DEVELOPMENT OF PORTABLE SENSOR ARRAY SYSTEM FOR THE AIR QUALITY MEASUREMENT

R. Wagiran[1], S. L. Loh[2], I. Ahmad[3] and A.B. Salleh[1]
[1]Institute of Bioscience, Universiti Putra Malaysia, Serdang, Malaysia.
[2]Dept. of Electrical and Electronic Engineering, Universiti Putra Malaysia, Serdang, Malaysia.
[3]Dept. of Electrical, Electronics and System Engineering, Universiti Kebangsaan Malaysia, Bangi, Malaysia
E-mail: rwagiran@eng.upm.edu.my

ABSTRACT

The development of sensor array system for the air quality measurement based at least of two sensors are discussed. The system consists of three elements namely sensory for detection of the target gas, data acquisition via a micro controller and the display of target gas concentrations. The results show that the sensitivity for cigarette smoke was high, for insecticides was very high and for coffee was low. Hence the response was quick for cigarette and insecticides. As conclusion the sensor array system is able to detect the presence of carbon monoxide in the air.

Key words: *Sensor Array, Data Acquisition, Programmable Integrated Circuits, Air Quality*

INTRODUCTION

Gas chemical sensors respond to the presence of gases. Ideally, one would prefer to use selective sensors, with each sensor responding to the presence of a unique gas. In reality, gas chemical sensors respond to multiple gases. For example, the resistance of metal oxide sensors can be altered due to changes in the concentrations of O2, CO, CO2, H2O, CH4, and other hydrocarbons. In this case, multiple sensors with orthogonal responses are necessary to identify the components of a gaseous mixture. When used simultaneously, such a collection of sensors is commonly called a sensor array [1,2,3].

A gas sensor array consists of two or more sensors that respond to the presence of different gases. Most often, a given sensor will not be selective. It will respond to the presence of more than one type of gas. Thus an array of sensors is necessary to extract information about the types and quantities of gases present. To use a sensor array to detect gases, the response of each sensor to the various gases present must be known. Then the collective response of the array can be translated into quantitative information about the composition of a mixture of gases [4]. After understanding the definition of the gas sensor array, a system based on this concept is developed. At the beginning, air quality sensor which can detect multiple toxic gas such as nicotine, hydrogen sulphide, ammonia, trimethylamine, toluene, methylmelcaptan, acetone, carbon monoxide and others contaminants is being used. If the sensor is giving any response, user can switch to others sensors which can sense and identify a specific toxic gas. For example, nitrogen sensor can detect existence of gas nitrogen excellently while propane sensor can give response quickly when it senses the gas propane. However, only the carbon monoxide sensor is being used here for initial study.

SYSTEM DESIGN METHODOLOGY

Generally, the purpose of this project is to design and develop a sensor array system that can detect contaminants in the air. Two gas sensors the carbon monoxide sensor and air quality sensor is involved. Besides, an analog to digital (A/D) converter is used to transmit the analog input from sensor to the PIC chip, a LCD to display the output and an alarm system to draw user's attention when the level of toxic gas exceed critical value. Hardware design methodology will cover the full circuit implementation of the sensor array system while the software design is to develop a set of instruction that can determine the behavior of the system. Meanwhile, the software is being developed using the MPLAB assembly language for PIC programming using PICStart Plus Programmer. PIC is a type of programmable ICs. The programmable design approach could offer several benefits on system development. Design time is frequently less, giving shorter time to market. Equipment can be smaller and lighter and hence cheaper to manufacture or more advance functionality could be provided without going through the complicated fabrication processes. Apart from that, lower component count means lower cost and fewer connections, and hence greater reliability.

Air Quality Sensor

For more than a century, severe air pollution incidents in cities have shown that breathing dirty air can be dangerous and, at times, deadly. Since then, many nations have adopted ambient air quality standards to safeguard the public against the most common and damaging pollutants. These include sulfur dioxide, suspended particulate matter, ground-level ozone, nitrogen dioxide, carbon monoxide, and lead all of which are tied directly or indirectly to the combustion of fossil fuels. Although substantial investments in pollution control in some industrialized countries have lowered the levels of these pollutants in many cities, poor air quality is still a major concern throughout the industrialized world. Table 1 below shows the results using EPA's Air Quality Index (AQI), a uniform index that provides general information to the public about air quality and associated health effects [5].

