Proposal for a Computational Intelligence in Modelling Leak Detection for Crude Oil Pipelines

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***Abstract*— The transportation of hydrocarbon deposit beneath the earth surface are mostly safer and cheaper using pipelines. However, these pipelines are frequently challenged with damages such as corrosion, manufacturing errors and environmental degradation that often lead to leakages and can result into gross economic lost and explosion which could also be a threat to lives. Leak detection is a technique used in the Oil & Gas Industry to monitor variation in essential properties of the hydrocarbon product such as pressure or temperature and compare these values at different intervals on the pipeline between the inlet and the outlet. This technique is highly inefficient when a real-time and accurate point of leakage is desired. In most case, multiple excavations need to be done before an exact leak location can be detected. With abundant records of previous leakages and recorded reading of these leak detection system such SCADA, a machine learning architecture is proposed in this paper and a conceptual framework was developed to achieve the paper's proposed idea.**

Keywords*— *Leak detection, oil pipelines, computational intelligence, SCADA, machine learning.

I. Introduction

Natural oil and gases are nature given endowments buried in reservoirs or bedrocks in large water bodies. Man in his quest to ease his day to day activities discovered these resources and looked for ways to make them useful for a better standard of living. The exploration of such is a search for hydrocarbon deposit beneath the earth surface. Oil and gases are mostly produced from oil bedrocks or reservoirs as opinioned by [1]. These natural oil and gases will not serve their purposes if they are not being moved from source locations to the final consumers. As early back as 400 BC, the ancient China discovered how pipelines could be use in the transportation of petroleum products. Recent researches still indicate that pipelines are the most effective and efficient medium for transporting large volumes of crude oil and gases over short to medium distances [2]. These pipes being the safest medium for transporting fluids are virtually everywhere, planted under seas, buried through deserts or across swamps.

Over a prolonged time of usage, these pipes suffer material defects from faulty designs, corrosion or wear, environmental effects or deliberate attacks in form of oil buckery or vandalism. All of these acts compromise the integrity of these pipelines and thereby resulting in leakages. With some millions of kilometers of pipelines, approximately three, running constantly across the globe [2], constant monitoring to detect malfunctioning that could lead to leaks in the pipelines becomes necessary so as to minimize the harm that may follow from loss of lives and properties, loss of produce, environmental damages to other costs that may be inquired in the process.

Pipeline rupture results into sudden change in pressure, which can have a severe hazardous impact on the immediate environment, lives, and result in huge economic loss [3]. An hour of crude oil pipeline leakage could translate into multiple thousands of dollar economic loss, the longer it takes to detect leakage on the pipeline, the more devastating is the resulting economic loss and environmental threat. The tasks of monitoring, controlling and diagnosing crude oil exploration processes as well as transportation of its products is often challenging. Monitoring the process of data collection and analyzing the current condition is really difficult, detecting and diagnostic processes for anomalies on instant and continuous bases all requires effective procedures [3].

One means of monitoring the state of those pipes is by installing leak detection systems (LDS). The effective installation of reliable LDSs are a crucial task in the industry for prompt and efficient identification of the presence of a leak which calls for urgent responses [1]. This can help in mitigating the consequences of accidents resulting from small leaks before they degenerate.

In general, there are two methods for detecting leaks along pipelines; internal also called inferential and external or direct methods. For internal based system detection, the computational pipeline monitoring (CPM) technique is the most popularly adopted technique. It monitors any deviation in some company inferred variables like the pressure, flow rate or temperature of the pipelines. For the external methods, they detect leaks outside the pipelines traditionally by methods like the “right of way” technique for inspection, hydrocarbon sensing through the use of fiber optics or dielectric cables. This is why Instrumentation of the pipelines with regards to the Oil and Gas sector is limited only to the inlet and outlet of pipes.

