# Intelligent IoT Enabled Pipeline Leakage Detection and Monitoring System Using Machine Learning Algorithm

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***Abstract:*** Pipeline networks are the safest transportation of oil and gas-related products that may be susceptible to failures. These kinds of failures are due to the reason of manufacturing defects, degradation of the material, environmental defects, and interference of the third party. These issues are addressed through the Internet of Things (IoT) based solutions and give promising outcomes in predicting the failures and monitoring. The IoT can combine the sensor technologies to monitor the gas flow, pressure, temperature, condition of the compressor, concentration, and other related features inside the pipeline. The leaks in the pipe are measured as a pin-sized hole that is detected by the IoT sensor with advanced technologies such as deep learning. This project proposed deep learning with a meta-heuristic approach-based model to detect leaks in pipelines through IoT sensors.

The Deep Learning model called Deep Auto Encoder Neural network (DAENN) is the unsupervised model that can accurately classify the leaking and non-leaking pipeline conditions.

The detection accuracy is further enhanced with the Bat Optimization algorithm (BOA) which obtained improved accuracy while leaks occur in the pipeline inside the sensor monitoring area. This observation deploys the monitoring sensors to cover the mentioned monitoring area. The proposed model can increase the system's leak detection reliability and reduces the false alarm rate.

## INTRODUCTION

Nowadays, technology takes a major role in our lives and we are always searching for better solutions to solve everyday problems, mainly to improve and ease repetitive tasks in an autonomous way with less effort. This evolution in technology reached new potentials with the increase of devices being used every day, allowing for the concept of Internet of Things (IoT) to arise and be part of the proliferation of smart technologies and cities.

IoT is the evolution of the current Internet and consists of a network of devices that are capable of collecting and controlling data from the physical world, with these devices being capable of perceiving, computing, executing, and communicating between users and things. These networks of devices are usually associated with the concept of Wireless Sensor Networks (WSN) and multiple small nodes that communicate among them using wireless links, covering large areas and collecting data in real time. These enable control over the environment and an interaction with the users, with IoT and WSN being reliable features on the development of monitoring and control systems. IoT systems can be applied in multiple scenarios, as they are composed to retrieve information about the operation, conditions, and performance of any task or environment that can be remotely controlled. Therefore, in the last years, several sectors have adopted these systems, for example, in health, transport, retail, buildings, and agriculture.

Gas management depends on how well the use of gas is maximized and the gas losses are minimized. This type of management requires precise analysis which may be too complex for humans to perform correctly, and with the increase in human population, sustainability and efficient gas usage assume important roles. As gas is a scarce resource, detecting problems with the supply and distribution of gas as fast as possible can be achieved throughout a sensor network, leading to minimal to no waste in activities.

Typical solutions for leak detection in pipes include shutting down the gas supply system and using acoustic devices to check if the sound can reach the end of the pipe without losing strength, meaning that the pipes do not have any leakage points. These kits, available on the market and widely used by plumbers and inspectors, are portable devices capable of detecting flaws in pipes with sound, such as in. This solution not only requires additional manpower to be performed but also implies a break in normal activities of the system, leading to a potential reduction of performance in the irrigated field, making this type of analysis a maintenance checkup that occurs periodically instead of a real-time analysis. Another method commonly used is a visual inspection not only on the pipes themselves when they are exposed above ground but also on areas that have signs of flooding resulting from a burst pipe underneath. As in the previous method, this involves additional manpower and cannot be carried out on a real-time basis.

To improve the efficiency of gas distribution and to reduce waste related to leaks, a sensor network can be used to execute those analyses with precision and in an autonomous way. Some research and development can be found in both the academic and industrial worlds, ranging from expansive fixed systems that use ultrasonic clamps to analyze real-time gas flow, such as, to low-cost solutions found in the academic world, such as.

To optimize the daily management and control of possible leaks, this project aims to create a system that can control and monitor pipe line leaks through a system that collects data using a low-cost sensor network in order to evaluate possible leak points in the gas system. The data obtained from the sensors is stored and treated by a Machine Learning (ML) algorithm that will allow the user to be notified if the gas distribution system starts to leak, of the potential size, and of the location of those leaks. All interactions and notifications with the user are done through a mobile app, where they can also act upon and take care of the gas leak. This work proposes a new system to monitor and control the pipe line flow through a gas distribution pipeline, having in mind the reduction of gas wasted and a monetary saving for the final user. This project not only contributes a new way to monitor leaks with a low-cost solution that includes a complete ready-to-use system but also provides a detailed study on how machine learning can be used alongside sensor data to detect in real-time leaks in pipes based on that data as well as a comprehensive comparison between several algorithms in order to discover which best fits these problems.
The current research status on leak detection using IoT and ML, with some significant research being analyzed and compared with our approach. A detailed description of our system architecture, including hardware, for data collection, communications, data analysis, and visualization are described. Our approach on the machine learning training, with the methodology, the creation of a training and testing dataset, and the results of the training methodology. the experimental setup to validate our system methodology.