In this system, an air quality sensor is being used to detect multiple toxic gases in our environment. The semiconductor type gas sensor NAP-11AS have excellent sensitivity to various smells generated in normal living environment, such nicotine ($C_{10}H_{14}N_2$), hydrogen sulphide(H_2S), ammonia (NH_3), trimethylamine $(CH_3)_3N$, scatol (C_9H_9N), indoor (C_8H_7N), acetic acid(CH_3COOH), toluene(C_5H_5N), methylmelcaptan(CH_3SH), acetoaldehyde (CH_3CHO), formaldehyde (HCOH), acetone $(CH_3)_2CO$, carbon monoxide (CO) and etc. NAP-11AS is widely used for detection and control units for ventilators, air purifiers, and air pollution detection equipment. In the presence of a detectable gas, the sensor's output voltage will decrease depend on the gas concentration in the air.

Table 1: Air quality index [5]

Air quality levels of health concern	Numerical value (ppm)	Remarks
Good	0-50	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	51-100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for sensitive groups	101 – 150	Members of sensitive group may experience the health effects. The general public is not likely to be affected.
Unhealthy	151 – 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very unhealthy	201 – 300	Health alert: everyone may experience more serious health effects.
Hazardous	>300	Health warnings of emergency conditions. The entire population is more likely to be affected.

Carbon Monoxide Sensor

Carbon monoxide (CO) is a gas that can build up to dangerous levels indoors when fuel- burning devices are not properly operated, vented, or maintained. Because it has no odor, color or taste, CO cannot be detected by smell, taste, or sight. CO poisoning due to residential fuel-burning devices kills about 200 to 250 people every year in the United States according to the US Consumer Product Safety Commission estimates. In addition, they estimate that 8,000 to 15, 000 people each year are examined or treated in hospitals for non-fire related CO poisoning. Breathed over long periods of time, low levels of CO may also cause other illness. Refer to table 2 below for the details of carbon monoxide levels and their effects [5].

Semiconductor type as sensors NAP-11A is able to detect a low concentration CO gas generated by stoves or other heating equipment in rooms. NAP-11A is widely used as a controlling element for ventilating and air purifying apparatus which is useful in heated rooms especially in winter time. The output of the sensor is in voltage. When it senses the presentation of the carbon monoxide, the output voltage will started to decrease with the gas concentration getting higher, but it may not return to 0V because of the lower temperature of the element surface.

Table 2: CO levels and effects [5]

CO levels (ppm)	Effects
0	Desirable level
9	Maximum indoor air quality level
50	Maximum concentration for continuous exposure in any 8 hour period.
200	Slight headache, tiredness, nausea after 2-3 hours
300	Maximum short term exposure limit (15 minutes)
400	Frontal headache 1 to 2 hours, life threatening after 3 hours
1600	Headache, dizziness, nausea within 20 minutes. Can prove fatal within 1 hour
3200	Headache, dizziness, nausea within 10 minutes. Can prove fatal within 30 minutes

Analog-to-Digital Converter

PIC16F84 doesn't have built in A/D converter. An external A/D converter needs to be connected. The LTC1286/LTC1298, 12-bit, successive approximation sampling A/D converters was used since 12-bit conversion is an industrial standard. The converter is connected to the microcontroller via three lines: data, clock and CS (Chip Select). The CS line is used to select an input device, as it is possible to connect other input devices to the same lines of the microcontroller. The LTC1286 are permanently configured for unipolar only. The least significant bit of the ADC is 0.00122V (5V / 2^{12}). So, the voltage range from 4.9988 to 5V will be display as 4095. Table 3 simplifies the output code for the ADC.

Table 3: The output coding

Code	Input voltage	Input voltage Vref=5V)
1111 1111 1111	Vref-1LSB	4.99878V
1111 1111 1110	Vref-1LSB	4.99756V
1111 1111 1101	Vref-1LSB	4.99634V
.	.	.
.	.	.
.	.	.
0000 0000 0001	1LSB	0.00122V
0000 0000 0000	0V	0V

LCD Display

LCD display is used to display the information from the A/D converter. PIC microcontroller does not have video display. Hence, an alphanumeric LCD display will be connected externally to provide a useful interface for the user. The LCD will get the data from the 12-bit A/D converter which responsible getting analog input from the sensor and display the output in unit of voltage. Type of LCD display used for this project is Hitachi 44780. LCD displays designed around Hitachi's LCD HD44780 module, are inexpensive, easy to use, and it is even possible to produce a readout using the 8 x 80 pixels of the display. Hitachi LCD displays have a standard ASCII set of characters plus Japanese, Greek and mathematical symbols.

