International Journal of Scientific Research in Computer Science, Engineering and Information Technology
ISSN : 2456-3307 (www.ijsrcseit.com)
doi : https://doi.org/10.32628/CSEIT217631

Remote Pipeline Monitoring Security System

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Article Info
Volume 7, Issue 6
Page Number: 135-145

Publication Issue :
November-December-2021

Article History
Accepted : 20 Nov 2021
Published : 12 Dec 2021

ABSTRACT

Pipelines are regarded as the lifelines of the national economy of most oil producing countries. This is because these pipelines which cover thousands of kilometers are used to transport large volumes of refined and unrefined petroleum products, crude oil and natural gas. These pipelines often come under terrorist attacks and vandalism which can lead to pollution problems, theft of the contents of the pipeline and huge economic loss. In view of this, it is very necessary that these pipelines are monitored from time to time to forestall these losses. Manual monitoring of pipelines is a very expensive process and also dangerous especially in hazardous environments. Remote monitoring of these pipelines involves monitoring the pipelines from remote locations. This research work monitors pipelines by using remote monitoring to wirelessly monitor the pipelines in real time and reports to the control center whenever it gets a value above the threshold value. The parameters monitored are temperature around the pipeline, relative humidity surrounding the pipeline, dew point of the pipeline environment, the amount of carbon monoxide present, the amount of liquefied petroleum gas leakages, the movement of people around the facility, fire and smoke. A monitoring device for monitoring these parameters was designed and constructed and a software was developed in C- language which interfaced with the hardware to provide a robust solution for remotely monitoring the pipelines. The result of this research effort is a robust solution for the wireless monitoring of the pipelines of the different parameters embedded together.

Keywords : Pipeline, Wireless Sensor Networks, LPG Leakages, Remote Monitoring, Python Language

I. INTRODUCTION

Millions of kilometers of pipelines are deployed around the world to transport large volumes of fresh water, fuels, crude oil and natural gas. In most oil producing countries, these pipelines are regarded as the lifelines of the national economy of those countries. Pipelines are used as the main means of transporting goods from one point to another. Liquids, gases, chemicals, oils and other important goods are shipped using pipelines. Pipelines are also used to transport water for drinking or for irrigation purposes over long distances. The transportation can be over hills, canals or other cities (Stoica et al., 2016). Since the pipelines span over very long distances, tunnels, hills, canals, they are usually exposed to severe security threats such as pollution problem, leakage loss, terrorism, theft of the contents of the pipeline. These pipelines are buried under the soil or exposed to very high temperatures which may sometimes result to pipeline breakdown resulting to severe damage to humans and massive leakage of oil, gas, chemicals and water supply.

Pipeline structures buried underground are generally preferred for transporting oil or water to the ones above the ground because they are safer and are also concealed. Even though it is safer to transport large amounts of fluids through long distances using the underground pipelines, these pipelines are sometimes exposed to severe environmental factors such as extreme soil conditions, corrosion and some malicious attacks and these can cause pipeline leakages.

Pipeline leakage is defined as the undesirable flow of the liquid contained in the pipeline. Pipeline leakage causes heavy economic loss to the company and heavy pollution of the environment which can be dangerous to the health of the people in that environment (Rehman and Nawaz, 2017). The leakage can also have hazardous effect on the aquatic life in that environment. This mainly happens if the material moving in the pipes is corrosive or harmful. In a statistical analysis conducted by Junior et al (2010), large pipelines will normally experience one obvious leakage every year. Therefore it is necessary to secure and maintain the pipeline infrastructure (Ostfeld et al., 2008).

Detection of pipeline leakage depends on the periodic inspection of the pipeline by the personnel responsible for the maintenance (Duvoisin, 2003) and this requires intensive human involvement. This periodic inspection does not provide real time monitoring of these pipelines and therefore a leakage may occur between the time of the last check and the next check and this will cause huge economic loss and environmental pollution.

Pipeline monitoring can either be through the use of wires, it can be wireless or it can be a combination of both in order to transfer data from pipelines to the control stations.

