IMPLEMENTATION OF WIRELESS MOBILE SENSOR BASED ON FUZZY LOGIC CONTROL FOR LPG GAS PIPELINE LEAKAGE MONITORING

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ABSTRACT

The main purpose of the leakage detection system on a gas pipeline is to give a warning of the dangers related to a gas leak that could endanger human lives and cause material loss. There is a wide range of gas detection systems used to provide an early detection and warning in the event of a leak in a gas pipeline, one of which that is wired monitoring system. However, in its implementation, the wired-based monitoring system has many shortcomings. To overcome the disadvantages of the wired monitoring system, a wireless-based sensor network in detecting and monitoring gas pipelines is applied in this study by implementing mobile sensors as key components of the data collection. LPG mobile sensors used in this study are equipped with a pipe tracking algorithm based on fuzzy logic control algorithm, so they can easily track and monitor the installation of a gas pipeline. Fuzzy logic control achieves a success rate of 70%. The overall system testing results in the average error of 18.5%, indicating that the mobile wireless sensors can already detect leakage in LPG gas pipelines.

Keywords: mobile sensors, pipe tracking, TGS2610 Gas sensor.

INTRODUCTION

There are various forms of pipe applications, such as urban gas pipelines, sewage pipes, pipes in chemical plants as well as many other applications that really support the activities of human life. However, basically the pipe is the main medium for transportation of oil and gas. A number of countries have also used the main pipelines in the delivery of oil and gas. Therefore, it is important to supervise and monitor the condition of the pipe. This needs to be done because a leak in the gas transmission will cause material harms and endanger human lives and also inhibit the process of gas distribution.

A wide range of gas leak control methods have been developed, one of which is wired monitoring system. This method is a detection system that uses a cable as a medium of delivery of sensor data. To be able to monitor a large area, it requires a long cable accordingly. A cable-based monitoring system is considered to be less efficient. This is because of the growing area to be monitored so that a longer cable is needed. Besides the cable materials are highly susceptible to heat, so their working life is also limited [1].

Gas leak monitoring system based on wireless sensor network is a solution of the deficiencies found in the wired monitoring system method [2]. Wireless Sensor Networks (WSN) is a network that can be used in various applications. In general, these networks are often used to make observations on the condition of the observed area and the position of the observer that are wide apart, so very good media to transmit observation data are needed.

In general, WSN systems consist of a collection of a number of sensors for sending data using a wireless system that is generally known as the wireless sensor array. With the arrangement of the sensor, it is possible to perform a data transmission from a sensor reading more efficiently. This is due to the absence of cabling system that can lead to power dissipation that causes the noise. However, the wireless sensor network systems are flawed in that they take a relatively long time and the installation costs are more expensive. This is due to the increasingly wide area to monitor and thus requiring a lot of sensors [3].

Several studies have been done to solve these problems, among others, using mobile wireless sensor network algorithms (MWSN). This method is done by replacing the static sensor nodes contained in WSN network with mobilemobile sensor nodes [4]. Another study is using vehicular ad-hoc networks. These methods are intended to maximize the role of mobilemobile sensors. The process of communication among the mobile sensors only occurs if there is a particular event. If these conditions are met, all mobile sensors in the system will set up a certain pattern so that there will be an ad-hoc communication among mobile sensors.

To develop the potential and overcome the problems that arise in the earlier studies, a gas leak detection system combining wireless sensor networks and optimizing the role of mobile sensors is developed in this study. For further improving the efficiency of the performance of WSN, the static sensor nodes in WSN will be replaced by a mobilemobile sensor.

In order for a mobile sensor to work well in an area of the pipe installation, it is necessary to have a pipe tracking algorithm. One of the methods that can be used for tracking the pipeline is utilizing the fuzzy control algorithms.

There have been many researches being conducted in relation to fuzzy control algorithms on a mobilemobile robot, such as mobile robot navigation using

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the fuzzy logic controller. This study designs a fuzzy algorithm on a mobile robot for indoor applications that aim to perform an obstacle avoidance function [5].

Another study done in conjunction with fuzzy logic is fuzzy logic controllers for mobile robot navigation in unknown environments using kinect sensors. In the study, fuzzy logic is implemented in, image processing applications. This is because the sensor being used is kinect camera. By using the fuzzy algorithm, algorithm robot navigation is designed to explore an area that is not recognized by previous robots [6].