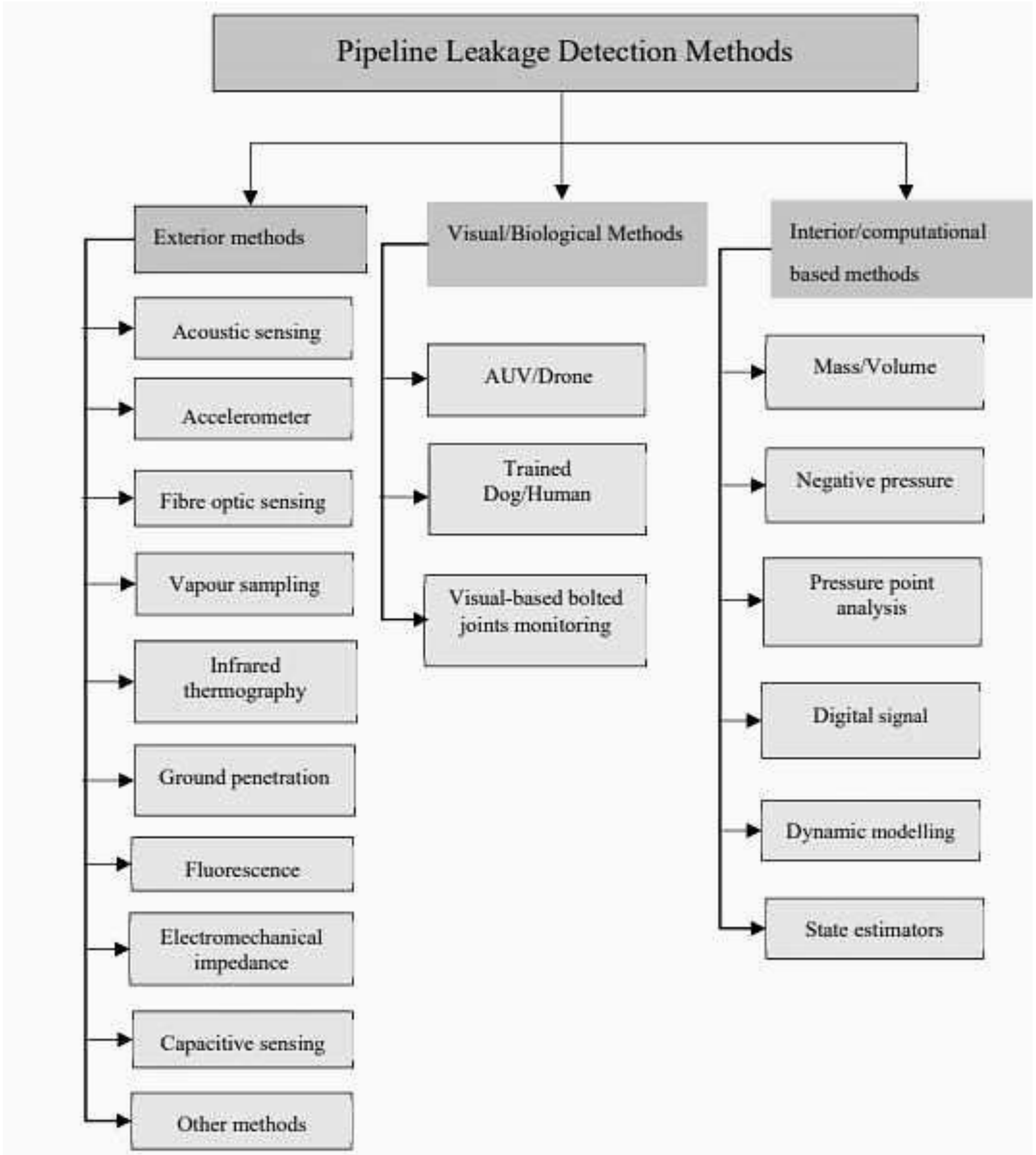

Figure 1:Flow-diagram of Leak Detection Techniques [15]

In the work of Hamilton 2009, the Authors considered that leak detection process is generally divided into three phases, localizing, locating, and pinpointing which occurs before the leak is excavated. They stated also that the best possible result that can be obtained during pinpointing operation is within the positive to negative of 20 cm of the established leak location, within a perfect working condition [4]. By localizing one tends to narrow down segments of the suspected leak. Techniques like step testing and other surveys like the fitting survey can be employed (Hamilton 2009). During locating, a meter radius is marked within an already established segment and is labeled as the leak area [5].

