Designing an Intelligent Microcontroller based Pipeline Monitoring System with Alarm, Sensor

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Abstract – Pipeline Vandalism is a serious issue associated with oil spill that has been happening in Nigeria on regular bases. According to an international report, "oil theft in Nigeria is on industrial scale". Oil theft poses serious threat to Nigeria's economy that largely depends on oil for her sustenance. Pipeline Vandalism can occur anywhere at any point in time within the areas covered by the pipeline network. This can lead to oil spillage, thus causing environmental pollution and public health issues. This paper deliberates on an intelligent architectural design and model for real-time detection of oil spillage using technology such as automated crack and vandalism detection sms alert for pipeline with remote monitoring and location specification. As part of this research, some mechanisms have been adopted for the design. They include communication system, Trans-receiver, micro-controller, assembly language program, GSM module, Alarm and power supply. The system is designed in such a way that whenever a leakage is detected in the pipeline, it will trigger alarm and send sms to the control unit. The control unit will use the system interface to ascertain the exact point of the leakage detected for possible action. During the design phase, simulation of system and all modules were tested individually. Similarly, the whole system was tested to perform the required task of detecting any leakage when the rubber on the pipes is removed which quickly triggers the microcontroller and subsequently alerts the personnel for necessary actions to be taken.

Index Terms – Oil industry, Network technology Microcontroller, Program, Short message service, Oil pipeline; intrusion detection; microcontroller; sensors.

1. INTRODUCTION

Over the years, there have been increased demands for a highly available and reliable system that will guarantee safe delivery and meet strict requirements for the transportation of liquids and gases in Nigeria. The liquids and gases in discussion may be crude oil, natural gas, liquefied gas, petrochemical products, water and other liquid or gaseous products.

This paper proffers the needed design solution with automated pipeline leakage detection system, which can be effectively deployed for multi-batch pipelines to monitor the movement of different fluid compositions. It will help to provide avenue for Flow Path Detection, Density Tracking, Temperature Tracking, Pump Monitoring and Operation, Improvement, Velocity Monitoring, Hydraulic Profiles, Leak Detection and Location, Tank Farm management, Pipeline Stress Monitoring, Pipeline Operation Analysis, Inventory Monitoring, Wall Roughness Monitoring, Scraper Tracking and Batch Tracking.

1.1. System for pipeline integrity, real-time leak detection and threat identification advantage

This system uses distributed sensing technology to monitor continuously the integrity of oil and gas pipelines for leak and threats. The system offers sensitivity & positional accuracy which is a very unique feature of this design. It operates using standard telecoms fibre as sensor with no complex components; no power is needed to operate the sensor along the pipeline route.

All instrumentation and processing takes place in the control room. The cable containing the fibre only has to be placed in proximity of the pipeline. This makes the installation process easy, straightforward and retrofitting is possible without having to conduct works on the pipeline. Certainly, early detection of a leak or intrusion together with the accurate identification of the location allows time quick dispatch of assessment and clean-up crews.

1.2. Background of the study

Vandalism and oil spillage is a regular occurrence in Nigeria, especially in the Niger Delta Region. This has brought untold hardship on the populace as their means of livelihood (farm land is infertile) has been destroyed by oil pollution. The Nigeria economy has suffered set back as a result of vandalism. As stated by Bakpo in the *Nigerian journal of technology*; "the activities of Vandals in Nigeria have resulted to the loss of billions of crude oils and corresponding loss of income every year. An average of 35,000 barrels of crude oil is stolen per day in circumstance that constitute risk to life, properties and the environment" *28(1).* Vandalism and oil spillage is a major problem affecting the livelihood, environment and oil exploration and production in Nigeria.

Pipeline network is a vital part of the Nigerians' national energy transportation infrastructure and the national economy. It is an indispensable means for conveying water, gas, oil and all kinds of products. Undoubtedly, the pipeline project is one of the most important infrastructures in Nigeria as it stretches several thousands of kilometers and passes through cities, villages and rural communities across the country.

