



**PIPELINE MONITORING SYSTEMS:THE CASE OF THIRD PARTY
INTERFERENCE**

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CERTIFICATION

This is to certify that this project was carried out by the persons listed above, from the Department of Mechatronics Engineering, Faculty of Engineering, University of Benin, Benin City.

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DECLARATION

We listed below hereby, declare that the project work titled “**PIPELINE MONITORING SYSTEMS: THE CASE OF THIRD-PARTY INTERFERENCE**” is an original work done by us under the supervision of Prof. G.O Ariavie. The work has not been submitted in candidature for any degree and is not currently being submitted for any other degree, to the best of my knowledge

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DEDICATION

We hereby dedicate this project to God Almighty for the strength and understanding to undertake this work.

We would also like to dedicate this project to our beloved parents whose unwavering support, encouragement, and sacrifices have shaped our academic journey.

We also extend my heartfelt gratitude to our project supervisor, Prof G.O Ariavie, whose invaluable guidance and expertise have been instrumental in the completion of this work.

Lastly, we dedicate this project to family, friends and colleagues, whose encouragement and shared experiences have enriched our learning.

This work stands as a testament to the collective support and inspiration we have received throughout this journey.

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ABSTRACT

Pipeline infrastructure plays a critical role in Nigeria's energy sector, yet persistent challenges like unauthorized third-party activities threaten its security, reliability, and efficiency. This project focuses on improving pipeline monitoring systems, particularly in the context of Nigeria's challenges with third-party interference like vandalism and oil bunkering. The research examines existing monitoring methods (fiber-optic sensing, acoustic leak detection, real-time surveillance, and SCADA), analyzes successful global pipeline monitoring strategies (Trans-Alaska and Nord Stream) and addresses the limitations of current monitoring systems. The study proposes an Improved Hybrid Pipeline Protection System (IHPPS) that integrates multiple technologies (flow measurement sensors, acoustic monitoring, GPS tracking, and IoT-based remote surveillance). The IHPPS aims to enhance detection accuracy, minimize false alarms, and improve real-time response, ultimately reducing economic, environmental, and security risks. The study concludes that a multi-layered monitoring system is crucial for improving pipeline reliability and security.

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CHAPTER ONE

INTRODUCTION

In today's world, collaboration between countries both regionally and cross regionally has seen the adaptation of different technologies used by first world countries. Such collaboration has seen the global adaptation of the pipeline technology. Generally, pipelines are seen as a line of pipe with pumps, valves and control devices for carrying liquids, gases and finely divided solids.

There are different types of pipelines that serve different purposes. There are the **software pipelines**--These pipelines are an automated sequence of tasks that allow developers to automatically compile, test and deploy code. There are also **data pipelines**--These pipelines refer to a sequence of processes that collect data from various sources, process it as required, and load it into a designated destination (such as a database or data warehouse). They (processes) automate the flow of data across systems. Furthermore, we have the **machine learning pipelines**, pipelines in graphics processing, pipelines, in networks and communication and finally we have the **Oil and gas pipelines**.

Oil and gas pipelines play a vital role in the global energy supply chain, offering a dependable and efficient method for moving these resources. Just as pipelines are of different types and functions, oil and gas pipelines are also of different types and functions. The types of oil and gas pipelines include; crude oil pipelines, product pipelines, natural gas pipelines and liquefied natural gas pipelines. Crude oil pipelines transport raw crude oil from extraction locations, like oil rigs or drilling sites, to refineries where it is processed into different petroleum products.

After the crude oil is refined, product pipelines are used as the means of transporting the refined products which could be gasoline, diesel, jet fuel and heating oil to various storage facilities or to the points where they are distributed. The **natural gas pipelines** as the name implies are designed to transport natural gas. This natural gas could either be in its gaseous state (using high-pressure systems) or as liquefied natural gas (LNG). The flow of transportation (process of supply) is from gas fields to processing plants and then to power plants or residential and commercial users. Lastly, the Liquefied Natural Gas Pipelines (LPG) transport natural gas that has been cooled to its liquid state for easier transport and storage. Before pipelines are used, they are firstly built and tested. Some of the components used in pipelines are pipes, pumps and compressors, valves and monitoring systems. The monitoring system consists of a combination of sensors and systems that are used to detect leaks, pressure changes and other anomalies thereby ensuring safety and operational efficiency.

In order for pipelines to maintain their operational capability, maintenance has to be done regularly. There are three types of maintenance that can be carried out on pipelines. They are preventive maintenance, predictive maintenance and corrective maintenance. Preventive maintenance is done to prevent a total breakdown of the pipeline system; corrective maintenance is carried out when there is a total breakdown. This would require stopping the pipeline from being in use till it is repaired. Repair could require replacing faulty parts and sometimes a complete overhaul of the system. Predictive maintenance is done when there are signs in the pipeline system showing that a complete breakdown is soon to occur. Of the three, preventive maintenance is best as it can be carried out without affecting the supply of oil and gas locally, nationally or internationally.

1.11 HISTORY OF PIPELINES IN NIGERIA

To comprehensively understand the history of pipelines in Nigeria, it is essential to trace their origins back to the bedrock of the nation's economy: oil. The inception of pipelines is inextricably linked to the discovery and subsequent exploitation of crude oil reserves.

The journey begins with the audacious exploration for this black gold. When substantial quantities of crude oil were unearthed within Nigerian soil, primarily in the Niger Delta, a formidable challenge emerged: how to transport this vital resource efficiently and effectively to refineries and export terminals. Pipelines, with their capacity to convey vast volumes of liquid over long distances, emerged as the most practical and economical solution. Therefore, to delve into the history of pipelines in Nigeria is to embark on a parallel exploration of the nation's oil industry, from the initial spark of discovery to the intricate network of infrastructure that supports its economic vitality.

Pipeline vandalism and third-party interference are significant challenges in Nigeria's oil and gas industry, resulting in revenue loss, environmental damage, and safety risks. Effective pipeline monitoring systems are crucial to prevent and detect such incidents.

Despite maintenance being carried out on pipeline systems, breakdown can be prevented but it is inevitable. These breakdowns can be as a result of operational failure or as a result of third-party interference. Breakdowns as a result of third-party interference constitute majority of the challenges being faced in pipeline systems today both globally and In Nigeria. It is a big challenge that has affected the global energy supply and also the local supply of oil and gas in our country Nigeria.

Locally, third party interference in Nigerian pipeline systems has been a major challenge as many sects, groups and ill meaning politicians have resulted to oil bunkering. Oil bunkering involves the illicit siphoning, theft, or redirection of oil from pipelines, vessels, or storage tanks, typically in nations with weak security or inadequate regulation of their oil resources. In this section, oil bunkering in Nigeria will be considered extensively.

The Nigerian constitution states that all natural resources in the country's soil are owned by the federal government. Any oil extraction conducted without an agreement with the federal government is deemed illegal. As a result, anyone engaged in crude oil extraction must have the necessary licenses, and specific crimes have been defined related to the damage of oil facilities or the illegal siphoning of petroleum products. Else, such an act is termed oil bunkering. Illegal oil bunkering refers to all acts involving oil theft, which usually includes the smuggling and diversion of oil. Typically, a small team of welders is hired to puncture the pipelines at night (a form of third-party interference), creating an opening for others to steal crude oil, which is then transported to be refined and sold internationally.

In the Niger Delta, illegal oil bunkering is now a booming business. The illegal oil bunkering activities involve various groups, including local militant factions in the creeks, commodity traders, military personnel, international businessmen, and some indigenous oil servicing companies. The ongoing success of illegal oil bunkering is due to the sophisticated nature of these operations. Each participant plays a distinct role: local militants in the creeks are responsible for cutting and tapping crude oil from pipelines, loading it onto tankers and barges with military protection. International businessmen handle the marketing and money laundering processes. Nigerian oil traders then connect with international partners from countries such as

Côte d'Ivoire, Senegal, Russia, Eastern Europe, Australia, the Netherlands and other willing buyers in other countries.

Years before oil bunkering began to make wave in Nigeria, Nigeria was foremost the fifth biggest producer of Oil in the worldwide. However, Nigeria is currently the thirteenth biggest producer of oil. The cause of this drastic fall can be traced no farther than oil bunkering. This has affected the nation's economy in diverse ways. For a long time, Nigeria has operated a monolithic economy as the revenue gotten from oil and gas was enough to keep the country running. However, in recent years, this has not been the case as the effects of oil bunkering and fluctuations in the global price of oil has hit the nation's mono-economy hard. Other examples of countries that run mono-economies are Saudi Arabia, Venezuela etc. Oil bunkering in Nigeria has serious repercussions for the economy, environment, social stability, and security, exacerbating the country's challenges and hindering its development. Some of the effects of oil bunkering on Nigeria's economy are:

1. **Economic Losses:** Oil bunkering results in significant revenue losses for the Nigerian government. The illegal extraction and sale of crude oil divert funds that would otherwise contribute to the country's national income, undermining economic stability.
2. **Environmental Damage:** The unlawful extraction and transportation of crude oil often led to spills that cause widespread environmental pollution. These spills harm aquatic life, ruin farmland, and damage biodiversity, especially in the Niger Delta region.
3. **Corruption and Criminal Activities:** Oil bunkering promotes corruption and encourages illegal activities, such as bribery and extortion, within both government and private sectors. It also fuels organized crime, involving militants, criminal gangs, and corrupt officials in the illicit trade.

4. **Security Issues:** The activities linked to oil bunkering destabilize oil-producing areas, particularly the Niger Delta. This often results in violent conflicts between militant groups, security forces, and local communities, leading to loss of life and the displacement of residents.
5. **Social Displacement:** Oil bunkering frequently displaces local communities as conflicts and environmental damage force people to abandon their homes. Additionally, the profits from illegal oil trade rarely benefit local populations, exacerbating poverty and inequality.
6. **Undermining Legal Businesses:** The practice of oil bunkering harms legitimate oil companies and disrupts the formal oil market. This can discourage foreign investment in Nigeria's oil sector, further stalling economic growth.
7. **Impact on Infrastructure:** The illegal tapping and transportation of oil damages pipelines and other oil infrastructure. This not only results in financial losses but also disrupts the supply of oil to legal markets, affecting both local and global oil prices.

Maintenance as a way of ensuring stable operational capability of pipeline systems is not enough to stop oil bunkering in Nigerian pipelines. This is where pipeline monitoring systems come in. Pipeline monitoring systems can help to monitor pipelines effectively, thus preventing and reducing third party interference in Nigerian Pipelines.

1.12 ADVANTAGES OF PIPELINES AS A MEANS OF FLUID TRANSPORTATION

1. **Energy and cost effectiveness:** In terms of Energy consumption, Pipeline transport consumes significantly less energy, especially when compared to transporting fluid by rail or road. Also, in terms of cost, it only requires high initial cost meaning the cost to set it up for use thereafter requiring lower day-to-day operating cost

2. **Safety:** Pipeline transport system is relatively the safest means of transporting these fluid from one place to another. Transporting hazardous materials like oil and gas via a secure pipeline significantly reduces the risk of accidents, theft, or sabotage compared to road or rail transport.
3. **Minimal land destruction :** Underground pipelines use very little surface land, preserving agricultural areas and natural landscapes for other uses.
4. **Reliability:** This method of transporting fluid is relatively reliable in general, this is because, it is safe, durable and long lasting.
5. **Less dependency on weather conditions:** Unlike other means of transporting Oil and Gas, this method isn't affected by weather condition. It runs day in day out both in sunny and rainy days.

1.13 DISADVANTAGES OF PIPELINES

1. **High initial costs:** Pipeline system construction requires a significant upfront investment for pipes, storage, and pressurization stations.
2. **Environmental risks:** Leakages or spillages of oil can pollute our land, water, wildlife and vegetation. It's also prone to privacy encroachment which can result to legal issues and loss of property.
3. **Maintenance and repair costs:** Pipelines are challenging to monitor for issues like corrosion or leaks, and repairs can also be very costly when damaged.
4. **Risk of leakage:** Pipeline system is vulnerable and can be targets of sabotage by third party agents. Also, Natural disasters such as earthquakes can disrupt and damage pipeline system.

1.2 PIPELINE MONITORING SYSTEMS.

Pipeline monitoring systems play a vital role in maintaining the safety, efficiency, and reliability of pipelines that transport liquids and gases. These systems are designed to identify leaks, corrosion, pressure fluctuations, and other potential problems that could result in environmental harm, safety risks, or disruptions in operations. Pipeline monitoring systems could be in the form of internal monitoring or external monitoring.

1.21 INTERNAL MONITORING SYSTEMS

Internal monitoring systems : This monitoring systems involves using various tools and techniques to assess the condition of the pipeline from within that is to detect issues that may not be visible on the outside of the pipeline but could lead to significant failures if left undetected. Some of these monitoring systems include;

1. **Inline Inspection or Smart pigs:** this is one of the most advanced methods of internal monitoring. It involves the use of smart pigs and robotic inspection tools that move through the pipeline. These devices are equipped with a range of sensors, including magnetic flux leakage (MFL) sensors, ultrasonic sensors, and inertial measurement units (IMUs), to identify potential issues within the pipeline.
2. **Corrosion Monitoring System:** Internal corrosion is a major threat to pipelines, especially those transporting corrosive materials like oil or natural gas. Corrosion monitoring systems are designed to detect and measure the rate of corrosion inside the pipeline, which may be caused by the chemical composition of the materials being transported or by microbial activity.
3. **Fluid Flow and Temperature Monitoring:** Monitoring the flow rate and temperature of transported materials provides key information about the pipeline's health. Any

abnormalities in flow, pressure, or temperature can signal issues such as blockages, leaks, or contamination.

1.22 EXTERNAL MONITORING SYSTEMS

External monitoring This type of monitoring focuses on monitoring the pipeline condition from the outside. It typically detects problems related to the pipeline's external environment, like ground movement, corrosion, or external damage. Some common techniques for external monitoring include:

1. Surveillance Systems:

Surveillance technologies such as closed-circuit television (CCTV), drones, and satellite imagery are widely used to monitor pipeline routes. These systems detect unauthorized activities near pipelines, including excavation, construction, or vandalism, which could potentially lead to damage.

2. Leak Detection and Pressure Monitoring:

External factors such as leaks caused by physical damage or corrosion are monitored by sensors placed along the pipeline. These sensors, such as pressure sensors and flow meters, detect irregularities that could indicate third-party interference or other disruptions.

