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A MODEL OF PETROLEUM PIPELINE SPILLAGE DETECTION SYSTEM FOR USE IN THE NIGER DELTA REGION OF NIGERIA

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Abstract

In recent times, petroleum pipeline vandalism resulting into spillage has become a significant challenge in Nigeria. Citizens are regularly inundated with reported cases of vandalism which often lead to spillage and a drastic reduction in government's revenue as is currently the case in Nigeria. This paper focuses on the design of petroleum pipeline spillage detection system. The design consists of the power supply unit, the comparator unit, the microcontroller unit, the switching unit, the transceiver unit and the base station. Simulation of the various units was done individually using the procedural programming application Proteus 8. Most of the components used were according to design specifications from data book with alternatives used in cases where they are unavailable. Wiring sensors which provided continuous electrical paths to break the signal path and trigger an alarm at the base station were used The design was done in units and were tested individually and the whole system was tested to perform the required task of detecting petroleum spillage and alerting the control room for action. It is found that the designed system had the advantage of responding to intrusion and vandalism better than existing systems.

Keywords: Spillage; Vandalism; Transceiver; Petroleum Pipeline; Niger Delta Region of Nigeria

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1. Introduction

Petroleum pipeline Vandalism refers to illegal or unauthorized activities that result in the destruction of petroleum, gas and chemical pipelines. It is a negative activity aimed at getting

products for personal use or for sale in the black market especially in developing countries of the world where they are rampant, [1].

In recent times, petroleum pipeline vandalism resulting into spillage has become a significant challenge, [2]. Initial proactive measures of deploying police and patrol teams and the use of vigilante has become less result oriented as new strategies have been deployed to override these techniques. Human activities and those of oil exploration and exploitation continue to raise a number of issues such as depletion of biodiversity, coastal and riverbank erosion, flooding, oil spillage, gas flaring, sewage and wastewater pollution. Land degradation and soil fertility loss and deforestation as well as noise pollution are all major environmental setbacks that have negatively impacted the oil rich region of Niger Delta, Nigeria.

With an area covering over 20 thousand square kilometers, the Niger Delta region has, as part of its characteristics, a rambling waterways. A large part of the area consists of salt water swamp and parts of the fresh water have limited agricultural possibilities. The Niger Delta region got its name from being situated at the mouth of Niger River in the early 15th century, [3].

In related study, [4] observed that a large percentage of the world's petroleum flow through pipelines which run thousands of kilometers across some of the most volatile areas of the world, This accounts for why easy policing of petroleum pipeline is a herculean task. [5] stated that militants have repeatedly attacked pipelines and related facilities, including the simultaneous bombing of three oil pipelines in May, 2007

A report by the Nigerian National Petroleum Corporation (NNPC) and the Nigeria Extractive Industries Transparency Initiative (NEITI) puts the loss due to criminal activities on the nation's pipeline at a staggering N8.6 trillion in the last four years. On the average, N2.4 trillion was stolen every year since 2012. A former Managing Director of NNPC, Mr. Andrew Yakubu, put the yearly loss of revenue at $12 billion (about N2.4 trillion) yearly. According to the NNPC, incidents of pipeline vandalism rose by 4.54 per cent in 2014, compared to the situation in the preceding year. "A total of 3,732 line breaks was reported on NNPC pipelines out of which 3,700 was as a result of vandalism, while 32 cases were due to system deterioration, [6], [7]

Previous research have shown that the general impoverishment of the host communities can be linked to the years of perennial neglect and abuse of the environment of Niger Delta as major operators do not have recognizable remediation measures in place after major oil spills occur, [8]. The situation is worsened by a visible show of apathy to the fate of the environment by successive state and federal governments. While the drive is towards increasing the revenue of the country thorough optimum petroleum production, there is no corresponding passion directed towards ensuring ecological sustainability and management. This is evident in the way successive administrations have been shifting the dateline on gas flaring stoppage in oil field operations in Nigeria without an achievable blueprint towards ensuring total stoppage of flaring. The absence of a strong political will and alignment by the legislature and executive has worsened the hope for entrenching an environmentally friendly legal system that would protect the ecosystem while striving to restore an already battered environment,

Figure 1: Technicians carrying out repair work on a vandalized pipeline.
Source: http://sweetcrudereports.com/2016/01/01/nigeria-loses-n57bn-to-pipeline-vandalism-oil-theft/

It is near impossible to deploy a workforce that will monitor these assets physically on a 24/7 hour basis considering the fact that we have over 3000km length of pipe network crisscrossing this region, [9]. A better approach will be to use an automated system capable of monitoring activities and alerting a control station of any act of vandalism.

Daily Trust Newspaper of June, 2013 revealed that 6,000 Nigerians died of pipeline fire in 5 years. On the other hand, the Petroleum and National Gas Senior Staff Association of Nigeria (PENGASSAN) president reported that Nigeria loses 6 billion US dollars annually to crude oil theft and also lost 105 billion naira to theft of refined petroleum products. Officials of Pipelines and Products Marketing Company (PPMC), who are deployed to effect repairs on the broken pipelines often, taste the vandals' weapons. They are killed and buried in shallow graves.