To further improve the effectiveness and functionality of the wireless mobile robot used in this study, it is necessary to apply the fuzzy logic algorithm as the controller of the mobile robot. Thus, with the fuzzy logic control, mobile robots in this study are expected to be able to track the monitored area perfectly so that the data about the detection of the gas condition at the monitored area can be obtained.

LITERATURE REVIEW

Gas Sensor TGS2610

TGS 2610 sensor is a type of metal oxide semiconductor sensor that offers a low cost durability, and a good sensitivity to gas (the target) as it is censored by using a simple electronic circuit. The sensor is particularly suitable for applications in the detection of gas leak for toxic gases and explosive gases.

Elements used for LPG Figaro gas sensor is a semiconductor and tin dioxide (SnO_2) which has low conductivity in the clean air. If gas is detected, the conductivity of the sensor will increase, depending on the gas concentration in the air. The physical form of the TGS2610 gas sensor is shown in Figure-1 below.

A simple electronic circuit that can be used to change a conductivity into a voltage is made by adding a load resistance RL on the sensor, as shown in Figure-2 [7].

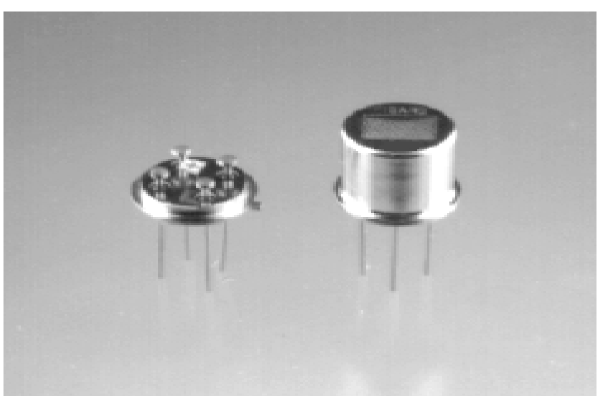

Figure-1. Physical form of gas sensor TGS2610.

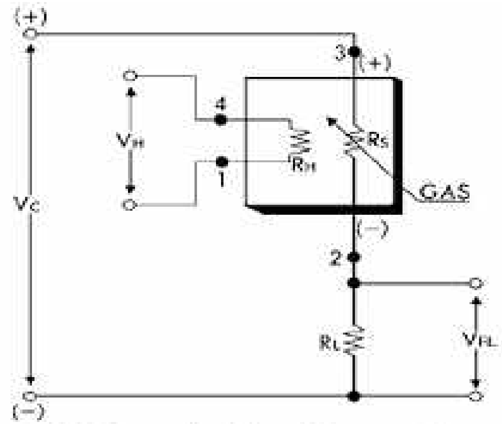

Figure-2. The series of measurements of TGS2610 gas sensor readings.

When the gas sensor Figaro TGS 2610 is given voltage input (VC) and heater voltage (VH) and placed on clean air, the sensor resistance RS will go down quickly so that the voltage across the load resistance (RL) will increase sooner and drop in accordance with the rising value of the RS until it reaches a stable value. This condition is called "first Action." Once the sensor reaches the Initial Action conditions, it indicates that the sensor is ready for use as a gas leak detector. When the sensor detects the presence of LPG gas content in the air, the sensor resistance will increase. A change of the sensor resistance is used as an indicator in the process of gas leak detection [8].

Infrared Range Finder Sharp GP2D120 Sensor

Infrared sensors are used as inputs of mobile sensors in detecting pipeline installation that will be monitored. These infrared sensors are a type of GP2D120 that has a detection range up to 40 cm. These sensors consist of two main parts, namely the IR transmitter that acts as an IR wave transmitter and an IR receiver that functions as an infrared wave receiver. The physical form of GP2D120 infrared sensor is shown in Figure-3.

The working principle of the infrared sensor in measuring the distance is different from that of the ultrasonic sensor that uses a time of sound wave reflection because the time of the reflected light is too short to be measured. Infrared lights with a frequency of 40 kHz are emitted and its reflection is received by the infrared detectors. A large intensity of infrared signals received by the receiver is used as a reference to determine the object distance.

In the process of object detection, infrared sensor is not affected by the color and constituting materials of the object being detected. This is in contrast with the ultrasonic sensor that is strongly influenced by the type of the constituting materials of an object. The existence of the infrared signal forms that are present in nature is basically a form of noise in the process of object detection by infrared sensors. However, these GP2D120 infrared

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sensors have been equipped with noise reduction that can minimize the noise.

