International Journal of Recent Technology and Applied Science
p-ISSN: 2721-2017, e-ISSN: 2721-7280

Original Research Paper

Investigation and Implementation of IoT Based Oil & Gas Pipeline Monitoring System

Muhammad Arif Zurkanain[1], Siva Kumar Subramaniam[2]

[1] *Department of Electronic Engineering, Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka. Melaka, Malaysia.*
[2] *Advance Sensors & Embedded Controls System (ASECS), Centre for Telecommunication Research & Innovation (CeTRI), Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer, Universiti Teknikal Malaysia Melaka. Hang Tuah Jaya, 76100 Durian Tunggal. Melaka, Malaysia.*

Article history
09.01.2023

Revised:
30.01.2023

Accepted:
15.02.2023

***Corresponding Author:**
Siva Kumar Subramaniam
Email:
siva@utem.edu.my

Abstract: Wireless Sensor Networks (WSNs) involve top potential technologies that will dramatically change the way of human living and working. Many scientific, industrial and environmental applications require real time information related to physical events like pressure, temperature or humidity. In the past the only way to transfer the sensed data to control center was through cumbersome and costly wires. But recent advancement in wireless networking enables WSNs to communicate the sensed real time event data wirelessly. WSNs have capabilities of sensing, processing and communicating which make them most suitable for monitoring different on and gas industries upstream, midstream and downstream operations which help to increase production, decrease the accidents, maintenance cost and malfunctioning.

Keywords: App Inventor, Internet of Things, Oil & Gas Pipeline, Wireless Sensor Networks.

1. Introduction

Wireless Sensor Network (WSN) is a collection of limited resource constrained sensor nodes capable of sensing, computing and communicating the events of interest. WSNs are among the technologies that will dramatically change the way of human living, working and change world with their advanced architecture and wide variety of daily life applications [1] [2] [3] [4] [5]. Indeed, modem industry is becoming increasingly dependent on the need for real-time seamless transfer and manipulation of data for quick decision-making process. Strict regulatory, safety, security, and cost reduction are driving companies in a wide variety of industrial fields to be very aware and extremely cautious of these concerns and measures.

Oil and Gas indusial operations involve a lifecycle of processes which are categorized into three major sectors/subdivisions; upstream (exploration and production), midstream (storage and transportation), and downstream (refining and marketing). In the upstream sector the raw materials are searched and extracted. In the midstream sector the produced oil and gas is stored and then transported to the downstream sector for refining processes. In the downstream sector the raw materials are processed to a finished product. This sector is responsible for refining, distributing and retail of petroleum products. Since almost all the assets in the oil and gas industries reside in remote and difficult to reach locations, the processes and equipment involved in these three sectors need to be managed properly and monitored remotely and continuously. A high level of cost, attention, significant travel and resources are required to maintain production and control of oil and gas assets.

Wired technology has been widely employed for monitoring purposes in oil and gas industries. But these wired technologies are expensive and their deployment and maintenance is difficult to handle in harsh environment like Oil and Gas [6]. Moreover, in large plants when cabling is adopted for interconnecting machines to monitor and control processes, it lacks flexibility and becomes unfeasible because of the increasing fluctuations of wiring costs to high values [7].

The advancement in Wireless technology continues to grow thus, eliminating the need for cables that ultimately allows cost efficient network deployments. Even it is documented that wirelessly connected assets are up to IOX less expensive than wired alternatives [8]. Thus, to remotely monitor pipelines, natural gas 1eaks, corrosion, equipment condition, and real-time reservoir status [9], the Oil and Gas industry is apparently looking towards WSN technologies. Wired technology has been widely employed for monitoring purposes in oil and gas industries. But these wired technologies are expensive and their deployment and maintenance is difficult to handle in harsh environment like Oil and Gas [6]. Moreover, in large plants when cabling is adopted for interconnecting machines to monitor and control processes, it lacks flexibility and becomes unfeasible because of the increasing fluctuations of wiring costs to high values [7]. Many aging Oil, Gas pipelines suffer from various defects such as corrosion, cracks etc and can cause failure of pipeline then subsequently this may damage to human health and interruption of oil and gas supplies. For instance, on March 2, 2006, a spill of about 1 million liters of oil at around five days in the area known Alaska's North Slope because of quarter inch a hole corroded in a pipeline. This example shows the magnitude of the problem in a fast and aging decaying pipeline system. These days in order to inspect pipeline system, sensor network technologies are usable. For instance, in the applications of in the applications of natural gas pipeline inspection and monitoring by acoustic sensors [10] [11] [12].