It is thus pertinent to fashion out ways of saving lives, the ecosystem and maintaining a stable transportation of petroleum products as pipeline vandalism has become a threat to development both of human, communities, states and the nation. The activities of the vandals have dealt a big blow to the psychic of victims of vandalism, as they have recorded loss of property and close relatives that cannot be categorized in monetary terms. Any knowledge that can contribute to the solution of the problem petroleum pipeline vandalism is important and relevant.

Petroleum pipeline vandalism is an unpleasant and destructive phenomenon that no individual or group of persons should tolerate if development is desired, [10].This study is topical and timely given the increasing rate of pipeline vandalism that is inherent in the Niger Delta region of Nigeria presently. This study will provide the intellectual window to address the persistent issue of vandalism in the region through the design of the modeled petroleum pipeline spillage detection system.

2. Theory of The System

A theory is a coherent statement or set of ideas that explains observed facts or phenomena or which sets out the laws and principles of something known or observed or a hypothesis

confirmed by observation, (Wiktionary, 2016) [11]. There are various theoretical explanations for actions that are commendable as well as prime causal factors of vandalism that in itself is a criminal offense liable to 45 years jail term.

The theory of modernity and the rational choice theory are used to explain the rational but destructive approaches of pipeline vandals while the theory of George Homan can be used to explain human interaction at all levels which is governed by reward and punishment. According to Homan, People exhibit various behavioral traits when they enter into interaction and each of the people in interaction carry with them portable aspects of self-such as values, beliefs and sentiments which are freely expressed to attract reward, gains or profits and avoid punishment and losses,[12]. The assumptions of Homan further see the social world as a market place where people strive to get better of the other person. However, the notion here is the multiplicity of approaches of the effective operation strategies of the task force assigned to oversee the policing of pipelines on the one hand, and the safety of the communities, the people and the oil pipelines, and maintaining the alliance with the government of their father land on the other hand.

Thus, according to [13], punishment should commensurate with the seriousness of the crime committed as it is needed to preserve the equity disturbed by vandals as it is a rational choice. It was further asserted that vandalism can be controlled or eradicated by convincing potential offenders that vandalism is an unhealthy choice, which can never bring anything other than suffering, hardship and pains either directly or indirectly on the vandals themselves.

3. Challenges of Petroleum Pipeline Spillage in Nigeria

Petroleum spill incidence through pipeline vandalism appears to be peculiar to Nigeria and has become rampant in recent times even as the activities of vandals continue to undermine Government's efforts at meeting its obligations in generating revenue to carter for the growing needs of the masses. Pipeline vandalism and disruption of oil production activities regrettably have become an integral part of oil and gas operations in Nigeria.

Pipeline project in Nigeria is an important infrastructure as it stretches several thousands of kilometers and passes through cities, villages and rural communities, most of which are found in the Niger Delta. These pipelines are operated at high pressure and any failure or damage poses a great danger to human health and properties, environmental and ecological disaster and interruption of gas or oil supplies [3], [5]. The pipelines are prone to losing their functionality by any internal or external corrosion, cracking, third party intrusion and manufacturing flaws, thereby leading to damage, leakage and failure with serious economic and ecological consequences. Pipeline vandalism has crippled fuel supply and incurred huge losses in product losses and pipeline repairs to government and oil companies, [14].

In a survey conducted between September, 2012 and August 2013 to determine the extent to which anti vandalism activities have been able to reduce the effect of vandalism in the 5 major oil producing communities of the Niger Delta, it was discovered that despite the efforts of the Nigerian Security and Civil Defense Corps (NSCDC), Nigeria Maritime Administration and Safety Agency, NIMASA, the Department of Petroleum Resources, (DPR) and the Nigerian police Force, (NPF), activities relating to oil theft have been on the increase[10]. The analysis is as presented below for each of the five major oil producing states of the Niger Delta region.

Table 1: Reference to September, 2012 and September 2013, Delta State Anti-Vandalism/Illegal Bunkering Activities Report.

S/N	Discovered Item	Quantity
1	Truck	1
2	Kidnapped Victims	2
3	Illegal refinery	7
4	Trucks	4
5	Pistol	5
6	Shovel	4
7	Cars	6
8	Cotonou Boat	8
9	Wheel barrow	10
10	Metal Drums	15
11	Dug Pit	19
12	Hose	24
13	Persons injured	24
14	Gee pee Tanks	35
15	Arrested suspects	80
16	Wooden Boat	177
17	Vessels	3,000
18	Jerry cans	6,205
19	Surface Tanks	105
20	Plastic/Iron drums	9,527
21	Quality of AGO	10,975 liters

The reports also include the number of mortality during the time, which is one.
Source: (http://www.interior.gov.ng/anti-vandalismreport), [10]

Table 2: Reference to September, 2012 and September 2013, River State Anti-Vandalism and Dismantling of Illegal Refinery Report.

