

TUTDoR

Development of a prototype test rig for leak detection in pipelines.

Item Type	Presentation
Authors	Daniyan, I. A.;Dahunsi, O. A.;Oguntuase, O. B.;Daniyan, O. L.;Mpofu, K.
DOI	http://dx.doi.org/10.1016/j.procir.2019.01.016
Publisher	Elsevier
Rights	Attribution-NonCommercial-ShareAlike 4.0 International
Download date	2026-05-09 16:51:04
Item License	http://creativecommons.org/licenses/by-nc-sa/4.0/
Link to Item	https://hdl.handle.net/20.500.14519/1501

26th CIRP Life Cycle Engineering (LCE) Conference

Development of a Prototype Test Rig for Leak Detection in Pipelines

Daniyan, I. A,^{a*} Dahunsi, O. A.,^b Oguntuase, O. B.^c Daniyan, O. L.^d and Mpofu, K.^a

^a*Department of Industrial Engineering, Tshwane University of Technology, Pretoria, South Africa.*

^b*Department of Mechanical Engineering, Federal University of Technology, Akure, Nigeria.*

^c*Department of Mechanical and Mechatronics Engineering, Afe Babalola University, Ado-Ekiti, Nigeria.*

^d*Department of Instrumentation, Centre for Basic Space Science, University of Nigeria, Nsukka, Nigeria.*

* Corresponding author. Tel.: +27815164149

E-mail address: afolabiulesanmi@yahoo.com

Abstract

Over the years, the conventional method most industries use in detecting pipeline leakages is called the pressure test. This method is too stressful and even takes longer time to locate the exact location of the leak. This work studies the unconventional way of detecting oil leakage with a view of designing a model control system to detect leak without human intervention, both on-the-job and off the job. In this work, a prototype test rig was designed and fabricated. Its components include pipes and piping components, air valve, adaptor, barometer, MxF Socket, non-return valve, pressure relief valve, and reducers. The rig was fabricated based on its 3D architecture using solid works application tool. The rig has four different flow line with pressure sensors and gauges mounted on each line. Pressure transducers on the rigs keeps monitoring the pressure inside the rig and immediately it detects a pressure drop below the threshold value, the micro controller based on the programmed code on it communicates with the SMS module which subsequently sends an SMS alert to the programmed phone number and gives the location of the leak as well as the actual pressure in that location. Thus, this study enhances quick leak detection, thus, gainfully helps to minimize losses during on the job operation in the case of spills and saves time in locating the exact point of leakage.

© 2019 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/3.0/>)

Peer-review under responsibility of the scientific committee of the 26th CIRP Life Cycle Engineering (LCE) Conference.

Keywords: Control, Leak, Pressure, Prototype, Test-rig

1. Introduction

Crude oil products are needed as a stable source of energy and income for many countries. For example, crude oil extraction, processing and production hold a strong market growth in countries that produce it and have been one of their major sources of energy and income. As of November 2012, Russia produced 10.9 million barrels of crude per day, while Saudi Arabia produced 9.9 million barrels [1]. The oil industry in Nigeria is the largest on the African continent. Its exports accounts for more than 98% of export earnings and about 83% of federal government revenue and it also provides 95% of foreign exchange earnings, and about 65% of government budgetary revenues. According to the CIA World Fact Book

[2], Nigeria's main export partners are the United States, India, Brazil, Spain, France, and the Netherlands. The Dutch firm, Royal Dutch Shell has been working in Nigeria, alongside many other foreign oil firms, since 1936, and currently dominates gas production in the country. The Niger Delta, which is rich in most of Nigeria's gas resources, also houses most of Shell's, and by extension, other foreign firms' hydrocarbon assets. Despite the fact that Nigeria economy benefits from production and exportation of crude oil, the country is faced with the problem of oil leakage while channeling oil from one point to another. Several defects occur in pipelines such as leakages, cracks, holes, corrosion and others, hence the need for real time inspection [3-6]. The leakage may be as a result of corrosion of pipelines, conveying