Furthermore, environmental regulations are constantly changing and becoming stricter day by day. In 2008, The Office of the Comptroller of the Currency (OCC) approved a set of rules on the management of surface waste from oil and gas operations that force companies to haul highly contaminated soil and water to permanent disposal sites rather than spread it back over the land after closing a well. The OCC also approved stricter penalties to enforce industry compliance with environmental standards [13]. Oil and gas companies must develop new methods to abide by new regulations and, reduce accidents and emissions without impacting production. Due to the evolution of digital technologies and wireless communications, wireless sensor networks can be quickly organized and continually adapted to monitor and control environmental conditions and machinery in response to business drivers and requirements.

2. Literature Review

2.1. Remote Monitoring of Oil and Gas Pipelines

The oil and gas pipelines are known as a cost-effective and a safer transportation medium that are still accessible towards dangerous accidents or physical damages [14] [15] [16]. Numerous studies have highlighted that pipeline transportation had a long history of failures however when compared with the traditional railroad transportation, the reported accidents are still significantly low. Oil leaks from accidents in a pipeline contribute to inconsistency in temperature readings beneath the pipeline, whereas a leakage of gas pipeline rapidly decreases the temperature above the pipeline [16] [17] [18]. Hence, constant monitoring of temperature and pressure changes on sensors can promptly detect leakage of pipeline practically for faster response to an impending accident.

The oil and gas industry face numerous challenges especially in complying with frequently changing environmental regulations in a pipeline monitoring and management system. The exceptional need to monitor the unknown states on the oil and gas pipelines is essential for the industry to wisely optimize the running resources [16] [19]. The unknown states or threats of an oil and gas pipeline could affect pipeline integrity, safety, reliability and security whilst simultaneously meeting the demands on delivery schedules as well as optimizing the cost factor at the same time. To oversee the entire process, a reliable and scalable WSN plays a crucial role in sensing the abnormalities on pipelines and to communicate them to a centralized monitoring station in a distance away from where the future decision is made [20] [21] [22].

Therefore, the rapid developments of WSN are gradually adapted for remote monitoring of oil and gas pipelines which empowers the monitoring station to oversee the entire stretch of pipelines regardless of the unique geographical terrain no matter how intense the environmental characteristics are.

2.2. Related Work

Traditionally, pipeline state information is gathered by video cameras and sensors, which are connected by copper wires or fiber-optic cables (such as system bus, Ethernet network etc.) or wireless communication methods (such as GPRS, microwave or radio modem etc.) [23]. but the practice has proved that these approaches are unlikely to popularize because some problems with them. For example, the required dedicated equipment is prohibitively expensive. And they involve much human labor. Furthermore, video cameras can't work well when the weather is bad due to the limited visibility. By contraries, the WSN has not these disadvantages.

Recently, researchers have proposed WSN applied in pipeline monitoring [24]. It is obvious that WSN have many advantages to construct oil and gas pipeline monitoring systems in the terms of the cost performance, flexible and control efficiency. For example, WSNs can monitor the pipeline information and estimate pipeline state unremittingly without manual intervention and work at the night and abominable weather. WSN can provide high network performance.

