

Design and Implement a Gas Pipeline Inspection System using Robotic Vehicle

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Abstract
Gas leak is an important safety issue in oil and gas production. During the past fifteen years, a considerable number of studies have been made into how to detect and localize gas leaks. Equipped with sensors measuring the point concentration of specific substances, a variety of mobile robots and technologies have been looking for gas sources. This paper presents a real-time system to detect abnormal events on gas pipes, by developing a data monitoring system to detect the gas levels and concentration using GAS leak detector system that is positioned on robotic vehicle (pioneer p3-dx) combined with modern communication technologies in terms of GPS to locate the robot in real-time accuracy of tracking process.
Keywords: Gas Detection, Robotic (outdoor seeker), EASYPEE (zigbee) board, GPS

1. Introduction

In our daily life the environment gives the most significant impact to their health issues. Therefore, environment and industry air quality issues are critically discussed to increase the awareness and responsibility regarding the threat on the environment towards public and workers health [1]. Most of the dangerous gas such as carbon monoxide (CO), Natural gas which is mostly (CH_4) and liquefied petroleum gas (LPG) are colorless and odorless compound that are produced by incomplete combustion. Therefore, gas detector device is needed in order to inform the safety situation continuously [2].

There are so many health, safety and finical issues related to dangerous gas through pipelines that vast for long distances. Thus, the atmosphere of the workplace should be regularly monitored and have some kind of control in order to maintain safe [3]. Many efforts in the industrial air control quality have impeded by the lack of science-based approaches to identify and assess atmosphere air quality and level of dangerous gas [4].

There is a popular misunderstanding that a mobile robot with gas sensors attached on its right and left could easily localize a gas source by steering toward the direction of the sensor showing the larger response. However, the airflows we encounter are almost always turbulent both in indoor and outdoor environments. Therefore, it is impossible to reliably determine the direction of the gas source by simply comparing the right and left gas sensor responses [5]. As a solution to this problem, a data monitoring system to detect the gas levels and concentration using gas leak detector system will be developed.

2. The proposed system specifications:

The proposed system will be an automatic system to indicate the levels of gas through the pipelines that passed through long and wide range areas in a real time by positioning seners on robotic vehicle (pioneer p3-dx) combined with modern communication technologies in terms of GPS to locate the robot tracking process, as shown in figure (1) :

Figure (1) : gas/odor source localization robot .

The data monitoring gas detector system will be consist of two parts the hardware part which consist of (robot movement vehicle, the sensing circuit, the wireless system GPS and the exhaust fan) while the software part will be concern by the (robotic programming and the electronic board programming of the sensors and the fan combined with the GUI of the monitoring system).

Mobile robots came in different size , shapes and capabilities .all robots are build of the same important parts , each of these parts are formed to be in compatibility with other parts to produce homogenous system to provide results with acceptable accuracy ; while the gas sensors that will be the nose of the system has been taken upon the job for detecting the levels of natural gas in addition to the Liquefied petroleum gas in the area around of the pipeline. The chemical composition of the natural gas in Iraq consist of CH4 (70-90 %), C_2H_6 (5-15 %) ,and C_3H_8 (> 5 %), because of that MQ-4 sensor has been selected for detecting the composition of gas.

The principle of the work can be explained briefly as the electrical resistance decrease when it comes in contact with the monitored gas. Sensitive material of MQ-4 gas sensor is SnO2, which work with lower conductivity in clean air. When the target combustible gas exist, the sensor's conductivity is higher along with the gas concentration rising. MQ4sensor 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 (V_{RL}) across a load resistor (RL) which is connected in series with the sensor.[12]

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 (RL) should be chosen to optimize the alarm threshold value, keeping power dissipation (PS) of the semiconductor below a limit of 15mW. Power dissipation (PS) will be highest when the value of Rs is equal to RL on exposure to gas. Figure (2) will present the MQ-4 circuit.