S/N	Discovered Item	Quantity
1	AGO	29,785 ltrs
2	Plastic drums containing crude oil	1
3	Crude oil	2420 ltrs
4	Welding gas cylinder	1
5	Pressure Gauge	1
6	Pumping machine	3
7	Pipeline leakage	1
8	Empty drums	10

Source: (http://www.interior.gov.ng/anti-vandalismreport) , [10]

Table 3: Reference to September, 2012 and August 2013, Bayelsa State Anti-Vandalism Report

S/N	Discovered Item	Quantity
1	Oil spillage and bunkering zone	1
2	Car	3
3	Shovel	5

4	Kidnap victims	2
5	Jerry can	3
6	Wooden Boat	4
7	Arrested Militant	4
8	Illegal refineries	8
9	Arrested suspects	8
10	Wheel barrow	10
11	Illegal Oil Distillery camps	42
12	Cotonou Boat	40
13	Iron Tanks	33
14	Plastic Drums	127

The reports also include the number of mortality during the time, which is one.
Source: (http://www.interior.gov.ng/anti-vandalismreport), [10]

Table 4: Reference to September, 2012 and September 2013, Akwa Ibom State Anti-Vandalism Report.

S/N	Discovered Item	Quantity
1	AGO	14,076 ltrs
2	Illegal refinery	2
3	Suspected vandals	9
4	AK 47	5
5	Rifles	2
6	Iron drums	69
7	Suspected vandals including a politician	3

Source: (http://www.interior.gov.ng/anti-vandalismreport), [10]

From the foregoing and tables above, it is obvious that many lives have been lost, billions of crude oil spilled away, many of which resulted in explosions and fire coming from vandalized pipelines carrying crude oil and refined products when they become vandalized. The environment has been degraded in the process with farmlands made unproductive. The design of this system could not have come at a better time.

4. Component Design - Hardware Sub-System

The design and development of the system has both the hardware, software and user requirements. The hardware subsystems include the hardware units used to realize the visible test-bed for the model of the pipeline spillage detection system for use in the Niger Delta region of Nigeria. The software sub – systems include the software units used to realize the sensor that initialize the process, data transfers from the deployed visible test-bed to the designated mobile phones and an online server and clients at the base station of the designed system. The user requirements requires that the users are conversant with the use of the computer system as well as being able to read, write and interpret instructions properly.
The hardware sub system is categorized into seven (7) major units namely:
   a.   The Power Supply Unit
   b.   The Comparator Unit
   c.   The Microcontroller Unit

d. The Switching Unit
e. The Transceiver Unit
f. The Base Station/Control Room Unit and

a. *The Power Supply Unit*

Power supply is needed for the proper functioning of any electrical or electronics system. Since most of the semiconductor components do not require a high voltage supply for them to work properly as a high voltage destroys them permanently, the value of the components used were designed according to the need of the pipeline detection system
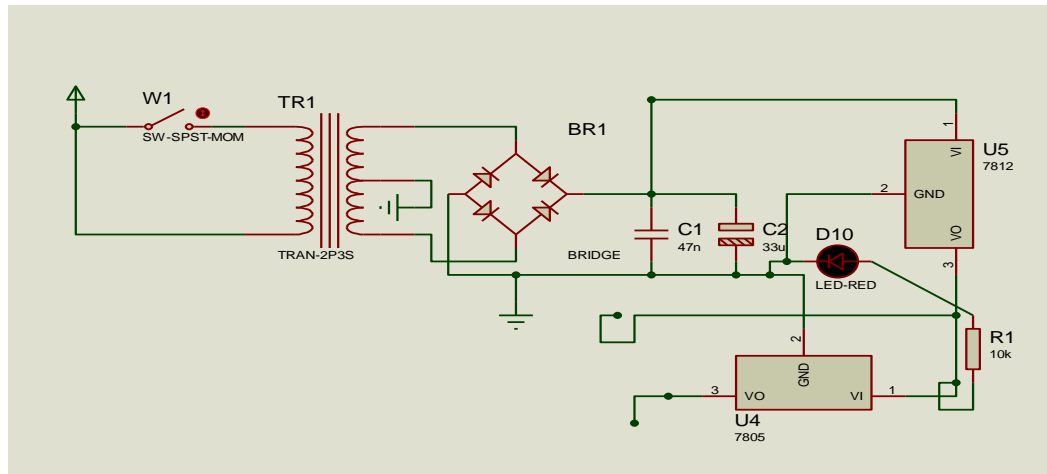

Figure 2: Power supply unit.

The power supply system consist of 220v/9v ac transformer, 25v by 2200uF or 25v by 3300uF capacitor, IN4001 diodes connected in bridge rectification.

The transformer to steps down 220/240V to 12V. This 12V AC was converted to DC to feed DC supply voltage to the control circuit, which includes; transistors and the relays.

The regulators produces the 9V and 5V used to power the rest of the circuit. In most designs, assumptions are always made to ensure certain conditions are accomplished. The assumed values hence help in calculating the variables.