Noise Correlation technique which stands to be the most adopted technique for identifying Leaks in pipes. It assesses the velocity of sound signals from different locations and uses the rate of change in their detection time to establish the presence of leak and the exact location. Pinpointing is the final phase before excavation, it determines the exact location where the leak is suspected. Techniques such as the use of listening sticks, hydrophones or geophones are employed. The device is expected to be within the range of the suspected leak and the area that has the highest amplitude will be the leak position [5].

Software-based methods for detecting leaks along pipelines achieve such by statistical processes on recorded data while other techniques involves models built based on physical principles [1]. Supervisory Control and Data Acquisition (SCADA) is a methodology on pipelines that makes it possible for dynamic parameters to be generated for the model building. SCADA system normally supports communication between a centralized unit of control (with advanced computation and communication facilities) and many other field devices equipped with several sensors and logical devices [6]. Some of these techniques include the volume-mass balance, acoustic monitoring, pressure monitoring, pattern matching and the transient leakage detection techniques. However, most of these techniques suffer one limitation or another like long response time, poor accuracy, false alarms etc., [1].

Artificial Intelligence (AI) is one of the newest fields in sciences where intelligent decision support systems are built to solve problems such as: diagnosis of complex reasoning activities, learning and perception, among others. AI techniques involves the modelling of the human brain in a computational environment for solving problems over a set of operations like association and logical reasoning and to a very large extend some forms of decision making processes as would the human brain [7]. With the adoption of AI techniques in pipeline transportation, state-of-the-art computer technologies have been developed for mitigating faults that may occur along those mediums of transportation like Leaks.

Figure 1 presents a summary of the basic leak detection techniques.

II. STATEMENT OF PROBLEM

Transportation of oil and gas as well as its products is a complex process that involves many process variables. However, [8] asserted that the process complexities can be reduced if important factors associated to this process are being identified early enough in the operational data.

With the use of SCADA system on crude oil pipelines, parameters like the pressure along pipes, flow rate of the content and temperature can be obtained thereby making it easier for instant and prompt pipeline leakage detection through development of highly reliable online monitoring models [1].

While it is general accepted that significant researches have been carried out in water leaks detection, very few of them considered the addressing of oil and gas leaks. This could be as a result of hazards that some emitted gases like methane can introduce during the process [9].

Many of the contemporary pipeline leak detection models have their shortcomings, that includes, long response time, false alarm reporting, inaccuracy of the leakage location, etc., [3]. Although, transient leakage detection method has been reported by [10] to have the advantages of speediness and exactness, researches done with this model are still manually computed, as such making it difficult to predict real-time pipeline leakages in an online basis.

Instrumentation in the oil and gas sector is basically done along the inlet and outlet of pipelines. This reason therefore makes it difficult to detect any such anomalies like leaks. Therefore, the development of effective and efficient models for the detection of such leaks cannot be overemphasized [1].

Smaller leaks are more difficult to identify and detecting such leaks may also not necessarily generate an analog deviation so as to help in building effective models. Therefore, more attention has to be paid to leaks as they occur and techniques that can sense them early enough needs to be investigated [11].

The traditional approaches to Leak detections do not usually meet up to the industrial performance metrics such as Accuracy of detection, sensitivity rate, model robustness and others. Therefore, there is need for the adoption of techniques such as intelligent models, big data as well as real time transient models for better detection [2].