Figure-3. Physical form of GP2D120 infrared sensor modulethat has been equipped with a receiver and transmitter.

However, the response formed between the analog output of the sensor and the calculated distance range is not linear. Figure-4 shows the analog response of the sensor to the measured distance.

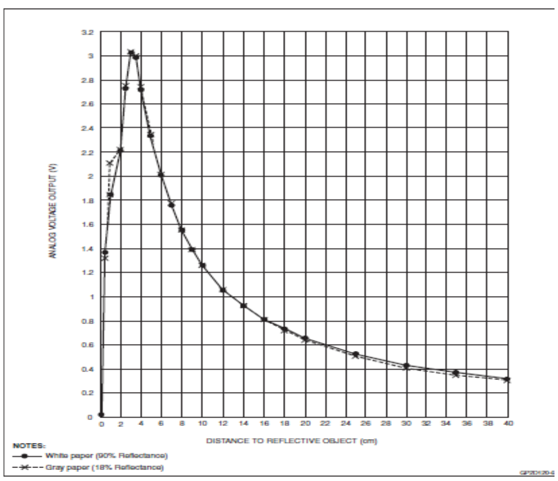

Figure-4. Graph analog infrared sensor response GP2D120 to the measured distance.

Pipe Tracking Method

Pipe tracking method is a method being implemented on a mobilemobile sensor mobilewhich is meant to enable it to identify pipe installation area that will be be monitored. By applying this method of Pipe Tracking, the mobile sensors can perform the monitoring process without having to put an additional installation or change the available systems of the piping design.

Pipe Tracking is an algorithm that provides a navigation orientation to the mobilemobile sensor by tracking a gas pipeline. One advantage is that a guide line or a distinctive mark as a direction for the mobilemobile sensor is not needed. It works by adjusting the distance of the wall to the mobile sensor to remain constant. If there is a change, the mobile sensor will move, and afterwards it adjusts the distance again. This process will be repeated.

In this study, three infrared sensors are placed at three different positions on the mobile sensors. The three sensors are placed on the front, right side and left side of the mobilemobile sensor. The configuration of the three sensors will determine the orientation of the movement of the mobile sensors.

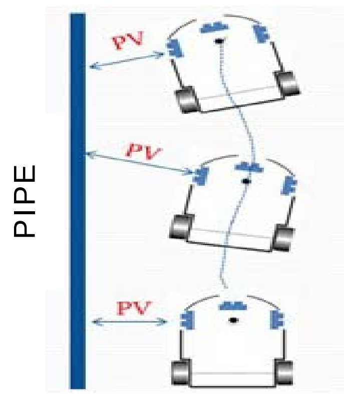

Figure-5. Illustration of pipe tracking method that is implemented on the mobile sensor.

Communication Module of Wireless Zigbee

One part of the basic construction of the mobile sensor is a wireless communication device. This device is used as a medium of communication of the mobile sensors to provide early warning alerts in the event of a leak on a gas pipeline. Wireless communication devices used in this study are of Zigbee type [9].

Figure-6. ZigBee wireless communication module is used as a communication device with mobile sensors.

Algoritma of Fuzzy Control

Fuzzy logic is one of the modern controllers that can work well on non-linear systems. It offers the ease in program design because it does not require a mathematical model of the process. Fuzzy logic is used to determine the decision-making process when a mobile sensor is tracking a particular installation of the pipe. However, in order to make the fuzzy logic control system work optimally, it first analyzes the shape of field test that will be used by the mobile sensors.

In this study, the shape of the pipe installation used as a test area by the mobile sensors is shown in Figure-7 below. Based on the test plan, it can be seen that the infrared sensors directly related to the installation of the pipe are the right and front sensors. Thus, the right and front sensor readings will be a reference for the fuzzy controller output.

