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PIPELINE INSPECTION USING A LOW-COST WIFI BASED INTELLIGENT PIGGING SOLUTION

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Abstract

This study presents a low-cost smart pipeline inspection gauge (PIG) designed for pipeline defect (leakage) detection, and for quick data access and recovery for the purpose of analysis, utilizing locally sourced materials and off-the-shelf sensors and electronics. The PIG's electronic circuit is designed to house the sensors and allow for easy reception and transfer of pressure measurements to the pipeline manager's laptop via a WiFi module. A pressure sensor, a motion sensor, a wireless communicator, and an Arduino Microcontroller are utilized in the development of this PIG. The PIG was tested experimentally by being put through stationary, no load-no defect, and no load-defect tests respectively. The PIG was kept still during the stationary tests but was conveyed within a 160 mm diameter Polyvinyl Chloride (PVC) conduit with a length of 6.7 m for both the no load-no defect and no load-defect tests, using a 0.125 Hp direct current (DC) motor, with a gearbox attachment to pull from one end to the other. Using a WiFi module and the PuTTY program, the pressure values were retrieved. The test results revealed that P_1 (front pressure) values were higher than P_2 (rear pressure) values for the no load tests. P_1 readings ranged from 1213 to 1214 Pa, with an average of 1213.86 Pa for the no load-no defect tests. The average P_2 value was 1094.24 Pa, with a range of 1094.24 Pa to 1094.75 Pa. The pressure values for the no load-defect cases began at 1226.8 Pa and steadily decreased for the first 1.5 minutes, then remained at an average of 1214.2 Pa for the next 20 seconds until they arrived at the first defected point, where a value of 1216.1 Pa was recorded. The PIG traversed the pipeline until it had caught all of the pressure pulses at the defective sites. The higher pressure pulses (spikes) observed at the points of defects created along the pipeline in the experimental results from the no load-defect tests indicates that the Smart PIG was capable of detecting the created defects and demonstrated that the low-cost Smart PIG can be used to detect leakages on a pipe and can also be deployed in real life situations.

Keywords: Low-cost, Smart PIG, Pipeline Defect Detection, WiFi.

1.0 INTRODUCTION

Visual examination is costly and time intensive, therefore predicting the inner or exterior state of a buried pipeline is difficult. Pipelines are regarded as the most effective method of delivering substantial quantities of oil, refined petroleum products, and natural gas over land from the time they were first introduced in the mid to late 1800s. These pipelines serve a major part in modern society, as they provide essential fuels for vital tasks such as power generation, heating, and transportation[1].Pipelines are the arteries of theoil and gas transportation industry, and any disruption would result in a massive loss of energy and financial resources [2]. Because they transport highly combustible gases and liquids, there is also a risk of explosion from leaks.

Pipelines are critical components of the oil and gas delivery system, hence they must be maintained. Pipeline Inspection Gauge (PIG) has been effectively used as a maintenance approach in scenarios such as cleaning, product separation, and pipe integrity inspection [3]. PIGs are the sole way to see damage in pipelines because seeing the inside surface of the pipeline using any other method is usually difficult [4]. PIGs are cleaning, and inspection devices that are inserted into a pipeline and travel along it. Some devices, such as magnetic flux leakage (MFL) sensors, are usually mounted to a smart pig to identify surface pipeline problems and their locations [4].

There are two types of leak detection technologies for pipelines now available: internal detection and external detection. Negative pressure wave, acoustic correlation, and optical fibre leakage are examples of the latter. All of these are commonly employed in land pipelines that are designed to identify leaks and can only detect leak rates of 1% of total flow for oil pipelines and 5% for gas pipelines [5]. Traditional internal detectors, such as PIGs, move forward as a result of pressure variations between the front and back of the detectors, collecting data on corrosion, defect, and weld states on the pipeline's inside walls [6]. The Pipeline Inspection Gauge, on the other hand, is big and fits near to the pipe wall, which makes a lot of noise due to friction between the Pipeline Inspection Gauge's wheels and the pipe wall when travelling along the pipe, making it difficult to extract the weak leak noise [7].

Mechanical pressure clamps are examples of cutting-edge tools used in the oil and gas sector to stop leaks from damaged pipelines. Clamps are not normally suggested if leaks occur as a result of a pipeline rupture. As a result, inspecting the leaky pipeline is critical when deciding on a repair approach [8]. Traditional inspection instruments (Intelligent PIGs) are expensive to operate and come with a large payment toll. An intelligent pigging operation might cost several hundred thousand dollars and cover a considerable area. More intricate pipelines are frequently charged far higher than this, necessitating periodic cleaning and inspection activities. As a result, pipelines are neglected and deteriorate quickly [9].

PIGs serve four (4) important purposes, according to Jasper [10]:

1. Physical separation of different fluids running through the pipeline;
2. Internal cleaning of pipelines;
3. Inspection of pipeline walls (also known as Inline Inspection);
4. Capturing and recording geometric information about pipelines (e.g., position and size).

Pipeline infrastructure is one of the most common ways to move items such as crude oil, gas, water, and chemicals around the world. Regular monitoring and maintenance of the pipeline is required to maintain it safe from disaster, which could result in a variety of environmental risks, reduced flow efficiency, and threats to human life. However, because of the tools and manpower necessary for the monitoring, this examination usually comes at a considerable cost.