tankers or the rupturing or leaking of old production infrastructures that often do not receive inspection and maintenance. Other causes include sabotage, inadequate or non-functional production equipment amongst others [7-8]. Consequently, oil leakage can cause explosion [9] or other negative effects which results in decline in the volume of global production of crude oil [10]. This has necessitated the development of non-conventional method to detect the leakages for prompt responsive actions [11]. Over the years, the conventional method most oil industries use in detecting leakages is called the pressure test. Pressure testing is a non-destructive test performed to ensure the integrity of the pressure shell on new pressure equipment, or on previously installed pressure and piping equipment [12, 13]. Pressure test can be performed using hydraulic or pneumatic medium [14, 15]. Due to the high level of potential energy stored during gas compression, pneumatic test tends to be more dangerous than hydrostatic test. Hence, care must be exercised to minimize the chances of brittle failure during testing by initially certifying the system is suitable for pneumatic testing. Pneumatic tests could be performed when the systems are designed in such a way that it cannot be filled with water or the systems are such that it is to be used in services where traces of the testing medium cannot be tolerated [16, 17]. During the process of carrying out pressure test, once leakage is detected, personnel will be deployed to the field to physically search for the leakage point with the pressure still built in the pipeline. This method is too conventional, stressful and even takes longer time to locate the exact location where there is leakage. Smart sensors with wired and wireless communication interfaces have been developed for real-time leak detection but the issue of pipeline monitoring in wired systems and energy consumption for wireless system is of great concern [18-22]. This work studies the conventional way of detecting oil leakage with a view of designing model control system to detect leakages without human intervention, both on-the-job and off the job. The novelty of this work lies in the combination of electronic monitoring and detection circuit as well as Real-Time Transient Model (RTTM) technology for leak detection hence, leaks can be detected during steady state and transient conditions. The development of an electronic circuit to detect leak will enhance quick detection, saves time in locating the exact leakage point and gainfully help to minimize loss during on the job operation in case of spills. The specific objective of this study is to design and fabricate a prototype test rig suitable for laboratory evaluation. The developed rig enables experimental and controlled physically evaluation of piping assemblies for leaks, which is made possible with the use of pressure gauges. Furthermore, the use of electronic leak detection procedures and mechanisms will boost productivity in the oil and gas industry by minimizing waste, increasing efficiency of oil and gas products distribution and provide an easier alternative to the generally more tedious conventional methods of detecting oil leakage. Leak detection methods can be classified as internal or external. Internally based systems utilize field instrumentation (e.g. for temperature, pressure, flow sensors etc.) to monitor and measure internal flow parameters in pipelines while external based systems uses devices such as camera, radiometers, acoustic devices etc. to monitor pipeline externally. The measured flow parameters are subsequently used for detecting and tracing a leak. The use of internal based systems boasts of relative simplicity and cost

effectiveness. An overview of the internally based leak detection methods is given in Fig.1 Internally based leak detection methods comprises of the following; pressure/flow monitoring, acoustic pressure waves, balancing methods, statistical methods, Real-Time Transient Model (RTTM) and Extended Real-Time Transient Model (ERTTM) [23-25].

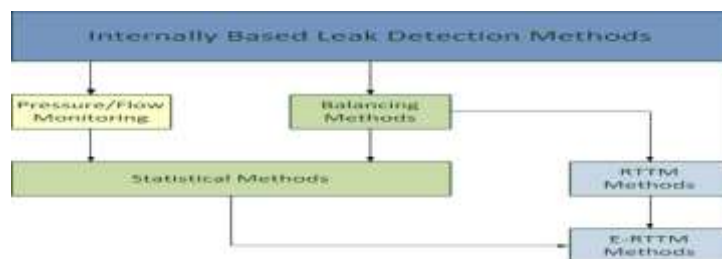


Figure 1: Overview of internally based leak detection methods [23-25].