1.3 HISTORY OF PIPELINE MONITORING SYSTEMS

Pipeline monitoring systems have evolved significantly over the years to ensure the safe and efficient operation of pipelines for transporting oil, gas and other fluids. The advent of such systems can be traced back to the early 19th century. At that time, mechanical gauges were used to monitor pressure and flow rates. These systems were rudimentary and required manual checks.

As time progressed gradually into the 20th century, visual inspections were introduced and were done with manual tools to detect leaks or other issues.

The 1960's saw a major advancement in the monitoring of pipeline systems as technology began to come into play. The advent of telemetry technology allowed for the remote monitoring of pipeline conditions. This system made use of radio or satellite signals to transmit data from remote locations to central control systems.

In the 1970's came the SCADA system. The Supervisory Control and Data Acquisition (SCADA) systems offered real time data collection, monitoring and control. These systems integrated sensors and computers to provide more sophisticated monitoring capabilities.

In the 1980's, the concept of the pigging system was introduced. "Pigs" were introduced to inspect the interior of pipelines. They could detect corrosion, blockages and other issues while travelling through the pipeline.

As time went by, there was technological advancement which led to the development of modern means of monitoring pipeline systems such as;

1. Advanced sensors and Instrumentation (1990s): development of more advanced sensors, including fiber optics and smart sensors enabled more detailed monitoring of pipeline conditions, including temperature, pressure and strain.
2. Automated Leak Detection Systems (2000s); enhanced algorithms and real time data analytics led to more accurate and quicker leak detection systems. These systems use a combination of sensors and computational models to identify leaks.
3. AI and Machine Learning (2010s-Present); the integration of artificial intelligence and machine learning algorithms has further improved predictive maintenance and anomaly detection.
4. Drones and Robotics (2010s-Present); drones and robotic systems are increasingly used for visual inspections particularly in difficult to reach areas. They provide high resolution imagery and can assess pipeline conditions in real time.

Future implementation of Pipeline Monitoring Systems could include the use of Internet of Things (IOT) and Blockchain for security.

1.3.1 ADVANTAGES OF PIPELINE MONITORING AGAINST THIRD PARTY INTERFERENCE

1. **Efficiency:** Pipeline Monitoring systems helps to checkmate possible errors of leakages or vandalizations by Third Party Agents thereby increasing the efficiency and reliability of the pipeline system.
2. Reduces downtime by employing systems that operate continuously and autonomously to provide alerts as soon as they are detected. This also help save cost thereby minimizing financial losses.

3. **Environmental protection:** Pipeline Monitoring system help to ensure protection of the environment from pollution by the release of harmful substances into soil,vegetation,water bodies etc.
4. Pipeline monitoring systems Reduces economic, environmental and social liabilities.These systems helps to reduce manual labor of guarding pipelines especially in remote areas and forests

1.3.2 DISADVANTAGES OF PIPELINE MONITORING SYSTEMS

1. **High initial cost:** Monitoring systems just like the pipeline itself are expensive to set up.They often require high initial investment and maintenance cost.
2. **Complexity:** Some of these monitoring systems can be complex to set up especially in remote areas.Some systems are effective in one region but ineffective in other regions due to factors like weather and climate differences. Therefore,setting up monitoring systems can be difficult.
3. **False alarms:** For monitoring systems like alarm methods,they can become faulty or tampered with overtime and hence give false alarm. Wrong programming information can also lead to this problem
4. **Data security:** Some pipeline monitoring systems with low security can be vulnerable to cyberattacks which can result to loss of data and also complete failure thereafter.

1.4 METHODS CURRENTLY BEING DEPLOYED AROUND THE WORLD

As previously stated, these researches can be grouped under the three categories which are the External methods, Internal methods and Biological methods, some of the researches and methods employed around the world are analyzed below.

1.4.1 THE FIBER OPTIC MONITORING SYSTEM

Fiber optic monitoring is a technology that uses thin strands of glass or plastic known as fibre optic cables to monitor things like temperature, pressure, and vibrations along pipelines over a distance. These fiber optic cables are special because they can detect even the tiniest changes in the environment around them.

1.4.1.1 THE TRANS-ALASKA PIPELINE

The Trans-Alaska Pipeline System (TAPS) is one of the world's most famous pipeline systems, running 800 miles from Prudhoe Bay to Valdez, Alaska. It uses a combination of acoustic leak detection, fiber-optic monitoring, and satellite-based surveillance. TAPS is also equipped with a SCADA (Supervisory Control and Data Acquisition) system for real-time monitoring of pipeline conditions. This system helps in detecting any signs of leaks, pressure drops, or third-party interference.

Fiber optic monitoring uses light signals to detect physical changes (temperature, pressure, and strain) along pipeline routes. This method enables continuous, real-time monitoring over vast distances. It is particularly effective in leak detection, damage assessment, and monitoring environmental conditions that could affect pipeline integrity.

The Trans-Alaska Pipeline System was designed and constructed to move oil from the North Slope of Alaska to the northern most ice-free port, Valdez, Alaska. The following are some basic facts about the Trans – Alaska Pipeline:

Project details

- Length: 800 miles.
- Diameter: 48 inches.
- Crosses three mountain ranges and over 800 rivers and streams.
- Cost to build: \$8 billion in 1977, largest privately funded construction project at that time.
- Construction began on March 27, 1975 and was completed on May 31, 1977.
- First oil moved through the pipeline on June 20, 1977.
- Over 14 billion barrels have moved through the Trans Alaska Pipeline System.
- First tanker to carry crude oil from Valdez: ARCO Juneau, August 1, 1977.
- Tankers loaded at Valdez: 16,781 through March 2001.
- Storage tanks in Valdez: 18 with total storage capacity of 9.1 million barrels total.
- The mission of Alyeska's Ship Escort Response Vessel System is to safely escort tankers through Prince William Sound.

(Trans-Alaska Pipeline System, n.d.)



Fig 1.4.1: Ground-level view of an elevated portion of the Trans-Alaska Pipeline, Alaska, U.S. Source: (Encyclopaedia Britannica, 2023.)

1.4.1.2 Challenges/limitations:

-Costly and Complex Equipment: Smart pigs (devices used for inline inspection) are expensive to deploy and maintain, with costs running into millions of dollars. This makes it difficult for pipeline operators to use them regularly on all pipeline segments. Maintenance of these pigs, especially in difficult terrains like Alaska, adds to the operational cost.

Inability to Detect Small Leaks: Smart pigs excel at detecting large, noticeable anomalies, but they struggle with identifying small or slow leaks that occur over extended periods. This is critical for pipelines carrying hazardous materials, where even minor leaks can have significant environmental impacts.

-Operational Complexity in Remote Locations: The Trans-Alaska Pipeline, located in a harsh environment with extreme cold, makes it difficult for maintenance and sensor checks to be carried out regularly. The remote and rugged terrain often makes it hard to access the pipeline sections where pigging inspections are required, leading to operational inefficiencies.

1.4.2 PRESSURE MONITORING AND ACCOUSTIC LEAK DETENTION METHOD

Pressure monitoring in pipelines refers to the continuous or periodic measurement of the internal pressure within a pipeline to ensure the safe and efficient transport of oil or gas. It involves using sensors or pressure gauges at key locations along the pipeline to detect any abnormal pressure variations, such as over-pressurization or under-pressurization. Pressure monitoring method is used to track the pressure inside a pipeline system between one point to another. This is done with the aid of pressure sensors and other related devices placed around points such as pump stations, end points, valves and junctions, which helps to collect pressure data for processing.

Acoustic monitoring refers to the use of sound waves or vibrations to detect and analyze changes or anomalies within a pipeline system. It typically involves using acoustic sensors or devices to listen for sounds that indicate potential problems, such as leaks, cracks, or pressure fluctuations.

1.4.2.1 THE NORD STREAM PIPELINE :

The Nord Stream pipeline, transporting natural gas from Russia to Germany, utilizes acoustic leak detection systems and pressure monitoring. The pipeline, which spans over 1,200 kilometers under the Baltic Sea, also employs a SCADA system to monitor real-time pipeline status.

Acoustic systems can detect the specific frequency of gas escaping from the pipeline, while pressure monitoring systems alert operators to sudden pressure drops, which are signs of a potential leak. The pipeline is constructed from high-quality steel and coated with protective layers to resist corrosion and environmental damage from the seabed.

Project Details:

Offshore natural gas pipeline under the Baltic Sea.

Route: Vyborg (Russia) to Greifswald (Germany).

Includes Nord Stream 1 (operational) and Nord Stream 2 (completed but not commissioned).

Length: ~1,224 km each line.

Data Collection and Use: Real-time data, including pressure and flow measurements, are transmitted to centralized monitoring systems in both Russia and Germany. The information helps ensure the pipeline's integrity and immediate response to threats.



Fig 1.4.2 Nord Stream 2 gas pipeline Source:(OE Digital, 2023)

1.4.2.2 Challenges/limitations:

-Susceptibility to Physical Damage: Pressure and Acoustic sensors are prone to physical damage from external forces, such as construction activities, fishing, and anchoring in underwater pipelines like Nord Stream. These damages can lead to data loss or inaccurate readings, affecting the reliability of the system.

-Signal Degradation Over Distance: The longer the distance, the more prone fiber optic cables are to signal degradation. This means that pipelines with longer sections, like Nord Stream, might face challenges in maintaining signal quality, especially in remote sections under the sea, where maintenance and repair operations are difficult.

-High Initial Cost: Deploying these monitoring systems is an expensive process due to the cost of laying the optical fibers and integrating them with the pipeline monitoring systems. This high cost makes it difficult to implement over large areas or older pipelines that were not initially designed for this technology.

1.4.3 REAL TIME MONITORING

Real-time monitoring refers to the continuous, instantaneous observation and analysis of data from a system or process as it occurs. It involves collecting data from sensors or other devices placed along the pipeline, and transmitting this information immediately to operators for immediate analysis, decision-making, and action.

1.4.3.1 FORTIES PIPELINE SYSTEM

The Forties Pipeline is part of the UK's largest crude oil export pipeline. It uses a combination of remote sensors, aerial surveillance, and data from remotely operated vehicles (ROVs) for underwater inspections. It also employs leak detection technology that is designed to identify small leaks over long distances. It is one of the largest North Sea pipelines, uses SCADA technology combined with pressure, flow, and temperature sensors to continuously monitor pipeline conditions. The system integrates real-time data from sensors placed at various points along the pipeline to identify abnormal conditions. The data is transmitted to a central control center for analysis and action.

Project Details:

Oil pipeline network in the North Sea.

Transports crude oil from offshore Forties field to Cruden Bay, Scotland.

Capacity: ~575,000 barrels/day.

Owned/operated by INEOS FPS.

Materials: Made from high-strength steel, the pipeline is constructed to resist corrosion, and its underwater segments are covered with concrete weight coatings for stability on the seabed.

Data Collection and Use: Data from pressure sensors, flow meters, and temperature readings are sent to a centralized monitoring facility, where operators ensure safe operation and manage maintenance schedules.



Fig 1.4.3 Forties Pipeline Source: (Oil Price, n.d.)

1.4.3.2 Challenges/Limitations:

-False Positives: Leak detection systems (LDS) are often prone to false positives, where the system detects a leak that does not exist. These false alarms can lead to unnecessary shutdowns, loss of productivity, and high operational costs due to system downtime. This is a significant issue in large-scale systems like the Forties Pipeline, where operational efficiency is paramount.

-Sensitivity to Environmental Factors: External factors like temperature variations, weather conditions, or sudden pressure changes in pipelines like Forties can interfere with the accuracy of LDS. Such factors can cause incorrect leak detection signals, further complicating maintenance efforts.

-Inability to Detect Small Leaks: While LDS is effective for detecting large and fast leaks, they are less reliable at detecting smaller, slow leaks that could persist for weeks or months before causing noticeable issues. Such leaks can go undetected for longer periods, resulting in environmental contamination or safety hazards.

1.4.4 METHOD: LEAK DETECTION AND REMOTE MONITORING

Remote monitoring involves viewing and monitoring pipeline system virtually from a distance. It means operators can monitor the condition and performance of pipelines from a central control room or even from their offices. This process involves the use of sensors to read parameters such as pressure, temperature, flow rate etc which goes further to transfer the collected data into a central monitoring unit with the aid of wires or wireless networks which then passes the processed data to a control system where the data is interpreted and alerts are sent to operators in case of detected anomalies.

1.4.4.1 KEYSTONE PIPELINE

The Keystone Pipeline, which transports crude oil from Canada to the United States, uses Fiber-optic technology to detect leaks. Acoustic sensors are also installed at critical points to detect changes in pressure and flow, allowing for early identification of leaks. The system integrates remote monitoring for real-time analysis, which improves the pipeline's operational safety. The Keystone Pipeline uses a combination of remote sensors, aerial surveillance, and real-time leak detection systems. It is monitored by the operator, TransCanada, through a state-of-the-art control center that can monitor and control the flow of oil across vast distances.

Project Details:

Crude oil pipeline from Alberta, Canada to U.S. refineries (Illinois, Oklahoma, Gulf Coast).

Length: 3,460 km.

Capacity: 830,000 barrels/day.

Built in phases; Keystone XL extension was cancelled.

How it works:

Data Collection and Use: Data from pressure and temperature sensors are collected and transmitted in real-time to the control center, which analyzes the data for irregularities and possible threats. The data is also used to predict maintenance needs and prevent future leaks.



Fig 1.4.4 Keystone Pipeline Source:(Express.co, 2025.)

1.4.4.2 Challenges/Limitations:

The pipeline system faces vandalism, and third-party interference remains a challenge. In some cases, the detection of small leaks can be slow due to the limitations of the sensors or environmental factors that interfere with their readings.

Limited Detection of Small Leaks: Aerial surveillance is typically ineffective in detecting small leaks or slow leaks, especially in remote areas. While it is useful for monitoring pipeline routes, it is not capable of picking up minor issues that might lead to significant environmental problems over time

1.4.5 DRONE AND SATELLITE-BASED MONITORING

Drone and satellite-based monitoring involves the use of Unmanned Aerial Vehicles (UAVs) commonly known as drones and satellite imaging systems to observe, inspect, and analyze

pipeline infrastructure remotely. It is often employed in areas that are not easily accessible by man e.g in large terrains etc.

1.4.5.1 WEST-EAST GAS PIPELINE

The West-East Gas Pipeline, spanning over 4,000 kilometers, is equipped with an extensive monitoring system that includes automated leak detection, pressure monitoring, and data acquisition systems. Fiber optic cables are also used for real-time monitoring, which can detect vibrations and leaks along the route. It uses satellite surveillance and drone inspections to monitor its infrastructure across remote and mountainous terrains. These technologies are crucial for tracking the pipeline's condition in areas that are difficult to reach by conventional means. The real-time data gathered from drones and satellites are sent back to control centers for analysis. The pipeline is made from high-quality steel designed to handle high-pressure natural gas transmission. The pipeline is coated with protective layers to prevent corrosion and Data is collected via pressure sensors, flow meters, and inline inspection tools (smart pigs). The information is transmitted to central control stations for analysis, enabling quick responses to potential problems.