2.3. Previous Work

2.3.1. The Electrochemical Monitoring System

Monitoring technology can detect instant corrosion speed and reflect sensitively. Metal institute of Chinese Academy of Sciences in Shenyang has done a great deal of related work [25], developed many electrochemical monitoring systems on pipeline corrosion, such as CMB-1511A electrochemical corrosion monitoring system. Professor Song Shizhe, from Tianjin University, also did research on corrosion monitoring equipment based on electrochemical noise [26]. Professor Guo Xingpeng from HUST (Huazhong University of Science and Technology) did research on intelligent monitoring system for integrated electric dipole corrosion probe, electrochemical permeability hydrogen probe and Resistance probe techniques [27]. However, electrochemical monitoring method exist some disadvantage. The method will make destruction on pipeline somehow, which bring potential risk on pipeline operation service safety.

2.3.2. Ultrasonic Monitoring System

Most widely used because of its readability of testing result and characteristic of easy-to-use. Ultrasonic wave sensor is used to monitor thickness of key points in circumferential direction, and the big errors and mistakes caused by traditional monitoring methods can be avoided. Echo signal detected by multi-crystal ultrasonic wave sensor which installed in the pipeline wall would be transferred into thickness ratio and then be conveyed to field data relay, after some data processing, the signal data is delivered to the monitoring station of oil and gas station. The whole system adopts C/S model, which is Customer/Service model. But some problems still exist when the ultrasonic monitoring system applied to pipeline corrosion detection. The existing ultrasonic detection methods mostly are off-line spot testing [28], which is difficult to meet the need of Oil and gas industry's digitization and networked trend.

2.3.3. Acoustic Monitoring System

As soon as a leak takes place in a pipeline, it creates acoustic sound waves. This acoustic signal moves along the pipeline therefore operators can detect the leakage by investigating the acoustic signal. A leak's frequency behaviors, as well as its amplitude, rely on lots of factors, for example, the size of leak, the composition of transported liquid (i.e., water, oil), and pipeline pressure. If the pipe is larger than normal in diameter or less solid, then the leak sound holds lower frequency signals and if the pressure is high, higher-frequency signals will be showing. How much the signal can move also depends on many conditions like type of pipeline (i.e., PVC, iron) and the pipe's surrounding atmosphere. When pipe is placed underground, a leak signal is decreased more than whereas the pipe is above land. The signal is decreased in lower rate in sandy soil, asphalt, and concrete but declines more in clayey or grass areas [29]. These strategies have drawn backs while being complex and accurate. Leak location results are great under experimental conditions, yet results will be less productive practically speaking. These strategies don't manage noise, and noise can make the outcome misleading.

2.3.4. Flat Data Collection Algorithms

In these algorithms every node in the network is assigned the same role. The data sensed by sensors are transmitted to base station by multi-hops. And, the data are unnecessary to be buffered a long time and can be relayed to next hop sensor node immediately. Furthermore, there are multi-transmitting paths between source sensor and base station. So, these category algorithms have low end to end delay and high reliability. But, the flat structure aroused a severe drawback, which is non-uniformity of energy consumption among the sensor nodes. In fact, the nearer a sensor node lies with relative to the base station, the faster its energy will be depleted.

2.3.5. SCADA Pipeline Monitoring Systems

SCADA (Supervisory Control and Data Acquisition) is a real time industrial automated control and monitoring system, transmitting data from remote sites after interaction (using Human Machine Interface) with various industrial machines pumps, valves, motors etc., The whole system runs automatically and can be monitored without human interference. Besides a number of benefits provided by these SCADA systems they have also major shortcomings. This system is expensive in terms of equipment and maintenance of various assets. Next, SCADA systems are inf1exible when there is a need to change the protocol or update the software and SCADA systems provide data with a long delay since field engineers need to control and maintain the equipment manually. They also suffer from IP performance over head.