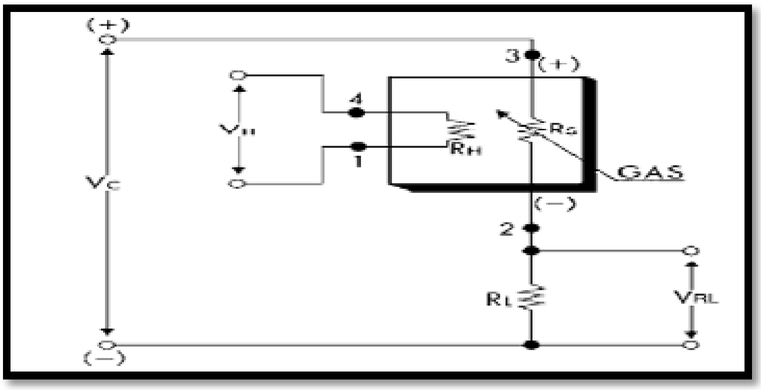


Figure (2) : Basic Measuring Circuit of MQ-4[12]

The ZigBee is a specification board for wireless personal area networks (WPANs) operating at 868 MHz, 902-928 MHz, and 2.4 GHz. ZigBee can communicate at speeds up to 250 Kbps while physically separated by distances of up to 50 meters in typical circumstances and greater distances in an ideal environment [6].. It is based on the 802.15 specification approved by the Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA). Figure (3) will show the zigbee module which will be used in the proposed system.

Figure (3) : view of EasyBee board .

While the Exhaust fan control board and its circuit diagram that shown in Figure (4) has been designed and Built to control the ventilating of the interior by drawing air from the interior and expelling it outside. This Project needs a system combination with exhaust fan as the precaution step before entering the dangerous level. Exhaust fan will suck out all the air inside the room or Box that had been installed with the system to the outside of it. Therefore, the air quality inside the box will maintain in the safe air quality.

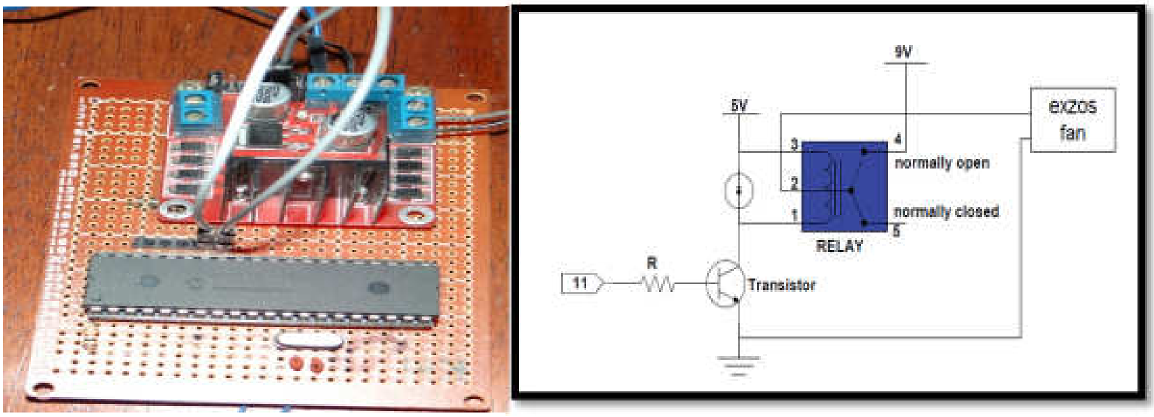


Figure (4) : The control board of the Exhaust fan with the connection circuit diagram .

Finally the GPS is a space-based radio navigation system which is managed and developed as a military force enhancement system and will continue to play this role [7]. The purposed system will used the GPS2click from mikroelkronica, GPS2 Click™ is an add-on board in mikro BUS™ form factor. It includes Quectel L30 GPS module as well as SMA antenna connector [8]. Module has advanced jamming suppression mechanism and innovative RF architecture ensuring maximum GPS performance.