Project Details:

Long-distance natural gas pipeline network in China.

Transports gas from Xinjiang (west) to eastern industrial regions.

Length: ~8,700 km (Line 1), expanded with Lines 2 and 3.

Operated by PetroChina.



Fig 1.4.5 West-East Pipeline Source:(constructconnect, 2025.)

1.4.5.2 Challenges/Limitations:

The terrain can limit drone access, and data transmission can be delayed if the satellite communication is obstructed by weather.

Also aerial surveillance is often affected by weather conditions such as fog, snow, rain, or poor visibility, which can limit its effectiveness. This is a major issue for pipelines like the Keystone Pipeline, which spans long distances across various climate zones .

1.5 PIPELINE MONITORING IN NIGERIA

The Nigerian National Pipeline Company (NNPC) Limited, on August 13, 2022, launched an app to monitor and help curb oil theft and pipeline vandalism. The Crude Monitoring Application allows communities and other Nigerians to report oil theft incidences. The NNPC Limited launched the application on Friday, August 12, during the signing of the Product Sharing Contract (PSC) between the oil agency and its Oil mining Lease partners. The portal's link address, ("stopcrudetheft.com") is also available for mobile phone users. The portal has several application options for reporting incidences and crude sales document authentication. According to Malam Mere Kyari, NNPC Limited's Group CEO, vandals' actions on pipelines had become challenging to deal with. Still, several partners were involved to ensure that the situation was under control. The Group CEO said government regulatory bodies, host communities, and security agencies were involved in formulating a robust framework to deal with the menace. There are still ongoing activities of oil thieves and vandals on our pipelines and assets, very visible in the form of illegal refineries that are continuously put up in some locations and insertions into our pipeline network," said the Group CEO. (Oyango,2022)

Also, Nigeria has recently planned on adopting newer methods like the popular OptaSense system by offering projects to companies. OptaSense has appointed Fairtex Integrated Services Ltd as its agent in Nigeria for the supply of its advanced monitoring & detection system, for pipelines and production facility to the oil & gas, power, refinery, petrochemical, chemical and other industrial application in Nigeria.

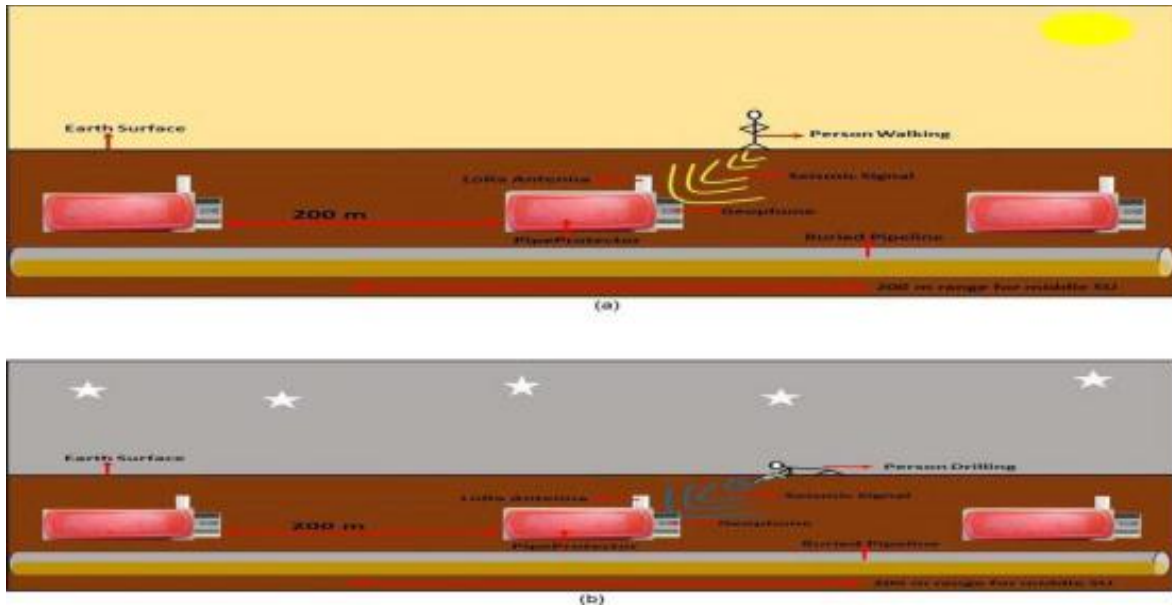


Fig 1.5. Stages of Pipeline monitoring system in Nigeria

Source:(Automated Oil and Gas Pipeline Vandalism Detection System, 2020)

Pipeline Monitoring

1. Pipeline Leak Detection
2. Ground Movement Monitoring
3. Intrusion Monitoring
4. Inline Inspection Tools Tracking

Oil Field Monitoring

1. Completions Monitoring
2. Production Monitoring

3. Reservoir Monitoring

Power Cable Monitoring

1. Power Cable Condition Monitoring
2. Power Cable Damage Prevention
3. Power Cable Fault Detection
4. Power Cable Seismic Monitoring

1.6. CURRENT PIPELINE MONITORING SYSTEMS IN NIGERIA

1.6.1 FIBRE OPTIC SENSORS

Fiber optic monitoring is a technology that uses thin strands of glass or plastic known as fibre optic cables to monitor things like temperature, pressure, and vibrations along pipelines over a distance. These fiber optic cables are special because they can detect even the tiniest changes in the environment around them.

1.6.1.1 ESCRAVOS-LAGOS PIPELINE SYSTEM

The 36-inch Escravos-Lagos Pipeline System (ELPS) is a vital natural gas pipeline in Nigeria, commissioned in 1989 to transport gas from the Niger Delta to various consumption hubs across the country. The pipeline begins at the Nigerian Gas Company's (NGC) gas treatment plant in Warri, with its gas sourced from Chevron's Escravos Gas Plant in Delta State.

The pipeline is a critical infrastructure for Nigeria's energy supply, facilitating the transport of natural gas to power plants in southwestern Nigeria. It also serves as a feeder to the West African

Gas Pipeline (WAGP), a regional project that connects to the larger Nigeria-Morocco Gas Pipeline, enhancing Nigeria's role in the international gas market.

Spanning over 400 kilometers, the ELPS has a capacity of approximately 1 billion cubic feet of natural gas per day. It integrates fiber optic sensors to ensure safety and operational efficiency. These sensors provide real-time monitoring of pressure, temperature, and potential leaks, enabling swift response to issues and minimizing disruptions.

The pipeline's strategic role in supplying energy domestically and its contribution to regional energy trade underline its significance in Nigeria's energy framework.

Project details

Operator: Nigerian Gas Company Limited

Owner: Nigerian Gas Company Limited

Parent: Nigerian National Petroleum Corporation (NNPC)

Capacity: 1.1 billion cubic feet per day

Length: 342 kilometers

Status: Operating

Diameter: 36 inches

Start Year: 1989

(Global Energy Monitor, 2024)



Fig 1.6 Escravos-Lagos Pipeline system. Source:(Lee engineering, 2023.)

Challenges/Limitations:

Aging problem: The pipeline, being over three decades old, requires frequent maintenance to ensure operational safety and efficiency.

Deploying fiber optic monitoring systems across long distances like ELPS requires significant financial investment, especially considering the challenging terrains in Nigeria's Niger Delta region.

1.7. STATEMENT OF PROBLEM

Even though methods are currently being deployed to curb third party interference in pipeline systems, there are a number of ways in which such disturbances occur. They could be as a result of the following;

1. Lack of efficient methods for monitoring and preventing third party interference.
2. Limitations of current monitoring methods which include, cost of maintenance, small range and so on.

1.8. AIMS AND OBJECTIVES

Aim:

1. To provide more efficient ways to monitor pipeline systems against third party interference.
2. To improve and automate already existing methods for pipeline monitoring systems by working on their limitations ie To develop a multi-layered, technology-driven pipeline monitoring system that integrates fiber-optic sensing, acoustic surveillance, GPS tracking, and IoT-based solutions to enhance real-time detection, minimize false alarms, and improve security against third-party interference in Nigeria's pipeline infrastructure.

Objectives:

1. Evaluate existing pipeline monitoring systems, including fiber-optic sensing, acoustic leak detection, real-time surveillance, and SCADA frameworks.
2. Analyze global best practices, such as the Trans-Alaska and Nord Stream pipeline security models, to identify effective protection strategies.
3. Assess Nigeria's pipeline security challenges, particularly oil bunkering, vandalism, and unauthorized excavation.
4. Develop the Improved Hybrid Pipeline Protection System (IHPPS) by integrating flow measurement sensors, GPS tracking, acoustic monitoring, and IoT-based remote surveillance.
5. Optimize detection algorithms to reduce false alarms and enhance threat identification accuracy.

6. Propose a real-time response framework to improve incident mitigation and prevent economic, environmental, and security risks.

1.9. SCOPE OF PROJECT

The scope of this project encompasses the design of an automated system capable of monitoring and detecting possible threats to pipeline systems and also providing information in real time.

1.10. RELEVANCE OF WORK

The necessity of this work all over the world cannot be overemphasized. The relevance of pipeline monitoring systems is a worldwide relevance that is based on the fact that it can provide a viable means that would mitigate if not totally eradicate third party interference in pipeline systems.

1.11. LAYOUT OF REPORT

This project consists of basically five (5) chapters one contains the introduction aspect of the project, Chapter two: literature view and theoretical background of the project, chapter three: System design and calculation, while chapter four: construction, testing and packing, finally chapter five: conclusion and recommendation.

CHAPTER TWO

LITERATURE REVIEW

It is pertinent to state that before the design of this system, relevant and related works that had been done previously had to be consulted. This is done because the foundations to whatever work is to be done on the field like improvement and a complete over haul of some systems have already been laid.

Contextually, this project will be focusing on the oil and gas pipelines as regards monitoring and third-party interference. In oil and gas, pipelines are extensive systems designed to transport oil, natural gas, and other liquids over long distances, from extraction sites (such as oil rigs or gas fields) to refineries, storage units, or distribution centers. Oil and gas are the world's leading fuels. They account for up to 55 percentage of the world's global energy consumption. (Energy Institute, 2024).

Globally, third party interference in pipelines could be external actors which are government, corporations or non-state entities that disrupt or influence the development, operation or management of pipelines. These pipelines transport energy resources like oil, gas or water across borders or regions. These interferences stem from political, economic, environmental, or strategic motives, and can have significant consequences for global energy security, environmental protection, and international relations. An example of third-party interference in global pipeline systems is the blowing up of the Nord stream 1 and Nord stream 2 pipelines.

These pipelines carry natural gas from Russia to Germany and were blown up for political reasons. (Moniek de Jong, 2023)

The word oil bunkering has been widely known to be a criminal activity that sometimes makes use of violence. Well, that is not often the case. Oil bunkering can be legal and other times illegal. Upon Its initiation into the Nigerian oil and gas sector, it was meant to be a legal business that can be carried out by anyone that has governmental authorization to do so. (Batombari and Kementoye, 2020). It is an international trade that is carried out in the high seas and oceans and practiced between the oil-producing countries and the other coastal countries. (Batombari and Kementoye, 2020).

In Nigeria, Oil bunkering was once a legitimate business activity licensed by the Department of Petroleum Resources (DPR) since 1979. However, the practice was suspended over time due to misuse by unlicensed operators, and in 2000, the federal government halted it due to the subsidy on petroleum products. (Batombari and Kementoye, 2020).

2.1. REVIEW OF PREVIOUS WORK ON THIRD PARTY INTERFERENCE OF PIPELINE SYSTEMS

As natality rate continues to increase at an alarming rate worldwide, the increasing need for technology and comfortable lifestyles has driven the dependency on oil energy into an excessive demand. It is on record that the global energy demand will rise by 54 percent over the next twenty years with oil consumption making up to 40 percent of this energy demand (EIA, 2007).

This increased demand for more oil encourages exploration and the production of more petroleum resources and thus the creation of more pipelines. As a result, energy infrastructures

like pipelines, refineries, oil and gas terminals have become targets for terrorists and saboteurs hoping to sabotage the economy of oil rich countries.

This third-party interference has been given limited attention within research literature, majority of studies has focused on corrosion and mechanical failures of pipelines.

A substantial number of literatures published to address and enlighten on this topic showed that third party interference is the leading cause of pipeline failures. (Daco et al, Concawe, 2007, Parfomak, 2008)

Rezia.A et al (2021) “Dynamic reliability model for subsea pipeline risk assessment due to third-party interference” The accidents of subsea pipelines due to third-party interference often result in catastrophic impacts, therefore, risk assessment has progressively become substantial to ensure the safety and reliability of the systems. However, the current risk analysis approaches are unable to minimize the uncertainties in the analysis due to high demands of qualitative inputs.

Jinqui.H et al (2011) “Intelligent Risk Assessment for Pipeline Third Party Interference”

This study showed that pipeline is singled out as the safest and most economically viable means of transporting large quantities of oil and natural gas. However, accidents to pipelines because of the third-party interference have been recorded. AN intelligent risk assessment approach nis proposed to estimate the risk of each pipeline section and classify various risk patterns using self-organization mapping neural network theory, which incorporates the factors of pipeline laying conditions, historical damage records, management measures and the environment around the underlying pipeline.

Roland, P.H (2003) “Evaluation of satellite technology for pipeline route surveillance and the prevention of third-party interference damage”

The damage caused by third party interference is one of the major causes of pipeline failures. Consequently, new technologies for identifying activities that may cause damage to our pipelines are constantly being developed. A recently completed project sponsored by a number of pipeline operators has investigated the use of higher resolution satellites for the integrity management of onshore transmission pipelines. The project started with a general review of the satellite technologies available and their potential. The study was then focused on the identification of activities that might result in damage to the pipeline and the potential of higher resolution optical satellites in identifying hazardous activities.

Cross country analysis recorded by relevant bodies like UKOPA'S Pipeline Fault Database (PFD) covering pipeline loss incidents from 1962, also showed third party interference as the largest single cause of damage to pipelines in the UK (UKOPA, 2002; UKOPA, 2008).

Papadakis, (2005) reviewed tragedies involving twenty-four people who died alongside several casualties and others hospitalized when a Major Accident Hazard Pipeline (MAHP) near Ghislenghien, Belgium operated at a pressure of 70 bars failed due to third party activities.

