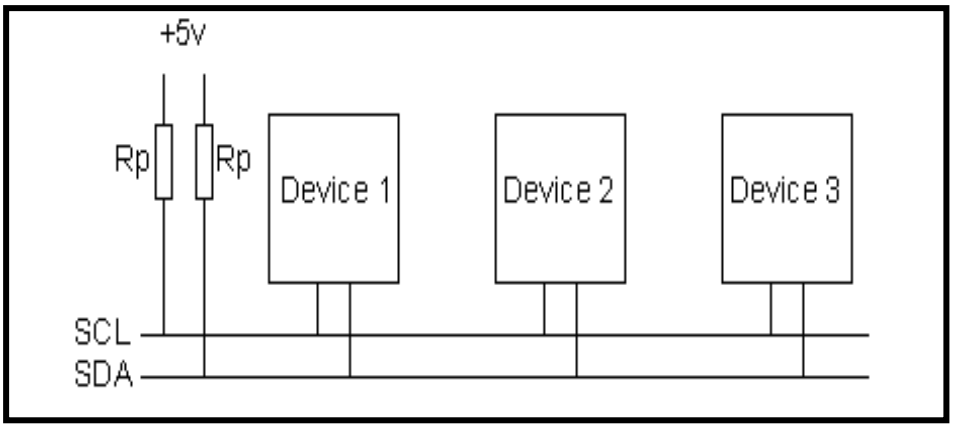


Figure 2.7: Inter-Integrated Circuit Bus

2.10 Indicator

1. **Light Emitting Diode (LED)** - Device that act as receiver that indicates sensor node and overall system is working by emitting low intensity light. This semiconductor diode has lower energy consumption, longer lifetime, improved robustness, smaller size and faster switching.

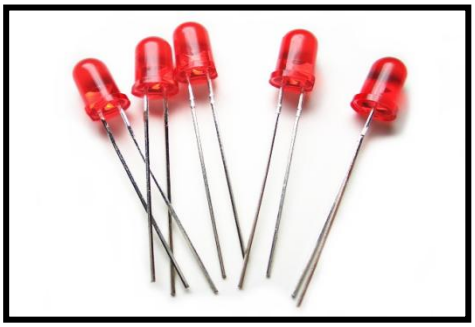


Figure 2.8: Light Emitting Diode

2. **Liquid Crystal Display (LCD)** – An electronic display device which has a flat panel display type commonly used in digital devices. In this project, LCD will display the readings and measurement of parameters. LCD 2x 16 characters was used.



Figure 2.9: 16x2 Character LCD Display

3. Buzzer – Electronic device which is defined as audio signaling device. Buzzer functioned as alert system and automatically produced sound when reading is out of the specified range.

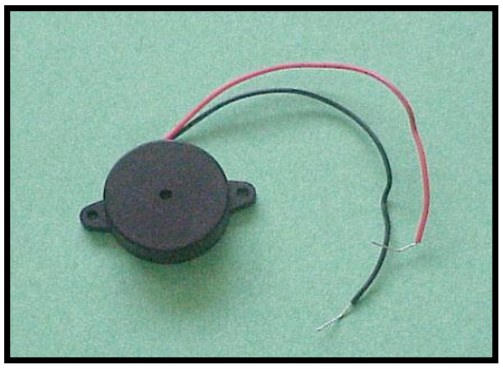


Figure 2.10: Buzzer

2.11 Components

Several extra components were used to design this project. All the listed component is a compliment to both sensors in order to make it regulates reading and measurement.

I. Resistor (100kΩ and 47kΩ)

II. Capacitor(47µF)

CHAPTER 3

METHODOLOGY

3.1 Introduction

The project will be conducted in phases and explained in this chapter. This chapter will give the sufficient detail of the exact steps which act as a guidance in order to complete this project. The discussion continues with specific block diagram which include the component that will be used to complete the hardware parts. Lastly, this chapter shows the flow chart that explained the whole system.

3.2 Research in Phases

Phase 1: Literature Review (Done in chapter 2)

i) Study the concept of Humidity and Gas Contaminants Monitoring System.

ii) Review on sensor node study and comparison study.

iii) Study the related components.

iv) Study the related software.

Phase 2: Designing Sensor Node

i) Study the component that will be used.

ii) Finding sources regarding arrangement of component on the strip board.

iii) Including designing hardware for I2C and alert system.

Phase 3: Designing Programming for Microcontroller

i) Controlling data acquisition in microcontroller.

ii) Programming for interfacing the module and sensor.