Real time monitoring systems which are based on wired or wireless sensors were developed by David and Allan, (2001), Janhar et al., (2007) and Stianov and Nachman, (2007). The wired techniques are used to connect the sensors to the pipelines with wires and the measurements from each sensor are transmitted to the monitoring center through these wires. Wire-based systems, however are not very efficient because any damage on any part of the connection affects the entire network. Wireless sensor networks are more robust and more efficient but can only be used to monitor aboveground pipelines (Akyildiz et al., 2002)

The sensors inside the pipelines measure the pressure and the velocity of the oil/water flow, as well as the acoustic vibrations caused by the leakages. These sensors are resource-rich, high-power devices and have higher processing capabilities. They are also deployed at the checkpoints or pump stations of the pipelines. Sensors, which are outside the pipelines, measure the temperature, humidity, and properties of the soil around the underground pipelines. The outside sensors are buried under the ground near the pipelines and can provide high granularity for the detection and localization of leakages.

Wireless Sensor Networks (WSN) are wireless sensor nodes which are interconnected wirelessly and are able to measure temperature, gas leakage, fire outbreak etc.

Wireless sensor networks have low cost, are reliable, available and compatible with other methods and thereby provide redundancy and reliability (Yu & Cuo, 2012). Pipelines cover wide geographical areas and therefore there is need to provide a robust real time monitoring for adequate security. WSN are well suited for this task because of their low cost.

Active and manual monitoring of pipelines is a very expensive process and also dangerous especially in hazardous environments. It is also a very tedious job which involves workers to physically cover large areas to examine and repair the pipelines. Remote monitoring is therefore the solution to these problems. This paper is aimed at using wireless pipeline monitoring system to monitor pipelines for: temperature around the pipeline, relative humidity of the surrounding pipeline, dew point of the pipeline environment, the amount of carbon monoxide present, the amount of Liquified Petroleum Gas (LPG) leakages, if any around the pipeline, the movement of people around the facility, fire and smoke.

Gas pipeline leakage may lead to large economic loss. Leakage in the supply pipeline may lead to disasters. Hence a proper monitoring is important. Leaking pipelines can pose a lot of risks including product ignition, massive destruction and damage to the environment which can lead to the incursion of substantial cleanup cost, regulatory fines and damage to corporate reputation.

Pipeline monitoring can be used to identify fire outbreak in any part of the pipeline. Temperature can also be monitored remotely. This is achieved by using wireless network sensors which can easily detect gas leakage, fire outbreak, temperature and motion detector and triggers an alarm and sends messages to the control center notifying them of danger.

II. RELATED WORK

Underground pipelines are considered as the safest way in which liquids and gases are transported across the globe. Statistical observations however have proved that large pipelines experience at least one harmful leakage every year (Junior et al., 2010). Junior et al reported that pipeline leakage can cause huge economic loss and environmental pollution problems. Risk of human injuries is also increased. Thus the security and monitoring of pipeline infrastructure becomes a major challenge (Ostfeld et al., 2008). Pipelines which are old and weak, with poorly maintained valves and which do not have enough corrosion protection can contribute to leakages in pipes (Oren and Stroh, 2012). These leakages lead to economic losses which increases annually and which can cause accumulating losses (Lambert, 2002).

Leaking pipelines can pose safety risks of product ignition, and exposure leaks can result in damage to the environment, leading to the incursion of substantial cleanup costs, regulatory fines, and damage to corporate reputation.

Junior et al (2010) presented a paper which uses a time series strategy for detecting, locating and quantifying leaks in large pipeline systems. Their technology employed two active components, which operated sequentially, the detector and the localizer. While the detector continuously screens real time data searching and detecting any anomalies like leaks, the localizer tries to diagnose the leak through estimation of its parameters, diameter and location using recorded data on a search time window. The localizer can recognize an active pattern of leak parameters and this it does by maximizing the adherence of its predictions to data in the search time window.

Due to increases in terrorist attacks on water supply systems, which can be deliberate chemical or biological contaminant injection and the uncertainty of the time and location of the injection, an online contaminant monitoring system can be considered as a major opportunity to protect against the impacts of a deliberate contaminant intrusion (Ostfeld et al., 2008). Ostfeld et al (2008) stated that even though optimization models and solution algorithms have been developed to locate sensors, little is known about how the design algorithms compare to the efforts of human designers. In view of this Ostfeld et al (2008) presented a paper at the 8th Annual Water Distribution Systems which summarizes the outcome of the Battle of the Water Sensor Networks (BWSN) efforts and suggests future directions for water sensor networks research and implementation.

Oren and Stroh (2012) built a device which is designed to detect leakages in water systems and stop them. Their system uses a mathematical model to analyze consumer's average water consumption in real time. When it detects a great deviation from the average or steady water consumption over a period of time, it alerts the consumer by cellular communication and if possible disconnects the leaking system from the water supply.