(a)

(b)

Figure 1 (a) picture of a shell pipe sabotaged by vandals
(b) picture of dead vegetation due to oil spill

https://www.google.ca/search?q=vandalism+and+shell+oil+pipelines+in+nigeria&biw=1024&bih=673&source=lnms&tbm=isch&sa=X&ved=0CAcQ_AUoAmoVChMI7aX7hsuByQIVyBceCh3tgwTX#imgrc=EP8NZlE7HK1RDM%3A

These pipelines are operated at high pressure and any failure or damage poses a great danger to public health and properties. Environmental and ecological disaster and interruption of gas or oil supplies are inevitable in the occurrence of spill. The pipelines are prone to losing their functionality due to damage caused by internal or external corrosion, cracking, third party intrusion and manufacturing flaws. More so, leakage and failure has serious economic and ecological consequences.

2. RELATED WORK

Assist. Prof. Timur Chis Phd, Dipl.Eng. Researched and did a good work with respect to safeguarding and monitoring pipeline. The disadvantage of this system was Insufficient coverage of all the area of interest e.g. under water coverage and on land long distance coverage are easily damaged (rain/sun and animals and environmental hazards). It was not reliable, so it made the job boring for the operators. The work could not do justice to the wide area such as leakage detector, there were no instrument selection as it is needed to develop better thermodynamic model for new systems so that they can be more accurate and reliable.

3. CIRCUIT DESIGN

A functional design is the initial process of deriving a potential and realizable solution from design specifications and requirements. This is sometimes referred to as modeling and includes activities such as hardware/software tradeoff and a micro-architecture design from the functional design model. The hardware design team proceeds to the Register Transfer Level (RTL) design phase. During this phase, the architectural description is further refined: memory element. And functional components of each model are designed using a Hardware Description Languages (HDL). This phase also sees the development of the clocking system of the design and architectural trade-offs such as speed/power.

The Design of the Circuit was done on Vero board. In order to implement the Smart Traffic Signal Simulator, one needs to setup and assemble the hardware components and write a program to control the smart traffic signal simulator. The design circuit consists of transceiver (GSM module), microcontroller, and 12volts power supply and alarm units. Simulation of the various units was done individually using Proteus simulation software. A continuous electrical path was provided by resistant sensor and any break in the signal path causes cessation of signal and provides detectable change in the state of the system. The system was tested on performance of the task of detecting breakage on pipelines and the exact location of such leakage. When there is no gas leak the green light will be on, but in the case of leakage, the system will try to detect the intensity, if it is low, then yellow LED will be on but if the intensity is high, the LDC will display “status Danger” then trigger alarm and send sms.

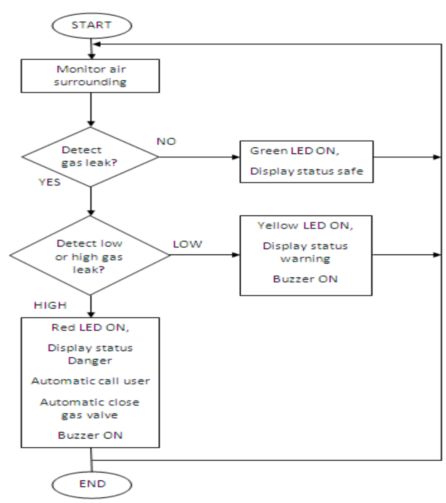


Figure 2 Flow chat representing the system algorithm (afiqridhwanahmad.blogspot.com)

As shown in the circuit diagram below Sensors are positioned at both ends of the monitored section to capture the transient signals, The sensors track the dynamic pressure signals and convert them into electrical signals which are read and analyzed by a dedicated electronics running sophisticated detection and filtering algorithms for proper leak-pattern recognition. The detection time at each sensor is precisely determined and registered, and the leak-location can be calculated based on the arrival times and a few other known parameters gathered from the pipeline since the propagation velocity in the media is known, In the case of a leak, an alarm will be triggered and short message service (sms) will be sent to the operator by the central monitoring station (CMS),this will contain some information such as the exact time and location of the leak with its associated coordinates. Febbo agrees that "effective signal processing associated with multilayer detecting algorithms is also a key to ensure 100 per cent of pipeline coverage, from sensor to sensor, with no mute or silent zones in the protected section. In case of a communication fault, the detected events are stored in internal buffers and automatically transmitted to the CMS when communication is re-established" (Maurino et al., 2013). Also any leaks which may occur during the faulty period can still offset alarm with correct time stamp and location.