Phase 4: Thesis Writing

3.3 Approaches

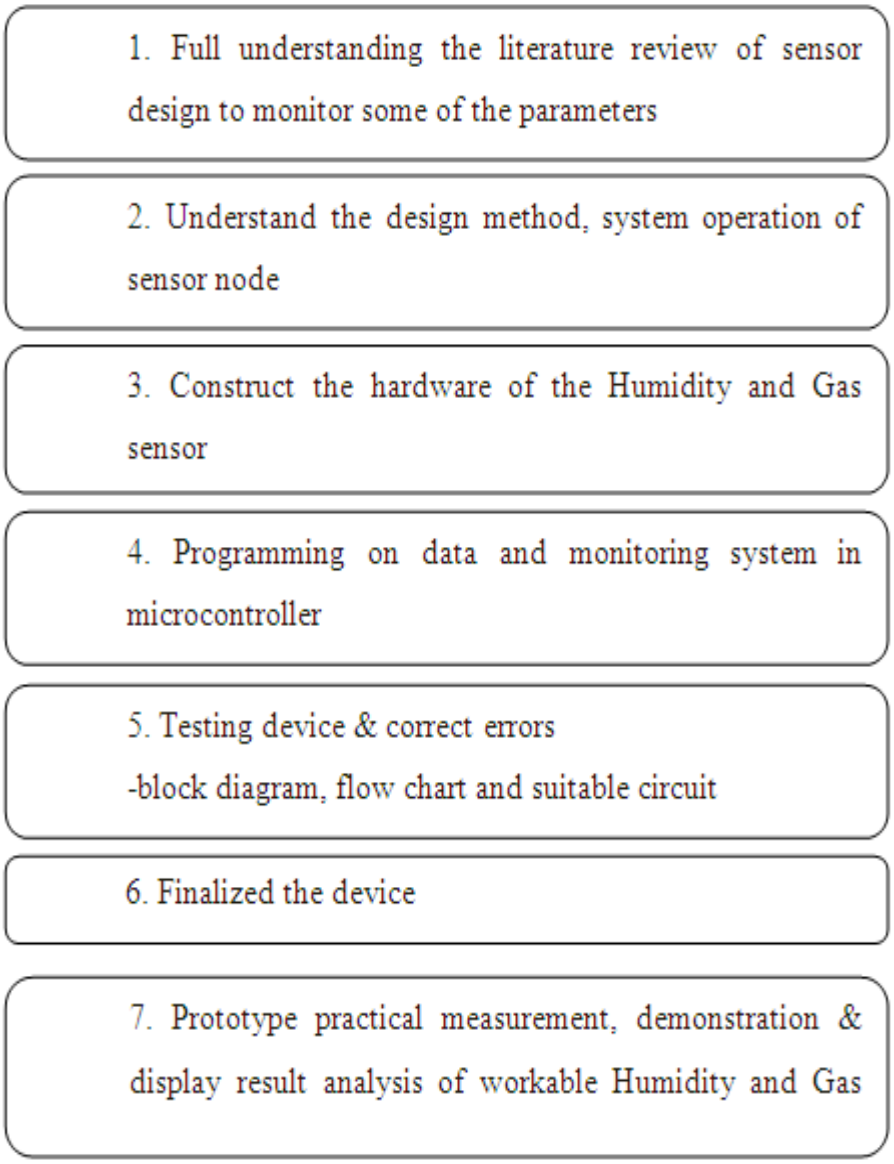


Figure 3.1: The Methodology Approach

3.4 Phase2: Designing Sensor Node

The most complicated part of designing a monitoring system is to design a sensor node. Working an analog sensor demands high understanding on how and the range sensor will operates. It involved two components for both sensors which is hardware and programming interface. Most of the hardware part is given in the datasheet while for programming, some important specification need to be extracted from datasheet and reliable sources.

3.4.1 Humidity Sensor (HSM 20-G)

To enable this sensor to read the moisture/ water vapor in air is by focusing on the connection part. Few things need to be considered such as the external circuit. To make sure the relationship between humidity and voltage is linear, some components were needed to build the desired circuit as in Figure 3.2.

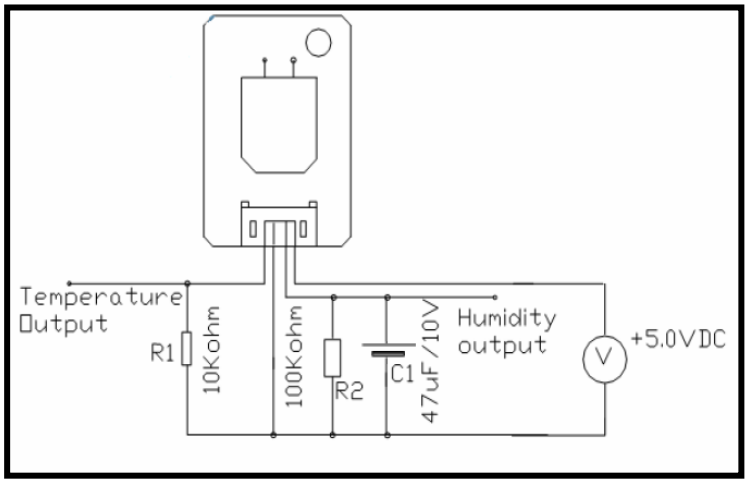


Figure 3.2: Circuit for Humidity Sensor

In order to use this sensor, a connector cable was build to connect the sensor to strip board. 4-pin header was connected to the circuit required such that:

I. (-) pin connects to GND

II. (+) pin connects to Vcc

III. H (humidity sensor) pin which included 47μF capacitor and 100KΩ resistor and connects to microcontroller's I/O pin. (to be set as ADC mode)

IV. T pin not included in this project as the reliability is arguable

To ensure the sensor works in the specified range, detailed programming must be considered, since the sensor is sensitive towards vapor produced by exhalation or heater. Refer to Appendix A.

3.4.2 Gas Sensor

Operation of gas the sensor is the same as the humidity sensor, but some consideration needs to be taken in order to interface sensor with programming and hardware. In this subtopic, most of the discussion is focused on hardware interfacing part.

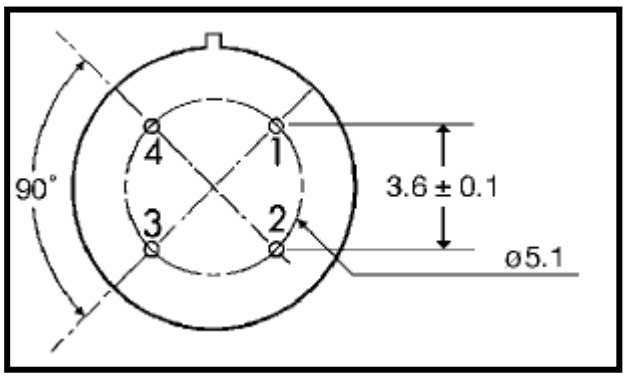


Figure 3.3: Bottom View of Gas Sensor

Gas sensor needs a voltage of 5V to operate and it resistances changes with gas concentration and act as a potential meter. The connection of each pin is determined as Figure 3.4. Some of specification is essential to continue with next step which is programming part and react significantly with methane in the cigarette lighter. Refer to Appendix B.

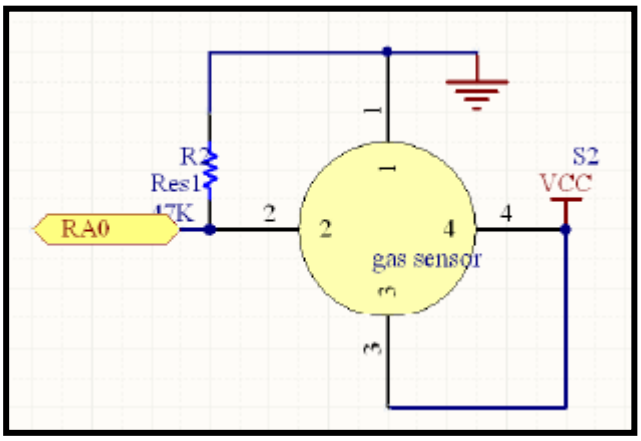


Figure 3.4: Gas Sensor Connection

3.4.3 Hardware of Humidity and Gas Sensor Monitoring System

After considering all the important software criteria, the flow of project continues with the construction of hardware. The connection of sensor nodes and the related component was built using strip board. Before components were placed, the strip board design was sketched by using Strip board Designer 1.0.