Furthermore, most traditional Pipeline Inspection Gauges (PIGs) have exorbitant procurement and operational costs, and they typically come in enormous sizes, making them prohibitively heavy to install. Magnetic Flux Leakage Inspection Tools and Ultrasonic Inspection Tools are two examples of such tools. They also necessitate extensive planning prior to their operational actions; as a result, cases requiring immediate attention are difficult to handle. To avoid leak accidents and reduce potential security threats in pipeline operations, prompt methods to detect and find minor leaking in these pipes must be performed. With the use of some specialized sensors, this study provides a cheaper and better approach of constructing a smart pig that can inspect and detect leaks along pipes delivering water and petroleum products.

This study also provides a significant approach for producing a low-cost in-line inspection instrument to assure regular inspection of pipelines with defects. This will aid in the prompt assessment of pipelines, extending their longevity. The use of PIGs for pipeline line monitoring from previous research exists. According to Murayama [11], there are now only a few sensors that can do non-destructive testing in a high-temperature setting. At temperatures above 50 degrees Celsius, the ultrasonic sensor is typically not employed. A particular sensor for high temperatures is also already available, although it has a number of limitations and has not yet achieved a level of utility in industry. As a result, this study developed a new sensor system that uses a long waveguide to send an ultrasonic wave across a long distance. Muggleton and Brennan [12] in their investigation on the sound attenuation in plastic pipelines submerged in water verified that tracing acoustic transmission on water pipeline at depth of 12 m would not represent a significant barrier and may even prove to be easier than land based pipelines. Lima et al. [13] used pressure transducers and Hall Effect sensors to estimate the speed and pressure of a PIG around defective areas of a pipe. To research speed control strategies for PIGs, a testing facility with a testing loop and a supervisory system was constructed. With the use of data from the supervisory system, pressure transducers were put on the pipeline outside walls to identify PIG movement and leakage region. At the same time, data from the odometer was received by the electronic board inside the PIG, which estimated an average speed of 0.45 m/s. The study's findings demonstrated that it is possible to successfully construct a testing laboratory that can detect the PIG's passage and measure its speed and pressure at leaking spots. Based on the pressure differential, Araujo et al. [14] investigated the use of artificial neural networks to compute the PIG's velocity and leakage zone. In the investigation, a prototype PIG was placed inside a testing pipeline, where it acquired velocity data from an odometer-based system and pressure data from the testing pipeline. To forecast velocity, a Multilayer Perceptron (MLP) was trained, and data was collected using a Nonlinear Autoregressive Network with exogenous inputs (NARX) network. The findings suggested that a neural network may be used to simulate the PIG's velocity based on pressure differential readings.

To the best of the author’s knowledge, related works to the scope of this study exists as discussed above, but not much works exit in the use of WiFi for the transmission of pipeline inspection data as captured by sensors along the pipe to a suitable device for viewing and analysis. Pipeline monitoring and inspection technology has gotten a lot of interest across the world. In this study, pressure pulses based on the idea of pipe vibration were employed to assess the presence of damages/defects in conventional pipeline systems utilizing a low-cost smart PIG. The ability to execute damage detection using a combination of pressure pulse propagation, an active sensor network, an Arduino microcontroller, and a WiFi module gives this research study a competitive advantage and makes a contribution to knowledge. With this system, damage data acquired by sensors is transmitted wirelessly via WiFi to the monitoring platform, replacing the conventional procedure of removing the PIG from the pipe and recovering the data collection box for further inspection data processing and analysis.

To the best of the authors' knowledge, previous pipeline inspection research using PIGS has rarely focused on wirelessly transmitting damage data to an appropriate device for viewing and analysis. The authors also used an Arduino microcontroller and a Wi-Fi module to transport pressure pulse data from sensors on pipes on an experimental test rig to a laptop for viewing and analysis. The data and methods used for this investigation are discussed in the section below. The results of the methods used are discussed in the third section. The study's findings are presented in the fourth section.

2.0 MATERIALS AND METHOD

2.1 MATERIALS

The major test apparatus for the Smart Pig includes:

- Test leads;
- DC motor and gearbox unit (for no load test);
- Strings (for no load test);
- Laptop with installed PuTTy software; and
- Test Rig

The equipment used for the construction of the rig are labelled respectively in Figure 3 as:

1. Mild steel Support;
2. 160mm diameter pipe;
3. End attachment;
4. Pig assembly; and
5. Pulling Mechanism

The electronic components that were employed were chosen depending on the design requirements. The features and descriptions of some of the critical components utilized in the electronic module are provided in the following sub-sections.

2.1.1 Sparkfun pressure sensor breakout: MS5803-14BA

This is a new generation micro pressure sensor module with a high resolution of 0.2 mbar that operates in the range of 0 to 14 bars. The communication protocol is straightforward, with no need to program the device's internal registers. It is also waterproof against 30 bar overpressure thanks to the gel protection and antimagnetic stainless steel lid. This new sensor module generation is based on cutting-edge MEMS technology and takes advantage of Intersema's proven experience and know-how in high-volume pressure module manufacture, which has been widely used for over a decade. Because of the sensing principle used, the pressure and temperature signals have very low hysteresis and are very stable [15]. Two of these sensors were used to assess the front and back pressures on the smart pig. Any microcontroller can be connected to the MS5803-14BA.