The following assumptions were made:
Input frequency = 50Hz
Secondary voltage of the power transformer = 9Vrms
 Diode voltage = 0.7V. (Silicon semiconductor)
Using $Vmax = Vrms * 2$
          $= 9 * \text{root } 2 = 12.726V \approx 13V$.

This value helps in calculating the peak inverse voltage of the rectifying diodes which was calculated to be 12.3V.

The major source of power for the designed circuit is from the Power Holding Company of Nigeria (PHCN). Network service providers' source of power supply could also act as the source of power supply since the designed model will be located in service provider mask points. The objective of locating the designed model is to ensure that there is always a strong signal as the designed model is wireless. The other objective is to ensure that there is a constant power supply to the designed model.

b. The Comparator Unit

As the name implies, a comparator compares two input voltages and gives an output depending on the voltages at any of the positive or negative terminal. Comparators are closely related to operational amplifiers. An operational amplifier is basically a voltage amplifying device designed to be used with external feedback components such as resistors and capacitors between its output and input terminals. Operational amplifiers are a three- terminal electronics device which consist of two high impedance inputs, one is called the inverting input which is marked with a negative sign (-) while the other is called the non-inverting input, marked with a positive sign (+).

In the design of this model, LM324N because of its ability to accommodate a low voltage power supply. It is a 14 pin integrated circuit that consists of four independent operational amplifiers in a single package.

In the design of the comparator circuit shown in fig. 3 below, three operational amplifiers are used with each of the operational amplifier connected to a pipeline with the help of a 5V voltage regulator that helps to determine when the operational amplifier will send signals to the switching circuits and whether an alarm should be triggered or not depending on the voltage received by either of the inputs of the operational amplifier
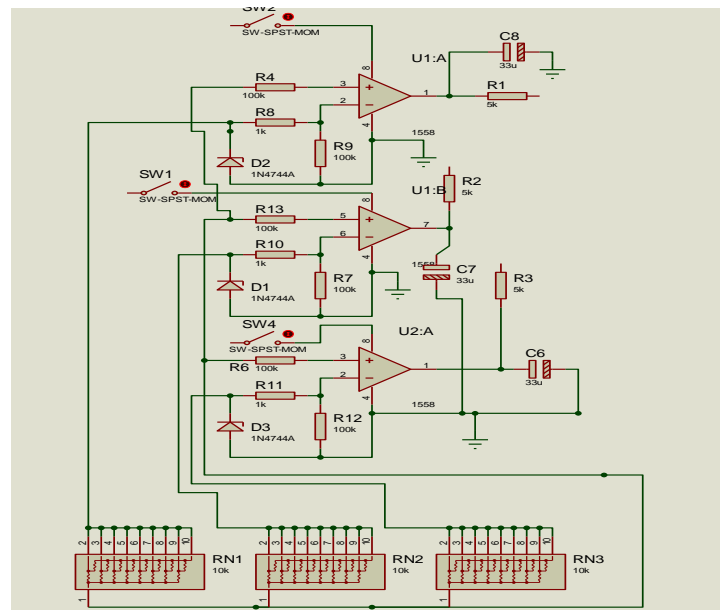

Figure 3: Comparator unit circuit design.

c. The Microcontroller Unit

This is the intelligent part of the system. It is the component responsible for detecting and interpreting signals received from the sensors. It is also responsible for information transmission between the system and the base station unit. This means that it directly controls the functions of the transceiver with the help of the switching devices, that is, the 9V relay and transistors. The microcontroller in this system performs the same functions a processor does to a computer system; it governs its operations. The microcontroller chosen for this function in this design is the PIC16F 628A, a product of Microchips. The Functions of the microcontroller-16F628A include amongst others: to turn on the system automatically when power is connected, to interpret signals, to send an alert signal to the base station in case it senses an intruder by making the sender Bluetooth device to switch ON with the help of the switches, to notify the control room of intrusion using the Liquid Crystal Display (LCD) to show the actual point (s) of intrusion, to clear the transceiver's screen and to relay audio signals around petroleum pipelines to the base station.
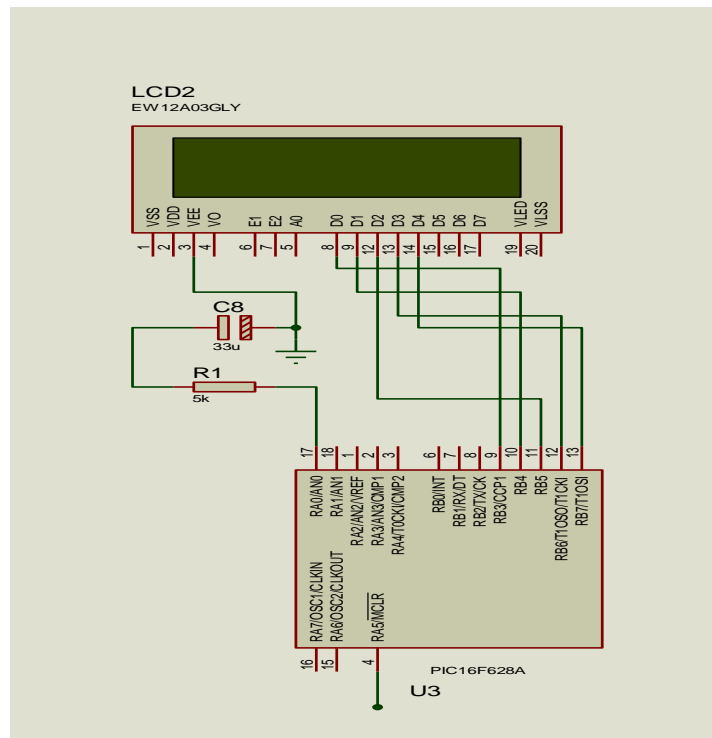