CONCAWE (1994) detailed how over 500 people died in 1995 when attempting to lift oil product from a pipeline under its jurisdiction failed. It also recorded how in 1993, 51 people were burnt to death when a gas pipeline failed in Venezuela.

Jaffrey et al (2002) did a study on how the knowledge and understanding of third-party interference is important in pipeline management to overcome the problem of third-party pipeline failures.

CHAPTER THREE

METHODOLOGY

3.1. RESEARCH / DESIGN METHODOLOGY

Pipeline monitoring systems are important in ensuring that the oil and gas sector contributes effectively to the economy of the country. Thus, making this project very significant as the dangers of third-party interference on our pipeline systems in Nigeria cannot be overemphasized. Areas of significance of this project include the economic growth, economic diversification, development, revenue generation and so on.

In addition, this pipeline monitoring system is designed to meet the aims previously tested in chapter one. For correlation, they are again stated below.

1. To provide more efficient ways to monitor pipeline systems against third party interference.
2. To improve and automate already existing methods of pipeline monitoring by working on their limitations.

Before designing pipeline monitoring systems, a variety of factors have to be considered. They are discussed below:

- i. **Terrain:** Terrain-related challenges in Nigeria's pipeline industry arise from the country's diverse and complex landscape. Swamps, forests, mountains, and coastal regions each present distinct obstacles, ranging from accessibility difficulties to the damaging effects of saltwater and unstable soil conditions. These challenges contribute to higher installation and maintenance costs, longer construction periods, and the need for

advanced technology to monitor and safeguard the pipelines. The Niger Delta, where much of Nigeria's oil and gas reserves are found, is especially known for its swampy, marshy, and flood-prone areas. These environments are hard to reach, necessitating the use of specialized equipment for both construction and maintenance. For instance, the Nembe Creek Trunk Line (NCTL) and the Trans-Forcados Pipeline traverse the swampy landscapes of the Niger Delta, where conditions are particularly harsh. Building pipelines in such areas requires complex logistical coordination due to the wetland terrain. (EPCM).

- ii. **Depth of pipelines:** In the Niger Delta, where a significant portion of Nigeria's oil and gas production takes place, pipelines are typically buried between 1 and 3 meters (3 to 10 feet) deep. This depth is crucial due to the swampy, flood-prone landscape, as it helps protect the pipelines from erosion, flooding, and soil movement. The pipelines are positioned at such depths to shield them from water damage while still allowing for maintenance access. Additionally, monitoring systems must be adaptable to a range of terrains, including urban environments, forests, deserts, mountains, and underwater areas. (Ibeawuchi, 2024).

- iii. **Climate:** Weather patterns, climate conditions, and fluctuations in temperature are vital in shaping the design, installation, and operation of pipeline monitoring systems. These elements not only affect the physical structure of the pipeline but also the performance and reliability of the systems used to maintain pipeline integrity and prevent damage. Severe weather events, such as heavy rain, flooding, storms, hurricanes, tornadoes, and

snowstorms, can interfere with monitoring systems, particularly those relying on remote sensors, satellite communication, or radio signals. In regions prone to such conditions, both the pipeline infrastructure and monitoring systems must be built to endure extreme environmental conditions. (Jinxin et al, 2022) Extreme weather conditions, such as high temperatures, snow, or humidity, can affect sensor durability and functionality.

- iv. **Seismic Activity:** Areas prone to earthquakes, such as parts of California or Japan, require systems that can withstand ground movements. Seismic sensors and structural health monitoring systems help assess the impact of earthquakes on pipeline integrity. In earthquake-prone areas, monitoring systems must detect and withstand ground movements. (Oluwaseun, 2017)

- v. **Corrosive Environments:** The Niger Delta is highly vulnerable to corrosion due to the saline environment and constant exposure to water. Corrosion monitoring technologies, such as electrochemical sensors and intelligent pigging, are necessary for maintaining pipeline integrity. Coastal or industrial areas may require corrosion-resistant equipment. (Okoro, 2023)

- vi. **Temperature Fluctuations and Seasonal Impacts:** Temperature is a key factor influencing the operation, integrity, and performance of pipelines. Its impact largely depends on whether the environment is hot, cold, or experiences drastic fluctuations. In Nigeria, the temperature differences between the hot northern regions and the humid southern areas can lead to variations in the pressure and flow properties of the substances

being transported through the pipelines. For instance, during the dry season in the north, temperatures can rise as high as 40°C (104°F), causing crude oil to become less viscous. This can slow down its flow and place additional pressure on the pipeline pumping systems.

3.2 CONCEPTUALIZATION

In solving the problem of third-party interference as regards liquid pipelines, the above factors prompted the identification of the concepts and models which are analyzed below.

3.2.1. CONCEPT ONE: ACOUSTIC MONITORING METHOD

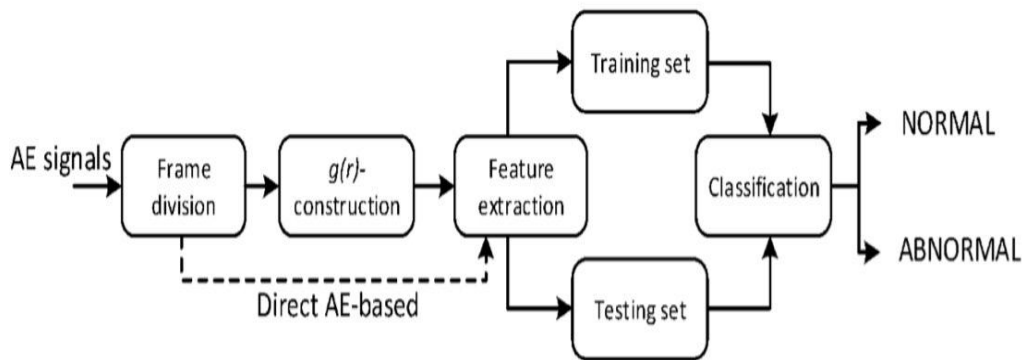


FIGURE 3.1 PROCEDURE FOR DETECTING LEAKS BASED ON ACOUSTIC EMISSION TECHNIQUE (Thabang and Chauke, 2021)

Figure 3.1 is further analyzed below.

- 1. AE Signals (input):** these are acoustic waves, sound vibrations and emissions from the pipeline due to stress, leaks, or external interference.
- 2. Frame Division:** incoming acoustic signals are divided into small frames for easier processing.
- 3. Feature Extraction:** important acoustic parameters such as frequency, amplitude, and noise levels are extracted from the signals.
- 4. Training Set:** this is a machine learning model that is trained on known acoustic patterns of normal and abnormal pipeline conditions.
- 5. Classification:** the system classifies the detected sound patterns as Normal (No Leaks) or Abnormal (possible leaks or damage).

This system is comprised of sensors responsible for monitoring the pipeline for any variation from the normal sound on the pipeline. These sensors, should there be any changes to the sound on the pipeline, trigger other sensors to begin recording the acoustic data. The triggered sensors only begin recording data when the sound emanating from the leak is greater than the ambient sound (normal sound in and around the pipeline). (Ismail and Yie, 2012) The data after being transformed to a digital form are then sent for analysis.

From the figure above, direct transformed AE signals are used to train the classifier instead of direct Acoustic Emission signals thus improving the accuracy of the system. With the trained classifier, accurate classification of data into the presence of suspicious activity is guaranteed.

Thus, the operator is able to act on the leak before it turns to a secondary damage. (Thabang and Chauke, 2021)

Acoustic monitoring systems detect Acoustic waves, sound and vibration (Acoustic Emissions) patterns caused by leaks, structural stress, or third-party interference like digging or drilling.

Acoustic detection systems basically listen to the activity of a pipeline for any unusual sounds whereby sensors work together to assess and locate leaks that may often go undetected. The Acoustic emissions appear randomly on the pipe as noise. When a leak occurs, the source of acoustic emission events is highly concentrated on the leak location. Hence, the source of Acoustic emission events might be a potential feature for identifying the appearance of leaks.

The Acoustic Sensors capture sound waves or vibrations near the pipeline. Examples:

Hydrophones such as Teledyne Reson TC4013 to detect sound waves in water or fluid environments to identify leaks, Piezoelectric Vibration Sensors such as Dytran 3055B2 to Monitor vibrations caused by drilling, tapping, or structural stress, MEMS Microphones such as Analog Devices ADMP504 to Capture high-frequency acoustic signals near pipelines.

Furthermore, the signal processors analyze acoustic data to differentiate between normal operational sounds and anomalies. Examples: Arduino Mega 2560 commonly used for controlling multiple sensors and actuators in pipeline monitoring prototypes.

Generally, acoustic systems are comprised of sensors responsible for monitoring the pipeline for any variation from the normal sound on the pipeline. These sensors, should there be any changes to the sound on the pipeline, trigger other sensors to begin recording the acoustic data. (Ismail and Yie, 2012)

3.2.2. CONCEPT TWO: FLOW MEASUREMENT MONITORING METHOD

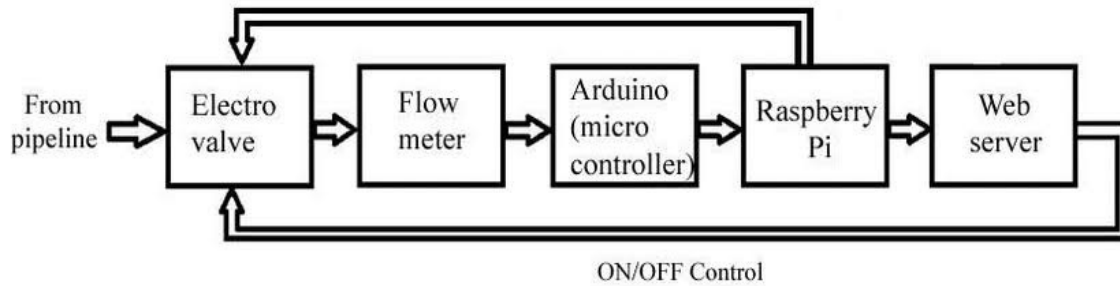


FIGURE 3.2 BLOCK DIAGRAM OF A RASPBERRY PI BASED SYSTEM TO MONITOR LIQUID FLOW (Suresh et al, 2014)

From the block diagram above, measurement of flow rate is achieved by using a hall effect sensor-based flow meter. Arduino and Raspberry Pi act as the microcontroller and microcomputer respectively. The electro valve is physically connected to the pipeline in which the flow is to be measured. The electro valve is connected to the flow meter or to the flow sensor. The flow meter measures the flow and generates analog pulses. The flow sensor is connected to the Arduino in order to read signals generated from the flow sensor. The Arduino reads the analog pulse from the flow sensor and sends the signal to the raspberry pi which is the main component to control the electro valve. The electro valve is electrically connected to the raspberry pi and when it is energized, it opens or closes the valve. The raspberry pi is programmed to read the Arduino signal and to control the electro valve. The flow meter is interfaced with the Arduino directly and the Arduino is responsible for collecting the data from the flow meter.

Generally, flow measurement technique is a very effective method of monitoring pipelines against Third Party Interferences. Flow analysis is crucial in the case of pipeline systems and therefore it is imperative to have a comprehensive and detailed record of flow parameters across pipelines daily. For this reason, monitoring flow parameters will help obtain these details on a consistent and constant basis which means regularly.

Some of these parameters are; Temperature, Pressure, flow rates, velocity etc.

Flow monitoring involves putting the right sensors, controllers, modules and actuators in place to monitor, measure, record and transmit information in real time in case of obvious changes in these parameters which may signify a potential leakage or vandalism. The flow meter is a relevant sensor to make this type of system effective.

Flow meters are devices designed to measure the flow rate of fluids (liquids or gases) in a pipeline. There are several types of flow meters that can be used to measure flow rates including Electromagnetic Flow Meters (Mega-meters) based on Faraday's Law of Induction, these meters measure the voltage generated when a conductive fluid flows through a magnetic field, Ultrasonic Flow Meters are also a type of flow meter. It makes use of the principle of sound waves to measure flow. Lastly, the Positive Displacement Flow Meters measure flow by capturing a specific volume of fluid in a chamber and counting the number of times it fills and empties.

Asides flow monitoring, pressure and temperature monitoring also contribute to flow monitoring systems. Monitoring pressure along the pipeline helps detect flow changes, blockages, or leaks. A combination of pressure sensors is used to assess pressure at different points along the pipeline. Examples of pressure sensors are Honeywell 31 Series, Ashcroft 1009, Yokogawa EJX

Series, Emerson Rosemount 3051. Temperature is often monitored alongside pressure and flow to ensure that the fluid is within operational parameters. Any deviation in temperature can signal changes in viscosity (for oils) or indicate a potential leak. Examples of temperature sensors are Siemens SITRANS F M MAG 8000, Honeywell STT800, LM 35 Temperature Sensor and so on.

In typical flow monitoring systems, pipelines are equipped with various sensors such as pressure sensors, flow meters, temperature sensors, and acoustic detectors. These sensors continuously monitor the pipeline's operational parameters, generate substantial amounts of data, and capture information about the pipeline's normal operational patterns and any anomalies that occur.

Machine learning models are trained on historical data to recognize patterns associated with normal pipeline operations and those indicative of leaks. The trained models continuously analyze incoming data in real time and compare it against learned patterns. The system identifies deviations from the normal operating condition that may suggest a leak (Oak,2024).

Each of the sensors above are integrated with controllers and Data recorders and connected with the necessary communication devices to send alerts in real time. Flow analysis is essential for every pipeline system and this system certainly can meet the need for constant monitoring and real time communication with pipeline management organizations. However, just like the acoustic monitoring systems, this system also has its drawbacks. In a country with diverse environment and climate like Nigeria, sensors are always prone to failure during rainfall and other factors such as accessibility in terms of regular maintenance etc.

3.2.3. CONCEPT THREE: SATELLITE GPS TRACKING AND MONITORING SYSTEMS

This is also a very useful method especially in less accessible and remote areas around the world and Nigeria to be specific.

Satellite GPS monitoring is an advanced method of overseeing pipeline networks, especially those spanning large and remote areas. It combines satellite technology, GPS tracking, and data communication systems to provide real-time location tracking, surveillance, and anomaly detection. Components such as the GPS Neo-7m module integrated with leakage detection sensors and microcontrollers help to identify exact locations of leakage giving accurate coordinates. The ESP32 GPS tracker can also be used, the exact location is made known via mobile devices or computer systems monitors for virtual and remote monitoring

This method is very effective because it allows us know the exact location of TPIs such as vandalism, construction activities and typical pipeline failures that result in leakage especially in remote areas around the Niger-Delta region in Nigeria especially where other sensor- based methods fails.