The paper by Leeuwen et al (2013) performed a field test with five simple Co_2 sensors placed for more than one year in a field in Ten Post Groningen, The Netherlands. The aim of Leeuwen et al (2013) was to monitor pipelines used for transporting CO_2 for capturing and storing carbon.

. The sensors they used reacted differently on temperature changes which decreases signal to noise ratio. The detection limit for leak detection was improved by a factor of 2.5. The result of their analysis showed that a leak of >3g/s would be easily detectable with sensors placed in a 70m grid.

Sun et al (2011) used Magnetic Induction-Based Wireless Sensor Network (MISE – PIPE) to monitor underground pipeline. They introduced MISE – PIPE to provide low-cost and real time leakage detection for underground pipelines. MISE-PIPE is able to detect and localize leakage by utilizing measurements of different sensors located in the underground pipelines. Their system reports the measurements of the different sensors in the entire pipeline network to the administration center in real time.

Many of the people who have worked on pipeline monitoring have only worked on one parameter, either to detect gas leakage or to detect terrorist attacks on water pipelines, but this research work is based on monitoring different parameters ranging from gas leakage, temperature around the pipeline, motion detector, fire and smoke and this makes it a very robust monitoring system.

III. METHODS AND MATERIALS

A. SYSTEM OVERVIEW

A remote pipeline security monitoring system has been proposed. The system provides a remote wireless monitoring of pipelines by providing security and surveillance system throughout all the distance in kilometers where the pipes are laid. The parameters monitored are gas leakages, motion activity, temperature, fire and smoke. This is achieved by using sensors to monitor the different parameters. The system provides a remote monitoring of the pipeline in real time and sends the information to the control center where adequate measures are taken to correct any anomaly detected.

The gas sensor monitors the pipeline and tries to detect the presence of gas/smoke i.e. carbon monoxide, LPGas, around the vicinity of the pipeline. The gas/smoke sensor issues a signal when the gas leakage reaches the preset threshold value in the vicinity and sends a signal to the control unit via the fire alarm unit and processor, while the smoke detectors generally issues a local audible or visual alarm from the detector itself. The motion sensor attempts to detect motion activity i.e. movement of people around the pipeline. If there is heavy movement of people around the pipeline, the motion sensor sends information immediately to the processor which performs a process through the control unit and sends the output to the control center in real time. The temperature sensor monitors the temperature around the pipeline and triggers an alarm to the control center when the temperature becomes unusually high or unusually low. The temperature sensor detects and measures hotness and coldness and converts it into an electrical signal. The flame sensor checks for the presence of fire and reports immediately to the control center.

These various sensors perform the monitoring of the different parameters and send the result to the processor in real time. The processor ***massages*** the raw data received into useful information and send them out to the control unit, which in turn activates the appropriate actuator for adequate actions to be taken to correct any anomaly.

B. SYSTEM ARCHITECTURE

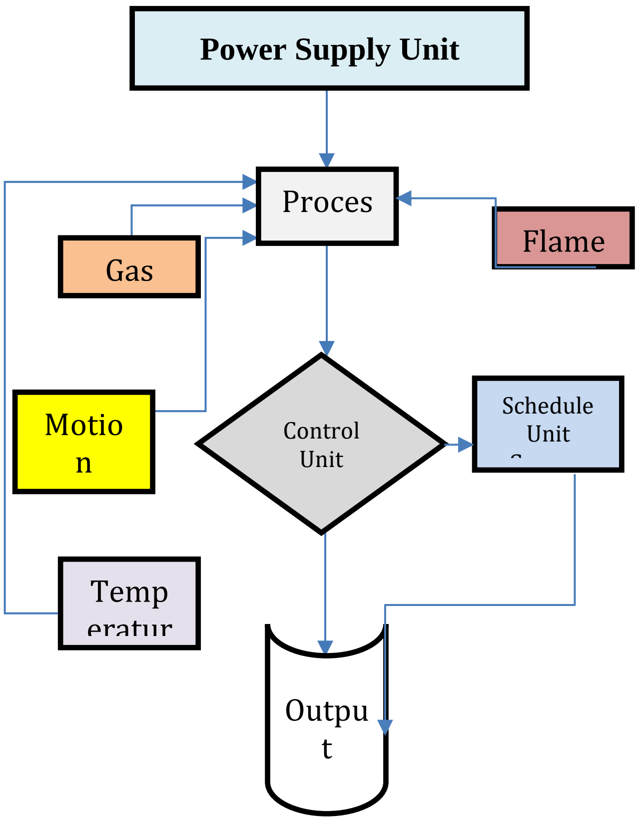


Figure 1: Architecture of the Remote Monitoring Pipeline Security System

Figure 1 above shows the architecture of the remote monitoring pipeline security system. The security and surveillance system was achieved by putting all the various blocks together.