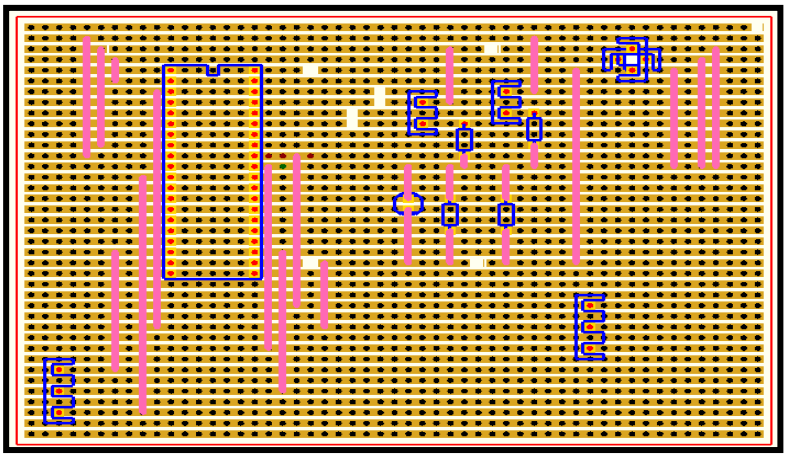


Figure 3.5: Strip Board Design

This design work as a connection reference needed for hardware including sensor node interfacing with microcontroller, I2C connection and alert system. Most of the component in the designer does not represent the actual components due to the software limitations. However, the main concern is the exact holes connection. By following the layout, the complete design was soldered**.**

3.5 Phase 3: Software (Programming for Microcontroller)

This section will specifically discuss the methodology to interface the sensor and hardware module. The most important part is to enable the analog sensor to sense analog data and represent it in digital. It can be done with various techniques. One of the reliable techniques is to produce a relation between the sensor analog range and microcontroller analog to digital converter (ADC) specification. This relation is based on some calculation and will be clearly explained in the next section.

3.5.1 Humidity Sensor Programming for Microcontroller

For humidity sensor, the relation will be extracted from the datasheet and focused on some specifications. The following calculation will clarify the process to construct an equation for this sensor. Based on the datasheet of HSM-20G the essentials information is given in Table 3.1. Refer to Appendix A.

Table 3.1: Humidity Sensor Specification

Number	Specification	Gas Sensor
1.	Input voltage range	DC 5.0±0.2 V
2.	Output voltage range	DC 1.0—3.0 V
3.	Storage RH Range	0 to 99% RH
4.	Operating RH Range	20 to 95% (100% RH intermittent)

As mentioned before, PIC18F452 is 10 bit analog- to digital converter microcontroller and based on the hardware, the real input voltage of humidity sensor is 4.75 V.

Step 1:

Since the binary is 10-bit, it is equal to 2^{10}-1= 1023 steps or levels of resolution. 4.75V is then divided into 1023.

$$\frac{4.75}{1023} = 4.64mV\ per\ resolution$$

Step 2:

The output voltage range is 1-3 V. Thus, it will represent as the reference voltage and microcontroller only read digital values from

$$\frac{1023}{4.75}\text{x}1 = 215 \leq \text{adc_read} \leq \frac{1023}{4.75}\text{x}3 = 646$$

The differences of this step will be 431 steps

Step 3

The operating range of humidity sensor is 20-95% RH with 75% differences. It shows that at 20%RH the analog value is 1V while binary is 215 and at 95% RH the analog will be 3V while binary is 646.

Step 4

The humidity relation was then obtained as:

$$\%RH = \frac{75\%}{431}\text{x}\ (\text{adc_read} - 215) + 20\%$$

Step 5

Based on Table 2.1, the %RH will be limited to 80%RH which represented a dangerous limit of humidity in the air and automatically set the alarm systems.

```
text = "Humid:";                    // print string a on LCD, 2nd row, 1st column
Lcd8_Out(row, 1, text);

adc_rd = ADC_read(1);               // get ADC value from 2nd channel
 if(adc_rd<215 || adc_rd>646){
        Lcd8_Out(row,8,"ERROR");
        return;
    }
humid = adc_rd-215;
humid *= 0.17;
humid += 20;

 if(humid>80){                              //alert system
       buzzHumidity = 1;
       LED_humid = 1;
    }
    else{
       buzzHumidity = 0;
       LED_humid = 0;
    }
displaynum(humid,row,7);                    //display value
 Lcd8_Out(row, 13," %RH");
```

Figure 3.6: Source Code for Humidity Sensor

3.5.2 Gas Sensor Programming for Microcontroller

For gas sensor, the relation will be extracted from the datasheet and focused on some specifications. The following calculation will clarify the process to construct an equation for this sensor. The main considerations for TGS 2600 are shown by Table 3.2. Refer to Appendix B.

Table 3.2: Gas Sensor Specification

Number	**Specification**	**Humidity Sensor**
1.	Circuit voltage range	DC 5.0±0.2 V
2.	Sensor Resistance, Rs	10 k- 90k Ω in air
3.	Sensitivity(change ratio of Rs)	0.3-0.6
4.	Typical Detection Range	1-10 ppm of H_2

The concept is still the same as previous but extra requirement needed to be considered. Gas sensor is measured in term of the ratio between sensor resistance in displayed gas and sensor resistance in fresh air (Rs/Ro). For TGS 2600, Ro is at the range of 32.8- 39.6 kΩ.

The calculation involved for converting analog to digital values of gas sensor will be based on the following steps:

Step 1:

Rs/Ro can be verified by using the formula given in the datasheet

$$\text{Rs} = \frac{Vc - R_L}{Vout} - R_L$$

As mentioned before the value of Rs will vary from 10-90 kΩ. V_{out} need to be determined in order to find Rs.

Step 2:

The value chosen for Ro is 32.8 kΩ. This value meets some condition stated at the datasheet where at the gas detection range of 1-10 ppm, gas sensor will be more sensitive when sensor resistance ratio is about 0.3-0.6 Rs/Ro. It can be seen clearly from Figure 3.7 provided in the datasheet (red line area).

The value of Rs is then divided with the chosen value of Ro

When Ro=32.8 kΩ

$\frac{\text{Rs}}{\text{Ro}} = \frac{10k}{32.8k} = 0.30$ and $\frac{\text{Rs}}{\text{Ro}} = \frac{90k}{32.8k} = 2.74$

When Ro=39.6 kΩ

$\frac{\text{Rs}}{\text{Ro}} = \frac{10k}{39.6k} = 0.25$ and $\frac{\text{Rs}}{\text{Ro}} = \frac{90k}{39.6k} = 2.27$

So, it can be conclude that the sensor resistance ratio is 0.30 which in the range of 0.3-0.6 if Ro = 32.8 kΩ.