3. Methodology

3.1. Information Acquisition Methods

To construct a pipeline monitoring system which can trigger a tower light and alarm when the sensor detects any abnormal behavior from the pipeline surrounding. The tower light and alarm make it easy to detect any unwanted incident at pipeline area. The first thing before starting design and develop the program is to obtain relevant data and material in studying and understanding the wireless pipeline monitoring system. The information obtains include the program structure, research and studies on the current solutions that involve to wireless pipeline monitoring system problems, and finally the technique to design and implement that should be in the program. The methods in finding the information consist of reading articles, reports, journals, and books. There are several steps procedure to achieve this research. This research consists of two parts; hardware part and software part. Due to that, two processes has been divided before combine to complete a wireless pipeline monitoring system.

A simple circuit is needed to complete hardware part. Meanwhile for the software part is used Arduino UNO using C program and PROTEUS is needed to create output for the hardware.

Figure 1 shows architecture wireless pipeline monitoring system. Status of sensor are monitored by microcontroller. Microcontroller processed status that has been triggered by sensor and data will be send to cloud. The data will be sent through network to web base and mobile web base.

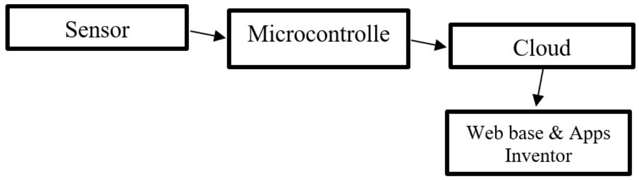


Figure 1. System Architecture of Monitoring System

3.2. Flowchart

There are two types of flow chart that need to be made to ensure the smoothness of this research. The first work flowchart is for writing on a story; that is planned for a task, putting through the hardware and software that need to be on the research and analyzing the overall of the research which conforming that the research is a winner. Also included is the qualitative method of obtaining the information concerning to a task. The second work flowchart is a method of a systematic progress that implemented into the task to analyze it theoretically step one by one.

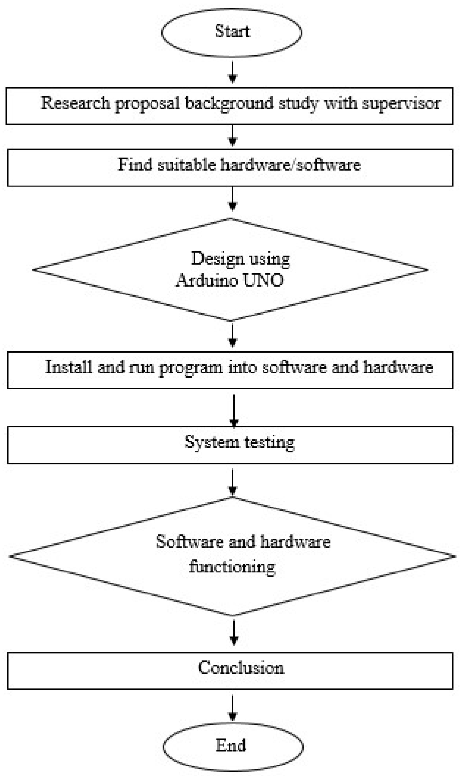


Figure 2. Research Process Flowchart

Figure 2 shows the detail progress of the research. The first stair is to develop an idea and planning the design of the research. Next after agreed with the title, background study related to the research need to research and understand. Estimated time to do back ground study is two to three weeks. Then, design the schematic using the software chosen. After finish all the schematic design, assemble and implement into Arduino Uno which is use Arduino IDE as code language and do a trial run. Analyze the trial run to see the output. If wrong output is given, check again with the software and hardware development and run test once again. If right output is given, complete the full research with report.

3.3. Synopsis for Methodology

Research methodology of the researcher can be structured and modified after reviewing the literature. The review assists in identifying various variables in the research research and conceptualizes their relationship. All the data and information are acquired from the books, journal, forum, and internet to complete this research. The primary focus on this research is on, the software and the hardware. For software part, it uses Proteus ISIS 7 professional is a VSM (Virtual System Modelling) that combines circuit simulation, components and microprocessor models to co-simulate the complete microcontroller-based designs. For the hardware part the section that responsibility with the researching and constructing the circle and does troubleshooting to the tour. It uses an Arduino UNO, gas sensor, flame sensor, temperature and humidity sensor and ESP 8266 Wi-Fi module.