SENSORS

FLAME SENSOR

The flame sensor detects the presence of fire or other infrared source (Flame or a light source of a wavelength in the range of 760 nm to 1100 nm can be detected). The features of the flame sensor include: small and compact in size, have an adjustable threshold value, has a two-state binary output (logic high and low), Easy mounting with a screw hole, High Radiant Power LEDs, Superior Weather-resistance, 5mm UV Resistant Epoxy resin package, Color Transparent Type, Detection angle about 60 degrees, It can detect the flame and the light in the wavelength range from 760nm to 1100nm.

Design Analysis of the Flame Sensor

The flame sensor, can be applied in the following detecting process as:

- Fire detection
- Firefighting robot
- Fire alarm

HARDWARE CONNECTIONS

The module has simple 3 pin male berg connector having Vcc, ground and output pin. The potentiometer is provided to adjust the threshold level. To read sensor status A0 pin should be connected to a ADC module of the microcontroller. Figure 2 below shows the pin layout for flame sensor as was configured, viz.

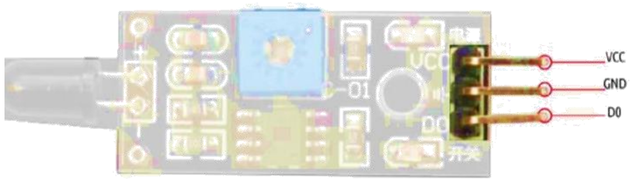


Figure 2 : The Flame Sensor

In the case of working with a MCU:
VCC ↔ 3.3V ~ 5.3V
GND ↔ power supply ground
AOUT ↔ MCU.I/O (analog output)

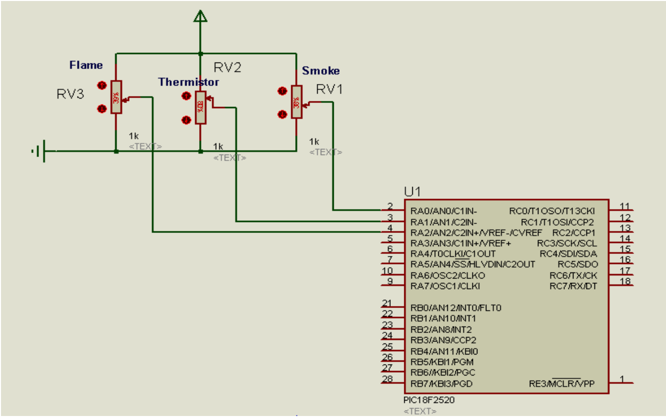


Figure 3 : Interfacing Flame Sensor with Microcontroller

Software Design of the Flame Sensor

The software consists of the program or set of instructions upon which microcontroller runs. The software program determines the operation of the system in general. First approach in the development of the program code, involves generating the program algorithm. Thereafter an effective code was generated. The program was written in embedded C language.

DESIGN FOR MOTION DETECTION USING PASSIVE INFRA-RED (PIR)

PIR sensors allow you to sense motion, almost always used to detect whether a human has moved in or out of the sensors range. PIR sensors are small, inexpensive, has low-power, are easy to use and do not wear out.

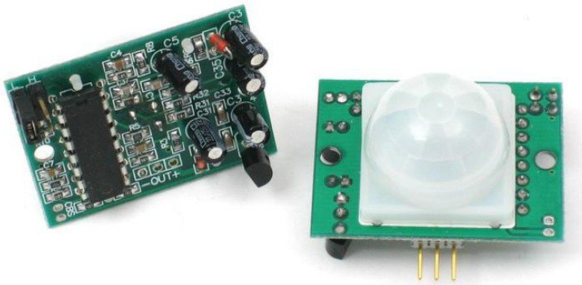
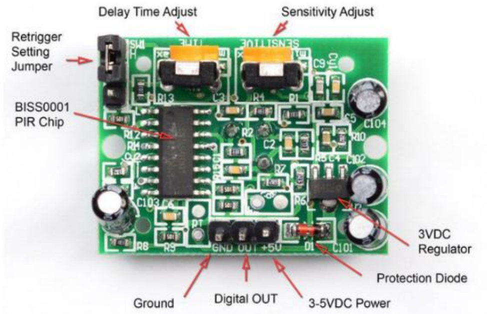