2.1.2 Motion sensor (Sparkfun 9DoF IMU break-out: LSM9DSI)

The LSM9DSI, a flexible motion sensing system in a chip, is installed in the smart pig. It combines a 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer into a single IC with nine degrees of freedom (9DoF). Even though the LSM9DSI has a digital interface, it is adaptable because it supports both IC and SPI. As a result, finding a microcontroller that it doesn't work with is extremely rare [15]. The

LSM9DSI is one of the few integrated circuits that can measure three fundamental aspects of motion in a single chip: angular velocity, acceleration, and heading. You can learn a lot about an object's movement and orientation only by measuring these three qualities. Each of these movement qualities is measured in three dimensions by the LSM9DSI. That is to say, it generates nine pieces of information: x/y/z acceleration, angular rotation in x/y/z, and magnetic force in x/y/z. The accelerometer and gyroscope axis orientations are labeled on the LSM9DSI Breakout, and they share a right hand rule connection. The accelerometer's scale may be set to 2, 4, 8, or 16g, the gyroscope can be set to 245, 500, or 2000 °/s, and the magnetometer offers full-scale ranges of 4, 8, 12, or 16 gauss. [15].

2.1.3 ESP-01S ESP8266 WiFi module

The data from the smart pig's sensors was sent to a collection location for processing via the wireless communicator. The ESP-01S ESP8266 Wi-Fi module was employed as the wireless communicator in this study. The module is a self-contained SOC with an integrated TCP/IP protocol stack that may provide access to a personalized Wi-Fi network to any microcontroller. An AT command set firmware is pre-programmed into each ESP8266 module. This means it may be connected to an Arduino device and provide nearly the same amount of WiFi functionality as a Wi-Fi shield [16].

2.1.4 Turbine flow meter

A bladed turbine rotor is included in the turbine flow meter, which was positioned in the pig's annular bypass. As shown in Figure 1, the turbine rotor is suspended axially in the flow direction, and the momentum of the flowing fluid turns the turbine blades on their axis. The rate of liquid flow through the bypass is proportional to the rotation.

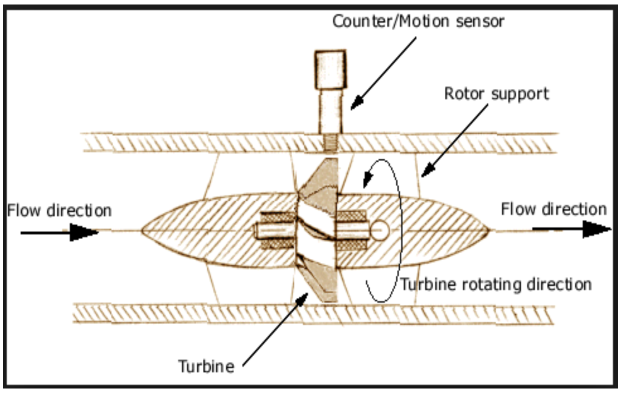

Figure 1: Cross-section of a Turbine Flow Metre [17]

The 'Principle of Reluctance,' in which a pickup coil wrapped around a magnet and located outside the annular bypass produces a voltage pulse when each rotor blade passes the coil, generates an electrical signal pulse. This is because the turbine blade's motion generates a deflection in the magnetic field, resulting in voltage fluctuations. The number of electric pulses is used to calculate the flow rate.

2.1.5 Fluid solenoid valve

Valves can be used to implement the notion of adjusting the bypass velocity to control the pig's motion. The valve is located in the annular bypass and in the fluid flow route, and it can be opened or closed to control bypass velocity. If the pig is slowing down, the valve should be closed to allow enough pressure to build up behind the pig to overcome the wax deposits' resistance and keep the pig moving at the proper speed. Figure 2 shows a schematic of a standard Fluid solenoid valve.

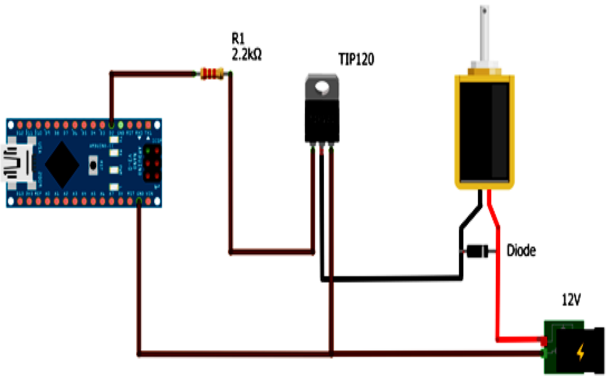

Figure 2: Schematic of a Fluid Solenoid Valve Layout

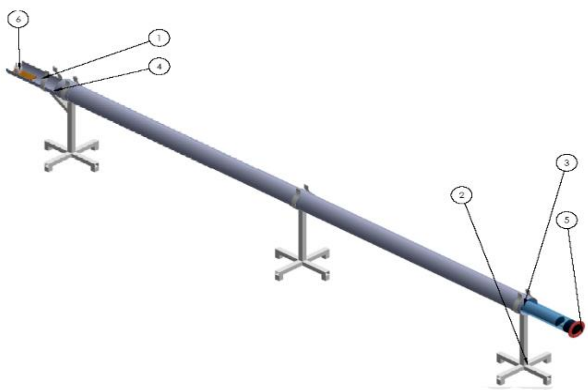

Figure 3: Set-up of the No-Load Test Rig

2.2 METHODS

2.2.1 Visual inspection

After construction, the smart pig was visually assessed. The purpose of the visual assessment was to look for any early non-conformities with the build instructions. The inspection regions are highlighted as follows:

- Component damage;
- PCB track damage;
- Short circuits or solder bridges;
- Damaged or dirty connectors;
- Loose connections

2.2.2 Environmental test

The PIG's operating environment was simulated to guarantee that the electronics component (particularly the pressure sensors) could execute the necessary function. This was accomplished by placing the PIG in still air and using the laptop screen to watch the pressure readout.