**OBJECTIVE OF THE PROJECT**:

- Design and fabricate experimental setup for representing oil station replicating industrial oil pipe line system.
- Develop integrate IOT architecture with local intelligence for online monitoring and control of entire oil pipe line system with centralized cloud server
- Identify initial occurrences of crack and blockages using matching learning approach to classify normal and abnormal working condition
- To estimate the occurrence of missing sensor data using advanced machine learning algorithm..

**PROPOSED SYSTEM**:

Physical Layer: The physical layer is responsible for the interaction of the pipeline environment which consists of motion sensors, temperature sensors, pressure sensors, vibration sensors, flow sensors, camera, GPS with actuators, Radio Frequency Identification (RFID), and remote terminal unit (RTU) which is the microprocessor that provides the interface between the physical world to the control system. The motion sensor is responsible to monitor the objects that move closest to the target pipeline.

Network Layer: The network layer is the interface between the physical and Data processing layer. the sensor data such as text, images, and videos which are collected from the physical layer is transmitted to the data processing layer in real-time through Wi-Fi, wireless and wired networks. To communicate over a short-range, Wi-fi and other networks are used. For long-distance communication, 4G and 5G networks were used.

Data Processing Layer: It is the place where the collected data from the physical layer is stored over a cloud server and analyzed for intelligent processing. In this layer, the technologies such as database, cloud computing, and big data analytics are used. Big data analytics used data processing, data fusion, data mining, and machine and deep learning approaches for leak detection. Intelligent decision-making is obtained through the proposed Deep Auto Encoder Neural Network with BOA for leak detection in the pipeline system
.
Application layer: This is the layer where the user directly interacts and the processed results are visually presented to the users. Notification about the processed result, warnings, and corresponding alert reports are presented to the user. The diagnosis and control are implemented in case of emergency warning or critical danger about the leak.
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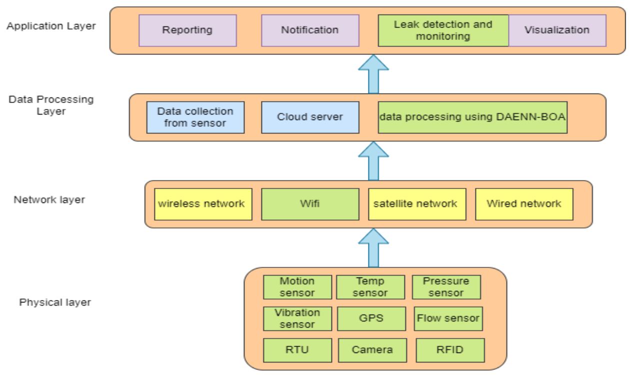
**BLOCK DIAGRAM:**




**Aggregation node**

The aggregation node is the central node of the network and the one responsible for keeping the network connected. The aggregation node does not collect any data; it just sends the information it receives to the server. In our system, it works as a bridge between the sensors that gather the data and the server that stores the data.
The aggregation node receives messages from the other nodes via LoRa, and for the server communication, Message Queue Telemetry Transport (MQTT) is used via an NB-IoT connection, using the SIM7000E module. For that, the node

cannot be connected to a battery, since it needs to always be listening for new messages, being connected directly to the electrical grid using a 5V power supply.

**Sensor node**

The sensor node is the simplest and the lowest level of our WSN, with their sole purpose being to collect data from the attached sensors and to send it to the aggregation node.
In order to perform these tasks, the sensor node needs a microcontroller and a set of sensors that can be permuted from node to node depending on the different needs for the solution.

The sensor nodes consist of, as mentioned before, an ESP32 microcontroller, a RFM95W module, and an array of sensors suited for retrieving information and sending it to the aggregation node. To transmit the information collected from the sensors to the aggregation node, it uses a LoRa connection through the RFM95W module.

**Dataset creation**

In order to train the algorithm, first, it was necessary to create a dataset with similar data to the one that will be used in the future, containing all possible outputs.

As if an output never happens in the dataset, the algorithm will not be able to predict it. In the intended system, the ML algorithm will only be used for analyzing a specific scenario: gas leaks and its location.
In order to have a good dataset that allows for the proposed machine learning methodology to work properly, for each of the output possibilities, multiple tests were performed, changing the duration of the test and pressure applied by the pump or length of the pipes, each of these being also performed multiple times to guarantee that small changes in data are recorded Although the collected data show information from multiple sensors, each individual record only has the timestamp and the data collected from the sensor.
Therefore, the first thing that we intended to analyze was how the data that is inputted into the algorithm can affect its accuracy. For that, two datasets were created using the same collected data. One is the data collected according to the sequence of sensors in the system, and the other is where the data was clustered to show how the entire path of pipes works. This was done in order to understand which of the datasets presents the best results for the intended scenario and system.