While the software part specification of the gas detector system came through using the LabView as a dataflow visual programming language and environment that used in this project to build the monitoring system, USB port will be interfacing to get data from the ZigBee board. The interfacing process will be build using Virtual Instrument Software Architecture (VISA) which is a standard I/O language for instrumentation programming. VISA by itself does not provide instrumentation programming capability. It is a high-level API that calls into lower level drivers. (VISA) configures USB port connectivity and will use other component to provide the final result. There are three stages in the GUI system that has been build:

1- Receive data from external port.
2- Make blocks inside the system to made tasks like convert from D/A, compare between the input data to give the (graphs, voltage value, concentration of gas) depend on the limits was specified before.
3- Display the necessary information like graphs, numeric values.

3. Gas detector system design

The gas detector Design block diagram for the program implementation will be shown in Figure (5); the output voltage from the gas sensor will be delivered to the EasyPic board, which is the heart of the system. All the inputs and the outputs will be connected to the EasyPic board. During the work of the robot holding the system when the sensor MQ-4 detect the presence of gas (natural gas) the response will be send as an analog signal (voltage) to the input port that had a converter from the analog to digital inside PIC18f45k22 (ADC convertor).The PIC18f45k22 will process the input signal using specific software to deal with the input signal and transfer the condition signal to the LabView through the Zigbee (easybee) as shown in figure (6). This PIC18f45k22 will analyze the signal according to the threshold value of the gas concentration when it will reach dangerous level it will trigger the buzzer to warn the nearby (in case someone around) to the gas concentration is at dangerous level.