Figure 4: The microcontroller unit with an LCD for intrusion information.

d. The Switching Unit

The switches used in the design of this system are the relays and transistors. A 9V relay and a C1815 transistor were used. A relay is an electromagnetic device that is capable of isolating two circuits electrically and connecting them magnetically. Relays are useful devices as they allow one circuit to switch another one while they are completely separate. The relay switch can be divided into two parts: the input and the output. In the 5-terminal relay switch used, two terminals are used to give the input 9V DC voltage as the operating voltage of the relay while the

remaining three terminals are used to connect the high voltage AC circuit. The C1815 transistor conducts current across the collector-emitter path when a voltage is applied to the base while it switches off when there is no voltage applied to the base. The switching and transceiver configuration of the designed circuit is as shown in fig. 5 below.
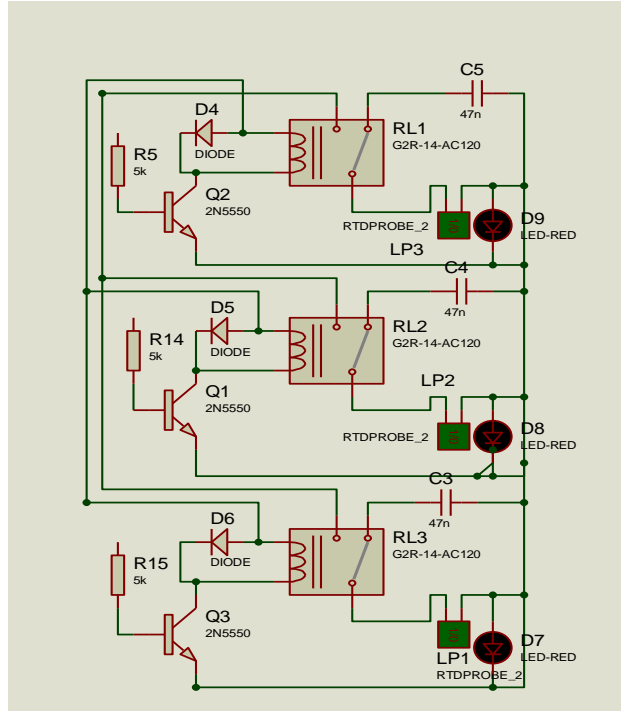

Figure 5: Circuit showing the switching and transceiver circuit configuration.

e. The Transceiver Unit

Transceiver is a blend of a transmitter and a receiver in a single package. The name applies to wireless communication devices like cellular telephones, handheld two-way radios, cordless telephone sets, and mobile two-way radios.

This unit is capable of sending and receiving signals via wireless communication channels. The transceiver is a very important part of the system, and its mode of operation is better explained by the operation of radio signal. In the design of this device, the transceiver operates at a frequency of 900MHz. This is the operating frequency of a GSM phone.

The transceiver is a modified GSM phone. Through it, a wireless information exchange can be achieved. The mode of communication here is similar to that of FM but it is not a broadcast. The transceiver, which is a GSM device is a modified Nokia (or a Bluetooth device) android phone. It is hosted on a network through a SIM module. Every SIM module has a unique identification number. Through this identification number it can send and receive data on the local and global GSM network transmitter and receiver. The transceiver unit transmits and receives signals at a certain frequency.