Figure 4: Passive Infra-Red Sensor and rear view



PIRs have more adjustable settings and have a header installed in the 3-pin ground/out/power pads.
PIRs won't tell you how many people are around or how close they are to the sensor, the lens is often fixed to a certain position.

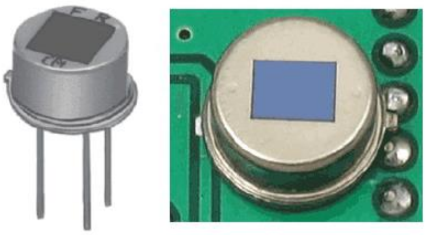


Figure 5: PIR Motion Sensor

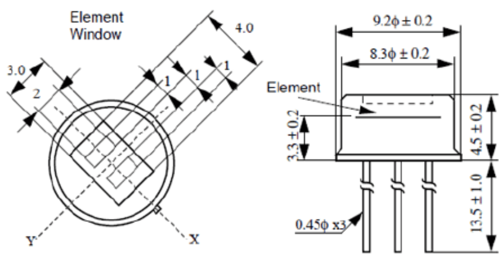


Figure 5 : Schematic diagram of the PIR Motion Sensor

The diagram above shows the element window and the two pieces of sensing material

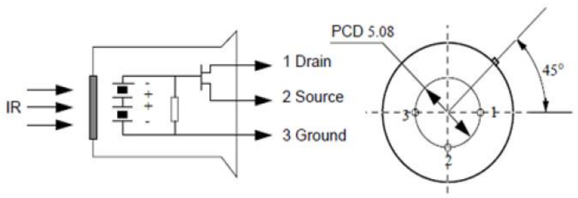


Figure 6: The Internal Schematic of the PIR sensor

This image above shows the internal schematic of the PIR sensor. There is actually a JFET inside (a type of transistor) which is very low noise and buffers the extremely high impedance of the sensors into something a chip can sense.

CONNECTING TO A PIR

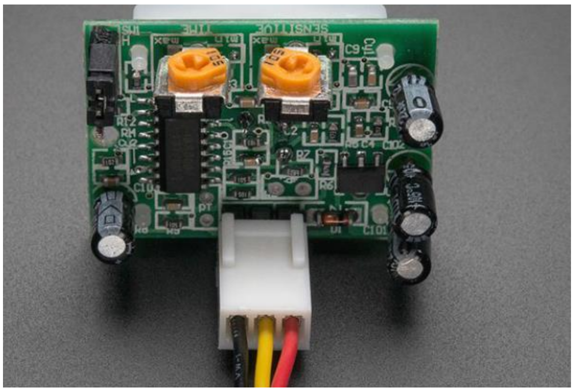
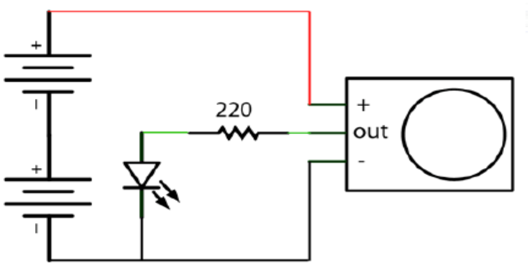


Figure 7: Connecting to a PIR sensor

Most PIR modules have a 3-pin connection at the side or bottom. One pin will be ground, another will be signal and the final one will be power. Power is usually 3-5VDC input but may be as high as 12V. For PIR's the red cable is + voltage power, black cable is - ground power and yellow is the signal out.



DESIGN ANALYSIS ON SENSITIVITY

The PIR has a trim pot on the back for adjusting sensitivity. You can adjust this if your PIR is too sensitive or not sensitive enough - clockwise makes it more sensitive.

Tx = The time duration during which the output pin (Vo) remains high after triggering.

Ti = during this time period, triggering is inhibited.