2.2.3 No load test

The goal of the experiment with set up as shown in Figure 3 was to test the smart PIG without any liquid in the pipeline and tomanually propel it over a specified distance using a pulling mechanism.

2.2.4 The Constructed Smart Pig

The elements indicated in Table 1 were used to make the smart pig. The majority of the materials were gathered from within the community. The components in Figure 4 are labeled as follows:

1. Pig casing: this was made from a PVC pipe with a diameter of 120mm and a length of 600mm.
2. Pig cap: this was made from a normal PVC pipe cover with a diameter of 120mm. Hot glue was used to adhere a 10mm thick foam strip to the top of the hat.
3. Electronics compartment: constructed from a PVC pipe with a diameter of 90mm.
4. Flow pipe: this was similarly made of PVC pipe with a diameter of 20mm.
5. Electronics compartment cap: for this, a 120mm diameter PVC cap was employed.
6. Battery: A Lithium ion 5V-12V battery was acquired at a local store.
7. Electronics circuit: All of the various components of the electronic circuit were soldered and bonded as needed.

2.3 COST ANALYSIS

One of the goals of this study was to create a low-cost smart pig. By providing a thorough list of things used in the course of the study and their respective costs, a correct assessment of expenses made is carried out, resulting in the PIG being termed low-cost.

The smart pig's fabrication costs are divided into three categories:

i. Material costs;
ii. Labour costs;
iii. Overhead costs

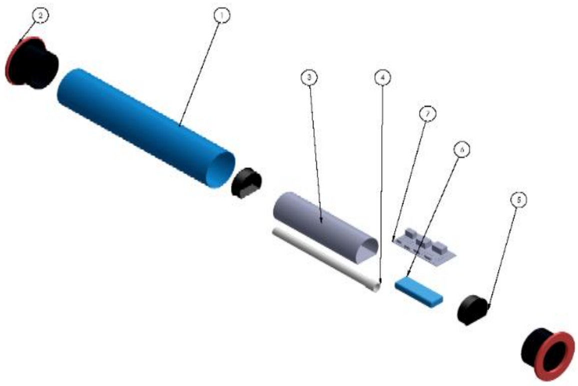

Figure 4: Exploded View of the Constructed Smart Pig

2.3.1 Material costs

Table 1 gives a cost breakdown of the materials used for the smart pig construction.

Table 1: Bill of Engineering Measurement and Evaluation for the Smart Pig

S/N	Materials	Quantity	Cost(₦)
1	Pressure Sensor MS5803-14BA	2	47,000
2	Water-Proof Temperature Probe w/cable	1	1,800
3	9DoF IMU Breakout-LSM9DS1	1	13,000
4	Liquid Flow Sensor, Turbine Meter	1	2,500
5	Flow Meter Counter 1--60L/min	1	2,700
6	12V Solenoid Valve—3/4 inch	1	5,100
7	Solenoid Valve ½ inch 6V DC	1	5,200
8	Piezo Element	2	1,600
9	Surface Transducer—Large	1	11,000
10	Surface Transducer—Small	1	5,100
11	ESP-01S ESP8266 WiFi Module	2	3,200
12	Raspberry Pi A+	1	14,000
13	Edimax WiFi Adapter (EW-781UN)	1	7,500
14	Arduino-Compatible Pro Mini EDArduino	4	6,400
15	FTDI Basic USB-TTL Programmer	1	5,000
16	Battery Pack Lithium ion 5V-12V	1	20,000
17	Alligator Test Leads-Multicoloured (10 Packs)	10	15,000
18	Break Away Headers- Straight	4	2,800
19	F/M 40P Prototype Cable (Male and Female)	1	1,500
20	6 inch diameter pipe	7	14,000
21	1000 Litre tank	1	40,000
22	Meter Support	5	15,000
23	5.5hp pump	1	40,000

24	Miscellaneous	20,000
	Total	**299,400**

2.3.2 Labour costs

The labour cost was taken as 15% of the material cost. Hence the labour is given as:

$$\text{Labour cost } = \frac{15}{100} \times Material\ Cost \qquad (1)$$

$$= \frac{15}{100} \times 299{,}400 = \text{N}44{,}910$$

2.3.3 Overhead costs

Overhead costs are referred to as the indirect cost and expenses which cannot be recognized with any particular fabrication or operations. For example electric power expenditure, indirect labour cost, and rent e.t.c.

Overhead cost was allocated as 10% of material cost. Thus the overhead cost was taken as:

$$\text{Overhead cost } = \frac{10}{100} \times Material\ Cost \qquad (2)$$

$$= \frac{10}{100} \times 299{,}400 \ = \text{N}29{,}940$$

2.3.4 Total cost of construction:

The overall cost of production of the smart pig is given as:

$$Overall\ cost = Cost\ of\ Materials + Cost\ of\ labour + cost\ of\ overheads \qquad (3)$$

$$= 299400 + 44910 + 29940 = N374{,}250$$

Using an exchange rate of 1 US Dollar (USD) = 411.13 Naira (N); the total cost of construction in USD = $910.40. This amount is very little when compared to the cost of monitoring and inspecting pipelines using PIGs which can cost as much as $56,000 per km of pipeline [18].