Just like other methods, this method is not often reliable for monitoring pipelines in a place like Nigeria with diverse climatic conditions as weather condition may change at any given point in time. Other factors like Electromagnetic (Signal) interference from nearby equipment or natural phenomena can disrupt GPS signals.

3.2.4. CONCEPT FOUR: IMPROVED HYBRID PIPELINE PROTECTION SYSTEM (IHPPS)

From the above analysis and comparing the above, it is recommended that a hybrid system which we have termed an Improved Hybrid Pipeline Protection System (IHPPS) should be selected and designed based on the following reasons:

1. **Enhanced Detection:** By combining several monitoring techniques (such as acoustic, pressure, temperature, and flow sensors), the hybrid method improves the accuracy and reliability of detecting third-party interference, including both obvious damage and subtle signs of tampering.
2. **Real-time Data Integration:** The hybrid system can process data from various sources simultaneously, enabling quicker response to emerging threats and preventing further damage.
3. **Fewer False Alarms:** Integrating multiple methods reduces the chances of false positives. When one method detects an issue, others can confirm or dismiss the alarm, providing a clearer understanding of the pipeline's condition.
4. **Greater Resilience:** By using multiple methods, the hybrid system is more robust against environmental challenges or the limitations of individual technologies. For example, when acoustic monitoring faces challenges in noisy areas, other methods like pressure monitoring can still function well.
5. **Wider Coverage:** The hybrid method can address a broader range of monitoring requirements, ensuring that various forms of third-party interference (such as digging, vandalism, or illegal tapping) are detected across different sections of the pipeline, even in areas where one method might not be sufficient.

In conclusion, the hybrid method provides enhanced sensitivity, flexibility, and precision in detecting third-party interference compared to individual monitoring techniques, making it a more comprehensive solution for pipeline integrity and security.

By designing a hybrid-system we aim to improve on the design of single monitoring systems by addressing their limitations.

The hybrid pipeline monitoring method, which integrates multiple monitoring technologies, provides numerous advantages over individual techniques such as flow monitoring, acoustic monitoring, and gas tracking when it comes to detecting third-party interference. Stated below are the limitations of some of the concepts we have analyzed and how we aim to overcome their limitations with this hybrid system.

1. Flow Monitoring:

Limitation: Flow monitoring tracks the volume of substances flowing through a pipeline but isn't very effective at detecting external damage or interference from third parties. It only alerts when there's a significant impact on flow rates.

Hybrid Advantage: The hybrid method incorporates additional technologies (e.g., acoustic or pressure sensors), which make it more sensitive to unusual changes caused by external interference, such as digging or sabotage, even before these changes significantly affect the flow.

2. Acoustic Monitoring:

Limitation: Acoustic monitoring detects vibrations or sounds caused by leaks, but it can sometimes struggle to distinguish between normal operational sounds and third-party activities like excavation or drilling near pipelines.

Hybrid Advantage: By integrating acoustic sensors with other techniques like pressure or temperature monitoring, a hybrid system provides more accurate detection of third-party interference, allowing better differentiation between normal operational noise and potential tampering.

3. GPS Location Tracking and Monitoring Method:

Limitation: While GPS tracking offers accurate location data for the pipeline, it doesn't detect internal problems like leaks or damage from third-party interference. It is primarily used to locate the pipeline or equipment but doesn't provide real-time insights into the pipeline's condition.

Hybrid Advantage: By integrating GPS tracking with other monitoring techniques such as pressure, temperature, or acoustic sensors, the hybrid system improves its capability to not only track the pipeline's location but also identify disruptions or signs of third-party interference. It can notify operators of unusual activities, like unauthorized digging or pipeline damage, which GPS alone cannot detect.

The above models will be integrated together to create a new and more vast pipeline monitoring system with amazing performance objectives.

3.3.IDENTIFICATION OF HYBRID SYSTEM REQUIREMENT

This system is developed to monitor liquid pipelines in real time. It consists of various sensors connected to a microcontroller unit to aid effective monitoring of abnormal pipeline conditions that may suggest interference in the day to day running of the system. Figure 3.1 shows a block diagram describing the interaction between the subsystem components of both modules in the device.

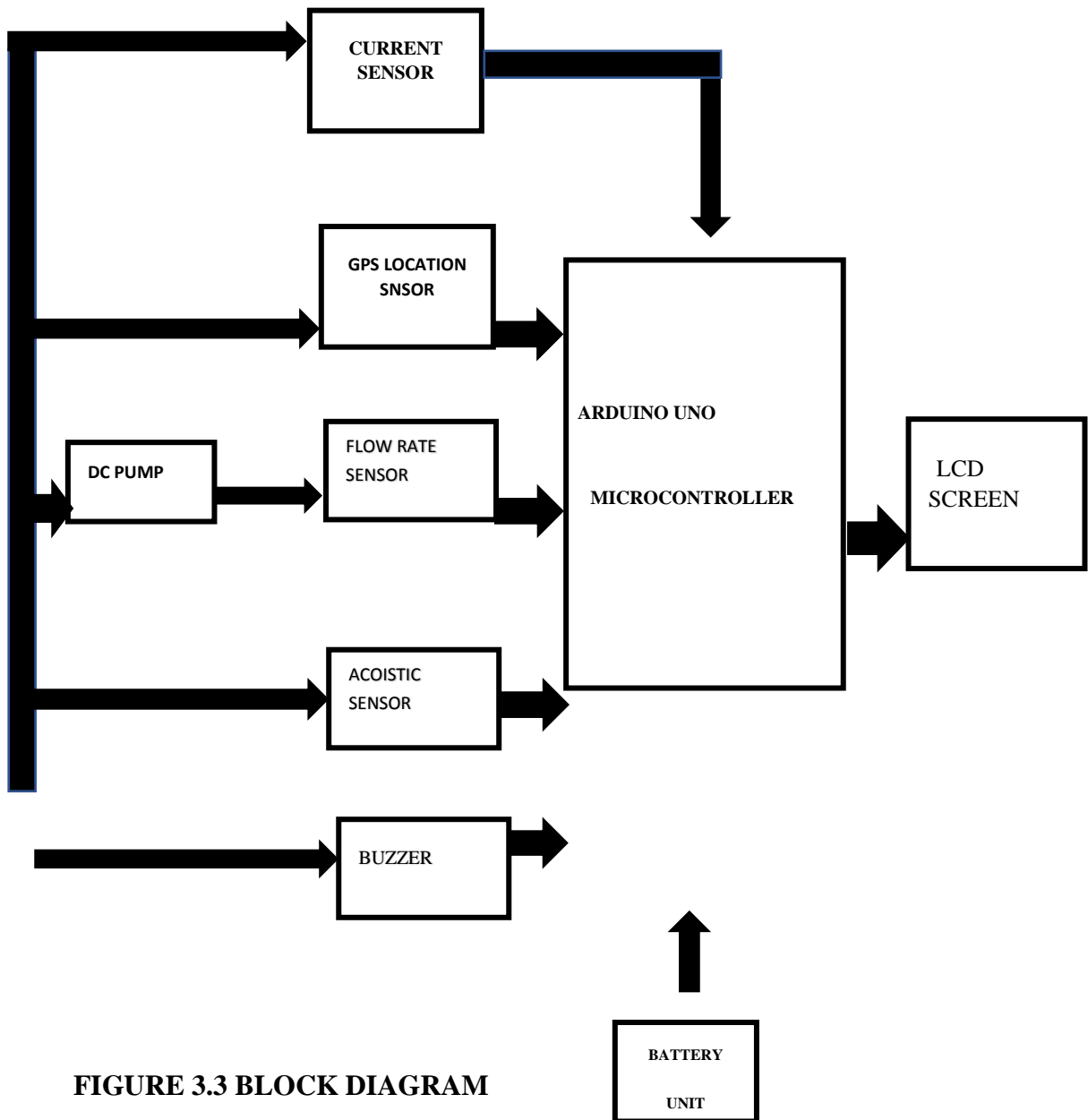


FIGURE 3.3 BLOCK DIAGRAM

3.4.DESIGN CONSIDERATIONS

The design of this project includes the following blocks;

1. Microcontroller block
2. Gas sensing block
3. Flow Rate sensor block
4. Acoustic Sensor
5. Power source block
6. Display block

3.4.1. THE MICROCONTROLLER BLOCK

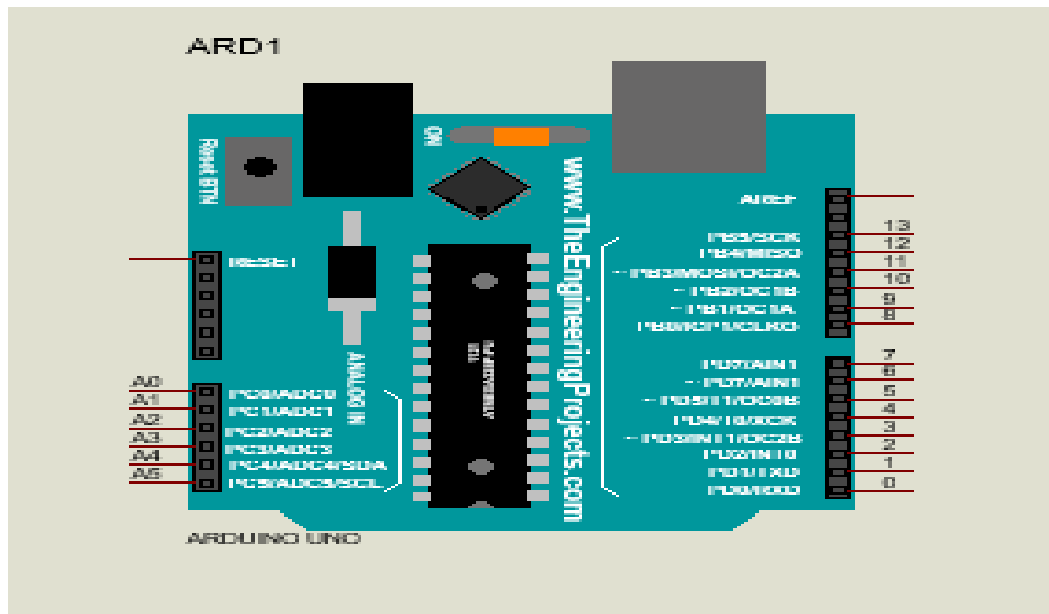


FIGURE 3.4: A MICROCONTROLLER MODULE

TABLE 1. RECOMMENDED OPERATING CONDITIONS FOR THE MICROCONTROLLER

DESCRIPTION	MIN	MAX
Conservative thermal limits for the whole board	-40OC (-40OF)	85OC (185F)

3.4.2. CURRENT SENSING BLOCK

This block consists of the current sensor which is responsible for measuring current using the hall effect principle. The chosen current sensor here is the ACS 712 current sensor. It can measure current over multiple ranges which include +5A to -5A, +20A to -20A and +30A to -30A.

This sensor can be easily interfaced with the microcontroller.

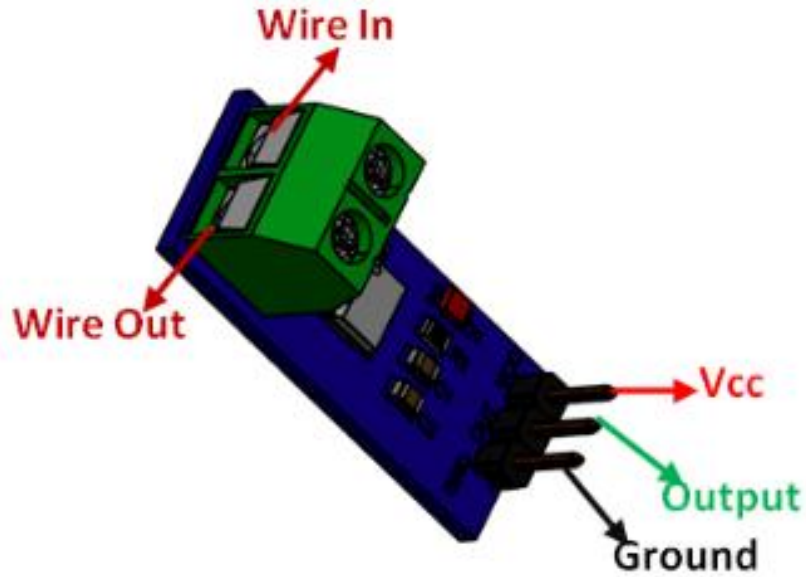


FIGURE 3.6: THE ACS 712 CURRENT SENSOR SHOWING ITS PIN CONNECTIONS

Features of this sensor making it suitable to be used in this design are stated below:

1. Wide detecting range
2. Stability and long life
3. Provides isolation from the load
4. Fast response and high sensitivity

TABLE 2. below gives the specifications of this sensor.

5A MODULE	20A MODULE	5A MODULE
185mV/Am	100mV/Am	66mV per Amp

3.4.3. DISPLAY UNIT BLOCK

The display unit consists of a Liquid Crystal Display screen. The chosen LCD screen is the 16 by 2 LCD screen. This screen has 16 columns and 2 rows. It was chosen because of its

Features of this display screen include;

1. Display mode and backlight variations.
2. 16 characters and 2 lines display
3. 5 x 8 dots with cursor
4. Built in controller

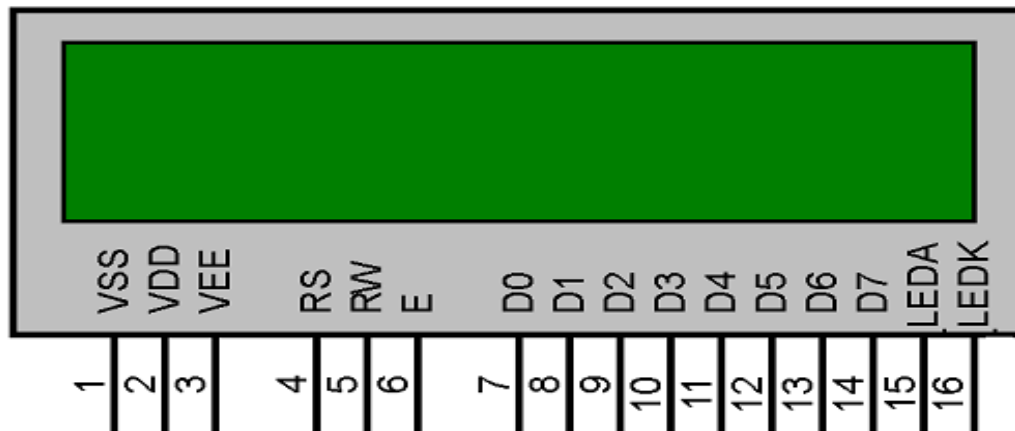


FIGURE 3.7: A 16 X 2 LCD MODULE

3.4.4. FLOW RATE SENSING BLOCK

This block consists of two parts. They are:

1. The Flow rate sensor
2. The DC water pump

This block consists of the liquid flow sensor and the water pump. In this case, the selected liquid flow sensor is the YF-S201 water measurement sensor. Its mode of operation is based on the hall effect principle and it has a flow rate range of 1~30L/min.