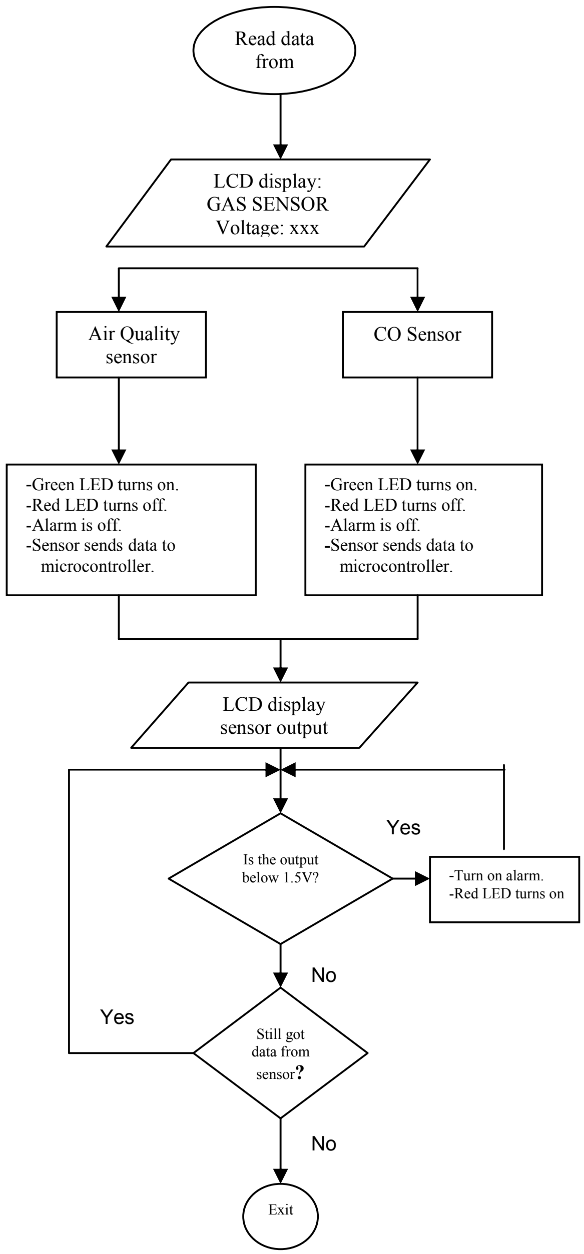

Figure 1: Programming Method

Software Programming

In order for the microcontroller to function, a series of program need to be done. It starts with microcontroller configuration before initialization of the I/O ports. After that, the messages will display on the LCD screen. The user then can select the system by using the switch. The green LED of corresponding system will ON if being selected. In contrast, the remains system LED will be set OFF. Then, the input from the selected sensor will be display on the LCD.

The values (measure in voltage) will start to decrease if the gas increases in concentration. Once the voltage drop to 1500 (1.8V), the beeper will be activated to audible alert the user. At the same time, the red LED will be turn on the give visually warning to the user. The flow chart in Figure 1 shows the software programming method. Absolute code is the default output from MPASM assembler. When a source file is assembled in this manner, all values used in the source file must be defined within that source file, or in files that have been explicitly included. If assembly proceeds without errors, a HEX file will be generated, containing the executable machine code for the target device [6,7]. This file can then be used in conjunction with a device programmer to program the microcontroller.

SYSTEM TESTING

After the hex file of has been downloaded into the PIC16F84 chip, the circuit as shown in the Figure 2 is constructed. This follows by a series of testing and debugging.

The system was tested using cigarette smoke, putrid smell, insecticides, cooking odors, organic solvent smells and etc. At the beginning, the sensor was explored to the clean air. The LCD will display voltage: 4095 (equivalent to 5V). After the system became stabilize, release insecticides on the surface of the sensor. We can observe the output value of toxic gas that shown on the LCD display keeps decreasing from 4095 to nearly 2454 (≈3.0V). The response is almost similar if the cigarette smoke is being used. Experiment is repeated by using fried meat and coffee. Table below simplify the results obtained from the experiments.