2.4 PIG DESIGN

2.4.1 Design Considerations

The primary design goal of that was to be met by the Smart PIG in this work was the reduction in the cost of smart pigging and this was achieved through a simplified design of the PIG using locally sourced materials.

2.4.2 PIG Launcher and Receiver

The design of the PIG launchers, PIG Traps, and related equipment was done in accordance with standards developed by several organizations. The design included a barrel, short pup joint, a trap valve, a side valve, and a bypass line as shown in Figure 5 and Figure 6 respectively. The barrel holds the pig for loading and unloading and is equipped with a quick-opening closure or blind flange.

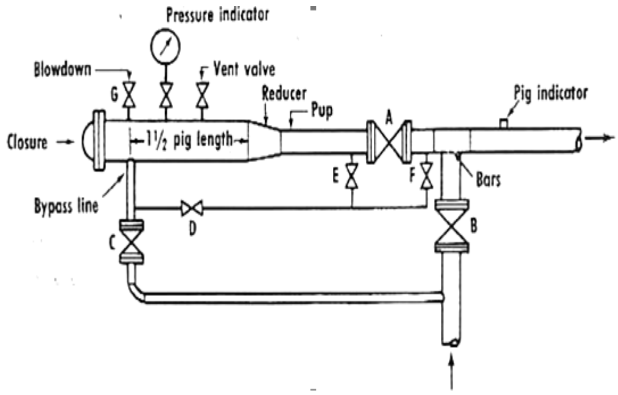

Figure 5: Pig Launcher Schematics [19]

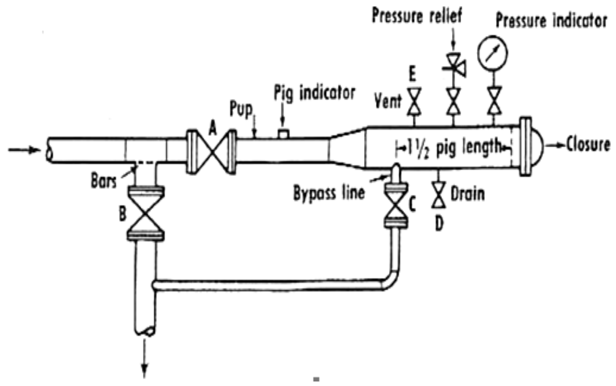

Figure 6: Pig Receiver Schematics [19]

3.0 RESULTS

3.1 STATIONARY TEST RESULTS

The experiments were carried out using the test rig shown in Figure 7. The test rig pulling mechanism is shown in Figure 8. Data (pressure readings) were sent to the laptop through Wi-Fi and the PuTTy software after the smart pig was allowed to run for five minutes at room temperature and still air. P_1 and P_2 are pressure readings from the Smart PIG's front and back, respect-