f. The Control Room/Base Station

The control room, as designed in this system, is located at the office of the company monitoring its pipelines. This is essential as it helps to save cost and ensures that only trained personnel are at the base station to monitor the pipelines. Also, most of these offices are equipped with state of the art facilities that will be handy. The Control room has a central server which has been programmed to send signals to various terminals to alert them of any intrusion. This is done with the aid of wiring sensors that have been wound round pipelines in remote locations. The alarm is set to go off if trespassers or vandals go beyond a certain limit nearer to the pipeline. The sensors wound round the pipelines acts as the actuator to trigger the alarm at the control room or base station once it detects the presence of people or animals. Light Dependent Resistors (LDR) is used in consonant with other resistors in the design so as to make it work properly at night. The designed circuit is put in a box and placed in any network provider mask area where it will have the best of network at all times for quick and uninterrupted transmission of information to the control room for action in cases of intrusion.
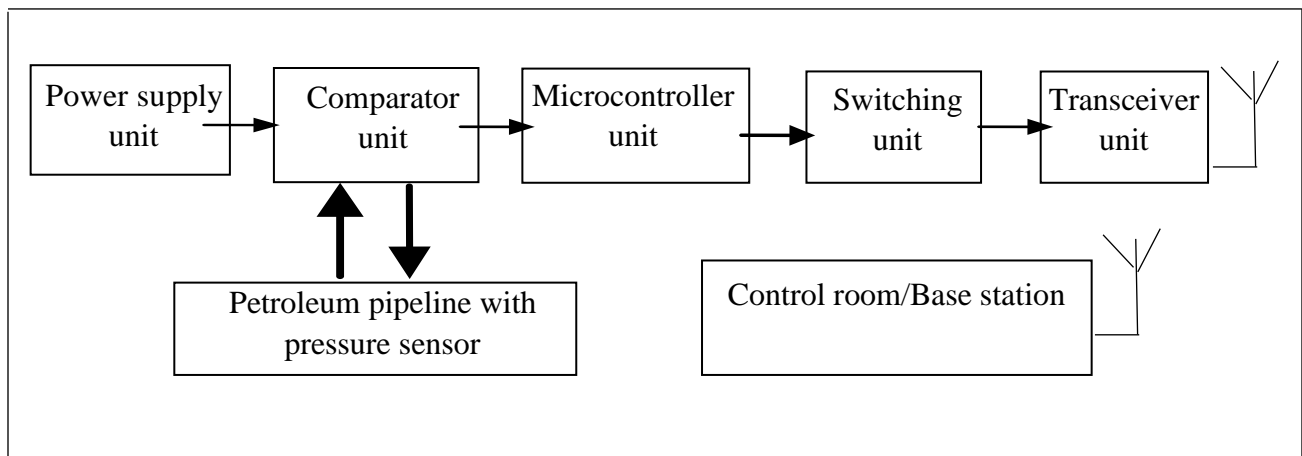

Figure 6: Block diagram of the petroleum spillage detection system.

5. User Requirement of The Model

The designed circuit is to be located within the premises of any network service provider while the control room and or base station is to be at the head office of any of the multinational oil company that has petroleum pipeline network. The mode of operation of the designed circuit is wireless and will be using the power provided by the service provider mask which is constantly on. The user requirement is thus needed only at the base station where the user is expected to understand the basic operations of the computer system and a basic knowledge of Microsoft access so as to be able to interpret different signals.

6. System Flowchart

The programming language chosen is Visual Studio, because it is easy to use in writing programs for Windows. It simply gives you maximum control over your computer. The programs can

automate your work; prevent mistakes and make you more productive. Writing programs can be complex, but fortunately Visual Basic makes it easy for one to get started. You can chose how far to go. Another advantage of Visual Studio is that it works with Microsoft Office and on the internet.

a. Algorithm of the Design

The sequence of stages of the design is as enumerated below:
Start
Monitor to line
If there is a break
Comparator output goes high
Microcontroller
LCD display, switching devices active
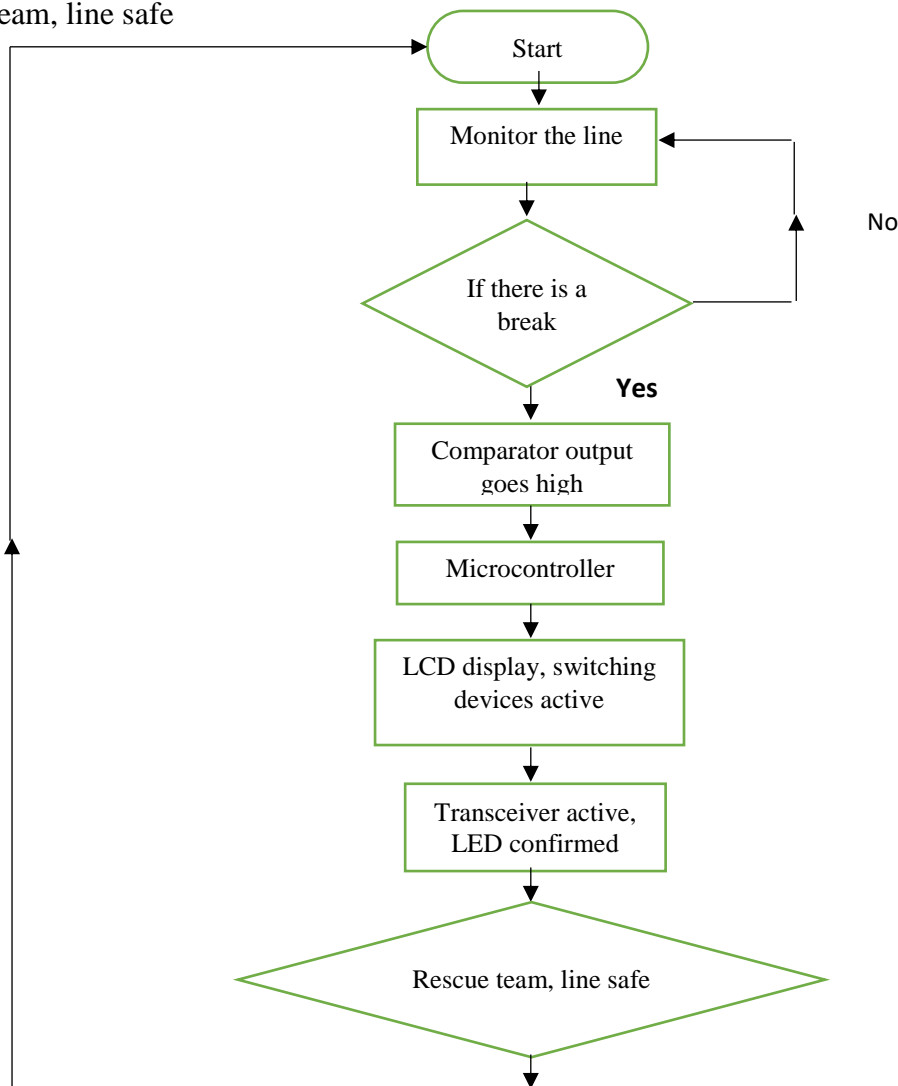Transceiver active, LED confirms
Rescue team, line safe