2. Methodology

This system is designed using AP-40 sensor with 31/2- digit, 2-colour, 7 segment LED with character height of 11 mm, display cycle of 5 times/cycle and a rated pressure of -15 to 110 % of F.S. The AP-40 is a sensor, which is specifically designed to detect the physical presence of hydrocarbons in all conditions and all locations. It is waterproof, shock proof and vibration proof. These oil leak sensors gives an alarm after coming into physical contact with hydrocarbons: as little as three drops. It can be used in locations that are subjected to water (rain, snow, ice, etc.) and will not give any alarm when in contact with water. For the purpose of this work, an electronic circuit using printed circuit board (PCB) with all components such as transistors, capacitors, inductors, diode assembled on it will be used as the controller. As shown in the design architecture (Fig. 2), upon reception of signal from AP-40 of product leakage, it instructs the buzzer based on the connection of component on the printed circuit board assembly (PCBA) to sound an alarm. In development of the test rig, PVC pipes are used and gate valves to control the flow. To physically check for leak in the pipe, pipe sections were made airtight using the gate valves attached to pipe for airtight condition. Pressure gauges are also attached to necessary points on the pipe to monitor the pressure. After all the fittings have been installed, air, which is the test medium, is introduced into the PVC pipe and built up to test pressure (1.5 times the maximum service pressure). Test pressure is then be observed for over 2 hours for pressure drop and obvious leaks. The pipe is said to have passed pressure-test when observed to have successfully held its test-pressure for the duration of 2 hours without any patent defect or significant pressure drop.

2.1 Rig Design and Architecture

The rig was designed using solid works application software tool. The rig has four different flow lines with pressure sensors and pressure gauges mounted on each line. In addition, the flow lines all have a single pressure source that can be controlled and manoeuvred using the air valves on it. Using the architectural design shown in Fig. 2, the pipe was cut into specified dimensions. During this process of cutting the pipe, the arc saw was positioned at angle of 30° with tension applied to ensure perfect and smooth cut. After a successful completion of

cutting different pipe sections, other components – non-return valve, elbows, sockets, unions, reducers, tees – are joined to the pipe using ‘top gum’ as adhesive. Also, pressure gauges are mounted on a separate flow lines with the pressure sensor capped for easy installation during the electronic circuit installation process. In development of the test rig, PVC pipes along with gate valves are used to control the flow. To physically check for leak in the pipe, pipe sections were made airtight using the gate valves attached to pipe for airtight condition. Pressure gauges are also attached to necessary points on the pipe to monitor the pressure.

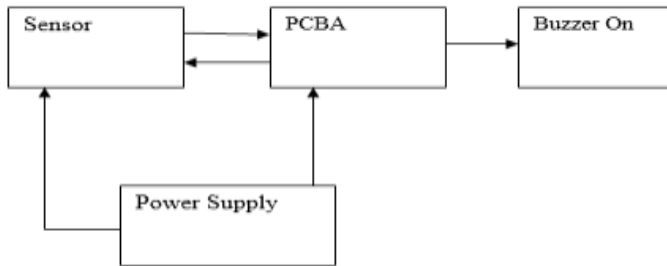


Fig. 2: Rig architecture for pipeline leak detection
The fixed pressure gauge is shown in Fig. 3.



Fig. 3: Fixed pressure gauge

2.2 Operation of the test rig

The test rig operates in a manner in which a single input source supplies pressure to all the flow channels. After pressure has been built inside the rig by a hydraulic pressure pump, the air valves on the rig is used to control pressure in form of water to any section of the rig. This idea is gotten from the real life scenario whereby irrespective of the channels to be supplied different oil products in an oil company, just a single pump is provided for all the ships at the jetty and the pipes are being pigged (flushed) after each delivery. In addition, during the pressure flow, pressure gauges on the pipe are used to observe the amount of pressure present in the rig.

2.3 Electronic circuit design/architecture

The following are circuit components used in designing the electronics circuit.

i. Pressure transducer

It interfaces the system’s controls with the physical factors governing the system. It converts pressure built up in the system into electrical signals by the physical deformation of strain gages, which are bonded into its diaphragm and wired into an electronic control configuration. The 5 V DC pressure transducer whose working pressure range and current is between 0-1.2 MPa and ≤ 10 mA respectively is shown in Fig. 4.



Fig. 4: The pressure transducer
ii. GPRS GSM shield

This is an Arduino compatible smart module used with Arduino to dial a phone number or send a SMS to personnel via UART using easy to use AT commands. The shield features a quad-band low power consumption module SIM900 and an on-board compact PCB antenna. The GPRS GSM shield also has 6 GPIOs, 2 PWMs and 1 ADC (They are all 2V 8 logic) which can be controlled by AT commands.

iii. Arduino micro controller

A microcontroller kit which links digital devices, interactive units and components that can sense and control objects in the physical world is used. It is pre-programmed with a boot loader that simplifies uploading of programs to the on-chip flash memory. The Arduino Nano is a compact and breadboard-friendly version board based on ATmega328 processor with type B USB [26-27]. The dimension of Arduino Nano is 43 mm x 18 mm, with 6 PWM I/O from the total of 14 digital I/O, as well as 8 analog inputs, 16 Mhz clock speed and 32 kB of flash memory, SPI I2C, with input range of 7-12V. The Arduino is programmed using the Arduino IDE with source code written in C.