Figure 7: Test rig set-up

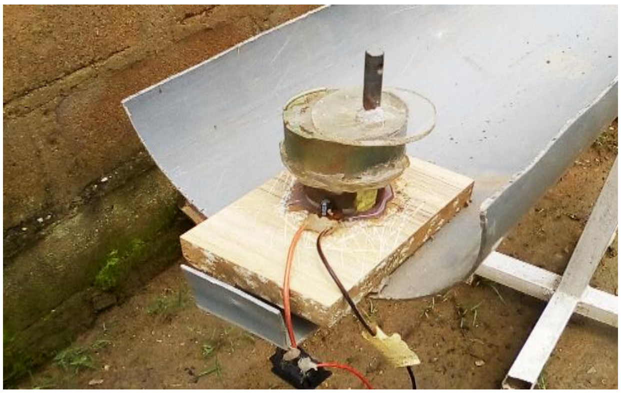

Figure 8: Test rig set-up pulling mechanism

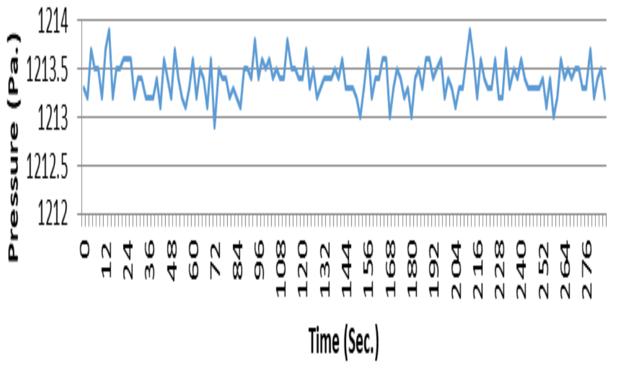

Figure 9: Graph of Pressure, P_1 against Time for Stationary Test1

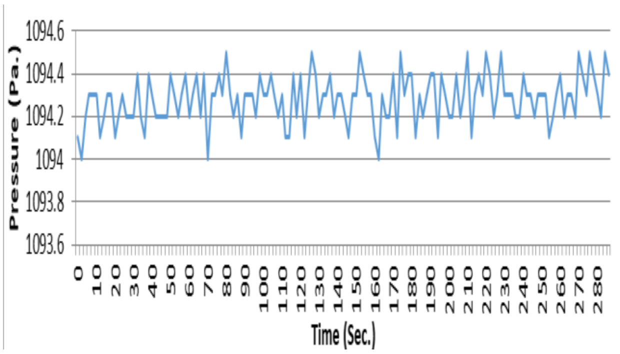

Figure 10: Graph of Pressure, P_2 against Time for Stationary Test1

ively. Figures 9, 10, 11 and 12 demonstrate the plotting of the $P_1$and P_2 values obtained from the stationary test against time using Microsoft Excel. As illustrated in Figures 9, 10, 11 and 12, this test was repeated twice to yield two sets of P_1 and P_2 values. Pressure pulses are the spikes shown on the graph. It suggests that due to extrinsic effects like as noise, external vibration, variations in altitude, and so on, the pressure measured cannot remain constant. P_1 values were found to be higher than P_2 values. The reason for this was due to a manufacture fault in which the two sensors were not correctly positioned on the same level. As a result, the values obtained from P_1 will always be bigger than those obtained from P_2. P_1 readings ranged from 1213 to 1214 Pa, with an average of 1213.86 Pa. The average P_2 value was 1094.24 Pa, with a range of 1094.24 Pa to 1094.75Pa.

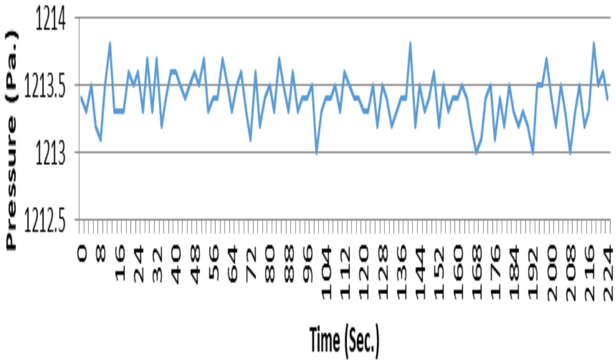

Figure 11: Pressure (P_1) Time Graph for Stationary Test 2

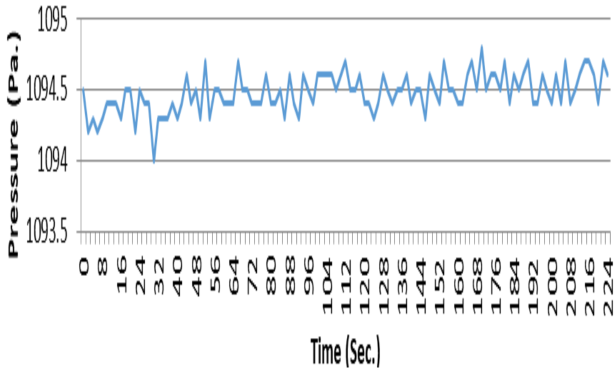

Figure 12: Pressure (P_2) against Time for Stationary Test 2

3.2 NO-LOAD-NO DEFECT RESULTS

After visually inspecting the pig and confirming its safety with a stationary test, it was put through its paces by traversing a 6.7-meter-long 160-mm-diameter conduit. Figure 13 and Figure 14 show the outcomes of this test. Figure 13 and Figure 14 show a trend that differs from that of the stationary test graph.

The first pressure, P_1, was 1221.8 Pa. For the stationary test, this is significantly higher than the P_1. This was due to the fact that the back side of the test rig was higher than the front, as well as the uneven ground on which the test was conducted. As a result, the pressure began at 1221.8 Pa and progressively decreased during the first minute until it reached an average of around 1214 Pa, where it remained steady until the completion of the experiment.

Similarly, during the last minute of the experiment, the pressure began to drop from an average value of 1094 Pa on the graph of pressure P_2 in Figure 13. This was due to the reversal of what occurred with pressure P_2. The test rig's front end was slightly depressed in this example, causing the measurement to fall below the average of 1094 Pa.

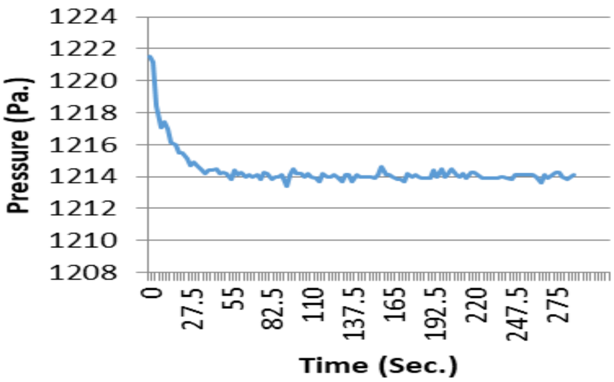

Figure 13: Pressure (P_1) Time Graph for No load Non-Defected Pipes

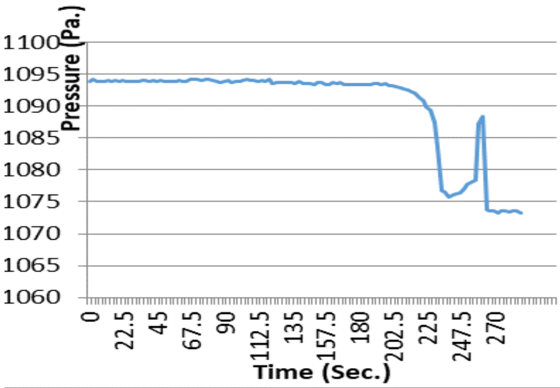

Figure 14: Pressure (P_2) Time Graph for No load Non-Defected Pipes

3.3 NO LOAD-DEFECT RESULT

A no load-defect test was performed once more by transiting the pig through the defective pipeline. The pig took about six minutes to cross the whole length of the conduit. Figures 13 and 14 show the results for P_1 and P_2, respectively.