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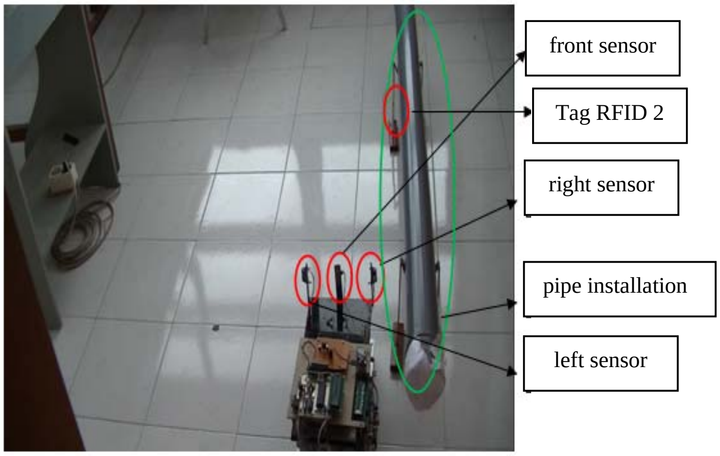

Figure-7. Design of mobile testing sensors used in this research.

Rule evaluation is the process of evaluating the degree of membership of each fuzzy set function input that is incorporated into the base of predefined rules. Overall, the number of possible combinations of the two fuzzy inputs with respective membership functions 3 and 2 are 2x3 or 6 rules. Fuzzy output will determine the orientation of the mobile sensor. More simply, 6 fuzzy logic control rules on wireless mobile sensors can be seen in Table-1. The method of decision making (inference) that is used in this program is a method of Max-Min.

	Small (right sensor)	**Medium** (right sensor)	**Large** (right sensor)
Large (front sensor)	Turn Left	Straight	Turn Right
Small (front sensor)	Turn Left Full	Turn Left Full	Turn Left Full

SYSTEM DESIGN

To be able to design a good detection system of gas pipeline leak, the data detection received by the system must be accurate and effective. In this study, mobile sensor is the most important part of the detection system of gas pipeline leak because the mobile sensors serve as the primary detectors that can evaluate the condition in the area of gas pipe installation. In the event of a gas leak, the mobile sensors will provide an early warning to the operator to reduce the risks of a gas leak. The design of a mobile sensor is shown in the block diagram in Figure-8.

The mobile sensor consists of several parts. The input consists of infrared sensors, gas sensors, and RFID Reader. The output of this device consists of a DC motor driver, an LCD as a display indicator and wireless communication device as a communication medium. The most important part of mobile sensor is a microcontroller that serves as the control center [10].

Figure-8 shows a model of mobile sensor design that has been equipped with infrared sensors and gas sensors.

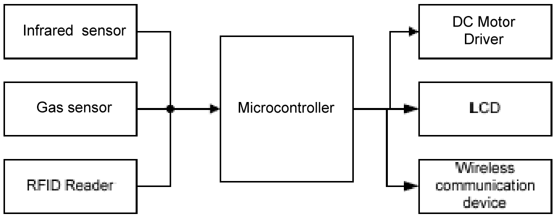

Figure-8. Block diagram of mobile sensor used in this study.

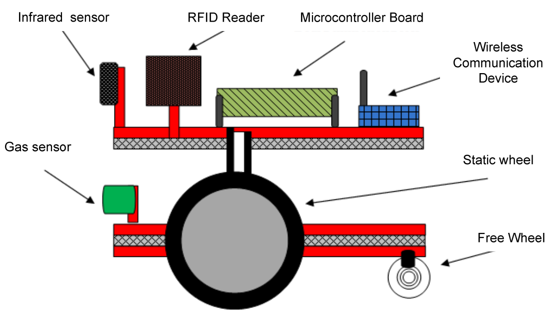

Figure-9. Design of mobile sensor.

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RESULTS AND DISCUSSIONS

Figure-10 shows the form of a specially designed room for the sensor TGS2610. The room is equipped with a fan which acts as an air distributor that will be detected by the sensor. Placed in the room the sensor is isolated from the outside air, so that the results of TGS2610 gas sensor readings will be more accurate.

Figure-11 shows the realization of mobile sensor design that has been equipped with a gas sensor and three infrared sensors. To support the maneuver of the mobile sensormovement, a pair of loose wheels is mounted to allow for free movement.

Figure-10. Chamber design of TGS2610 gas sensor.