III. AIM & OBJECTIVES OF THE STUDY

This research work aims at using machine learning techniques to create a model that can predict the exact leak position of pipelines, using the records of pipeline leakages recorded over a specific period in the Nigerian pipeline routes. To achieve this goal, the following objectives are set:

a. To critically examine the SCADA methods in the Nigerian energy industry and determine a harmonized data collection hub, storage and retrieval for effective data manipulations needed in machine learning techniques.
b. To collect and prepare the data of pipeline failure in Nigeria, based on SCADA’s information and the actual position discovered after excavation for machine learning usage.
c. To establish the best mathematical model used in leak detection systems.
d. To develop machine learning models for predicting an accurate leak position in pipelines when there is a leakage using the identified best mathematical model’s definition a guide.
e. To simulate the machine learning models developed with the data collected.
f. To evaluate the performance of the models and recommend the best.

IV. CONTRIBUTIONS TO KNOWLEDGE

After a successful completion of this proposed research, the outcome of the research work is expected to:

a. Identify the significances of each feature that makes up the historical records that would be used to select the optimal parameters for the model to be developed.
b. Justify the accuracy of the models previously used against the actual leak positions discovered after excavation.
c. Create a proactive maintenance/leak detection method for the pipelines.
d. Publish the research outputs in local and international conferences and journals.

V. LITERATURE REVIEW

In general, there are several methods and approaches to leak detection and researchers as well as industries have identified their strengths, weaknesses, and costs. These techniques are basically grouped based on methods of execution. Amongst them are the physical observation methodology, balancing systems like mass balancing, volume balancing and more. Then the Statistical models, RealTime Transient Models and more. All of these individual techniques and others can either fall

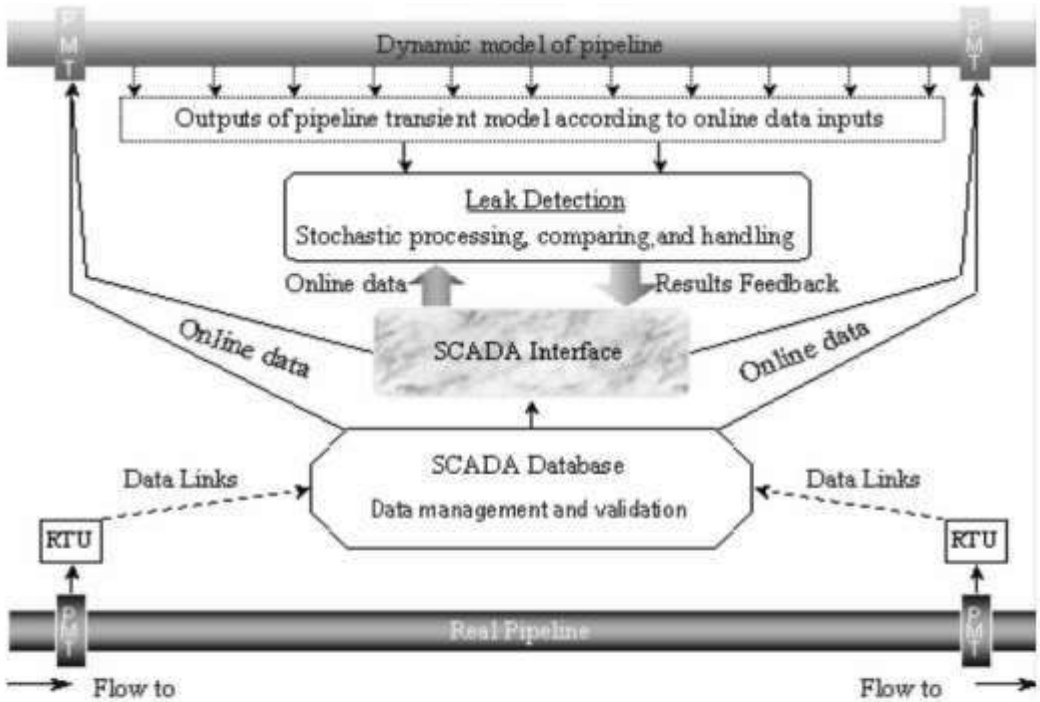

Figure 2: Example of a Transient Model for Leak Detection [16]