Its feature of consuming low current makes its suitable for the design of this project.

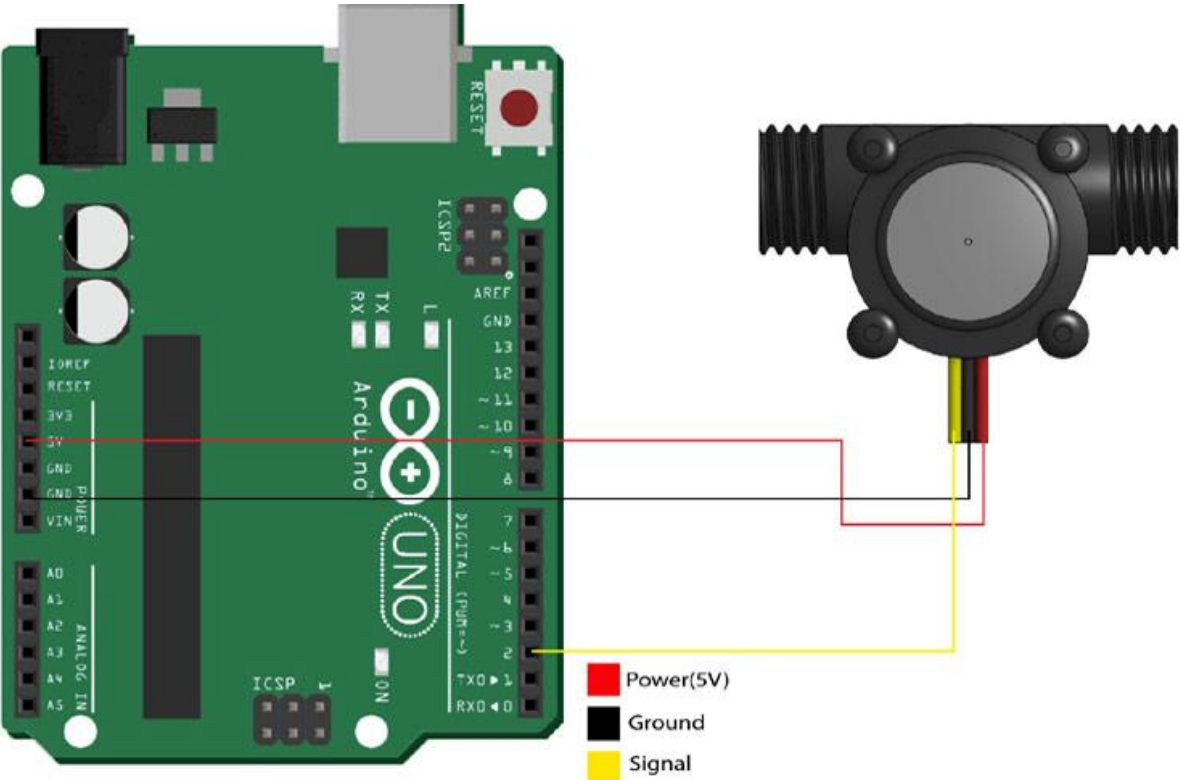


FIGURE 3.8: THE YF-S201 LIQUID FLOW SENSOR AND ITS CONNECTION TO THE ARDUINO UNO MICROCONTROLLER

The selected water pump is the R365 mini diaphragm water pump. It operates on 12v direct current. Some of its features are:

1. Working voltage DC 12V
2. No Load Current 0.23A
3. Pump length of 36mm
4. Maximum flow of 2-3 liters per minute



FIGURE 3.9: THE R365 DC WATER PUMP

3.4.5. LOCATION DETECTION BLOCK

The essence of this block is to detect locations of the pipeline that have been interfered with externally. It has a GPS module that enables this functionality. This GPS module is the U-blox NEO6MV2 Global Positioning System (GPS) Sensor. The module simply checks its location on earth and provides output data which is longitude and latitude of its position.

This GPS module was basically selected because it is an efficient upgrade on previous systems that have existed. The NEO-6MV2's cutting-edge design delivers superior navigation performance, even in the toughest conditions.

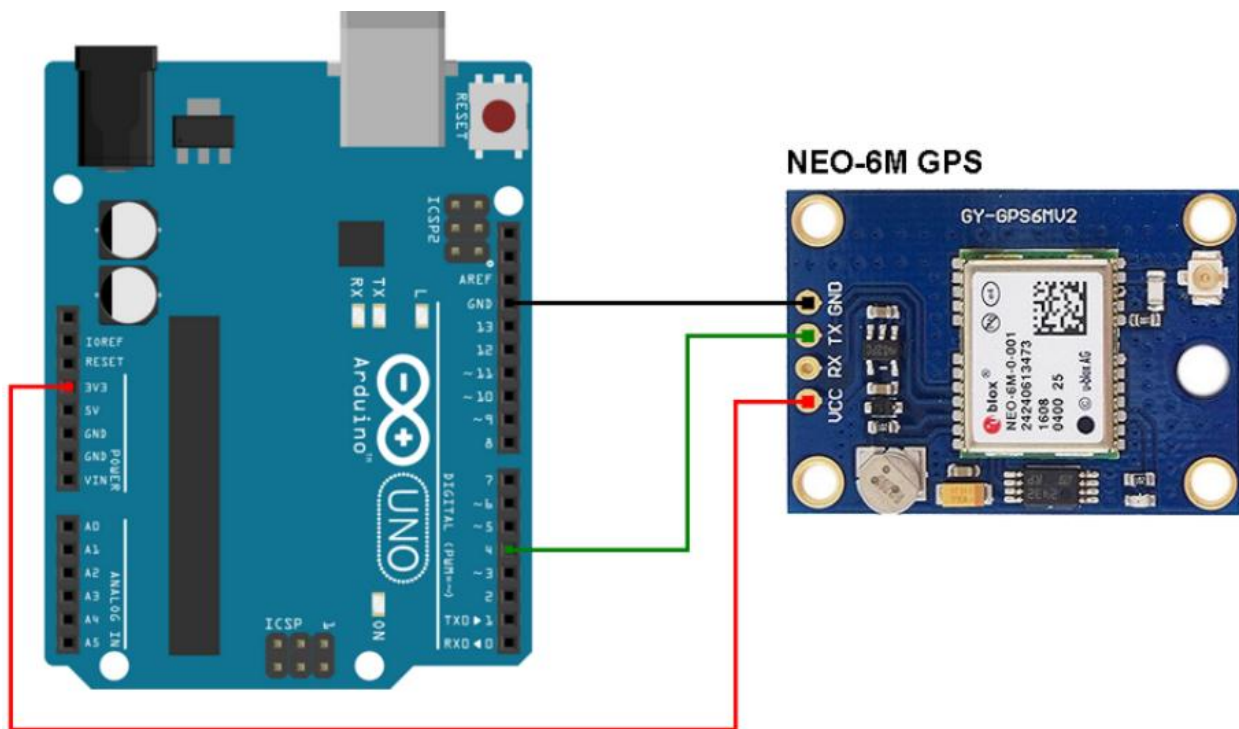


FIGURE 4.0: A CIRCUIT SHOWING HOW THE GPS MODULE IS INTERFACED WITH THE ARDUINO MICROCONTROLLER

CHAPTER FOUR

DESIGN AND ANALYSIS

The Improved Hybrid Pipeline Protection System IHPPS Design is analyzed below.

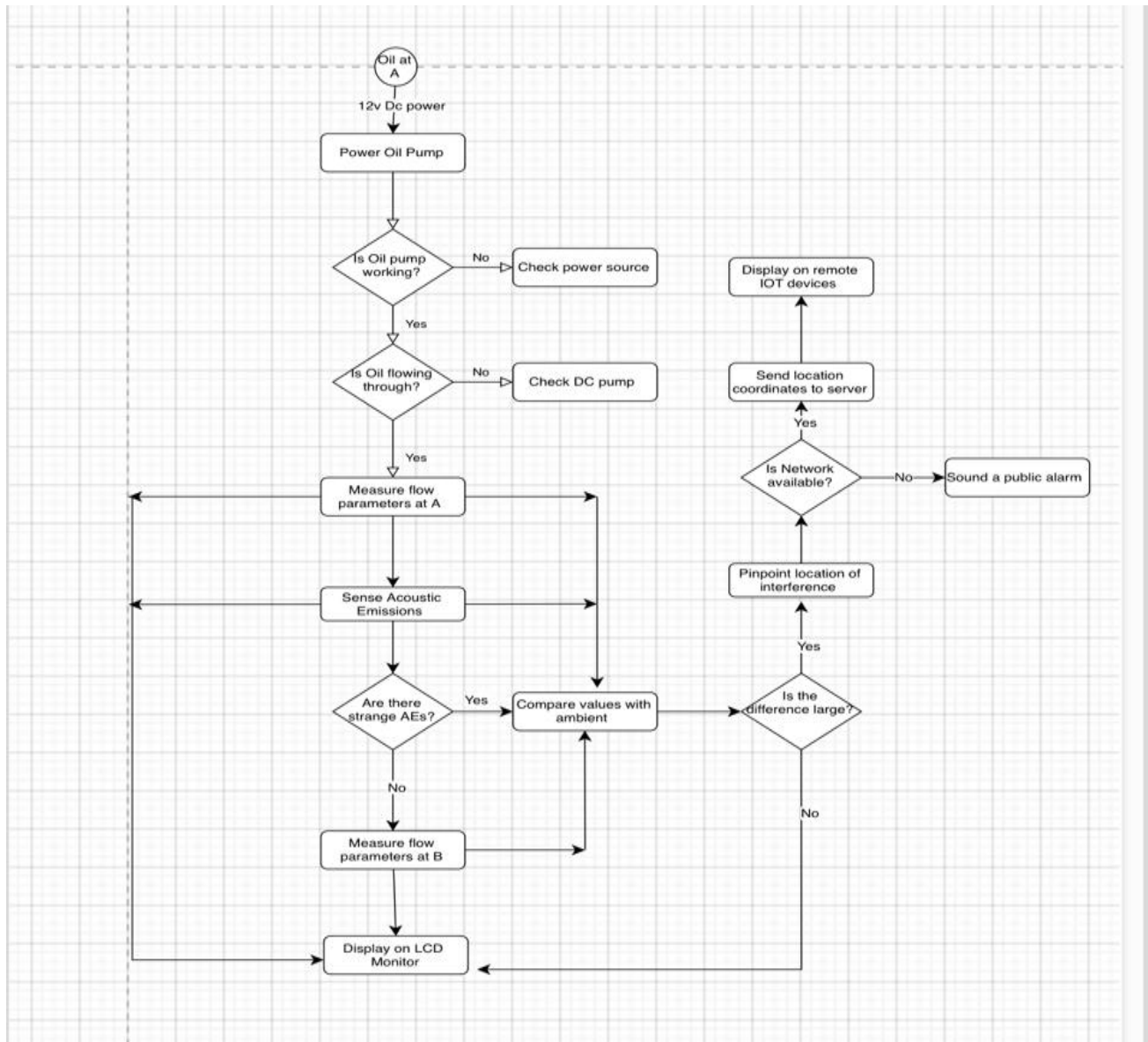


Fig 4.1 Flow chart of IHPPS

4.1.1. Explanation of flow chart:

The flow chart above provides the working principles and steps of the IHPPS which involves the following

1.Oil at A: Oil pipelines are connected over a long distance to transport Oil from one point (A) the Oil Extraction site to another point (B) the Refinery.

2.Power Oil Pump: A DC pump is placed at the Oil Rig to pump the oil and set it in motion through the pipelines, this Pump is powered by a 12 volts DC power source. If Oil pump fails to function properly or if Oil flows abnormally then it is important to check for errors in the power source and pump respectively.

3.Measure flow parameters: As soon as the oil Leaves the pump and sets in motion along the steel pipeline, the flow sensor takes immediate measurements of flow parameters and displays it on the LCD screen.

4.Sense Acoustic Emissions: The acoustic sensor acts as the first component to signify interference by sensing Acoustic Emissions and sending it to the controller to compare with ambient values set from its programming, if the difference is obvious then the controller sends signals to display them on the LCD screen.

5.Pinpoint location of interference: From the obvious difference between sensed values and ambient values of sounds or vibrations already interpreted as a threat, the GPS sensor helps to locate point of threat interference in longitude and latitude.

6.Send location coordinates to server: If Network is available, this information is sent to the server of the remote monitoring platform (IOT). If The Network is not available, it sends signals to a public alarm system.

7.Measure flow parameters at B: This often acts as confirmation because it measures the flow parameters at point B and compares the values with the flow parameters measured by the first flow sensor at point A and this difference is displayed on the LCD and IOT respectively.

8.Display: The information gotten from the above steps are finally displayed on both the physical LCD monitor and also on the IOT platform for remote monitoring.

4.2. Components and programming

4.2.1. The ESP32

The ESP32 is a low-power microcontroller with integrated Wi-Fi and Bluetooth capabilities, making it ideal for IoT applications. The sensors and modules such as the acoustic sensors, flow sensors, GPS modules, Wi-Fi modules were connected and soldered into it therefore enabling it to interact with all the components by processing signals from the sensors and sending the

processed information to the appropriate output devices based on its programming.