Tx = 24576 x R10 x C6; Ti= 24 x R9 x C7

DESIGN OF THE DISPLAY UNIT

In this project, a 16×2 LCD display will be used for displaying the value of heart Rate. There are 16 pins in whole in LCD. It was connected directly to the microcontroller. The pin diagram of LCD is shown as below.

Selection of the 16x2 LCD

For effective presentation of the state of the entire system, the 16x2 LCD was used. Below is the choice of selecting the LCD:

- Easy to interface with a microcontroller.
- Cost
- Availability.
- Operating voltage of 5-7v DC

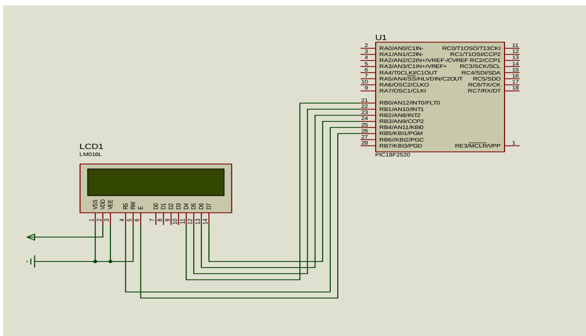


Table 1: Technical Specification of the Display Unit

DESIGN FOR TEMPERATURE DETECTION USING DHT 11 HUMIDITY & TEMPERATURE SENSOR

The DHT11 Temperature & Humidity Sensor features a temperature & humidity sensor complex with a calibrated digital signal output. By using the exclusive digital-signal-acquisition technique and temperature & humidity sensing technology, it ensures high reliability and excellent long-term stability.

The component is 4-pin single row pin package

Technical Specification

Overview

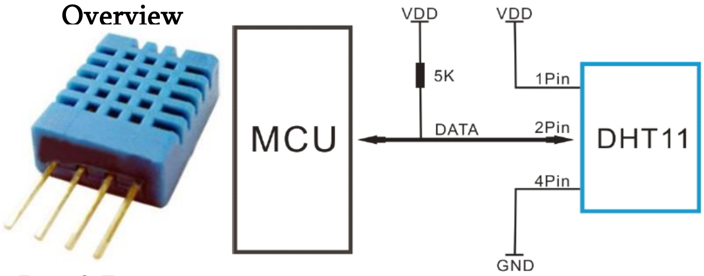


Figure 9: Temperature sensor

Item	Measurement Range	Humidity Accuracy	Temperature Accuracy	Resolution	Package
DHT11	20-90%RH 0-50 ℃	±5%RH	±2℃	1	4 Pin Single Row

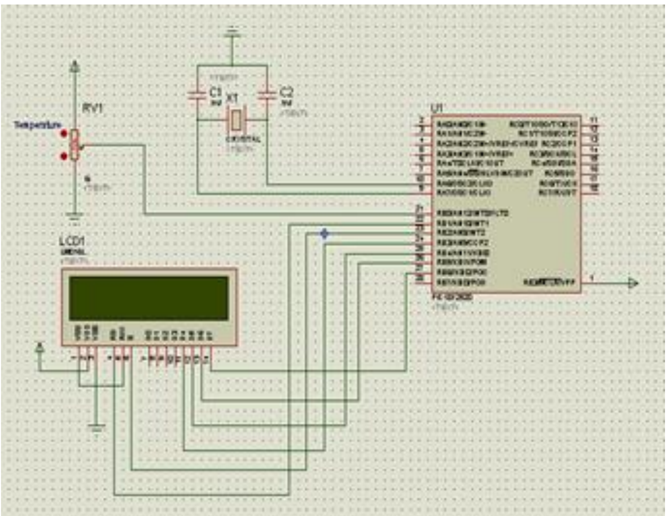


Figure 10: Interfacing DHT 11 with Pic18f2520 Microcontroller

GAS SENSOR MQ-2

They are used in gas leakage detecting equipment in family and industry, are suitable for detecting of LPG, i-butane, propane, methane, alcohol, Hydrogen, smoke

Structure and configuration of MQ-2 gas sensor is shown as Figure 11 (Configuration A or B), sensor composed by micro AL2O3 ceramic tube, Tin Dioxide (SnO2) sensitive layer, measuring electrode and heater are fixed into a Crust made by plastic and stainless-steel net. Electric parameter measurement circuit is shown as in