Recent applications of microcontroller started with the development of integrated circuits. This development has made it possible to store hundreds, thousands of transistors into one chip. This was where microprocessor stared from, so it was a pre-requisite for production of microprocessors, and the first computers were made by adding external peripherals such as memory, input-output lines and timers. As time goes on, increase in the volume of the package resulted in creation of integrated circuit. These integrated circuits comprises of processor and peripherals.

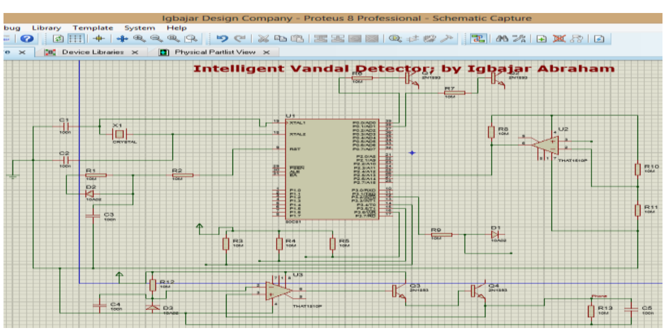


Figure 3 the System Circuit Design

In this design the microcontroller used in 80c51. There are many functions the microcontroller provides to the system, this ranges from initializing the GSM module, powering the system automatically, interpreting the received signals and sending the required signal to the GSM module or the transceiver. The GSM module used in this design is an already made module and was interfaced with the microcontroller through the serial interface unit. The SIM900 GSM module used has, Supply voltage range 3.4V to 4.5V, Quad-band 850/900/1800/ 1900MHz and Low power consumption.

Also, any mobile phone can be used as a transceiver. In the case of GSM module, MAX232 was included in the design for conversion purpose.

This AC to DC power supply utilizes a fly-back, which is the simplest SMPS converter topology. The switching devices it uses is N channel MOSFET. The input section includes a fuse, a full bridge rectifier CR1, EMI filter, inrush current limiting NTC resistor R1, and a DC bus filter capacitor C2.

The initial start-up current for the PWM IC is provided by "bleeding" resistors R3, R4 that allow small current which charges the Vcc capacitor C4. When the Vcc pin of U3 reaches the positive under-voltage lockout threshold (typically 14V-16V), the IC starts to operate. This will be driving ON and OFF the switch Q1 via a gate drive resistor R4 at a fixed frequency (in this circuit it is 100 kHz). When Q1 turns on, the DC bus voltage is applied across the transformer T1. When Q1 turns off, the energy stored in the magnetic field causes the voltages across all winding to reverse polarity. As a result, output rectifiers D4 and D7 conduct and the stored energy is transferred to the output and to the bias circuit. Once the converter is started, the bias for the control PWM comes from the bias winding of the transformer.

The secondary side feedback control loop uses a TL431 precision shunt regulator D1 as both reference and error amplifier. It compares divided output voltage to D1's internal reference 2.5V. An Opt coupler U1 feeds the current proportional to the error signal across the transformer galvanic isolation boundary back to the primary PWM. If accurate regulation of the output is not required, the feedback can be taken from the bias voltage at C9 and fed via a divider into feedback pin 2.

Primary current in T1 is sensed by a resistor R6. This current sense voltage is applied through a spike filter to the current sense terminal of U3, where it is compared against the scaled down error signal at compensation pin 1. When current sense voltage ramp reaches 1/3×(Vpin1-1), the pulse is terminated and Q1 turns off.

Diode D6 with opt coupler U2 provide a non-latching output's overvoltage protection.

Thermal switch shuts down the power supply when temperature on the MOSFET heatsink exceeds 95-100 oC

Sohraby in his *Wireless Sensor Network* defined wireless sensor network as "an infrastructure comprised of sensing [measuring], computing and wireless-based communication elements that gives an administrator the ability to instrument, observe, and react to events and phenomena in a specified environment. The environment being monitored can be the physical world, a biological system, or an information technology (IT) framework while the administrator is usually a civil, governmental, commercial, or industrial entity". (Sohraby et al., 2007)

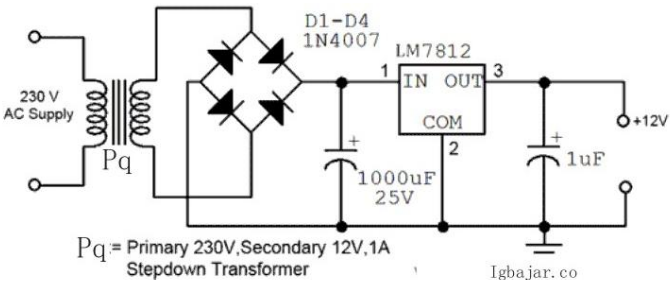


Figure 4 Schematic diagram of 12volts power supply

He further stated the four basic components in a sensor network as: "an assembly of distributed or localized sensors, an interconnecting wireless network, a central point of information clustering; another set of computing resources at the central point (or beyond) to handle data correlation, event trending, status querying, and data mining".