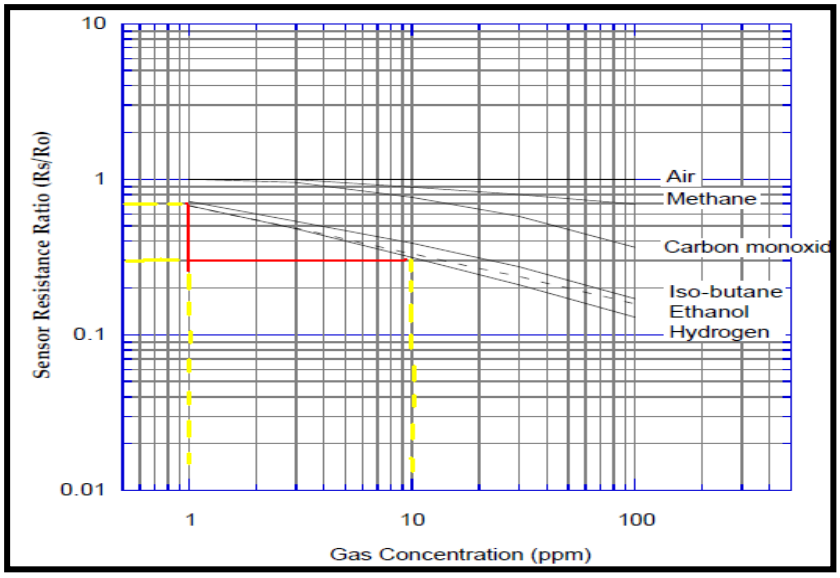


Figure 3.7: Gas Sensor Sensitivity Characteristic**.**

Step 3:

The last step will be the determination of V_{out}. Due to the 10 bit of analog to digital converter in PIC18F452, the resolution of 4.75V will be

$$V_{out} = adc_{read} \text{ x} \frac{4.75}{1023}$$

This equation will complete the finding of Rs which is

$$\text{Rs} = adc_{read} \text{ x} \frac{Vc - R_L}{adc_{read} \text{ x } \frac{4.75}{1023}} \text{ x } R_L$$

The value of R_L is 47kΩ (stated in datasheet)

Step 4

Based on Table 2.1, the Rs/Ro will be limited to 0.35 represents a dangerous limit of contaminant gaseous in the air and automatically set the alarm system.

```
Lcd8_Out(1,1, "Gas: ");                 //text at lcd, first row and column

adc_rd  = ADC_read(0);                  //get ADC value from 1 channel
val = (unsigned double)(adc_rd);
rs = ((1023*47000)/val)-47000;
rs /= 1000;
rs = rs/32.8;

 if(rs<0.35){                           //alert system
      buzzGas = 1;
      LED_gas = 1;
    }
    else{
      buzzGas = 0;
      LED_gas = 0;
    }

   displayNum(rs,1,5);                  //display value
    Lcd8_Out(1,12, "Rs/Ro");
}
```

Figure 3.8: Source Code of Gas Sensor

3.5.3 Programming for Inter-Integrated Circuit (I2C)

To enable the communication between this project and master-controller some programming need to be done. A unique address is created for slave in order to communicate with master-controller. This communication is based on the control, START and STOP signal by master while slaves simply listen to the bus and react on controls and data sent depending on the unique address.

```
SSPADD =  Addy;              // Get address (7bit). Lsb is read/write flag
SSPCON1 = 0b00110110;        // Set to I2C slave with 7-bit address
PIE1.SSPIE = 1;             // enable SSP interrupts
INTCON = 0xC0;
```

Figure 3.9: Source Code for I2C Unique Address

3.6 Component List and Total Cost

All the components used in this project are listed in order to finalize the total cost. Table 3.3 will show the complete components along with each price per item.

Table 3.3: List of Components and Cost

No	Component	Price Per Unit (RM)	Quantity	Price (RM)
1	Starter Kit Set	39.00	1	39.00
2	PIC18F452	35.00	1	35.00
3	HSM-20G	50.00	1	50.00
4	TGS 2600	46.00	1	46.00
5	PICUSB programmer	49.00	1	49.00
6	Adapter	15.00	1	15.00
7	LCD(2x16 character)	25.00	1	25.00
8	Resistor	0.25	4	1.00
9	Capacitor	0.50	1	0.50
10	Strip Board	4.00	1	4.00
11	Jumper	4.00		4.00
12	LED	0.25	2	0.50
13	Buzzer	3.00	1	3.00
14	Connector	0.50	2 set	1.00
Total				273.00

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter explains about the result achieved in this project and few discussions regarding on problem solving during the process of completing this. Final project overview such as block and flow diagram were included.

4.2 Project Description

This project was based on the objectives stated before which is designing a monitoring system for humidity and gas sensor (analog sensor). This sensor node will sense analog data, convert and displayed into digital. Furthermore, this system will enable 2-wire communication between devices which is I2C and complete with alarm system. After all the phases were completed, the whole project can be summarized as shown by Figure 4.1.

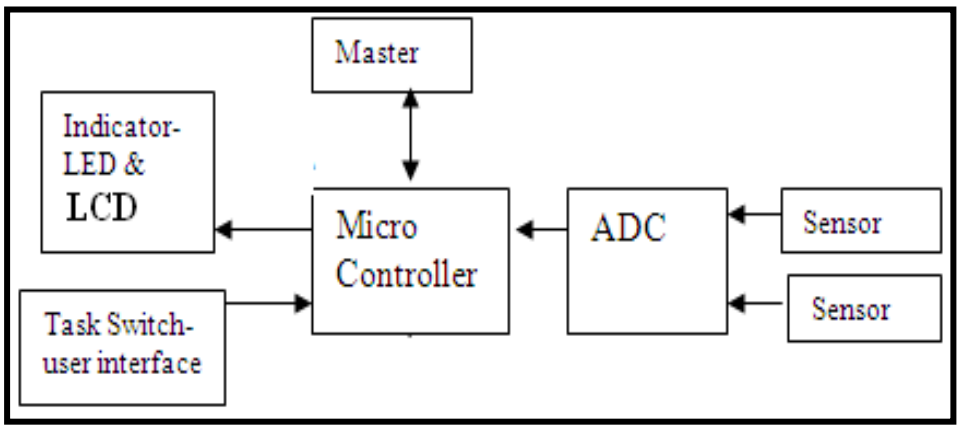


Figure 4.1: Block Diagram of Whole Project

4.3 Project Results

This project includes hardware and software parts. These two parts were highly dependent where the success of the whole project involves the interfacing between sensor nodes and programming of microcontroller.

The most critical element in designing hardware is to built up the component connection. For the first attempt, circuit is set up at proto board based on the theory gathered by some literature reviews done. This temporary circuit was use to make

sure the connection is working and to avoid errors. Then, the real connection was sketch using Strip board Designer 1.0 and directly soldered at strip board shown in Figure 4.2.