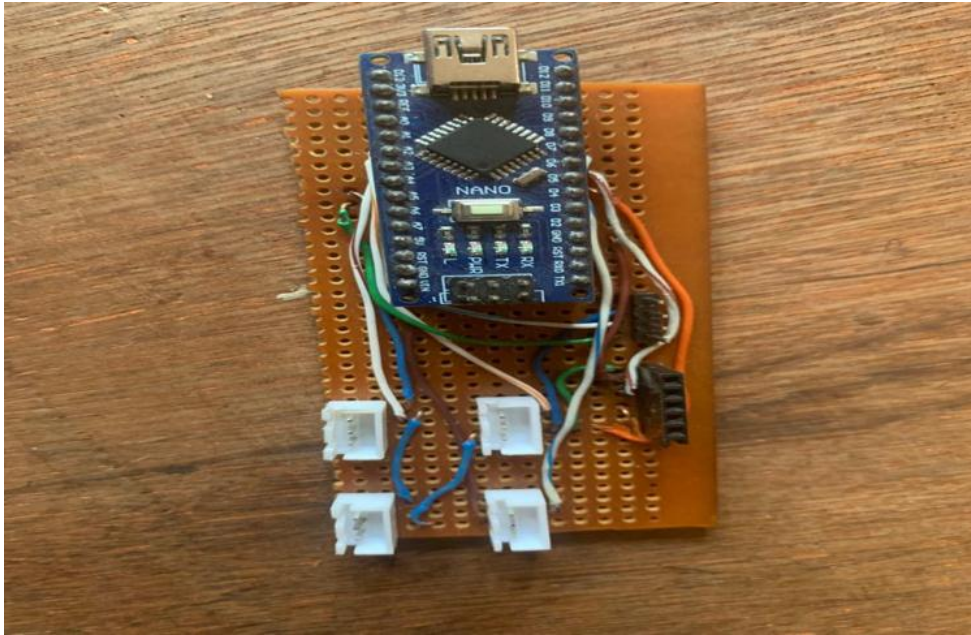


Fig 4.2.1 Working on ESP32 Arduino board

4.2.2. The LCD Screen

The 16x2 LCD (16 characters, 2 rows) with an I2C module allows easy communication with microcontrollers using only two pins. The LCD screen is connected to the microcontroller and hence used for physical display



Fig 4.2.2 the 16x2 LCD screen with i2c

4.2.2. The SF-Y201

The SF-Y201 is a liquid flow sensor that measures the rate of liquid flow using a hall-effect sensor that generates pulses. The SF-Y201 Flow sensor is placed on the steel pipeline to measure the rate of flow at point A and B at each point along the length of the pipeline.



Fig 4.2.3. Working on the SF-Y201 Flow Sensor

4.2.3. LM393 Acoustic Sensor (Sound Detection Module)

The LM393 sound sensor detects sound intensity using a condenser microphone and outputs both analog and digital signals. It is placed along the pipeline and detects sounds and vibration (Acoustic Emissions) in case of interference and sends signals to the microcontroller for comparisons.



Fig 4.2.4. LM 393 acoustic sensor

Source:<https://www.handsontec.com/dataspecs/sensor/Sound%20Detector.pdf>

4.2.4. 6M GPS Module

The NEO-6M is a high-performance GPS receiver that provides latitude, longitude, altitude, and speed data via serial communication (UART). It can in-addition be integrated with the acoustic sensors into the system to provide precise location of interference when it occurs.

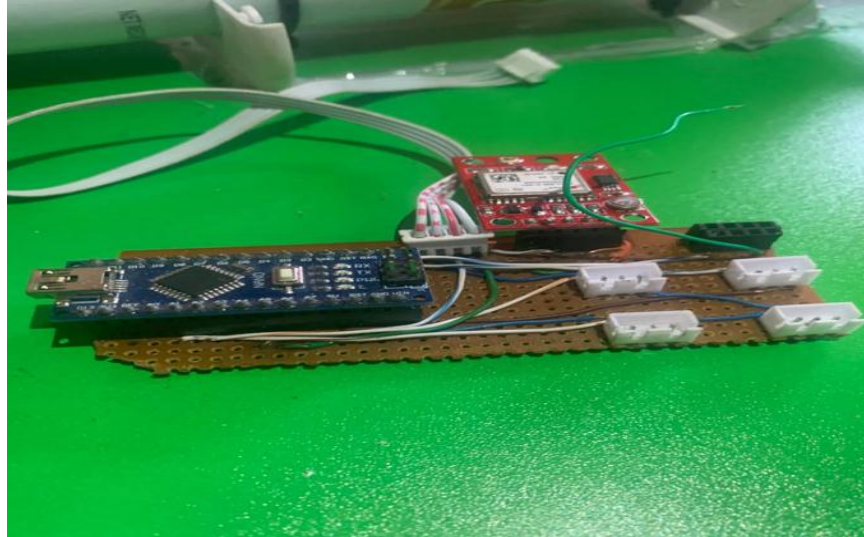


Fig 4.2.4. integrating the NEO-6M GPS module in the circuit

4.2.5. LM2596 Buck Converter

The LM2596 is a step-down DC-DC voltage regulator used to convert higher voltages (e.g., 12V) to a stable lower voltage (e.g., 5V, 3.3V). It was used to step down the 12 volts DC power into suitable 5v for use in the circuit.



Fig 4.2.5. Buck Converter

4.2.6. 12V DC Pump

A 12V DC pump is an electric pump designed to circulate or move liquids, typically used in water circulation and automation systems. In our system it was used to pump fluid (Oil) from the Extraction site to the Refinery through the steel pipe.



Fig 4.2.6. Examining the DC pump before coupling

4.2.7. IOT platform:

This is an online website known as Thing speak by MATLAB Inc. It is used to remotely monitor integrated devices irrespective of the distance. The details that are displayed on the LCD monitor are also viewed on this website with the help of the Wi-Fi module of the ESP32 Arduino microcontroller. The website is synchronized with our integrated systems and details of happenings around the pipeline are displayed in a graphical form on the mobile devices or computer screen operated by Pipeline operators.

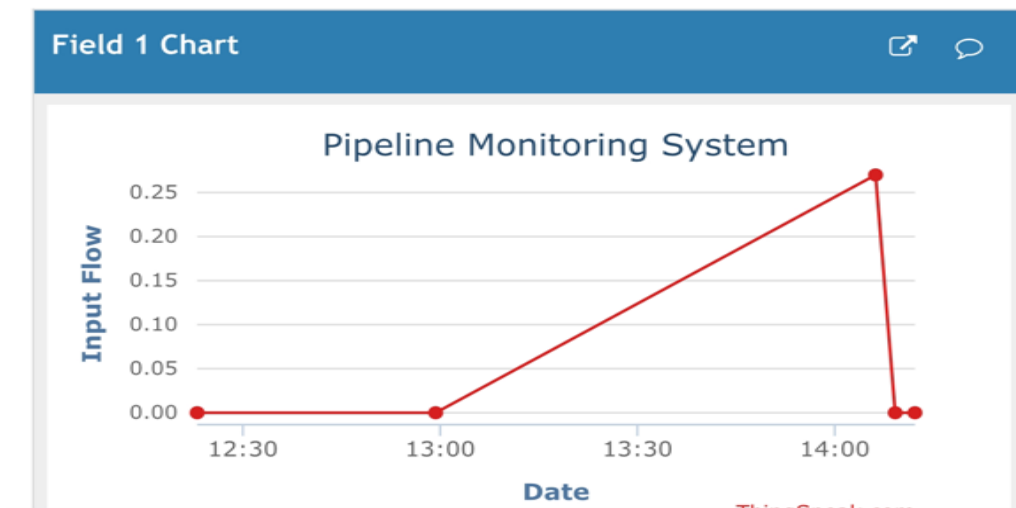


Fig 4.2.7. IOT input flow display.

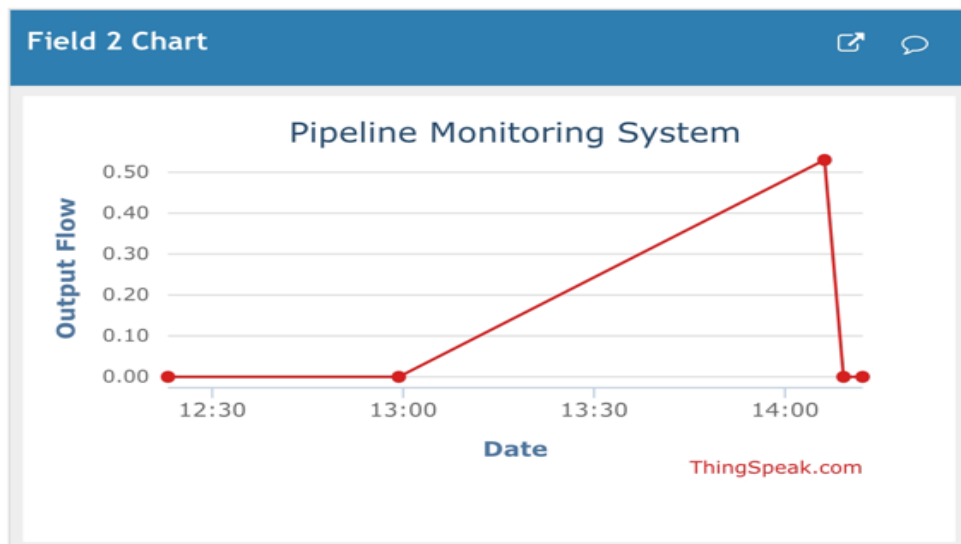


Fig 4.2.8. IOT output flow display

4.3. Programming of components

The following codes were used to program the ESP32 Arduino microcontroller integrated together with other components in order to function properly in measuring and comparing values from sensors and sending the processed information in real time.

4.1.1 Arduino IDE: The Arduino IDE is a free, open-source software that allows users to write and upload code to Arduino boards. It was used to write and compile software codes to operate the Arduino board to enable it communicate or interact with other components integrated on it.

4.1.2 Arduino IDE: The Arduino IDE is a free, open-source software that allows users to write and upload code to Arduino boards. It was used to write and compile software codes to operate the Arduino board to enable it communicate or interact with other components integrated on it.



Fig 4.3.1 Using the Arduino IDE for code compilation

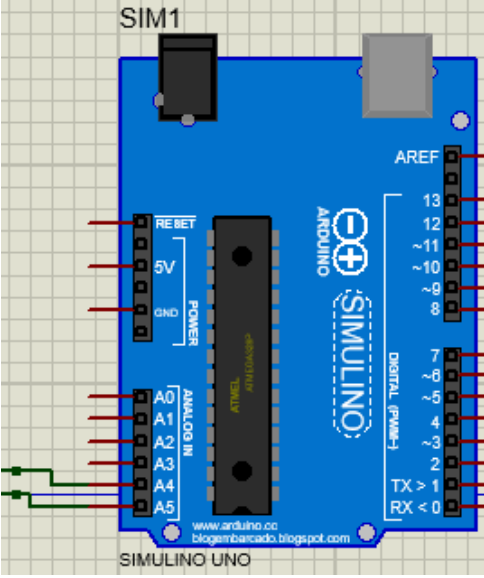
There are two methods in an Arduino sketch (program) named setup () and loop ().

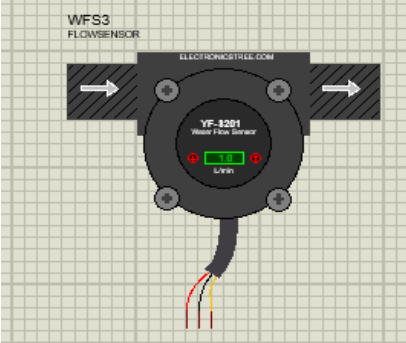
When the application launches, setup () is called once while The loop () method does exactly what its name implies—it loops back and forth after invoking the setup () function, enabling the software to modify, react, and control the Arduino board.

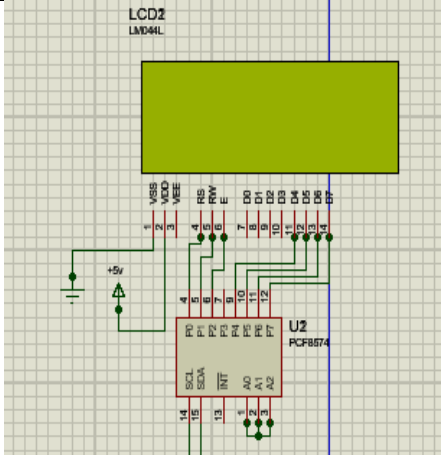
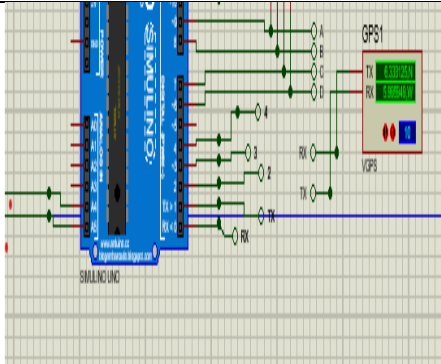
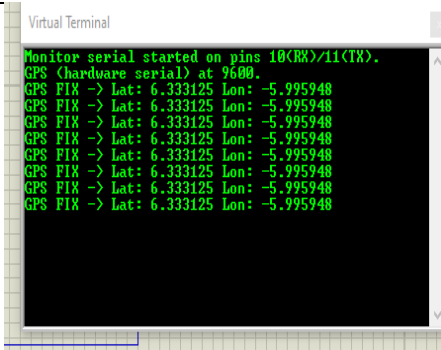
Below are the codes written and compiled to control the Arduino and sensors/modules integrated with it on our system.

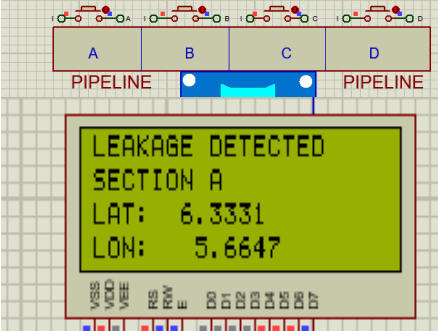
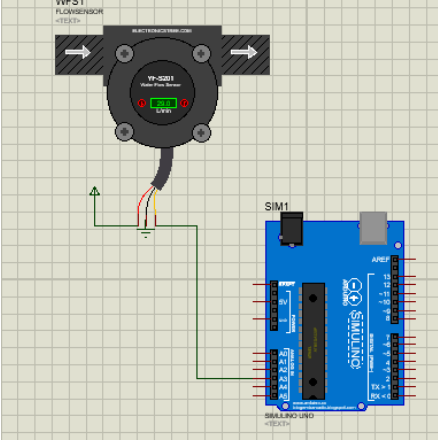
TABULAR REPRESENTATION OF CODE

Steps	Code/Program	Description	Visuals
1; Include Libraries	<pre>#include <TinyGPS++.h> #include <SoftwareSerial.h> #include <Wire.h> #include <LiquidCrystal_I2C.h></pre>	<p>These libraries enable GPS parsing (TinyGPS++), serial communication (SoftwareSerial), I2C communication (Wire), and LCD</p>	<pre>cpp #include <TinyGPS++.h> #include <SoftwareSerial.h> #include <Wire.h> #include <LiquidCrystal_I2C.h></pre>

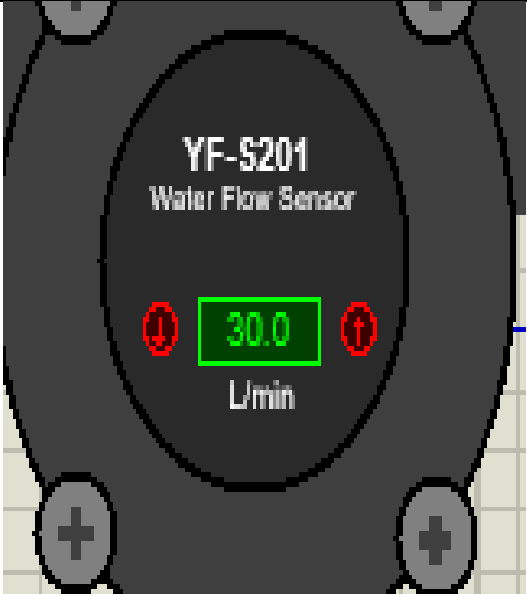

		control (LiquidCrystal_I2C).	
2. Define Pin Configuration	<pre> const uint8_t FLOW_UP_PIN = 3; const uint8_t FLOW_DOWN_PIN = 2; const uint8_t VIB_PIN = 4; const uint8_t BTN_A = 9; const uint8_t BTN_B = 8; const uint8_t BTN_C = 7; const uint8_t BTN_D = 6; </pre>	Pins for flow sensors, vibration sensor, and section buttons are defined.	