3.4. Planning

In the Planning phase, the objective and scope of the research are identified. The purpose and requirement for the research is identified and the labor cost estimate is made. This research initiation includes finding the background of research and problem statement; find out the significance of research, and completing the literature review. The methodologies applied in the planning phase are:

1. Design
   In this stage, the student needs to plan and choose the appropriate hardware and software to design a Wireless Pipeline Monitoring System. The area must be measure up with a right schematic so that it can connect smoothly with the cloud to produce the signal output wanted. The organization also should be designed with suitable components so that the organization will function smoothly. The process of designing the research is important because it should meet the requirement and must be functional.
2. Testing
   All products have components vital to its functionality and usability and these vital components require extra observation in the early development stage. When testing these key components, it's important to simulate conditions that will be as close to real use conditions as possible. Make sure that the test fixtures simulate real world use cases, with varied and imperfect use and conduct enough tests to make sure all the component are robust.
3. Troubleshoot
   After some failure, the system need's to be troubleshooting to identify the real problem facing by the product. Student need to solve the issue by applying engineering skills that had been learned. This process is needed to produce and maintain the efficiency of the system and sensor in full conditions.

4. Finding and Discussion

4.1. System Overview

This system consists of two part which are input and the output part. The main component of the input part are the gas, flame, temperature and humidity sensor. Each of the sensor have a different parameter to measure to provide more information and detail regarding the condition of the pipeline. All the real time data will be processed by microcontroller which are Arduino Uno.

While on the output part, the main component is ThingSpeak platrom, MIT App Inventor 2 application, tower light and buzzer. The ESP 8266 Wi-Fi module will act as a medium of communication between Arduino Uno and the output to provide the IoT platform. All the real time data regarding condition of the pipeline will be send to cloud to be stored. By using ThingSpeak platform, the data can be accessed by using computer at monitoring station. The data like amount of gas, temperature and humidity will be display as a graph in ThingSpeak platform. User also able to access the data by using MIT app inventor application installed on the smartphone. In this case, the data can be monitored everywhere and anytime directly from user smartphone.

The design of the IoT based pipeline monitoring is made to eliminate the use of wire or cable in pipeline system. Arduino Uno will trigger the tower light and buzzer if there have any abnormal behavior from the pipeline. If the condition of the pipeline is safe, the tower light will produce green light. Next, when in intermediate condition, the tower light will produce yellow light. Finally, if the pipeline is in critical condition, it will produce red light and will turn on the buzzer immediately. The sensors are place surround the pipeline area. All the sensed data from the sensors will be sent to the cloud for monitoring purpose.