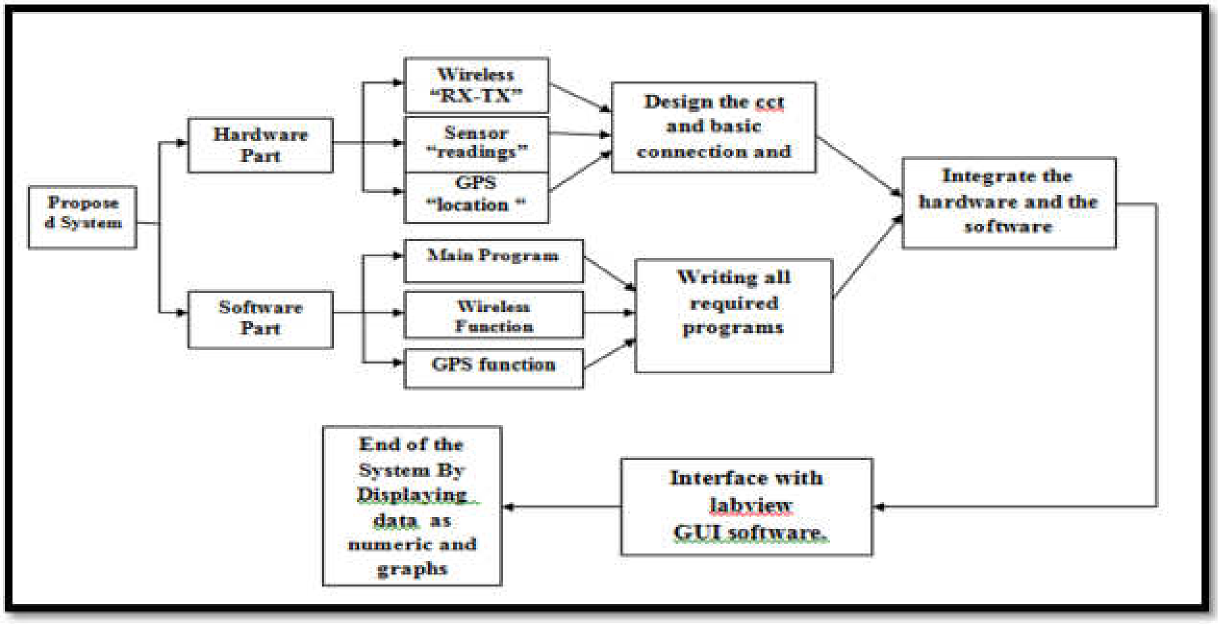


Fig (5): the Proposed System Block Diagram

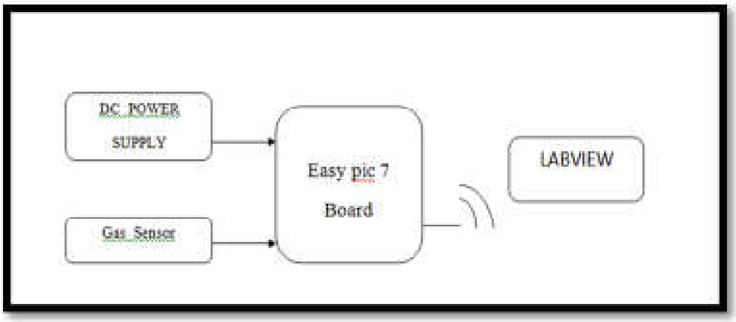


Fig (6): the circuit block diagram.

4. The gas concentration calculation

This section will clarified the route by which the sensor equation workout through number of sequential equations will be followed each other. The equations based on the the MQ-4 gas sensor characteristics as in Table (1). The analog to digital convertor (ADC) of PIC 18f45k22 has 10-bit; therefore the sensor MQ-4 (hardware competent) had real input voltage 5V.

Table (1) Gas sensor input and output voltage

Specification	Gas sensor MQ-4
Input voltage	**DC 5.0V±0.2V**
Output voltage	**DC 5.0V±0.1V**

- **First step:**

First of all we will puts the basic values of the conversion process from analog to digital and vice verse; the binary of the PIC18f45k22 is 10-bit, and the maximum output voltage is 5 volt then this step will equal to:

$$\frac{5}{1024} = 4.88\, mV\ per\ resution \qquad (1)$$

From the equation (1) each bit output is equal to 4.88mV in the real output voltage. As shown in figure (7) the relation between the voltage output from gas sensor and EasyPIC7 reading clearly.

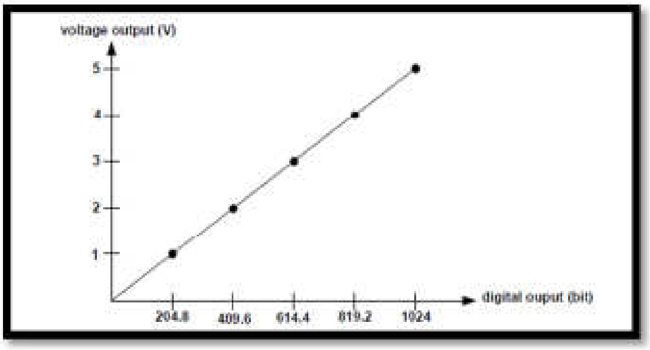


Figure (7): voltage output of gas sensor verse digital output.

- **Second step:**

The value of gas concentration can be obtained by calculating the value of the sensor resistor (Rs). The value of Rs is calculated using voltage divider in the gas sensor circuit diagram as explained in the equation (2):

$$Rs = \frac{5-Vo}{Vo} \qquad (2)$$

From the Rs value, we can compute the gas concentration. VO represents the voltage output from the gas sensor. Equation (2) is obtained from the gas sensor calibration datasheet. Once the Rs value is calculated, it will proceed to the next step.

- **Third step :**

Figure (8) shows the sensor resistance ratio (Rs/Ro) versus concentration gas in ppm for the MQ4. Ro is the sensor resistance (Rs) value at 1000ppm. Therefore, based on the figure above, Ro is equal to 1 (Rs/ Ro). From graph, we can get the relationship between Rs and LPG concentration in ppm. Equation (3) shows the relationship between Rs and LPG concentration value.