The trends in Figures 15 and 16 differ from those in the stationary and no defect tests. This was due to the fact that the pipeline had a flaw. The points of thesefaults are sharp spikes, as illustrated in both figures. The pressure P_1 began at 1226.8 Pa once more. For the stationary test, this is significantly higher than the P_1. This was also due to the fact that the back side of the test rig was higher than the front, as well as the uneven terrain on which the test rig was positioned. So the pressure began at 1226.8 Pa and progressively decreased for the first 1.5 minutes, then stayed at an average of 1214.2 Pa for the next 20 seconds until it reached the first defected point, where a value of 1216.1 Pa was recorded. The PIG traversed the pipeline until it had caught all of the pressure pulses at the defective sites. For the second and third defective points, the values obtained were 1216 Pa and 1217.5 Pa, respectively.

Similarly, during the last one minute of the experiment, the pressure began to decline from an average value of 1094.2 Pa on the graph of pressure P_2 for the no load-defect test in Figure 15. This was due to the reversal of what occurred with pressure P_2. The test rig's front end was slightly depressed in this example, causing the reading to fall below the average of 1094.2 Pa. For the first, second, and third defective spots, the sensor recorded values of 1095.2Pa, 1095.3Pa, and 1095.4Pa, respectively.

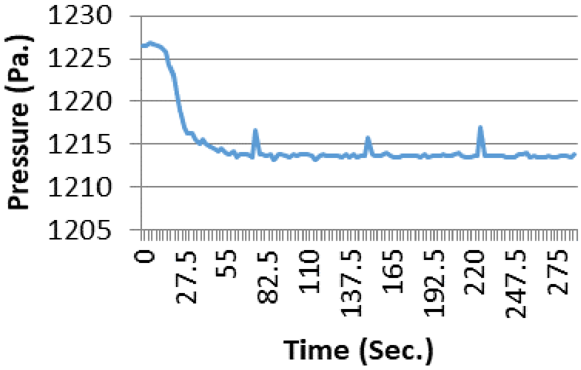

Figure 15: Graph of Pressure, P1 against Time for No load Defected Pipes

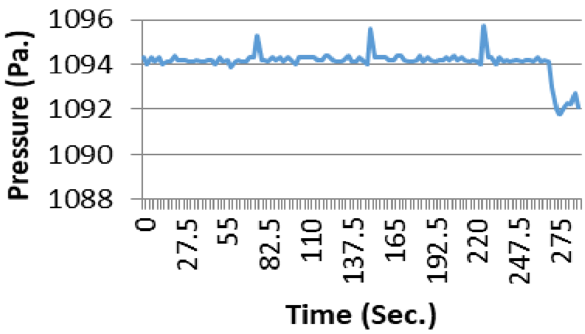

Figure 16: Graph of Pressure, P2 against Time for No load Defected Pipes

3.4 OBSERVATION FROM THE VISUAL INSPECTION

The electronic components were not damaged, the PCB tracks were not damaged, the solder bridges were not short circuited, the connectors were clean and tidy, and there were no loose connections, according to the visual inspection of the created smart pig.

4.0 DISCUSSION

All of these results obtained demonstrated that the PIG operated as intended, since the graphs revealed pressured pulses that were comparable to those reported by similar works. In the work by Lima et al. [13], a Testing Laboratory, containing a testing loop and supervisory system to study speed control techniques for PIGs was built. Obstructions on the pipe were created using pressure transducers, and there was an increase (spike) in the pressure readings obtained whenever the PIG came in contact with any of these obstructions along the pipe. This confirmed the results obtained in this study.

Araujo et al. [14] studied the application of artificial neural networks to calculate the PIG's velocity based on the pressure differential. A prototype PIG was launched inside a testing pipeline. Their obtained results showed that the pressure values as obtained by the sensors on the PIG increased whenever the PIG came in contact with any obstruction or defect. This is similar to what was obtained in this study, and also confirms the results obtained in this study. We believe our idea to improve the process of pigging will benefit the oil and gas business, as well as other industries that use pigging. Pipeline operators must monitor pipelines on a regular basis in order to detect faults that reduce the flow of oil and gas products and sub-products within by using sensors. This makes pigging a very important activity within the oil and gas industry. The cost of this activity though, has hindered operators, especially in under developed countries from adopting it. This study provides a low-cost alternative to the traditional PIGS that can be adopted by pipeline operators with low financial strength. The developed PIG is able to detect defects or obstructions on a pipe, and communicate the pressure readings obtained in real-time to a monitoring system for viewing and analysis.