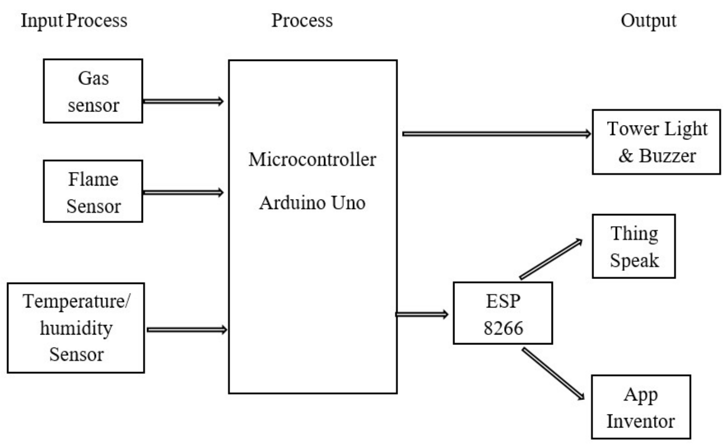


Figure 3. Block Diagram

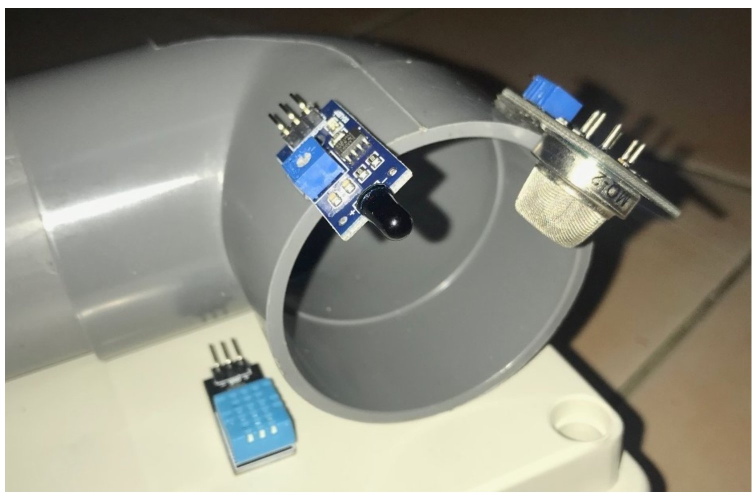


Figure 4. Sensors on pipeline

4.2. Overall Result

Analog and digital sensors had been used in this research. There have two analog sensor which are MQ-2 (gas sensor) and DHT11 (temperature and humidity sensor). These two sensors captured the current value of parameter that had been sensed by the sensors. The value that had been measure consist of precise real time data regarding the condition of the pipeline. For example, the current amount of gas in the air measured by MQ-2 sensor and the current value of temperature and humidity measured by DHT11 sensor can be collected precisely. Meanwhile, for digital sensor which are KY-026 (flame sensor) will produce only have "0" and "1". When there is no present of fire, it will send the value "0" to Arduino Uno and vice versa.

The output of the system is user able monitor the condition of the pipeline by using IoT platform ThingSpeak and App Inventor 2 application directly from user computer and smartphone. All the real time data from each sensor will be display in a graph as shown in Figure 5.

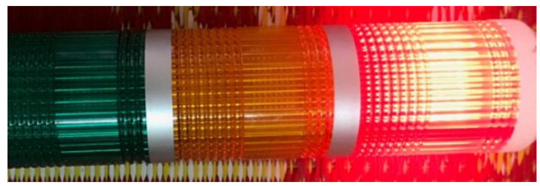
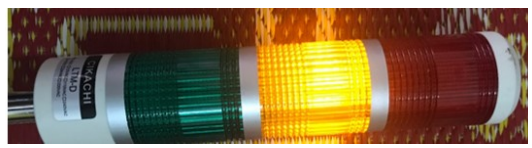
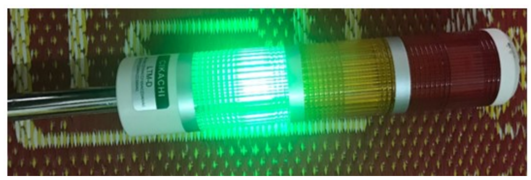
Next, user also able to monitor the condition of pipeline by using App Inventor application installed in user smartphone. All the real time data can be view directly from user phone by anytime and everywhere if needed. This application will be link with ThingSpeak platform by using the same channel ID to receive the same data as requested from the cloud. Figure 6 shows the interface of App Inventor 2 application for this system.

Figure 5. ThingSpeak graph of:
(a) Gas Sensor, (b) Flame Sensor, (c) Temperature Sensor, (d) Humidity Sensor

Figure 6. Interface of App Inventor application

For the condition of tower light, it had been set to some condition to indicate the current measurement of the pipeline. When there has a leakage at a pipeline, each temperature will give different reading based on the material inside the pipeline. If the leakage is gas, the gas will affect the reading on gas sensor (MQ-2). Meanwhile, temperature and humidity sensor (DHT11) will give different reading when there has a liquid leakage at a pipeline. Table 4.1 below shows the condition of tower light at different state.