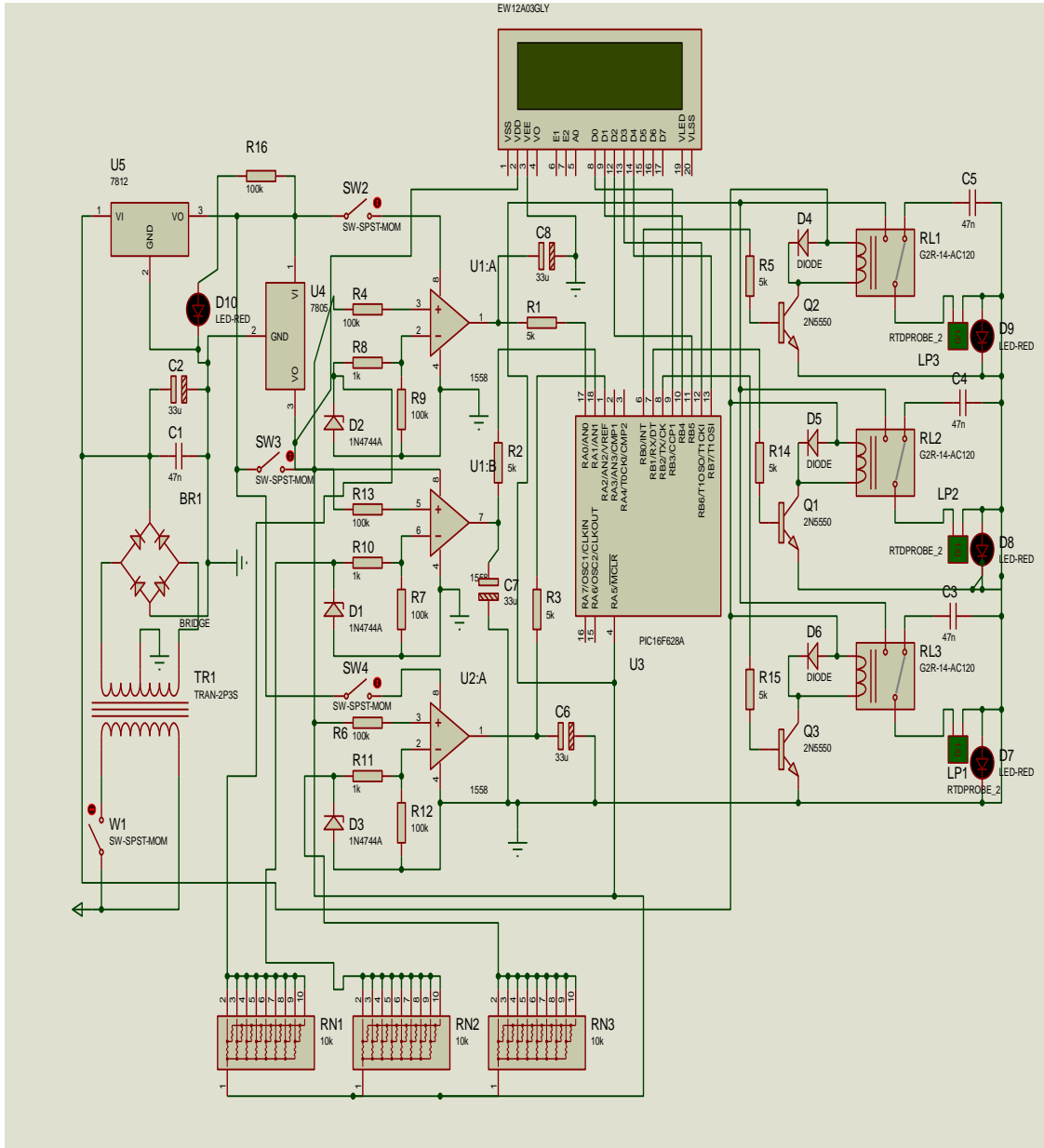Figure 7: Flow chart of a petroleum pipeline spillage detection system.