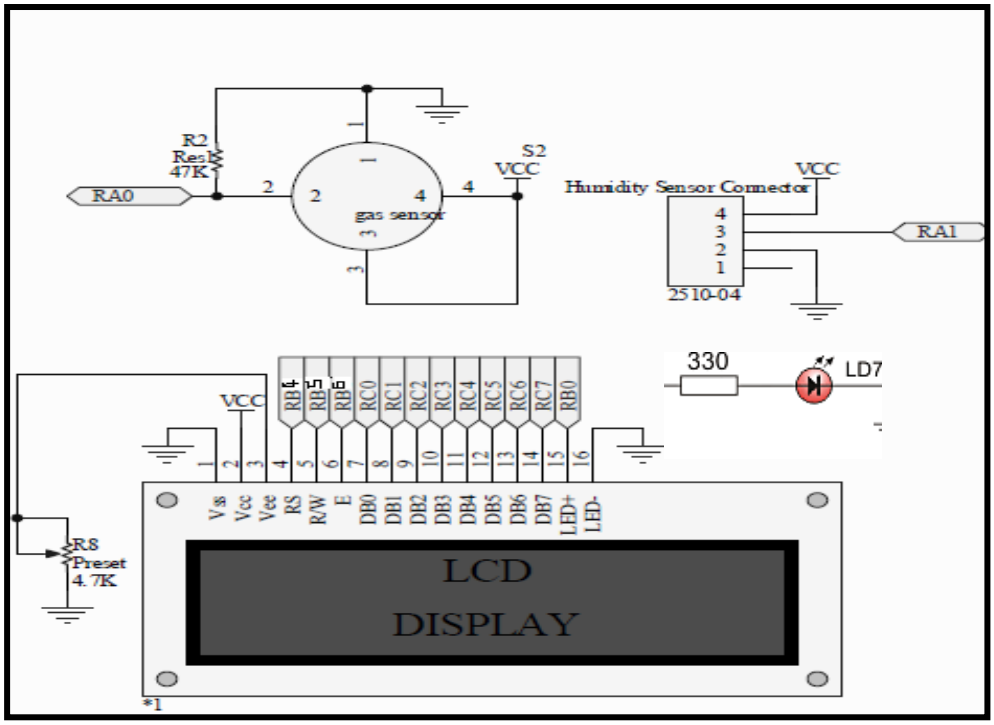


Figure 4.2: The Major Connection of Component

To continue with software part, some pins of the microcontroller were defined in order to permit programming installation. The program was then written by using C language, MikroC. MikroC is simple and flexible software that provides information, basic tutorial and details libraries which makes it easier to be used. This program was then installed to PIC18F452 by using PIC kit programmer.

Through programming, the flow of this system was created. Basically, this project will sense humidity and contaminants gaseous in the air. The monitoring system will continue working either in or out of the specified range. Based on the programmed, it will automatically monitor, show values and conditions whether it is danger or normal readings and finally produced alarm when the values were out of specified range.

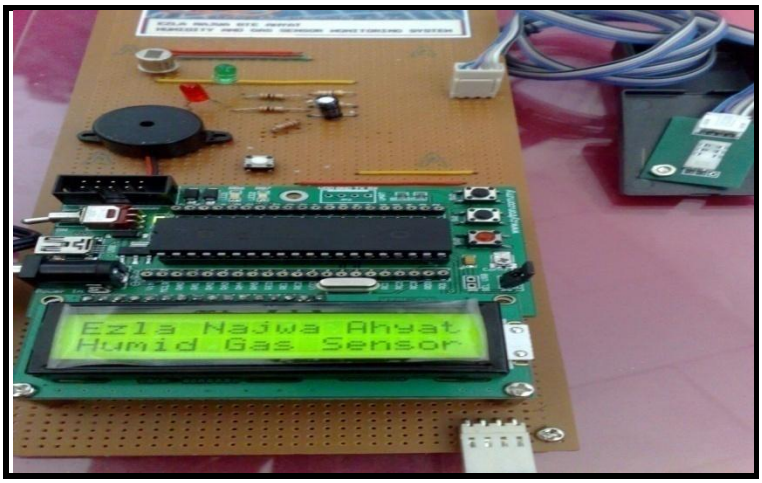


Figure 4.3: Complete Hardware of Humidity and Gas Sensor Monitoring system

‘

By pressing reset button, the whole system will be reset and display both humidity and gas sensor value. If a buzzer sound was generated, the sensor which is out of range will be indicated by LED as shown as Figure 4.4.



Figure 4.4: Humidity and Gas Reading

To enable or disable buzzer, user have to push switch 1 as shown in Figure 4.5.

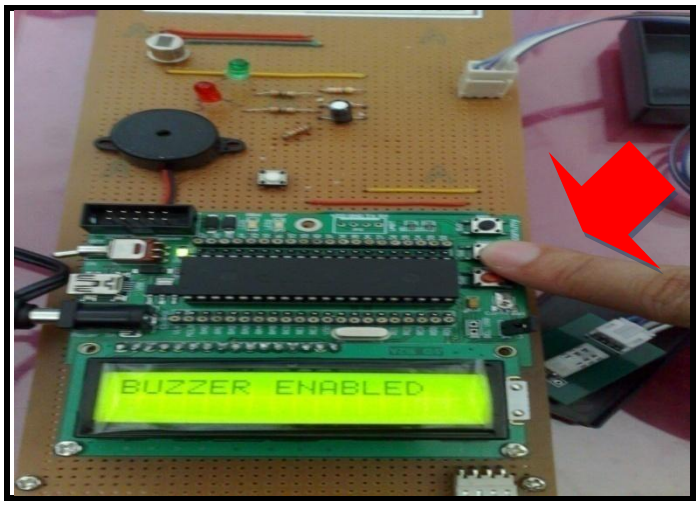


Figure 4.5: Enabled/Disabled Buzzer

Figure 4.6 shows the status of each sensor's reading. The user will have to push switch 2. It will display normal (in range) or danger (out range) and to choose displayed sensor, user have to push switch 2(work in toggle mode).

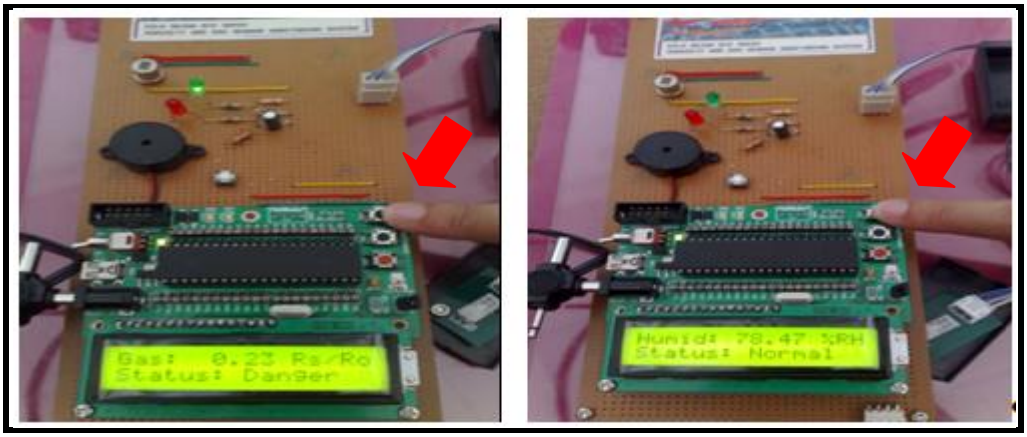


Figure 4.6: Status of each sensor

Additionally, the connection of I2C is set up, sensors will communicate or transfers data if requested by master while sensing the data at the same time.