iv. Hydraulic pump

This mechanical device converts mechanical power into hydraulic energy. It generates flow with enough power to overcome pressure induced by the load. This energy transferred from the pump to the fluid appears as the pressure and velocity of the fluid. The pump plays an important function during operation, allowing atmospheric pressure to push liquid into the inlet line from the reservoir to the pump. The hydraulic pump employed has a rated voltage of 12 V DC and rated output power of 45 W as shown in Fig. 5.



Fig. 5: The hydraulic pump

v. Circuit design architecture

The electronic circuit design architecture was executed using the Arduino package with the virtual interface of the program compilation on the processor, with aids the interfacing of circuit components. The processor was interfaced with the pressure transducer, as well as the SMS module. The pressure transducers were then mounted on position already provided on

the prototype rig. The positive and negative terminal of the pressure transducer was connected to a 5 V power source while the transducer output (yellow wire) was connected to its respective processor input terminal. The circuit design architecture is shown in Fig. 6.

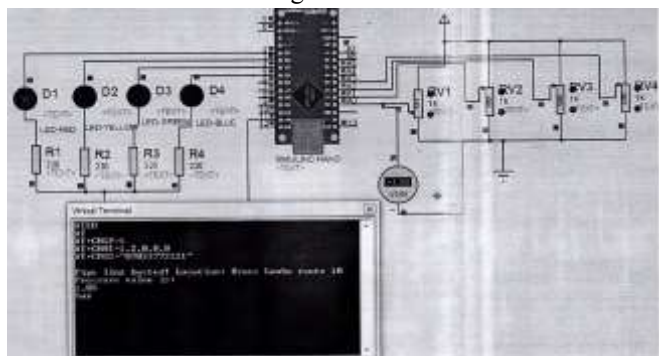


Fig. 6: Circuit design architecture

vi. SMS module

The electrical specification of the SMS module is presented in Table 1.

Table 1: The Specification of the SMS Module

S/N	Parameter	Unit	Min	Typical Max.
1.	Voltage	V	4.8	5.0
2.	Current	mA	40	400
3.	Length	mm		1800

The SMS module is shown in Fig. 7.



Fig. 7: SMS module

Based on the design architecture discussed earlier, after the compilation of the program on the processor, the circuit components were interfaced together. The processor was interfaced with the pressure transducer as well as with the SMS module.

The pressure transducers are then mounted on the position already provided on the prototype rig. The processor is then interfaced with the pressure transducers. The positive and negative terminal of the pressure transducer is connected to 5 V power source while the transducer output (yellow wire) is connected to its respective processor input terminal.

2.4 Leak detection method

The two leak tests carried out are the conventional method and the automated method. For both methods, water was used as working fluid since it is denser than oil and as such should the

test be positive using water, it is guaranteed to be successful using oil as working fluid in the rig. The rig was pressure tested to check for leaks, using the pressure gauge to monitor the pressure fluid inside the rig. Pipe sections were made pressure tight using valves attached to the pipe for pressure-tight condition. Test pieces and pressure gauge was checked to be in good working condition. After all the fittings have been checked, water, which is the test medium, was introduced into the pipe and built up to maximum service pressure. Test pressure was then observed for pressure drop and obvious leaks. To automatically check for leak in the rig, the threshold pressure (150 kN/m^2) which is equivalent to 1 V on the pressure transducer serve as input which is preset on the microcontroller. Pressure was observed to build-up in the rig after which the system was powered on by a 5 V power supply. Pressure transducers on the rig monitored the pressure in the rig and immediately a pressure drop below the threshold value was detected, the microcontroller based on the programmed code, communicates a signal to the SMS module which subsequently sends an alert to the programmed phone number giving the location of the leak and the actual pressure in that location. Otherwise, no message is sent if pressure is maintained above nominal pressure threshold. This process is repeated continuously in several cycles to further observe the pressure in the rig, comparing the pressure readings of the transducer to the threshold pressure, raising an alert when a drop is detected and carrying on when no pressure drop is detected, till the system is powered off. The system also incorporate the Real-Time Transient Model (RTTM) via mathematical models of the flow within a pipeline using basic physical laws such as conservation of mass, conservation of momentum, and conservation of energy. RTTM method of leak detection use the conservation principle of momentum and energy. It makes possible the computation of flow parameters such as mass flow, pressure, density and temperature at every point along the pipeline in real-time with the aid of mathematical algorithms. RTTM leak detection system can easily be employed for modelling steady state and transient flow in a pipeline in order to detect leak during steady state and transient conditions. With proper functioning instrumentation, leak rates are functionally estimated using available formulas. For the residual method, an RTTM module estimates M_i and M_o for mass flow at the inlet and outlet, respectively. This can be done through measurements for pressure and temperature at inlet (P_1 and T_1) and outlet (P_0 and T_0). These estimated mass flows are thereafter compared with the measured mass flows M_a and M_b for inlet and outlet respectively after some period of time yielding the residuals given in Equations 1 and 2.