Figure 11 below

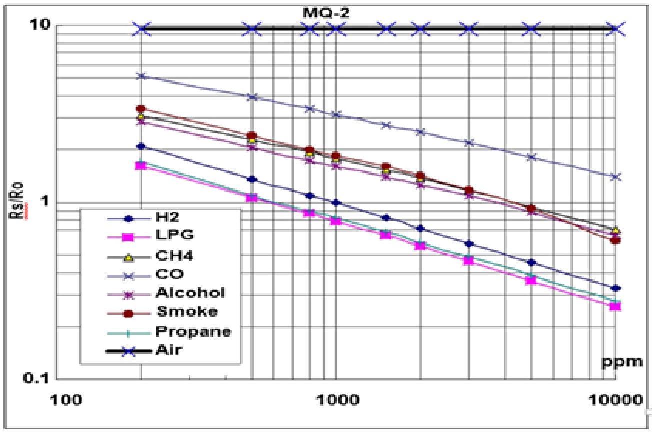


Figure 11: sensitivity characteristics of the MQ-2

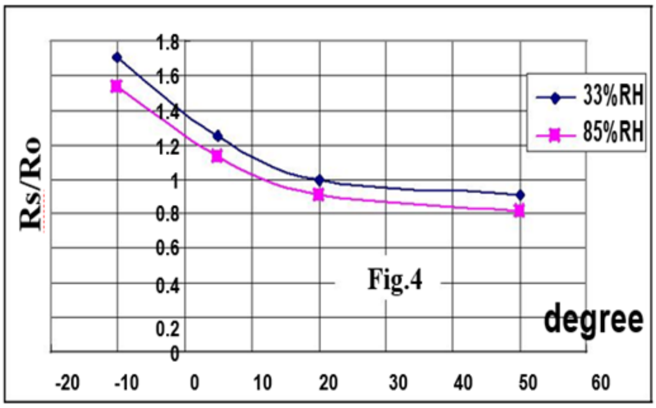


Figure 12 shows the typical dependence of the MQ-2 on temperature and humidity.

Ro: sensor resistance at 1000ppm of H_2 in air at 33%RH and 20 degree.

Rs: sensor resistance at 1000ppm of H_2 at different temperatures and humidity's.

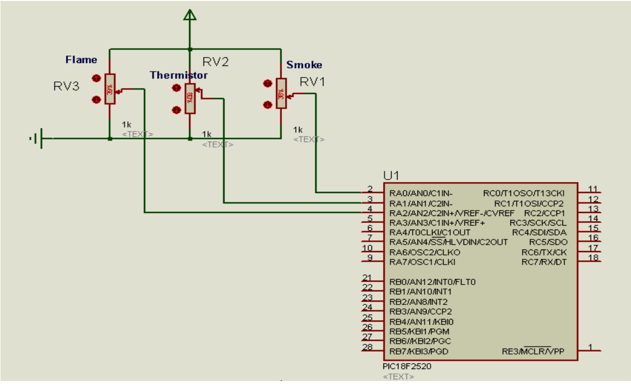


Figure 12: Interfacing Gas Sensor with Microcontroller

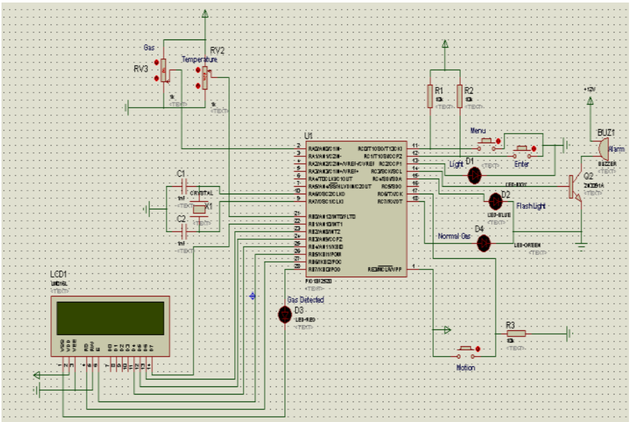


Figure 13: Circuit Diagram of the Remote pipeline Security Monitoring System

IV. RESULTS AND DISCUSSIONS

A. PRINCIPLE OF OPERATION

When the device is switched ON, a 220/240V_{AC} flows across the primary windings of the transformer, thus, an electromagnetic field is set up, and according to Faraday's law of electromagnetic induction; EMF is induced at the transformer's secondary windings. Relative to the transformer's ratio, 15V_{AC} is obtained at the secondary windings of the transformer. This 15Vac is fed into the input of a full wave bridge rectifier. The bridge rectifier converts the AC to DC with substantial amount of ripples present hence the DC produced by the rectifier unit is called *Varying DC*. Its value is 19.81V_{DC}. This 19.81V_{DC} is passed through a filter consisting of capacitor having a large microfarad to smoothen the output voltage (V_{dc}). The V_{dc} is fed to a +12Vand +5Vregulators respectively, to power the various components of the circuit.