4.4 Project Discussion

No project will work without any mistakes and errors. To achieve this, certain action was taken. The completed hardware for sensor monitoring was checked by using continuity test. This is to ensure the connection done was accurate and the project is working with the specification. The programming need to be totally reviewed to ensure no bugs distracts the whole system.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This section will conclude the whole project and future recommendations for students or individual who is interested in continuing this project as their research.

5.2 Conclusion

Sensor technologies are developing fast with time and innovative technology. This field is one of the most interesting area to be discovered continuously. So many new sensor designs will come out and develop in future hence increasing the competitiveness between researchers.

This project is a minor contribution to instill the interest of people. It also gives a very basic understanding which will be a good learning process to the beginner. The hardware and software part of this project is working based on the objectives mentioned before and based on the conduct test or experiments held towards the end this project, the results are stable and working as it should be.

5.3 Recommendation

Further research is recommended to improve the reliability of this project especially in communication. This project use wired communication as the medium to communicate due to some limitations of budget and the function which requires no spacious and heavy communication. To improve it, a wireless communication can be set up to broaden the ability of monitoring system communication in spacious place and wide spectrum.

For further improvement, the research can add some features that enable the master controller to control the sensing element. This is to guarantee there is a reliable back-up system for this project if any emergency occurs. In addition, this system was able to monitor and control air condition for various implementations with some system alterations.

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APPENDIX A

HSM-20G USER MANUAL

2. PRODUCT SPECIFICATION

2.1 The specifications of humidity sensor

No.	Specification	Humidity Sensor
1.	Input voltage range	DC 5.0±0.2 V
2.	Output voltage range	DC 1.0—3.0 V
3.	Measurement Accuracy	±5% RH
4.	Operating Current (Maximum)	2mA
5.	Storage RH Range	0 to 99% RH
6.	Operating RH Range	20 to 95% (100% RH intermittent)
7.	Transient Condensation	< 3%RH
8.	Temperature Range: - Storage - Operating	 20℃ to 70℃ 0℃ to 50℃
9.	Hysteresis (RH @ 25℃)	MAX 2%RH
10.	Long Term Stability (typical drift per year)	±1.5%
11.	Linearity	Linearity
12.	Time Response (63% step change)	1 min
13.	Dimensions (L*W)	30mm*22mm

Table 2.1

2.2 Pin Definitions and Ratings

Pin	Name	Function
-	GND	Connects to Ground
H	Humudity Output	Voltage analog output.
+	Vcc	Connects to Vcc (+5V)
T	Temperature Output	Voltage analog output.

Note: Please refer Getting Started for the pin connection

Table 2.2

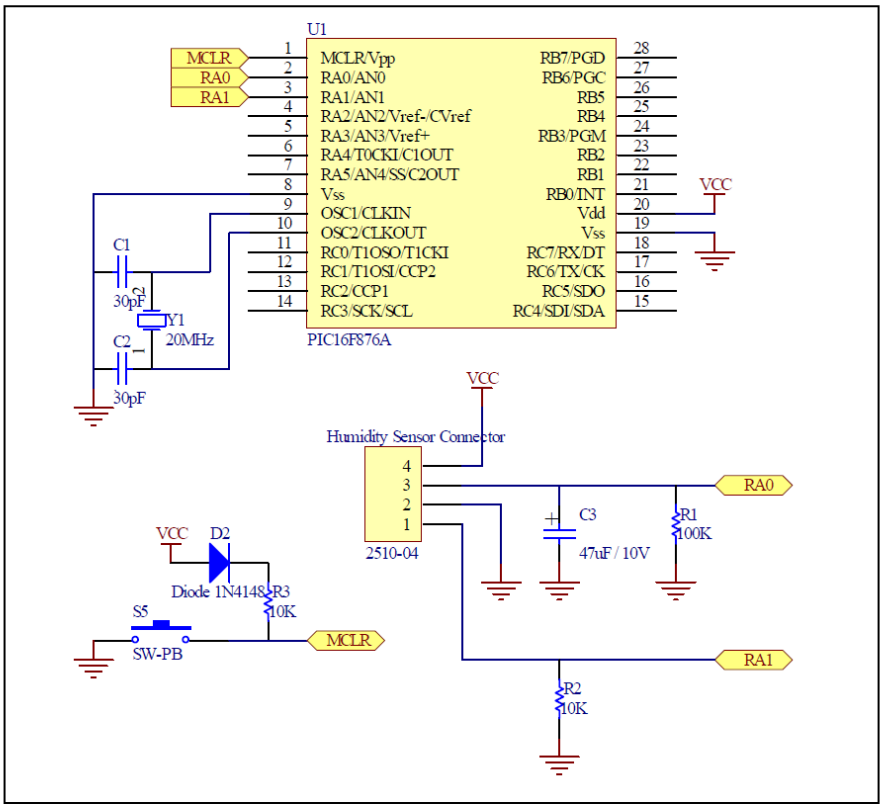


Figure 4.4

Figure 4.4 shows the connection of humidity sensor to PIC microcontroller, which is PIC16F876A. The voltage supply (VCC) of the circuit is 5V. The voltage analog output of humidity (H) is connected to RA0 (AN0) while the voltage analog output of temperature (T) is connected to RA1 (AN1). However, user is free to choose any type of microcontroller, just have to make sure that both of the voltage analog outputs of humidity sensor are connected to the ADC (Analog Digital Convector) pin of that particular microcontroller. For more details of example application, please refer Cytron product, PR15 which can be found in the web site: www.cytron.com.my .

APPENDIX B

TGS 2600 USER MANUAL

FIGARO

PRODUCT INFORMATION

TGS 2600 - for the detection of Air Contaminants

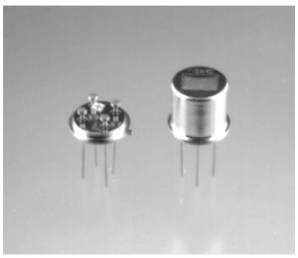
Features:

* Low power consumption
* High sensitivity to gaseous air contaminants
* Long life and low cost
* Uses simple electrical circuit
* Small size

Applications:

* Air cleaners
* Ventilation control
* Air quality monitors

The sensing element is comprised of a metal oxide semiconductor layer formed on an alumina substrate of a sensing chip together with an integrated heater. In the presence of a detectable gas, the sensor's conductivity increases depending on the 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.



The **TGS 2600** has high sensitivity to low concentrations of gaseous air contaminants such as hydrogen and carbon monoxide which exist in cigarette smoke. The sensor can detect hydrogen at a level of several ppm. Figaro also offers a microprocessor (FIC93619A) which contains special software for handling the sensor's signal for appliance control applications.

Due to miniaturization of the sensing chip, TGS 2600 requires a heater current of only 42mA and the device is housed in a standard TO-5 package.