Nodes in the sensor network typically have one or more sensors, a radio transceiver or other wireless communication device, a small microcontroller and an energy source, usually a battery. (Kay & Mattern, 2004)

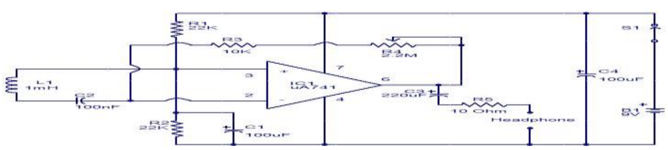


Figure 5 Schematic diagram of the sensor

(http://www.circuitstoday.com/wp-content/uploads/2009/03/electromagnetic-field-sensor-circuit.jpg (2009)

The sensor provided is an 8bits system, the sensors gather information about the pipe leakage such as light, smell, pressure, and break. Under normal operating conditions (when there is no pressure drop, break or exposure of optical fibres to light rays), the digital signal to the microcontroller is 00000000, the activating the green LED. Whenever the microcontroller senses a different digital input, it reads it as a break in one of the coils which also means a break in the pipe, then it will activate the red LED. The 10K resistors are to limit the maximum current into the microcontroller to 0.5mA.All the signals from the sensors are received and processed by the microcontroller. The processing of the signals is controlled by an assembly language program that is burned into the microcontroller using a program. The operations of these sensors can best be explained using the control program. In the case of Pressure Sensors, this can be done by pulling two pipe connections apart. The pressure switch loses contact and sends a signal for the transceiver to alert the receiving phone. This receiving phone stores the number of each SIM, on a module, with the pipe number. Through this, the exact location of the alerting module can be known. The phone is programmed to alert thrice (3 times) to compensate for bad network scenarios. Then the light sensors at normal operating condition should be kept in the dark. This condition will not cause any alert signal to be sent unnecessarily. When the light sensors are exposed to light by removing the protective cladding over the pipe, the Red LED indicator will be ON, signifying danger and an alert signal is sent to the control station. So while the vandals are trying to get to the pipe by removing the covering over it, the control station is alerted of their activity.

3.1. Parts Required

- resistors: 470 ×3, 22k, 100k
- capacitors: 0.1µF, 1µF 16V radial, 10µF 16V radial
- diodes: 1N4148 ×6
- LEDs Indicator: red,
- 1M preset, horizontal
- 4017 counter IC
- DIL sockets for ICs: 8-pin, 16-pin
- on/off switch
- 2-Pole Passive Low Pass Filter
- LM358 Inverting Amplifier
- MT8870 DTMF Decoder
- CD4066 DTMF Signal Input/output
- Power Supply
- RS232 Interface
- 800V/11A MOSFET (Q1) as the switching device
- PWM controller UC3844AN (U3
- sensor
- stripboard: 20 rows × 21 holes
- microntroller

3.1.1. Resistor

Resistor is a passive component used to control current in a circuit. Its resistance is given by the ratio of voltage applied across its terminals to the current passing through it. Thus a particular value of resistor, for fixed voltage, limits the current through it.

3.1.2. Capacitor

Capacitor is a passive component used to store charge. The charge (q) stored in a capacitor is the product of its capacitance (C) value and the voltage (V) applied to it. Capacitors offer infinite reactance to zero frequency so they are used for blocking DC components or bypassing the AC signals.


LED stands for light emitting diodes.

Light emitting diode, it serves as indicator light in case of normal (green), attention (yellow), Danger(Red). When there is no gas leakage the green light will be on, but in the case of leakage, the system will try to detect the intensity, if it is low, then yellow LED will be on but if the intensity is high, the LCD will display “status Danger” then trigger alarm and send sms.