$$x = M_a - M_i \quad (1)$$

$$y = M_b - M_o \quad (2)$$

Residuals x and y are zero or approximately zero, when there is no leak, otherwise the pipeline should be traced for leaks.

The flow chart for the leak detection process in pipeline using electronic circuit system is shown in Fig. 8.

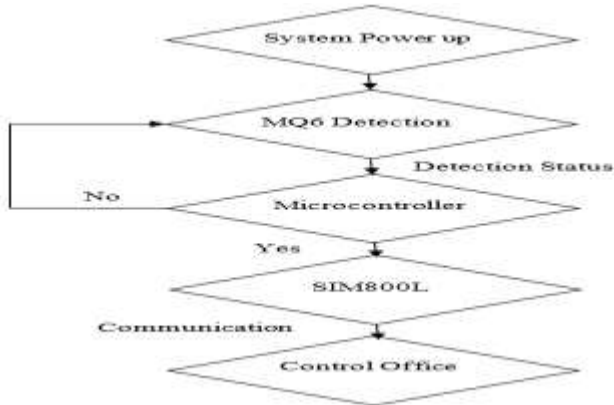


Fig. 8: The flow chart for the leak detection process
The 2 D mini-rig designed for pipeline leak detection is shown in Fig. 9.

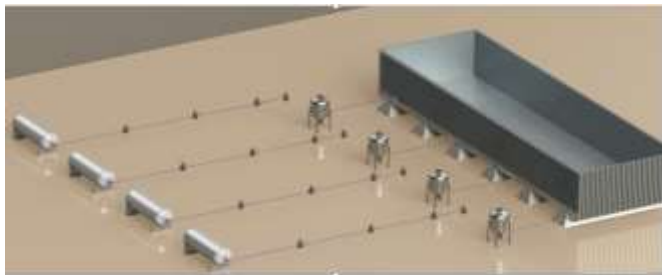


Fig. 9: The design of the mini rig
The mounting of the sensor and the micro controller on the test rig are shown in Fig. 10 to 13.



Figure 10: The mounted sensor



Fig. 11: The circuit under construction



Fig. 12: The Arduino microcontroller



Fig. 13: The developed prototype test rig

3. Results and discussion

The result of the pressure measurement using pressure gauges at six points for time interval 3600-21600 sec is presented in Table 2.

Table 2: Pressure measurements for 3600-21600 sec

S/N	Pressure (kN/m ²)	Time (hrs)
1.	1600	3600
2.	1600	7200
3.	1600	10800
4.	1600	14400
5.	1600	18000
6.	1600	21600

Fig. 14 shows there was no leakages at the six point tested. The pipe maintained a constant pressure for the period of 21600 sec (6 hours).

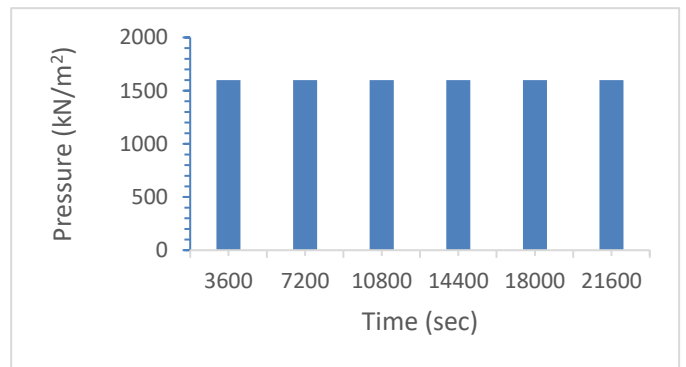


Fig. 14: Constant pressure at different points for 3600-21600 sec.