The figure below represents typical sensitivity characteristics, all data having been gathered at standard test conditions (see reverse side of this sheet). The Y-axis is indicated as *sensor resistance ratio* (Rs/Ro) which is defined as follows:

Rs = Sensor resistance in displayed gases at various concentrations

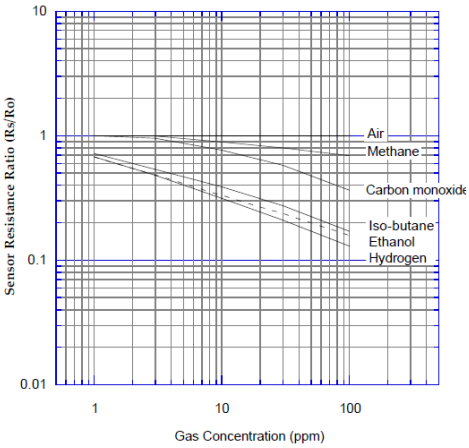
Ro = Sensor resistance in fresh air

The figure below represents typical temperature and humidity dependency characteristics. Again, the Y-axis is indicated as *sensor resistance ratio* (Rs/Ro), defined as follows:

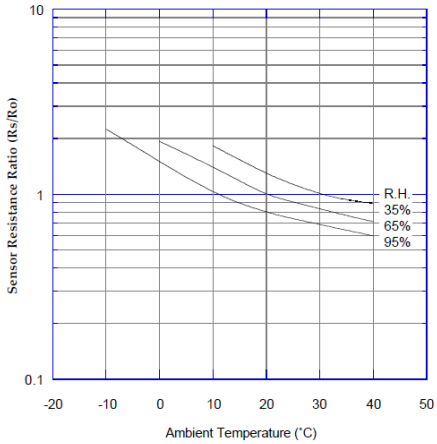
Rs = Sensor resistance in fresh air at various temperatures/humidities

Ro = Sensor resistance in fresh air at 20°C and 65% R.H.

Sensitivity Characteristics:



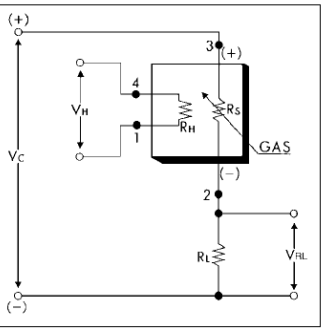
Temperature/Humidity Dependency:



IMPORTANT NOTE: OPERATING CONDITIONS IN WHICH FIGARO SENSORS ARE USED WILL VARY WITH EACH CUSTOMER'S SPECIFIC APPLICATIONS. FIGARO STRONGLY RECOMMENDS CONSULTING OUR TECHNICAL STAFF BEFORE DEPLOYING FIGARO SENSORS IN YOUR APPLICATION AND, IN PARTICULAR, WHEN CUSTOMER'S TARGET GASES ARE NOT LISTED HEREIN. FIGARO CANNOT ASSUME ANY RESPONSIBILITY FOR ANY USE OF ITS SENSORS IN A PRODUCT OR APPLICATION FOR WHICH SENSOR HAS NOT BEEN SPECIFICALLY TESTED BY FIGARO.

Basic Measuring Circuit:

The sensor requires two voltage inputs: heater voltage (V_H) and circuit voltage (V_C). The heater voltage (V_H) is applied to the integrated heater in order to maintain the sensing element at a specific temperature which is optimal for sensing. Circuit voltage (V_C) is applied to allow measurement of voltage (Vout) across a load resistor (R_L) which is connected in series with the sensor. DC voltage is required for the circuit voltage since the sensor has a polarity. A common power supply circuit can be used for both V_C and V_H to fulfill the sensor's electrical requirements. The value of the load resistor (R_L) should be chosen to optimize the alarm threshold value, keeping power consumption (P_S) of the semiconductor below a limit of 15mW. Power consumption (P_S) will be highest when the value of Rs is equal to R_L on exposure to gas.



Specifications:

Model number			TGS 2600	
Sensing element type			D1	
Standard package			TO-5 metal can	
Target gases			Air contaminants	
Typical detection range			1 ~ 10 ppm of H_2	
Standard circuit conditions	Heater voltage	V_H	5.0±0.2V DC/AC	
	Circuit voltage	V_C	5.0±0.2V DC	Ps ≤ 15mW
	Load resistance	R_L	Variable	Ps ≤ 15mW
Electrical characteristics under standard test conditions	Heater resistance	R_H	approx. 83Ω at room temp. (typical)	
	Heater current	I_H	42±4mA	
	Heater power consumption	P_H	210mW	V_H=5.0V DC
	Sensor resistance	Rs	10k~90kΩ in air	
	Sensitivity (change ratio of Rs)		0.3~0.6	Rs (10ppm of H_2) / Rs (air)
Standard test conditions	Test gas conditions		normal air at 20±2°C, 65±5%RH	
	Circuit conditions		V_C = 5.0±0.01V DC V_H = 5.0±0.05V DC	
	Conditioning period before test		7 days	

The value of power consumption (P_S) can be calculated by utilizing the following formula:

$$P_S = \frac{(V_C - Vout)^2}{R_S}$$

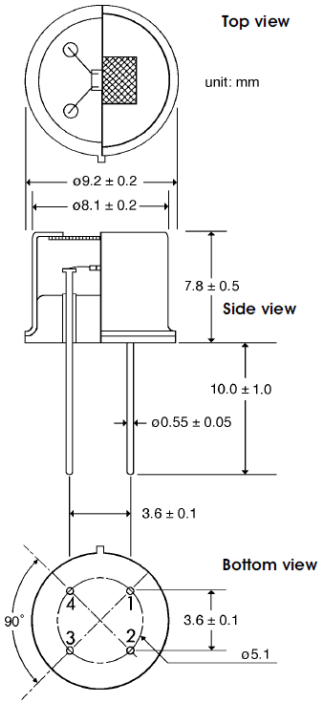
Sensor resistance (Rs) is calculated with a measured value of Vout by using the following formula:

$$R_S = \frac{V_C \times R_L}{Vout} - R_L$$

For information on warranty, please refer to Standard Terms and Conditions of Sale of Figaro USA Inc.

REV: 09/01

Structure and Dimensions:



Pin connection:
1 : Heater
2 : Sensor electrode (-)
3 : Sensor electrode (+)
4 : Heater

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APPENDIX C

PIC18F452 USER MANUAL

17.0 COMPATIBLE 10-BIT ANALOG-TO-DIGITAL CONVERTER (A/D) MODULE

The Analog-to-Digital (A/D) converter module has five inputs for the PIC18F2X2 devices and eight for the PIC18F4X2 devices. This module has the ADCON0 and ADCON1 register definitions that are compatible with the mid-range A/D module.

The A/D allows conversion of an analog input signal to a corresponding 10-bit digital number.

The A/D module has four registers. These registers are:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register 0 (ADCON0)
- A/D Control Register 1 (ADCON1)

The ADCON0 register, shown in Register 17-1, controls the operation of the A/D module. The ADCON1 register, shown in Register 17-2, configures the functions of the port pins.