$$\text{LPG} = 1000 \text{ x } Rs^{1/\alpha} \qquad (3)$$

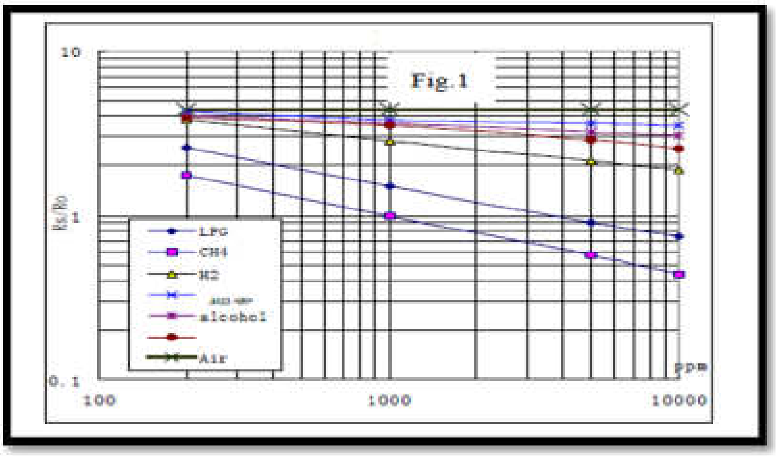


Figure (8): resistance ratio verse concentration Gas.[12]

Alpha (α) in the equation (3) shows the slope value that can be obtained using the equation (4).

$$\alpha = \frac{logx1-logx2}{logy1-logy2} \qquad (4)$$

From the above we will get the below values:
X1= 200 ; x2= 1000; y1=1.8 ; y2 = 1

$$\alpha = \frac{\log(200)-\log(1000)}{1.8-1} = -0.874 \qquad (5)$$

By taking the two points from the linear graph, we can calculate the slope of the LPG concentration gas which is equal to (-1). Therefore, with the slope value equal to (-1), equation (3) can be simplified into equation (6) by substitute the value of slope value of the graph.

$$\text{LPG} = \frac{1000}{Rs^{-1.14}} \text{ ppm} \qquad (6)$$

- **fourth Step:**

Since the EasyPic7 (PIC18f45k22) operate with 10-bit numbering , the data that will be input to the circuit will be converted to digital , the same will be done when transferred using Easybee as the string in a digital forum and after receiving it must be convert to analog again ; the threshold value for alarm system to be functional as well as the project set up, concentration value need to convert into 10-bit data to programmed the EasyPic7 programmer , The threshold values are based on the OSHA organization standard value. By using the equation (5) and (6) in step 3, value of gas concentration can be obtain. The calculation for converting the value of voltage output to digital output is based on the equation (7) below.

$$\text{Digital output} = \frac{V0 \times 1024}{5} \qquad (7)$$

5. The Proposed System Implementation

To implement the gas detection system strategies in the real environment, several of hardware and software parts had to be constructed. This process will partially carried out in parallel with the simulation of different maps and the properties of the system were incorporated in the simulation. some tests had to taken place to be sure that the GUI and the serial connection through (RS-232) will efficiently working, the practical experiments were all conducts on the selected robot (P3-DX) and it's program in the real environment in an easy and simple way. it provide digital values from (0) up to (1024) and get its response with special time combined by steps from (100) digital step and the result was accurate and identical with the input values , figure (9) will show the result of this simple test.