under internal or external methods as they are broadly classified. Pipeline operators have since engaged both the hardware-based systems (like acoustics, fiber optics, infrared signals) and software-based methods (transient methods, pressure analysis) and also biological based method [2]checking and detecting leaks. It is worthy to note that pipeline operators can combine more than one method in order to improve the efficiency and effectiveness of leak detection techniques.

A. Computational Intelligent Models

Computational Intelligent models are algorithmic models designed to learn from large volumes of generated data and draw then deduce valuable reasoning over them. Examples of such models include Neural Networks (NN), Decision Tree (DT), Support Vector Machine (SVM), etc. A computer-based model is said to be intelligent if it has the ability to learn a task from a training dataset or experimental observations.

B. Types of Intelligent Models

Unsupervised learning models: These are techniques that allows the system to identify patterns within a dataset on its own. That is, it reasons over a dataset that is neither classified nor labeled.

Nature inspired model: This technique is based on a collection of connected nodes referred to as artificial neurons that are loosely modelled like the neurons in a biological brain. Each neuron can transmit a signal to other neurons. The Artificial Neural Network is the most popular of this technique and can be of several types. Popular amongst them are the multilayer perceptron, neural network, convolutional neural network etc.

Tree-based models: These are tree-like structures in form of Flow-charts, each internal node denotes a branch representing the outcome of a test, and each leaf (terminal) node holds a class label

Ensemble models: This is usually a combination of two or more weak classifiers or intelligent models so as to produce a more robust model. These could be in form of either boosting, bagging or stacking

Generalized Linear Models: These are regression based techniques that could also be adapted for classification where the target outcome is in the form of linear combination of the input variables. Examples include Linear Regression, Bayesian Regression and Logistic Regression.

C. Transient Model of Leak Detection

With day by day increase in computational power of digital computers, it is possible to calculate in real time the profiles for flow of substance v, its pressure p and the density ρ of that substance along a particular pipeline [1].

This technique is what is referred to as real time transient modeling (RTTM) leak detection. This is the most reliable form of leak detection although it is expensive to set up. RTTM involves the computer simulation of pipeline conditions using advanced fluid mechanics and hydraulic modeling. RTTM software can predict the size of a leak and pinpoint its exact location by comparing the data obtained for a segment of pipeline with the predicted modeled conditions. Figure 2.0 shows an example of a Transient model with a SCADA database.

[10] developed a leakage detection model based on the on-line analysis of signals originated from the SCADA related

variables like the flow rate. This process enables leakage detection models to be built based on some of equations like the momentum, energy, volume-mass balance and state equations. They suggested that outlet pressure and leakages are the most fundamental parameters compared to the coefficient of frictional resistance and the pipeline diameter. The more leakage increases, the closer leakage point approaches pipeline outlet.

[12] described pipeline leaks with relation to an adequately estimate of oil spills and a justification to appropriate emergency action for mitigation such related cases. Internal diameters of pipes used in the study were within 4 inches. Leaks were simulated from plastic pipeline oil containment fitted with valves. The leak response with time when upstream and downstream valves were operated was studied.

[13] presented a transient flow analysis of fluid in pipeline to account for imbalances in the continuity and momentum equations. Measurements of flow parameters at inlet and outlet of pipeline were used in developing the model.

[14] investigated the accuracy of an optical fibre-based temperature sensing in subsea oil pipeline and developed a mathematical model that simulate the process. Their result was compared with productions from the theoretical models and were able to establish that the optical fiber cable detection system is capable of providing an accurate and rapid assessment of the location of a leak along a subsea pipeline.