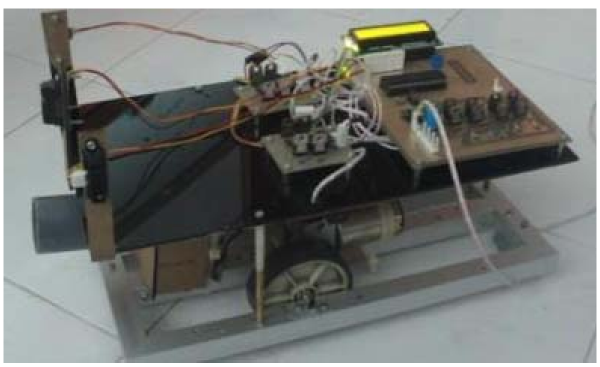

Figure-11. The results of the realization of mobile sensor design.

Testing TGS2610 Gas Sensor

Testing the sensors is needed to determine the characteristics of the sensor, as well as finding the value of the sensor output to be inserted into the ADC. The test is based on the response time and the response of the sensor resistance changes against the degree of LPG gas in the air.

Testing the response time is needed to determine the time required for the gas sensor reaching a stable value at the time of initial condition when the sensor is activated. Table-1 below displays the response time of the sensor when first turned on.

Table-1. The sensor response to time.

Time (second)	**Value of ADC**	**Voltage**
1	963	4.702148438
2	981	4.790039063
3	898	4.384765625
4	838	4.091796875
5	839	4.096679688
6	827	4.038085938
7	816	3.984375
8	807	3.940429688
9	801	3.911132813
10	797	3.891601563
11	792	3.8671875
12	789	3.852539063
13	785	3.833007813
14	784	3.828125
15	781	3.813476563
16	778	3.798828125
17	779	3.803710938
18	777	3.793945313
19	776	3.7890625
20	774	3.779296875
21	773	3.774414063
22	772	3.76953125
23	770	3.759765625
24	768	3.75
25	766	3.740234375
26	764	3.73046875
27	765	3.735351563
28	762	3.720703125
29	765	3.735351563

Table-1 shows the relationship between time and the ADC data from the sensor readings. Based on the data shown in Table-1, it indicates that during the initial seconds unstable values will occur on the sensor. The value of the sensor tends to decrease. This condition will last until up to 25 seconds.

TGS2610 sensor requires a relatively short time to reach a stable value. The time involved is approximately 29 seconds. This is due to the heating process of the heater located on the sensor.

The heater serves to minimize the amount of moisture content on gas being detected. Thus, with the air conditioner system it is expected to improve the accuracy of gas detection obtained by the sensors.

When the sensor reaches a steady state, the value indicated by the ADC is at a relatively steady state, namely at 762 to 766. This steady state will be used as a benchmark for the calibration measurements. This is in accordance with the tests performed by Luay Fraiwan, Khaldon Lweesy, Aya Bani Salma, and Nour Mani [9]. In the study it was indicated that the range of gas sensor value being used for the detection process was at a voltage level between 0.25 to 3.73 volts. This value is equivalent to the data ADC 0-764.

Testing the Infrared Sensor Sharp GP2D120

Based on the above graph of an analog sensor response contained in the sensor datasheet, it can be seen that the relationship between the measured distance and the analog output of the sensor is not linear. Here is an analog sensor response of several distance variations, as shown in Table-2.

Table-2. Response of sensor analog to the distance.

Distance	ADC	V_adc
10	400	2
15	236	1.18
20	171	0.855
25	134	0.67
30	100	0.5
35	84	0.42
40	73	0.365
45	61	0.305
50	52	0.26
55	48	0.24
60	44	0.22
65	40	0.2
70	35	0.175
75	36	0.18
80	32	0.16

Table-2 is a Table showing the data connection between the distance variation among the infrared GP2D12 sensors and a particular object. Data testing in Table-2 is obtained by changing the distance between the object and the sensor, so that different sensor data are obtained.

Table-2 shows that when the distance between the object and the sensor is made further away, the data of the sensor reading decrease.. This is in accordance with the working principle of GP2D12 infrared sensor in detecting the distance of an object being measured.

In detecting the distance from an object, this infrared sensor transmits infrared light beam through the light transmitter. When the infrared light beam is right on an object, some light will be absorbed by the object, and some will be reflected back. The absorption of some infrared light by the object causes a decrease in the intensity of light received by the receiver. The size of the infrared light intensity is used as the basis for determining the distance of an object to the sensor.

Based on experimental data of GP2D12 infrared sensor as shown in Table-2, it is found that the ideal distance range that can be detected by the sensor is between 15-80 cm. This is due to the fact that at the distance range, the change of the data values obtained from the sensor is linear. The test results are consistent with a research conducted by Saman Kumpakeaw, 2012[11]. In the study it was mentioned that the sensor GP2D12 was classified as a short-range infrared sensor that had a distance range between 20-100 cm.