Figure 8: Petroleum pipeline spillage detection control circuit design.

The relational database model will be used because of its simplicity to ease the job of the programmer and its primary data model for real time data processing application. It uses a collection of tables to represent data and the relationships among those data. Microsoft Access will be used to do the manipulations in the database system as well as report generation.

7. Results and Discussion

After the construction of the automatic petroleum pipeline vandalism detection device, the complete unit was tested and implemented. The implementation was done by assembling all the components together in a circuit box known as the control room which transmits and receives signals. The petroleum pipeline is coated with sensor wires, more so to the cell phones of every

team leader within the geographic areas where petroleum pipelines are laid. With the aid of telecommunication mask or company mask, battery and a generator to power the battery at all times, the transmission is very good. The system is set to read data along the petroleum pipelines, checking within the set perimeter for intruders by activating the detection sensor then set alarm if any action within the set perimeter is said to be true. As soon as the censored wire is tempered with, it shows on the screen the nature of damage done to the petroleum pipeline. Some of the results obtained while running simulation test using Microsoft access is shown in Fig. 6 indicating the exact pipeline that has been tampered with.

Table 5: showing result of tested value

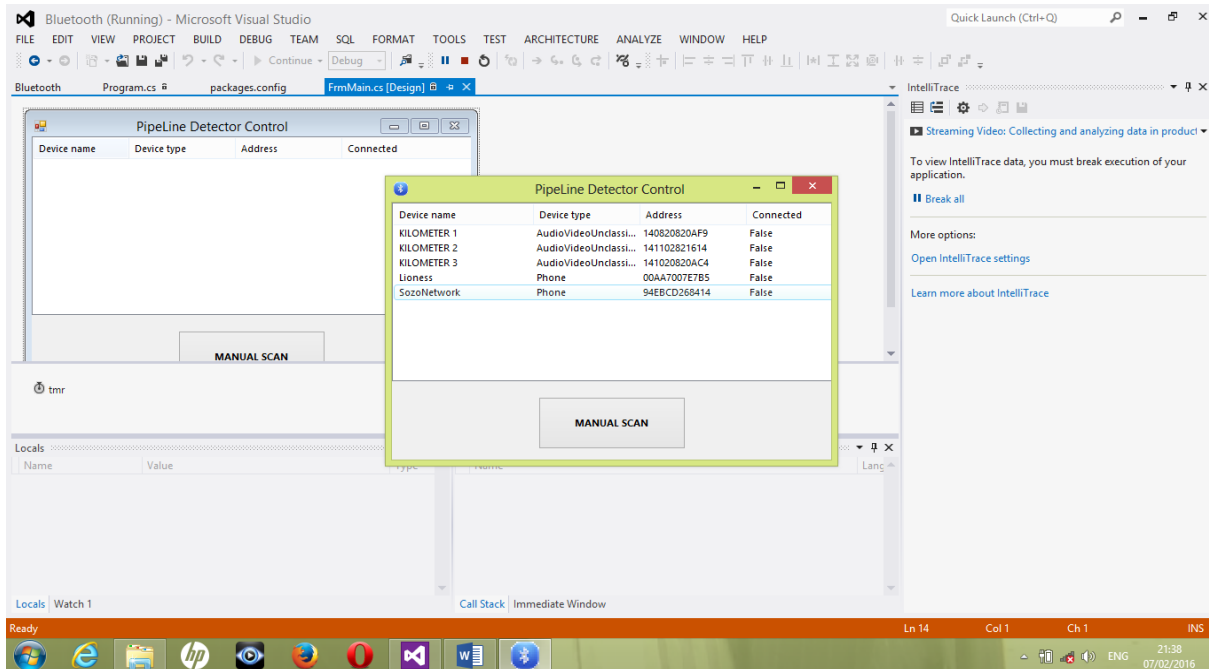| Pipeline	Sender Bluetooth	Receiver Bluetooth
Km 1 vandalized	ON	Connected
Km 2 vandalized	ON	Connected
Km 3 vandalized	ON	Connected
Km 1 vandalized	OFF	Not Connected
Km 2 vandalized	OFF	Not Connected
Km 3 vandalized	OFF	NOT Connected

Figure 9: showing location of vandalized pipeline.

The system produced results that met the system specifications and the entire system objectives. The indicator and the alarm continue to indicate a breakage at the sensor until it is noticed at the control room.

8. Conclusion

A model of petroleum pipeline spillage detection system capable of monitoring and detecting points of vandalism was developed in this study. Wiring sensors which provided continuous electrical paths to break the signal path and trigger an alarm at the base station notifying them of a breach in the programmed limit to petroleum pipelines is wound around the pipelines. This triggered alarm notifies the control unit whose function it is to send the assigned task force to points of suspected vandalism. The advantages of this system include prompt detection and response to petroleum spillage, increased government revenue, salvage the ecosystem, and increase agricultural proceeds, elongate lives and secure properties. The wiring sensors used in this study can be incorporated into the pipeline design system to make it not too visible by covering it with resin to increase the reliability.

Acknowledgement

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