[1] developed a transient model-based leak detection and localization technique base on the present state of technology in Nigeria. The model was able to detect a leak incident in a horizontal pipeline carrying Nigeria Bonny Light Crude Oil from the Nigeria Petroleum Development Company Limited, Olomoro flow-station into Ughelli Pump Station (UPS) truck line based on observations from pressure drop.

[3] designed a leak detection and location method based on the amplitude attenuation model of dynamic pressure waves. They compared their design with the traditional methods based on the propagation velocity and time differences in waveforms of upstream and downstream signals. The proposed design clarified the influence of gas flow on the waves.

[15] proposed a two-approaches methodology for leak detection and isolation (LDI) in pipelines based on data fusion known as a steady state estimation and an Extended Kalman Filter (EKF). Their approach considered only pressure and flow rate measurements at endpoints of pipelines and uses MATLAB environment to implement the real-time data captured from the sensors.

[2] carried out a study on the detection of small leaks using intelligent models and tested the performance of the model based on robustness, reliability and accuracy. Five intelligent models were used (Random Forest (RF), Gradient Boosting (GB), Decision Trees (DT), Artificial Neural Network (ANN) and Support Vector Machine (SVM)). Their results showed that RF and DT performed better with high reliability but suffers low accuracy with regards to ANN and SVM. The intelligent models had a time savings of 25% to 48% when compared to RTTM from literature.

[16] presented a review on Recent Advances in Pipeline Monitoring and Oil Leakage Detection Technologies. They grouped the different techniques into three broad categories. Exterior methods which make use of sensing systems to monitor the external parts of pipelines like fibre optic sensors, second category uses visual methods like smart pigging for detecting leakages. The interior method which involves the use of parameters associated with hydrocarbon fluid such as mass-volume balance, negative pressure waves etc. They concluded that each technique has some merits and demerit like the interior