Also, the result of the pressure measurement using pressure gauges for another six points for time interval 3600-21600 sec is presented in Table 3.

Table 3: Pressure measurements for 3600-21600 sec

S/N	Pressure (kN/m ²)	Time (hrs)
1.	1500	3600
2.	1000	7200
3.	800	10800
4.	600	14400
5.	200	18000
6.	0	21600

From Fig. 15, after the first cycle of 21600 sec, the pressure was observed to drop as read from the pressure gauge for

another cycle.

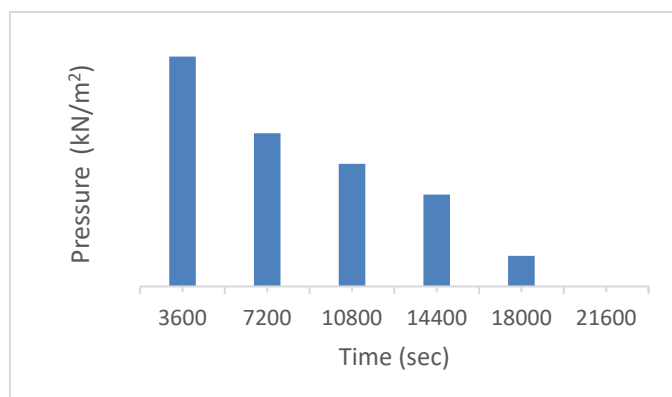


Fig. 15: Varying pressures at different points for 3600–21600 sec

During the process of carrying out the conventional test, when the pressure was constant, the graph was observed to be in the same level. The downward slope of the graph observed to be in different levels indicate the presence of leakages. In real life scenario, pressure is built continuously along the pipeline when in service. On detection of pressure lesser than the threshold pressure, an SMS alert was sent to the programmed phone number. The rig SMS alert module is shown in Fig. 16.

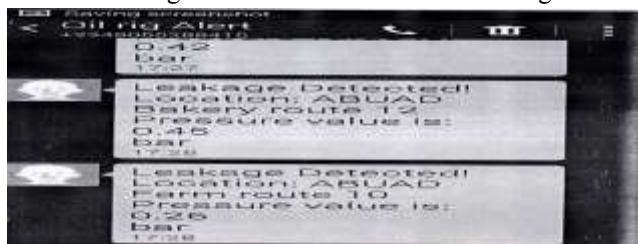


Fig. 16: Rig SMS alert module

4. Conclusions and recommendations

After the successful completion of the work, a prototype test rig suitable for leak evaluation was successfully developed. The leaks on the pipeline were physically evaluated using pressure gauges. Also, the developed electronic circuit was tested and found suitable for detecting oil leakage. The development of an electronic circuit to detect leak are areas of interest that could increase productivity, enhance quick leak detection and also gainfully help to minimize losses thus increasing pipeline reliability, integrity and downtime and inspection time.

In the light of the above conclusions, the use of wireless sensors should be applied for real-life scenarios of oil leakage detection in pipeline network. In addition, adequate mobile network service must be put into place where the system must be used. In addition, pipelines should be reconstructed to accommodate the installation, integration and implementation of remote sensors on it.