1M preset, horizontal: Preset

A preset is a three legged electronic component which can be made to offer varying resistance in a circuit.


8 Pin DIL IC Sockets (10 pack)

High quality, dual-in-line narrow sockets with black thermoplastic bodies and tin-plated copper alloy contacts. The sockets may be mounted end to end to achieve longer continuous runs. Sockets have chamfered side walls to assist insertion.

(ON/OFF).

This uses binary numeral system. 1 for on, 0 for off. This way it's understandable for everyone around the world, since not everyone understands English.


For point to point DIY soldering Pre-drilled and cleaned Easy to cut and drill Smooth solder flow.

How they function: the assembly language program coded in the microcontroller run and send signals to the LED which lights them. Appropriate outputs are combined along with the sensor to detect and trigger alarm, then send signal to the gsm control thereby sending sms to the control room.

3.2. Some of The Program Code

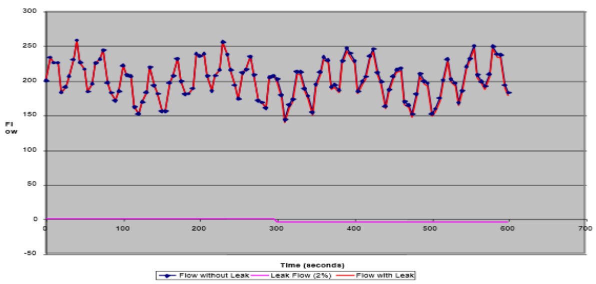
```
org 00h
start: mov p1, #09h
mov p2, #09h
call Igbajar
mov p1, #9Bh
mov p2, #0Dh
call Igbajar
mov p1, #64h
mov p2, #02h
call Igbajar
mov p1, #0F6h
mov p2, #06h
call Igbajar
sjmp start
Igbajar: mov r3, #100
mov r2, #181
mov r1, #125
ret
end
```

4. RESULTS AND DISCUSSIONS

Series of test and simulation were carried out; the result was analyzed and certified. Some of these tests were performed in real life scenario while others were simulated and results were obtained for the circuit diagram and design.

Simulation of the leakage test is with the aid of simulation software, Note that Leak detection and location in pipelines are based on regular measurement of pressure and / or flow. This is based on analysis of time series of pressure and/or flow imbalance as these present some well-known reaction to leaks, when there is a leak the pressures will drop in all/most locations along the pipeline for some time after the leak starts to develop. Note that the pressure drop caused by the leak will initially be greatest at the location of the leak and the flow measurements will show an imbalance between flow in to and flow out of the pipeline (imbalance caused by the leak). For very large leaks it is often easy to detect it has occurred by analyzing the trend of pressure or flow imbalance from a visual perspective. However, an accurate location of the leak always requires good synchronization of data and some level of numerical analysis of the trends. Hence, a smaller the leak, will result in smaller the trace of the leak in the pressure and flow imbalance trend. If the normal operation is very steady (time independent) when the leak develops, it may still be

Possible to detect the leak visually or at least with some fairly simple numerical analysis of the trends. (Energy Solutions International, Best Practices in Leak and Theft Detection) 2014.



(http://www.energy-solutions.com/wp-content/uploads/2014/07/pipelinemanger-best-practices-in-leak-and-theft-detection.pdf)

The effect of the leak on the measured flow signal leak occurs at 300s

(Energy Solutions International, 2014 http://www.energy-solutions.com/wp-content/uploads/2014/07/pipelinemanger-best-practices-in-leak-and-theft-detection.pdf)

In the figure above, the picture will change if the normal operation at the time of leakage shows significant variation with time (as a result of transients, interference from equipment operation, variable product properties etc).

5. CONCLUSION

This paper has demonstrated the usefulness of creating a monitoring system which can be employed in remote monitoring of pipeline activities. Different approach of designing security gadgets from analog to digital circuit was applied; one of such is the functional design model. This new system can solve the problem of pipeline damage and it will also aid government and the oil sector in combating the effect of pipeline vandal and oil leakage. In turn, this will enhance the growth of the national economy as it will reduce the loss of pipeline products due to third party intrusion and also save the cost of maintaining pipeline. An Effective pipeline monitoring such as the one proposed in this paper will improve pipeline performance, increase effectiveness and efficiency and as well provide the most needed protection for pipelines from third party damages, which will lead to economic growth above.

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