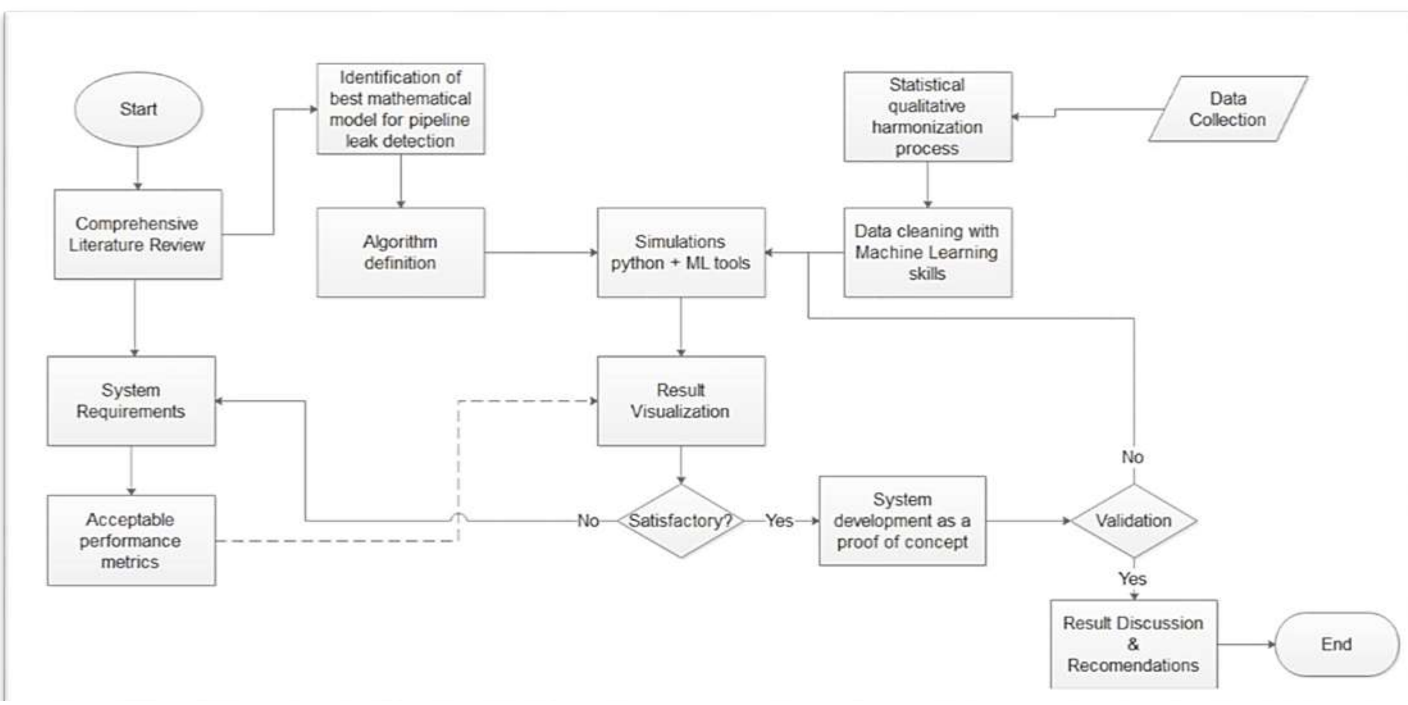

Figure 3: Research Conceptual Framework

methods are sensitive to small leakages but prone to false alarms. Mass-volume balance and numerical computation models exhibit good performance for high flow rates, in multiphase flow and subsea pipeline networks.

In the work of [9] titled “Leak Detection Systems in Oil and Gas Fields: Present Trends and Future Prospects” presented recent findings in acoustic and infrared (IR)-based leak detection techniques and also provided other alternative techniques such as photoacoustic sensing, ground penetrating radar (GPR), and temperature profiling methods. They presented several important research works and real-life application areas in order to provide a reasonable cross-section of all the various techniques for the monitoring and detection of leakages along pipes.

VI. RESEARCH METHODOLOGY

As depicted in the conceptual framework in Figure 3, the historical data on pipeline failures from the Nigerian National Petroleum Company (NNPC) and Department of Petroleum Recourses (DPR) will be collected using Supervisory Control and Data Acquisition system. Then, statistical qualitative harmonization process will be used to select data set; identify relevant cognitive domains and instruments; and identify variables of interest and their cofounding variables.

Then the cleaning of the harmonized data by amending and removing incorrect, incomplete, improperly formatted or duplicate data using appropriate machine learning tools and skills.

The skills of the best mathematical model will be transformed into a computer algorithm for an efficient automation, using machine learning models and/or Artificial Intelligence techniques.

Python programming language as well as appropriate machine learning tools (Jupyter Notebook, Scikit-learn, TensorFlow, Microsoft Azure ML, etc) will be used to simulate the algorithm with the historical data collected.

Suitable machine learning tools such as: Matplotlit, ggplot, Seaborn Zepplin, will be used to visualize the result.

VII. EXPECTED RESULTS AND DISCUSSION

Results of the dynamic parameters of fluids in a pipeline (flow, pressure, temperature, density, viscosity, etc) are expected to be generated, analyzed and their correlations with actual excavated point of leakage would be determined.

These analyses are expected to give a justified feature selection algorithm that could in another hand specify the casualty parameters (if any) to leakage detection.

These results all-together, would be used in developing an automated leak detection system that would be able to raise valid alarms and intelligently predict an accurate leakage position anytime there is leakage in oil pipelines.

VIII. CONCLUSION

It is the expectation of this research that historical records of pipeline failure in Nigeria based on SCADA information and the actual position discovered after excavation can be useful in developing a meaningful model that is capable of predicting an accurate leak position in Nigeria pipelines. This can be achieved by employing appropriate machine learning techniques on the SCADA information to serve as a training to the model, while the actual positions discovered after excavation will be used as test to evaluation and adjust the model to a perfect automation.

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