References

- [1] International Energy Agency, IEA. Annual Report. 2012, pp. 1-20.
- [2] Central Intelligence Agency, CIA. World Fact Book. 2012, pp. 1-5.
- [3] Ismail, I. N., Anuar, A., Sahari, K. S. M., Baharuddin, M. Z., Abd lalal, M. F. and Md Saad, I. Development of In-pipe Inspection Robot: a Review. 2012, pp. 310-315.
- [4] Nayak, A. and Pradhan, S. K. Design of a New In-Pipe Inspection Robot. 12th Global Congress on Manufacturing and Management, GCMM 2014. pp. 2082-2093.
- [5] Sebastian, B., Ray, D. N. and Majumder, S. (2015). Design, Analysis and Development of Pipeline Inspection Robot. 2nd international and 17th National Conference on Machines and Mechanisms iNaCoMM2015-104. 2015, p. 1-9.
- [6] Opobo J. "The Nigerian Oil and Gas Industry" *Oil and Gas Journal*. 2017, 115(4c):4-7.
- [7] Nwilo, P. C. and Badejo, O. T. "Impacts of Oil Spills along the Nigerian Coast". Frederiksberg, Denmark, FIG Publication, 2001(36).
- [8] Nee, L. V., Elamvazuthi, L., Ganesan, T., Ahamed Khan, M. A. K. and Parasuraman, S. Development of a Laboratory-scale Pipeline Inspection Robot. 2015 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS 2015). pp. 9-14.
- [9] Adnan, N. F., Ghazali, M. F., Amin, M. M. and Hamat, A. M. A. Leak detection in gas pipeline by acoustic and signal processing – A review. IOP Conf. Series: Materials Science and Engineering 100:01, 2015, pp. 1-8.
- [10] Viljeon. "A closer look at Nigeria's GDP rebasing". CNBC Africa. 12 February 2015. Retrieved 22 June 2015.
- [11] Alan, S. M. "Measurement and Instrumentation Principles", 3rd Edition, Butterworth-Heinemann 2001, pp. 16-64.
- [12] Spitzer, D. W. Flow Measurement: practical Guides for Measurement and Control, ISA Press, 2001.
- [13] Hague. Advanced Leak Detection in Oil and Gas Pipelines Using a Non-linear Observer and OLGA Models. 2007, pp 1 – 100.
- [14] Hellier, C. "Handbook of Non-destructive Evaluation", McGraw-Hill, ISBN 0-07-02-81-21-1, 2003.
- [15] Boaz, L., Kajjage, S. and Sinde, R. An overview of pipeline leak detection and location systems. Pan African International Conference on Information Science, Computing and Telecommunications, 2014, pp. 133-137.
- [16] Fraser, H. The electric Kiln: a user's manual, 2nd Edition, University of Pennsylvania Press, 2001, pp. 41.
- [17] Khonsari, M. M. and Booser, E. R. Applied Tribology - Bearing Design and Lubrication. New York, N.Y.: John Wiley & Sons, 2001.
- [18] Matsuo K, Elmazi D, Liu Y, Sakamoto S. and Barolli, L. A multimodal simulation system for wireless sensor networks: a comparison study considering stationary and mobile sink and event. Journal of Ambient Intelligence Human Computation, 2015, 6(4):519-529.
- [19] Mahshid, M. K. and Eslamipoor, R. An efficient and secure authentication for inter-roaming in wireless heterogeneous network. Journal of Soc. Netw. Anal Min2014, 4(1):1-10.
- [20] Adedeji, K., Hamam, Y., Abe, B. and Abu-Mahfouz, A. M. Improving the physical layer security of wireless communication networks using spread spectrum coding and artificial noise approach," in *Proc. Southern Africa Telecommun. Netw. Appl. Conf.*, Fancourt, South Africa, Sep. 2016, pp. 80-81.
- [21] Carrano, R., Passos D., Magalhaes, L. and Albuquerque, C. (2014). Survey and taxonomy of duty cycling mechanisms in wireless sensor networks". *J IEEE Commun Surv Tutor*, 2014 16(1):181-194.
- [22] Chen, K., Ma, M., Cheng, E., Yuan, F. and Su, W. A survey on mac protocols for underwater wireless sensor networks. *J IEEE Commun. Surv. Tutor* 2014, 16(3):1433-1447.
- [23] Geiger, G., Werner, T., Matko, D. (2003): Leak Detection and Locating – A Survey. 35th Annual PSIG Meeting, 15–17 October 2003, Bern, Switzerland.
- [24] American Petroleum Institute, API. Computational pipeline monitoring for liquids, 1st Edition, 2007.
- [25] Torres, L., Verde, C., Besancon, G., and González, O. High-gain observers for leak location in subterranean pipelines of liquefied petroleum gas. *International Journal of Robust and Nonlinear Control*, 2014, 24(6), 1127-1141.
- [26] Andek Corporation. *Flashband*. [Online]. (2015). Available from: <http://www.andek.com/AProducts/flash.html> [Accessed 14 April 2017].
- [27] Goodwin, S. Smart Home Automation with Linux and Raspberry Pi. 2nd Ed. New York: (2013).