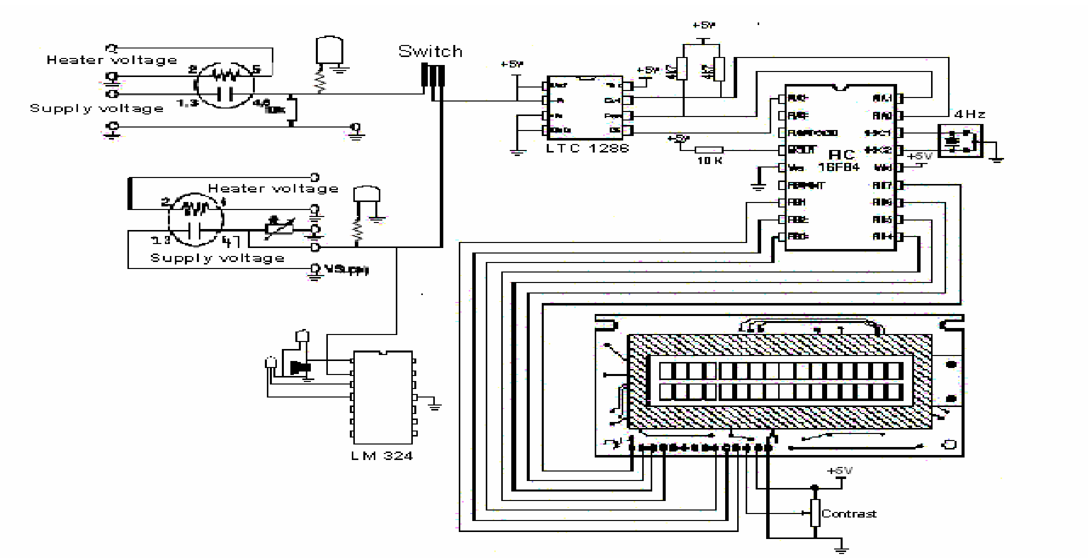

Figure 2: Overall system

The parameters of response and sensitivity are used to indicate indirectly the concentration of the toxic gas in the environment. Quick response means the display value will drop significantly from 4095 to a constant value in a short time. This means the concentration of the toxic gas is high. For example, the sensor gives fast response to cigarette smoke while very low response to coffee. This means the smoke is contributed high concentration of contaminants to the air. Somehow, the coffee didn't release any contaminant detected by the sensor. Sensitivity means the sensor is very susceptible to the spillage of the gas.

Table 4: Sensor response to sources

Source	Sensor response		Remarks
	Sensitivity	Response	
Cigarette smoke	High	Quick	5 pieces
Insecticides	Very high	Quick	Sprayed for 10s
Coffee	Low	-	4 cups

For the detection of CO, each time before testing, a heat cleaning treatment is required. 2-3 minutes heat cleaning treatment is sufficient in normal case. After all, the system was tested using cigarette smoke. At the beginning, LCD will display voltage: 4095 (equivalent to 5V). Once the CO gas form the smoke is trapped on the surface of the catalytic layer of the sensing body, the electrons are transferred to the semiconductor layer located under the catalyst layer. For this reason, a slightly longer exposure time is required compared to conventional sensors. However, because of the excellent gas selectivity of the catalyst layer, we can observe that the voltage display of this toxic gas shown on the LCD display keep decreasing from 4095 to nearly 500(≈0.6V) quickly. The experiment was repeated by using the oil mist and the voltage value drop from 4095 of 1300 (≈ 1.6V). These results show that the output voltage decreased when gas concentration increased. When the cigarette smokes is used, the LCD display droop to a lower value than when the oil mist is being used because the cigarette can release more CO gas than the other one. Table 5 simplified the experiments results.
For the alarm system, it will only be activated if the sensor output voltage dropped below 1.8V. At this moment, the beeper started to turn on. The red LED will be turn on also to visually warn the user. This is another precaution step to make sure that the user received the warning message if he or she is in a noisy environment that may cover over the audible alarm. The alarm will be off automatically once the environment became is clean and safe. Actually, the alarm critical value can be set by the user and it is now predefined as ≈1.8V (equivalent to 1500).

CONCLUSIONS

The system is accurate since stable temperature compensated sensors are involved. The two sensor array being developed can monitor over 10 combustible and toxic gases. The air quality sensor have excellent sensitivity to various gases included nicotine, hydrogen sulphide, ammonia, trimethylamine, scatol, indoor, acetic acid, toluene, methylmelcaptan, acetaldehyde, carbon monoxide, formaldehyde and acetone while the carbon monoxide sensor can detect the existence of CO gas precisely. At the beginning, the user can switch to the air quality sensor that can detect lots of contaminants for the checking purpose. If the air quality sensor is giving response, the user can switch to another system to check what types of contaminant is existed. This is the main concept of the sensor array system. But, only the carbon monoxide sensor is being used due to the reason of initial study. Somehow, the user can add or replace any other sensors to the system if they wish provided the sensor output is in the unit of voltage.

By using this device, the user will be feeling safe since they can perform the air quality checking at any new environment. Flexibility also inherent in the system because they can sense others targeted gases by changing a suitable and compatible sensor.

It is possible to expend the sensor array system by adding other sensor to the system as long as the sensor output is in the unit of voltage. Implementation of adding other sensor is a simple task because the present circuit is well designed. Just connect the analog output pin of the sensor to V_{in} (pin 2) of the A/D converter and the LCD will automatically display the value of the gas concentration.

Another improvement that can be made is from the point of software development. The array system can be design in order to have two different operation modes. Mode 1 can be classified as manual system while mode 2 is classified as automatic system. The mode 1 system is what the system can function at this moment. The user has to manually select which sensor's output to be displayed on LCD by using a switch. Meanwhile, the mode 2 is a new embedded system in which the LCD will automatically take turn to display each sensor's output. In this case, the user need not use the switch to select which sensor's output to be displayed at a particular time. This means, the user can select which mode they would like to use according to the situation.

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