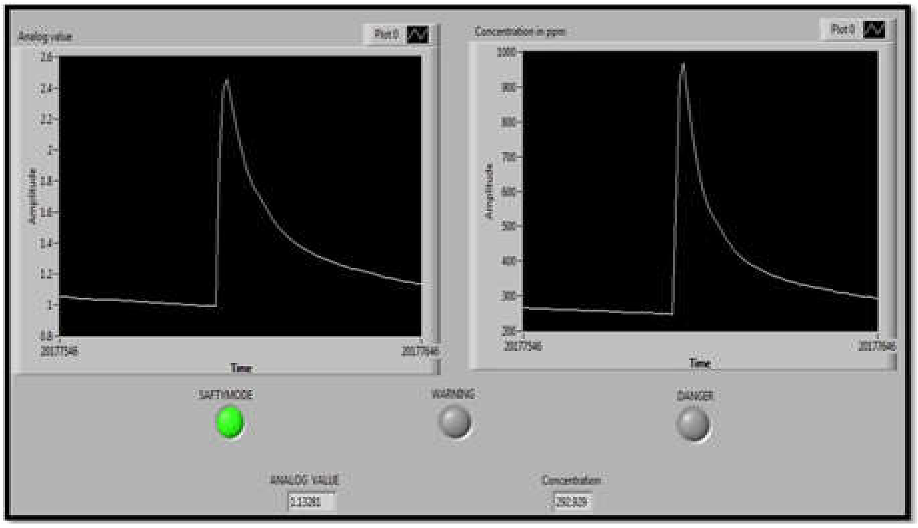


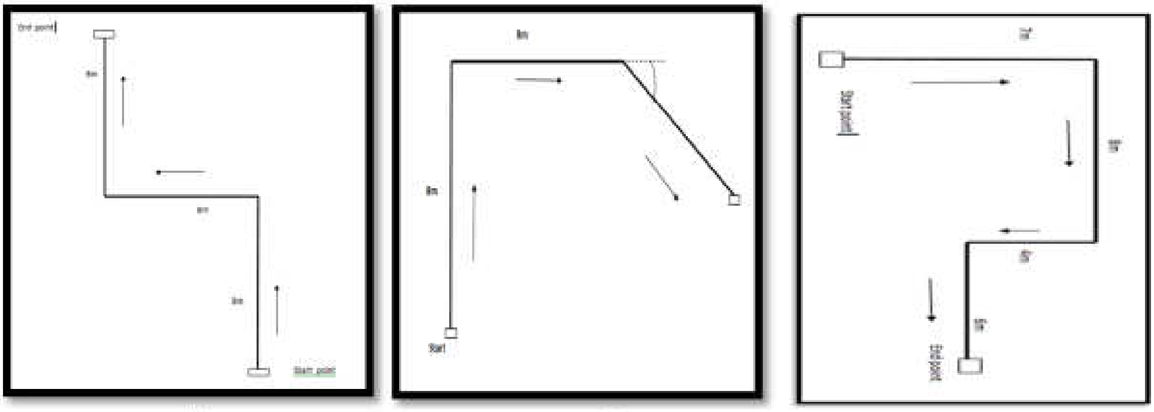
Figure (9) : The final GUI fourm

6. The Experimental work

After the first test the rest of the real world testes have taken place using different and many parameters that can affect the results and the response of the proposed system, by implementing and creating number of different cases concentrate on different maps with different dimensions that have been implemented in order to be comprised between them to provide the optimal conditions for getting accurate , reliable , in a real time results.

The test was done in the public environment like to the one in the real filed area where the pipes was founded originally and can seen an example in figure (10) . the readings from the experiments was in an area with dimensions of 30m × 15m , the change was (Longitudinally) on the Google earth from (33.15829) to (33.15819) when moving from south to north (from 0 to 30m) . To get an accurate reading we start by a distance at least (6-8) meters between any two possible leaks in order to have a change (so tiny) in the longitude. Figure (11) below will show the three main maps that have been used to test the proposed detecting leak system, these maps was combined with other components to build the prototype that has been used to finish the project result.

Figure (10):view of the second map from the work site.



(1) (2) (3)

Figure (11): the three maps in the experimental work.

7. The Conclusion

From the experimental result of the proposes data monitoring gas detection system in outdoor environments some of the most important features can be listed as a conclusion through these points:

1. we distinguish that the system sensing in the field has more accurate readings than the one at the lab (or indoor), we find that the sensor startup in the field will be in the lower levels (steady state) with a reading (0.8-1) volt while the reading was (1-1.2) in the lab. That will make the proposed system ideal for the real world gas and oil industry detection operations.
2. Using the GPS information to assign the position of the leak point help a lot to store information on the environment. proportion to GPS readings.
3. Concerning the speed of the robotic vehicle and from the experimental test we find that the speed which can combines between the time consumption in an acceptable error ratio in the path ,and get reliable readings will be the (0.4 m/sec).
4. The location of each point in the path was monitored and recorded through the use of GPS device with antenna in the work place.
5. A comparison between the experimental results and the expected results there is a match between the two.

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