**Data Visualization**

To provide the user with a way to see the data collected from the sensors, an Android mobile application was developed from scratch. The objective of the mobile application was to give the user a dashboard of the water distribution system, where it is possible to check all the values from the sensors in real time, everywhere. Regarding the values retrieved from the sensor nodes, the application gives the user the opportunity to check in real time not only the latest values but also the current conditions of the corresponding pipes, as evaluated by the machine learning algorithms as well as historical data and conditions. For the real-time system, the Paho Java MQTT library was used to subscribe to the topic to which the network publishes information. If the user does not check the application on a regular basis, it will warn the user via a notification if some problem is encountered by the system. In order for the user to have a visual interaction with the system and to be able to perform the described functionalities, the developed Android application is composed of a set of screens**,**

**ADVANTAGE:**

i. The main objective of an Intelligent IoT Enabled Pipeline leakage detection and monitoring system efficiently, quickly, and effectively.

ii. An IoT- empowered automated Pipeline leakage detection can be programmed to operate autonomously, using sensors to detect leak and avoid them.

iii. Pipe line equipped with sensors and AI can operate more efficiently, resulting in early detection of gas leaks and operational costs, leading to significant cost savings for pipe line industries.

iv. Human error is one of the primary reasons for accidents in the industry. Here the user does not check the application on a regular basis, it will warn the user via a notification if some problem is encountered by the system.

**APPLICATIONS:**

An IoT-empowered automated pipeline leakage detection and monitoring system using machine learning algorithms has various applications across different industries. Here are some potential applications:

Oil and Gas Industry: Pipeline leaks can have severe consequences in the oil and gas industry, leading to environmental damage, safety hazards, and financial losses. An IoT-based system can continuously monitor pipelines and detect leaks in real-time. Machine learning algorithms can analyze sensor data and identify abnormal patterns indicative of leakage, allowing prompt response and preventive measures.

Water Distribution Networks: Water supply networks are susceptible to leaks, which result in wastage and infrastructure damage. IoT sensors placed along the pipelines can provide real-time data on flow rates, pressure, and temperature. Machine learning algorithms can analyze this data to detect leaks, estimate their location, and prioritize repair efforts, optimizing maintenance and reducing water loss.

Chemical Processing Plants: Leakage detection in chemical processing plants is critical for safety and environmental compliance. IoT-enabled sensors and actuators can be deployed to monitor pipelines transporting hazardous substances. Machine learning algorithms can analyze sensor data, identify deviations from normal operating conditions, and raise alerts for potential leaks or abnormal behavior, allowing proactive intervention.

Smart Cities: In urban environments, IoT-based pipeline monitoring systems can be deployed to detect leaks in water and gas supply networks. Machine learning algorithms can analyze sensor data, identify anomalies, and generate insights to facilitate efficient resource management, reduce losses, and enhance overall infrastructure resilience.

Agriculture: Agricultural irrigation systems often consist of pipelines to deliver water to crops. Leaks in these pipelines can result in water wastage and reduced crop yield. By implementing IoT-enabled leakage detection systems with machine learning algorithms, farmers can be alerted to leaks promptly, minimizing water loss and optimizing irrigation practices.

Industrial Manufacturing: Many manufacturing processes involve the use of pipelines to transport fluids, such as chemicals, gases, or cooling liquids. An IoT-based leakage detection system can monitor these pipelines, and machine learning algorithms can analyze sensor data to detect leaks, prevent equipment failures, and ensure uninterrupted production.

Overall, an IoT-empowered automated pipeline leakage detection and monitoring system, combined with machine learning algorithms, offers numerous benefits, including early detection of leaks, reduced environmental impact, improved safety, optimized resource management, and enhanced operational efficiency across various industries.

**CONCLUSION:**

The recent research decades, the growing oil industries have highlighted the significance of monitoring the piping systems and its operation around the world. Efficient monitoring of pipeline network and timely identification and detection of malfunctions contributes to reduce the economic, environmental and social consequences. The major challenge is timely and accurate data collection from sensors that are integrated into the pipeline in an industrial scenario.

In this work, an efficient, robust and timely leakage detection system is proposed using a deep learning model for pipeline systems with the aim to detect the leakages in oil as well as gas pipelines. The data are collected from the accelerometers placed beside the pipelines, the data processing performs the early detection of leakages. Initially, the IoT sensors are used to collect the data and the data are processed using proposed Deep Auto Encoder NN. The collected data are preprocessed and fed as input into the classifier for detection. The classifier is further enhanced with an optimization technique called Bat optimization to choose the best value for weight and bias. Detection mechanism is formed and the requirement of detection mechanism is satisfied then the data are classified and leakages are notified to the user in application layer. the proposed model is evaluated with the simulated environment which having various leakage diameters and node distances. It is evaluated based on the evaluation metrics and compared with existing approach to show the efficiency of the proposed model.

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