Table 1. Condition of Tower Light at Different State

Light	Condition	
Red	• Gas, $x \geq 400$ • Temperature, $x \geq 50°$ Celsius • Temperature, $x \leq 20°$ Celsius • Flame, $x = 1$	
Yellow	• Gas, $200 \geq x > 399$ • Temperature, $40° \geq x > 49°$ • Temperature, $25° \leq x < 21°$	
Green	• Except from the condition mentioned above • Flame, $x = 0$	

Besides, tower light and buzzer will be placed at monitoring station acts as an indicator for early warning system. The condition of the tower light had been set in Arduino Uno earlier. If the condition of the pipeline is safe, the tower light will produce green light. Next, when in intermediate condition, the tower light will produce yellow light. Finally, if the pipeline is in critical condition, it will produce red light and will turn on the buzzer immediately. The sensors are place surround the pipeline area. All the sensed data from the sensors will be sent to the cloud for monitoring purpose.

Wi-Fi range of connection can be minimum of 20 meters. When operated at a supply of 3.3V, the sensors consume about 3 to 5 mA of current. All these voltages only take very low power only which will not take a lot of electricity even it is turned on. That's why it is economical and friendly user for consumers.

Finally, all the sensor had been tested for a week period by leaving the prototype in one place to determine the percentage of successfully data that had been send to cloud. Table 4.2 below shows the data distribution regarding this section. Internet connection plays a major role for sending data measured by each sensor and received by the cloud. If the system has a good internet connection, it will increase the percentage of data received from cloud.

Table 2. Percentage of successfully data received from cloud for each sensor

Sensors	Successfully data received from cloud (%)
Gas	83
Flame	79
Temperature	81
Humidity	85

5. Conclusion

IoT based pipeline monitoring system is successfully designed with early warning system and cloud platform to monitor the condition of pipeline from a distance for pipeline area. This system able to eliminate the use of wire in pipeline system which can reduce the cost and maintenance by implementing IoT platform. A complete functional prototype is focuses on gas leak detection and monitoring system is developed. Since this system requires sensing and wireless configuration, a various sensor is used in this research. Functional test for each component response was carried out.

To elaborate into security level system, this research provides early warning system and give access to monitor the condition of the pipeline through computer and smartphone. The processing system is from the Arduino IDE and microcontroller Arduino Uno thus it used to control and trigger the sensor and produced as the result.

The concept of this research is not to provide the entire solution of the pipeline system, but to avoid or reduce the use of wire and current expensive sensors. By implementing this new IoT system in pipeline structure, cost of sensor can be extremely reduced and have a closed monitoring system. All this sensor can be installed for each 100 meters of pipeline or can be focused on area that are critical such as terrorist attacks area and frequently people working place.

Finally, the overall is designed to protect the pipeline area and cannot be easily overlooked. IoT based pipeline monitoring system must have benefit to pipeline vendor and pipeline area and at the same times to reduce the occurrence of unexpected damage or loss for entire pipeline network.

Some suggestions that can be made to make it more benefit towards future users. The most general and versatile deployments of wireless sensing networks demand that batteries be deployed. Future work is being performed on systems that exploit piezoelectric materials to harvest ambient strain energy for energy storage in capacitors and/or rechargeable batteries. By combining smart, energy saving electronics with advanced thin film battery chemistries that permit infinite recharge cycles, these systems could provide a long term, maintenance free, wireless monitoring solution. Next, this research also can be innovate by implementing solar energy as power source. By doing this, the system will only use battery when there is no sunlight thus reduce the dependency of system on battery. Moreover, this system need to be tested on the real pipeline environment network in future to justify the needs required by Oil & Gas pipeline industry. This research can be improved by time to fulfill Oil & Gas pipeline industry criteria

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