At the heart of the smart pipeline security system, is a controller unit acting as a *Processor*. The term processor is used because it processes the various signal from the sensors all of which communicate with the controller unit at the same time. The controller unit is designed to power actuators like LEDs,

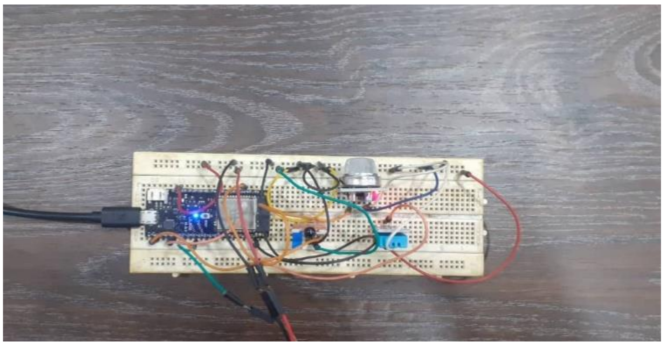
When the Integrated pipeline security system is powered on, an initialization process is established. This process makes a welcome remark and designation and displays same on the LCD screen. After this, it immediately creates a secure connection with the sensors attached to the processor. If the communication/connection is successful, there is a handshake between the processor and all the peripheral devices connected; this handshake is also broadcasted through the buzzer and LCD display screen.

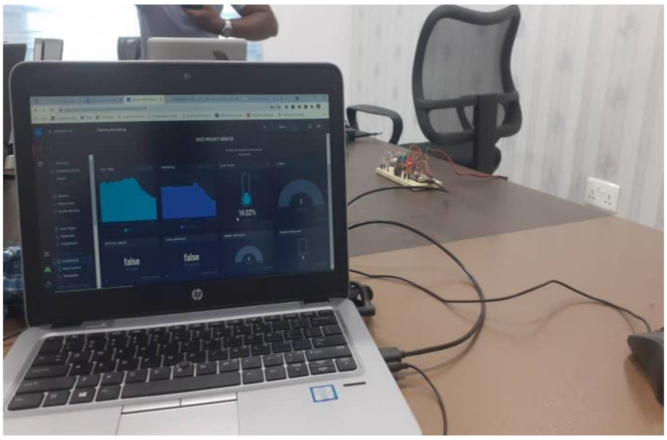
Due to the fact that each of the attached sensor has a transient starting time, which present itself as start-up noise, the processor unit create a 60 seconds stabilizing window for all the sensors. During this stabilization window, the control unit pay oblivious to any signal received. After the stabilization window, the system enters into an active state, at which point the integrated pipeline security responds to any increase in temperature beyond the set threshold of 40^{o}C, intruder alert, and presence of gas/smoke above the reference value.

There is a white blinker led that blinks every ten seconds indicating the system is normal and every activities as designed is perfect.

A green light indicates acceptable gas level in the environment the system monitors, while red led indicate presence of gas/smoke above the threshold values.

B. SYSTEM INTERFACES





V. CONCLUSION AND FUTURE WORK

As established from the scope of work, aims and objectives enumerated earlier were achieved. It is about the design and construction of Remote Monitoring Pipeline Security System in oil production. The work consists of the following sensors: Motion, Gas, Flame and Temperature sensor the sensors are active low but when the environment variables of interest are detected they output ***high*** and the control unit makes a pragmatic decision as appropriate.

Future work would be onboarding the sensors data unto the cloud (IoT – technology) for cloud computing, which would be developed further still for analytics using machine learning, a focus on industry 4.0

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Cite this article as :

Ifeoma V. Ngonadi, Sunday Ajiroghene, "Remote Pipeline Monitoring Security System", International Journal of Scientific Research in Computer Science, Engineering and Information Technology (IJSRCSEIT), ISSN : 2456-3307, Volume 7 Issue 6, pp. 135-145, November-December 2021. Available at doi : https://doi.org/10.32628/CSEIT217631
Journal URL : https://ijsrcseit.com/CSEIT217631