Testing of Pipe Tracking Method

On the application of pipe tracking algorithms implemented on the mobile sensors, three pieces of infrared sensors are used. Each piece is placed on the front position, right and left side of the mobile sensor. All three of these sensors will continuously monitor the distance between the pipe and mobile sensors. The ideal distance to be maintained between the mobile sensor and the pipe is 5 cm. Thus, by maintaining the ideal distance, the mobile sensors will be able to track the installation of a pipeline as shown by the graph in Figure-12.

As can be seen from the graph, the blue line is the installation of a pipe with a length of 300 cm. The red and green lines represent the movement of mobile sensors.

The illustration shown in Figure-12 indicates that the movement of mobile sensors is in accordance with the basic principles of the pipe tracking algorithm, namely by maintaining an ideal distance. The graph shows that the movement of mobile sensors is not always smooth. There are still errors, but it is still parallel with the existing orientation of the pipe installation.

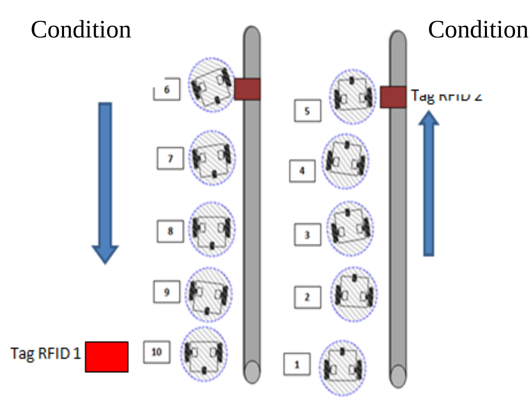

Figure-12. The testing result of the implementation of pipe tracking method.

Testing of the Overall Systems

In this testing phase, the response of the system that has been designed to carry out tasks in monitoring gas leaks is observed. Testing is done by making a simulation of a gas leak by flowing butane gas of a certain amount in the pipe installation.

Furthermore, the mobile sensors will perform their tasks in monitoring the pipeline area based on instructions from the server. After the monitoring software for the gas leak on Delphi is run, the server will send instructions to the mobile sensors wirelessly to do the monitoring process. Shortly after the mobile sensor has begun the process of tracking and monitoring the pipeline, the butane gas is flowed into the pipe installation.

When the mobile sensor detects the presence of butane gas content in the air, the mobile sensor immediately sends the data of gas sensor readings, as well as the spot of the gas leak. The test results are shown in Table-3 below.

Out of the 10 experiments conducted, the resulting average error is 18.5%. Based on the results of the overall testing of the monitoring system of gas leak, it can be concluded that all parts of the system have shown the right performance. The disadvantage is only in the counter program that determines the position of a gas leak. However, the resulting error is within a relatively small order that is in the order of centimeters so that it can still be tolerated.

Table-3. The overall testing results of the system.

Test	**The actual position** (cm)	**The position of the reader in the mobile sensor** (cm)	**Error** (%)	**Status**
1	50	80	37.5	Succes
2	50	50	0	Succes
3	75	0	100	Failed
4	75	90	16.66	Succes
5	100	110	9.09	Succes
6	100	110	9.09	Succes
7	120	118	1.69	Succes
8	120	125	4	Succes
9	150	140	7.14	Succes
10	150	150	0	Succes

CONCLUSIONS

The detection system of gas pipeline leak by implementing a mobile sensor is equipped with a gas sensor TGS2610. TGS2610 sensor instrumentation has been designed properly so that it can detect LPG gas levels in the level range of data readings between 0-776. Thus, it can detect very low LPG gas levels, reaching 56 PPM. As a result, it can recognize the presence of LPG gas leakage that occurs in the pipeline installation. With the addition of an infrared sensor GP2D120 combined with pipe tracking algorithm using fuzzy control, this system has properly performed the tracking process in a pipeline installation. The success rate reached 80%. To be able to know the position of the gas leak, the system uses a combination of rotary and RFID to produce a positioning method with an accuracy of 5 cm, with an error tolerance of 18.5%. As a wireless data transmission medium, ZigBee module that has a range of more than 5 meters is used. Therefore, by combining all these parts, an accurate and effective detection system of gas pipeline leakage is obtained.

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