REGISTER 17-1: ADCON0 REGISTER

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0
ADCS1	ADCS0	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	—	ADON
bit 7							bit 0

bit 7-6 **ADCS1:ADCS0:** A/D Conversion Clock Select bits (ADCON0 bits in **bold**)

ADCON1 <ADCS2>	ADCON0 <ADCS1:ADCS0>	Clock Conversion
0	**00**	Fosc/2
0	**01**	Fosc/8
0	**10**	Fosc/32
0	**11**	FRC (clock derived from the internal A/D RC oscillator)
1	**00**	Fosc/4
1	**01**	Fosc/16
1	**10**	Fosc/64
1	**11**	FRC (clock derived from the internal A/D RC oscillator)

bit 5-3 **CHS2:CHS0:** Analog Channel Select bits
000 = channel 0, (AN0)
001 = channel 1, (AN1)
010 = channel 2, (AN2)
011 = channel 3, (AN3)
100 = channel 4, (AN4)
101 = channel 5, (AN5)
110 = channel 6, (AN6)
111 = channel 7, (AN7)

Note: The PIC18F2X2 devices do not implement the full 8 A/D channels; the unimplemented selections are reserved. Do not select any unimplemented channel.

bit 2 **GO/$\overline{\text{DONE}}$:** A/D Conversion Status bit
When ADON = 1:
1 = A/D conversion in progress (setting this bit starts the A/D conversion which is automatically cleared by hardware when the A/D conversion is complete)
0 = A/D conversion not in progress

bit 1 **Unimplemented:** Read as '0'

bit 0 **ADON:** A/D On bit
1 = A/D converter module is powered up
0 = A/D converter module is shut-off and consumes no operating current

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
- n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

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REGISTER 17-2: ADCON1 REGISTER

R/W-0	R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	ADCS2	—	—	PCFG3	PCFG2	PCFG1	PCFG0
bit 7							bit 0

bit 7 **ADFM:** A/D Result Format Select bit
1 = Right justified. Six (6) Most Significant bits of ADRESH are read as '0'.
0 = Left justified. Six (6) Least Significant bits of ADRESL are read as '0'.

bit 6 **ADCS2:** A/D Conversion Clock Select bit (ADCON1 bits in **bold**)

ADCON1 <ADCS2>	ADCON0 <ADCS1:ADCS0>	Clock Conversion
0	00	Fosc/2
0	01	Fosc/8
0	10	Fosc/32
0	11	FRC (clock derived from the internal A/D RC oscillator)
1	00	Fosc/4
1	01	Fosc/16
1	10	Fosc/64
1	11	FRC (clock derived from the internal A/D RC oscillator)

bit 5-4 **Unimplemented:** Read as '0'

bit 3-0 **PCFG3:PCFG0:** A/D Port Configuration Control bits

PCFG <3:0>	AN7	AN6	AN5	AN4	AN3	AN2	AN1	AN0	VREF+	VREF-	C / R
0000	A	A	A	A	A	A	A	A	VDD	VSS	8 / 0
0001	A	A	A	A	VREF+	A	A	A	AN3	VSS	7 / 1
0010	D	D	D	A	A	A	A	A	VDD	VSS	5 / 0
0011	D	D	D	A	VREF+	A	A	A	AN3	VSS	4 / 1
0100	D	D	D	D	A	D	A	A	VDD	VSS	3 / 0
0101	D	D	D	D	VREF+	D	A	A	AN3	VSS	2 / 1
011x	D	D	D	D	D	D	D	D	—	—	0 / 0
1000	A	A	A	A	VREF+	VREF-	A	A	AN3	AN2	6 / 2
1001	D	D	A	A	A	A	A	A	VDD	VSS	6 / 0
1010	D	D	A	A	VREF+	A	A	A	AN3	VSS	5 / 1
1011	D	D	A	A	VREF+	VREF-	A	A	AN3	AN2	4 / 2
1100	D	D	D	A	VREF+	VREF-	A	A	AN3	AN2	3 / 2
1101	D	D	D	D	VREF+	VREF-	A	A	AN3	AN2	2 / 2
1110	D	D	D	D	D	D	D	A	VDD	VSS	1 / 0
1111	D	D	D	D	VREF+	VREF-	D	A	AN3	AN2	1 / 2

A = Analog input D = Digital I/O
C/R = # of analog input channels / # of A/D voltage references

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
- n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

Note: On any device RESET, the port pins that are multiplexed with analog functions (ANx) are forced to be an analog input.

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To calculate the minimum acquisition time, Equation 17-1 may be used. This equation assumes that 1/2 LSb error is used (1024 steps for the A/D). The 1/2 LSb error is the maximum error allowed for the A/D to meet its specified resolution.

EQUATION 17-1: ACQUISITION TIME

$$\begin{aligned} T_{ACQ} &= \text{Amplifier Settling Time} + \text{Holding Capacitor Charging Time} + \text{Temperature Coefficient} \\ &= T_{AMP} + T_C + T_{COFF} \end{aligned}$$

EQUATION 17-2: A/D MINIMUM CHARGING TIME

$$\begin{aligned} V_{HOLD} &= (V_{REF} - (V_{REF}/2048)) \bullet (1 - e^{(-T_C/C_{HOLD}(R_{IC} + R_{SS} + R_S))}) \\ \text{or} \\ T_C &= -(120\ pF)(1\ k\Omega + R_{SS} + R_S)\ \ln(1/2048) \end{aligned}$$

Example 17-1 shows the calculation of the minimum required acquisition time, TACQ. This calculation is based on the following application system assumptions:

- CHOLD = 120 pF
- Rs = 2.5 kΩ
- Conversion Error ≤ 1/2 LSb
- VDD = 5V → Rss = 7 kΩ
- Temperature = 50°C (system max.)
- VHOLD = 0V @ time = 0

EXAMPLE 17-1: CALCULATING THE MINIMUM REQUIRED ACQUISITION TIME

$T_{ACQ} = T_{AMP} + T_C + T_{COFF}$

Temperature coefficient is only required for temperatures > 25°C.

$T_{ACQ} = 2\ \mu s + T_C + [(Temp - 25°C)(0.05\ \mu s/°C)]$

$$\begin{aligned} T_C &= -C_{HOLD}(R_{IC} + R_{SS} + R_S)\ \ln(1/2048) \\ &= -120\ pF\ (1\ k\Omega + 7\ k\Omega + 2.5\ k\Omega)\ \ln(0.0004883) \\ &= -120\ pF\ (10.5\ k\Omega)\ \ln(0.0004883) \\ &= -1.26\ \mu s\ (-7.6246) \\ &= 9.61\ \mu s \end{aligned}$$

$$\begin{aligned} T_{ACQ} &= 2\ \mu s + 9.61\ \mu s + [(50°C - 25°C)(0.05\ \mu s/°C)] \\ &= 11.61\ \mu s + 1.25\ \mu s \\ &= 12.86\ \mu s \end{aligned}$$