5.0 CONCLUSION

The procurement and operational cost of most conventional PIGs are usually overbearing; and they usually come in huge sizes, making it too heavy to install. This inspection usually involves high cost of investment due to the kind of tools and man power required for the monitoring. There also require long time of planning prior to their operational activities; for these reasons, cases that require urgent attention are difficult to tackle. A smart PIG prototype was built and tested using an experimental test rig to simulate a real pipeline situation, and showed to be capable of identifying pipe defects by posting elevated pressure readings at defected points along the pipe, then communicating data (pressure readings) via a WiFi module to a personal computer (PC). The data that was transmitted into the PC was logged in using the Putty software. Using locally sourced materials, off-the-shelf sensors, and electronics, the smart PIG was created as a low-cost alternative to typical Intelligent PIGs.

The entire cost of building it was N374,250 ($910.40). In comparison to those evaluated using the pressure transducers monitoring technique, where the sensors were merely attached to places along the pipes, the Smart PIG was built with the capability to carry pressure sensors as an intricate component of the PIG. It can also transport data to a laptop swiftly and broadcast data over a 50-meter range via WiFi. The limitations of this study include the inability to accurately track the PIG movement along the pipeline. Also, due to the usage of the PuTTY software, they was an inability to rapidly plot data (pressure values) as the PIG traversed the pipeline.

As future directions for this study, it is recommended that a means of accurately tracking the PIG motion along pipeline should be incorporated in future version of the design. For this, a Global Positioning System (GPS) is proposed.Also, a means of rapid plotting of data should be incorporated in future designs.

REFERENCES

[1] Aba EN, Olugboji OA, Nasir A, Olutoye MA, Adedipe O (2020) Development of a petroleum pipeline monitoring system for characterization of damages using a fourier transform. Niger J Technol (NIJOTECH) 39(2):442–451. https://doi.org/10.4314/njt.v39 i2 .14

[2] Kumar, M., and Sorabh. (2013). Inspection of Pipelines Using MFL Technique. Journal of Pipeline Engineering, 2(6), 13–17.

[3] Freitas, V. C. G., Lima, G. F., Salazar, A. O., and Maitelli, A. L. (2016). " PIG " Detection with Pressure Transducers. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 5(9),7497–7503. https://doi.org/10.15662/IJA REEIE.2016.0509051

[4] Lesani, M., Rafeeyan, M., and Sohankar, A. (2012). Dimensional Liquid Pipeline. Journal of Applied Fluid Mechanics, 5(2), 75–83.

[5] Guo, S., Chen, S., Huang, X., Zhang, Y., and Jin, S. (2014). CFD and Experimental Investigations of Drag Force on Spherical Leak Detector in Pipe Flows at High Reynolds Number. CMES, 101(1), 59–80.

[6] Winters, B., and Williams, S. (2011). Cleaning PIG designs and applications. In 2011 Nace Central Area Conference (1–24). Houston, Texas, USA.

[7] Yang, Z., Liu, M., Shao, M., and Ji, Y. (2011). Research on Leakage Detection and Analysis of Leakage Point in the Gas Pipeline System. Open Journal of Safety Science and Technology, 1(December), 94–100. https://doi.org/10.4236/ojsst.2011

[8] Jasper, A. (2012). Oil / Gas Pipeline Leak Inspection and Repair in Underwater Poor Visibility Conditions : Challenges and Perspectives. Journal of Environmental Protection, 3, 394–399.

[9] Olugboji, O. A., Sadiq, A. A., Olorunsaiye, O., Peters, D. O., and Ajayi, B. A. (2015). Development of a smart pipe inspection gauge for detection of pipeline defects. In ASME 2015 International Mechanical Engineering Congress and Exposition (1–10). Texas

[10] Wang, L., and Sun, P. (2015). Long-distance Pipeline Pigging Technology. International Journal of Science, 2(11), 120–124.

[11] Murayama, R., Matsumoto, K., Ushitani, K., and Kobayashi, M. (2015). Pipe Inspection System by Guide Wave Using a Long Distance Waveguide. Modern Mechanical Engineering, 5, 139–149.

[12] Long, D. (2017). Application of Mobile Intelligent Inspection System in Substation Equipment Management. Journal of Energy and Power Engineering, 9, 408–413. https://doi.org/10.4236/epe.2017

[13] Lima, G., Freitas, V., Araujo, R., Maitelli, A., and Salazar, A. (2017). PIG's Speed Estimated with Pressure Transducers and Hall Effect Sensor : An Industrial Application of Sensors to Validate a Testing Laboratory. Sensors, 1(7), 1–12. https://doi.org/10.3390/s17092119

[14] Araújo, R. P. De, Carvalho, V., Freitas, G. De, Lima, G. F. De, Salazar, A. O., Adriao, D. D. N., and Maitelli, A. L. (2018). Pipeline Inspection Gauge's Velocity Simulation Based on Pressure Differential Using Artificial Neural Networks. Sensors, 2(9), 1–15. https://doi.org/10.3390/

[15] SparkFun Electronics ® (2021). www.sparkfun.com. Accessed 22 July 2021

[16] 4tronix (2021). https://shop.4tronix.co.uk/. Accessed 20 July 2021

[17] Wilkinson, G. (2011). Automatic Multiple Cleaning Pig Launching System Passes Test. Pipeline and Gas Journal, 1–4.

[18] Oil and Gas IQ (2015). Unmanned Inspection for Oil and Gas: ROVs, PIGs, ROI and Obstacles. https://www.oilandgasiq.com/strategy-management-and information/whitepapers/analysis-unmanned-inspection-for-oil-gas. Accessed 9 July 2019.

[19] Webb, B. (1978). Pipeline Pigging. *The Oil and Gas Journal*, *6*, 1–10.