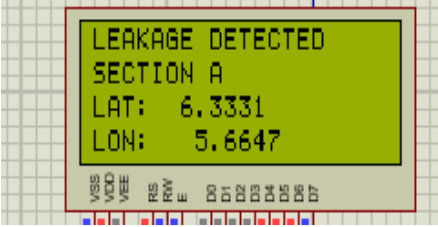
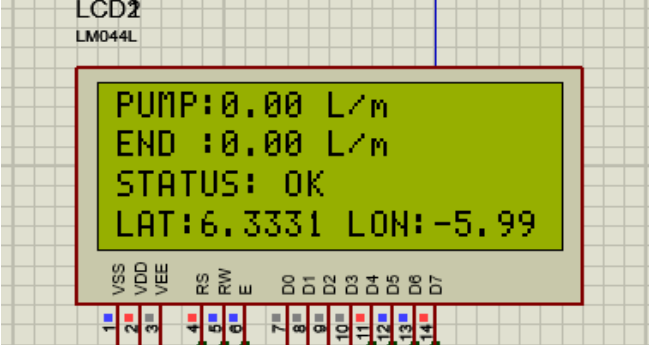
<p>3.</p> <p>Define Timing Constants</p>	<pre>const unsigned long REPORT_INTERVAL_MS = 1000; const unsigned long SECTION_CYCLE_MS = 1000;</pre>	<p>Controls how often the system reports data and cycles through multiple section buttons. (e.g., 1000 ms).</p>	<pre>cpp const unsigned long REPORT_INTERVAL_MS = 1000; const unsigned long SECTION_CYCLE_MS = 1000;</pre>
<p>4.</p> <p>Define Flow Sensor</p>	<pre>const float PULSES_PER_LITER E = 450.0;</pre>	<p>Used to convert flow sensor pulses into liters.</p>	

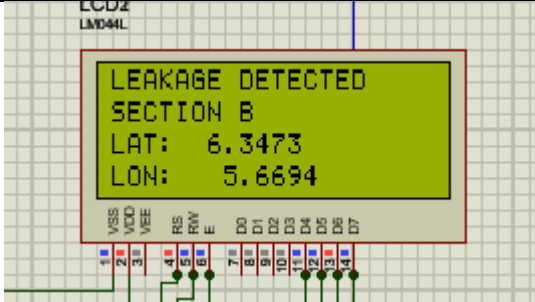
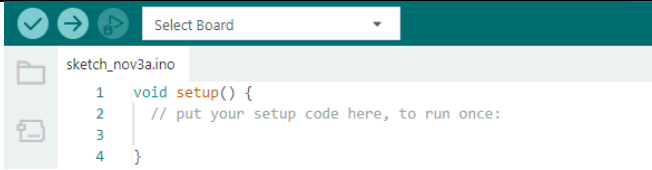
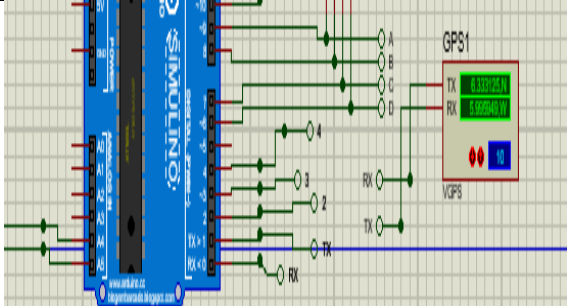
<p>5. LCD Configu ration</p>	<pre>const uint8_t LCD_ADDR = 0x20; LiquidCrystal_I2C lcd(LCD_ADDR, 20, 4);</pre>	<p>Initializes the 20x4 I2C LCD display object.</p>	
<p>6. Serial Configu ration</p>	<pre>TinyGPSPlus gps; SoftwareSerial monitorSerial(10, 11);</pre>	<p>Sets up GPS object and debug serial communicati on on pins 10/11.</p>	
<p>7. Define GPS Coordin ates for Pipeline</p>	<pre>const double START_LAT = 6.333134; const double START_LNG = 5.664700; const double END_LAT =</pre>	<p>Declares latitude and longitude for the pipeline's start and end points.</p>	

	<pre>6.375555; const double END_LNG = 5.678900;</pre>		
<p>8:</p> <p>Define Section Structure</p>	<pre>struct Section { char name; double lat; double lng; uint8_t btnPin; }; Section sections[4];</pre>	<p>Creates a structure (struct) for each pipeline section with name, GPS, and push button.</p>	
<p>9.</p> <p>Define Flow Sensor Counter</p>	<pre>volatile unsigned long pulsesUp = 0; volatile unsigned long pulsesDown = 0; unsigned long</pre>	<p>Counts pulses from the flow sensors. volatile ensures accurate</p>	

	<pre>totalPulsesUp = 0; unsigned long totalPulsesDown = 0;</pre>	<p>counting inside interrupts.</p>	
<p>10. Define Timing Variable s</p>	<pre>unsigned long lastReport = 0; unsigned long lastSectionCycle = 0; uint8_t cycleIndex = 0;</pre>	<p>Tracks time intervals for reports and button cycling.</p>	<pre>cpp unsigned long lastReport = 0; unsigned long lastSectionCycle = 0; uint8_t cycleIndex = 0;</pre>
<p>11. Define Interrupt Service Routine s (ISRs)</p>	<pre>void isrUp() { pulsesUp++; totalPulsesUp++; } void isrDown() { pulsesDown++; totalPulsesDown++; }</pre>	<p>Automaticall y increments pulse counters on rising edges from the flow sensors</p>	<pre>cpp void isrUp() { pulsesUp++; totalPulsesUp++; } void isrDown() { pulsesDown++; totalPulsesDown++; }</pre>

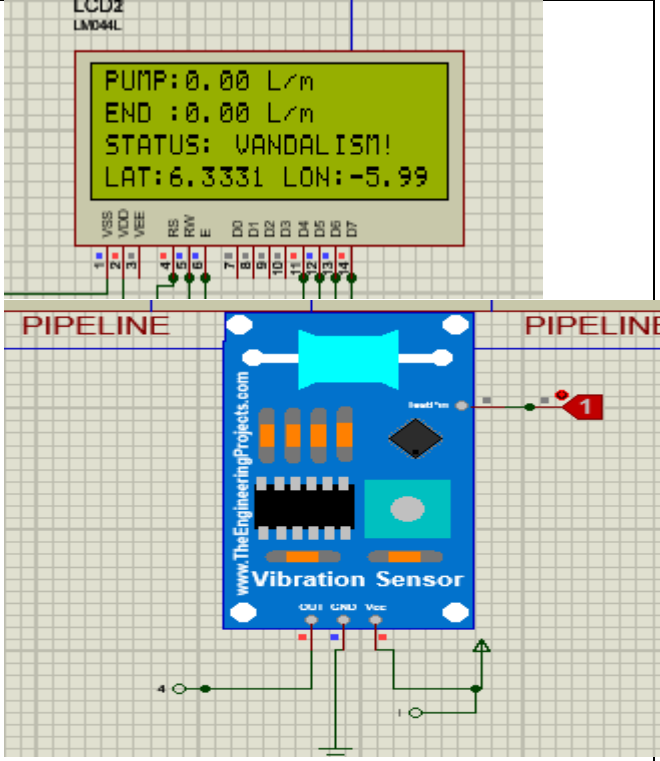
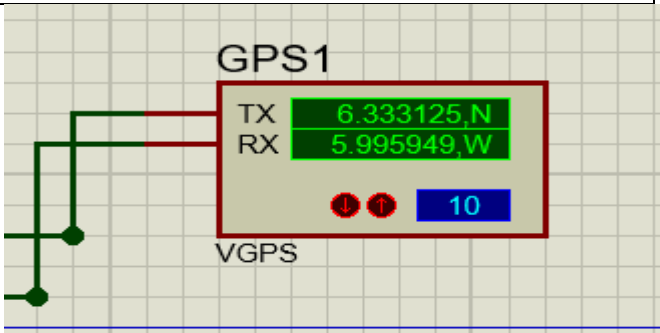
<p>12.</p> <p>Convert Pulses to LPM Function</p>	<pre>double pulsesToLpm(unsigned long pulses, unsigned long intervalMs) { ... }</pre>	<p>Converts the counted pulses into liters per minute using the sensor calibration.</p>	
<p>13.</p> <p>Build Pipeline Sections Function</p>	<pre>void buildSections() { ... }</pre>	<p>Linearly interpolates GPS coordinates between start and end, assigning section names and buttons.</p>	

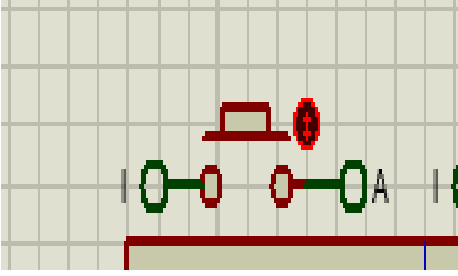
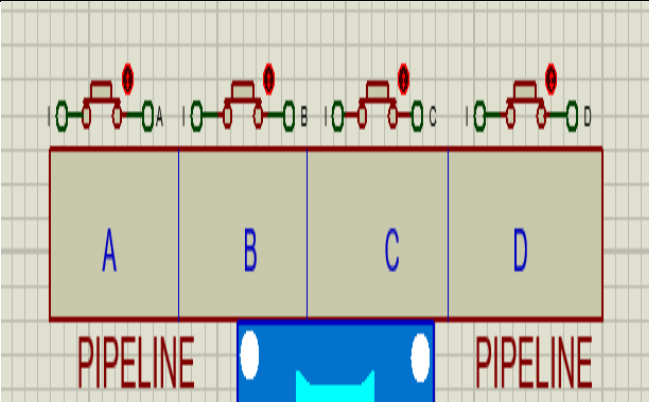
<p>14.</p> <p>Display Section Info on LCD</p>	<pre>void displaySectionOnLCD(const Section &s, bool vandal, double upFlow, double downFlow) { ... }</pre>	<p>Shows leakage alerts, section name, coordinates, and flow rates on the LCD.</p>	
<p>15.</p> <p>Display Flows on LCD</p>	<pre>void displayFlowsOnLCD(double upFlow, double downFlow, const char *status, double lat, double lng, bool gpsValid) { ... }</pre>	<p>Shows flow rates, GPS status, and overall system state</p>	

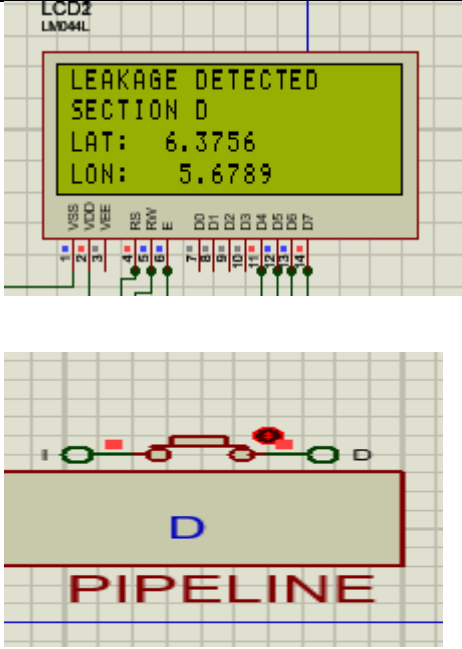
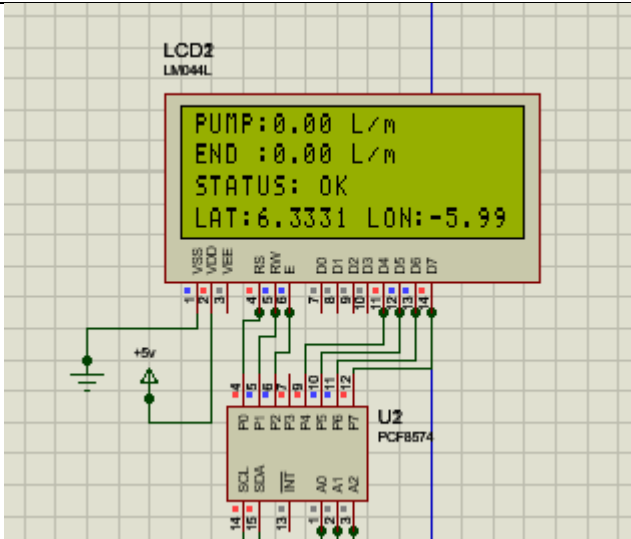
<p>16.</p> <p>Read Section Buttons Function</p>	<pre>uint8_t readSectionButtons() { ... }</pre>	<p>Reads which buttons (A–D) are pressed and returns a bitmask.</p>	
<p>17.</p> <p>Setup: Initialize Monitor Serial</p>	<pre>void setup() { ... }</pre>	<p>Starts serial communication for debugging.</p>	
<p>18.</p> <p>Setup: Initialize GPS Serial</p>	<pre>while (Serial.available() > 0) gps.encode(Serial.read());</pre>	<p>Starts hardware serial communication at 9600 baud for GPS data.</p>	

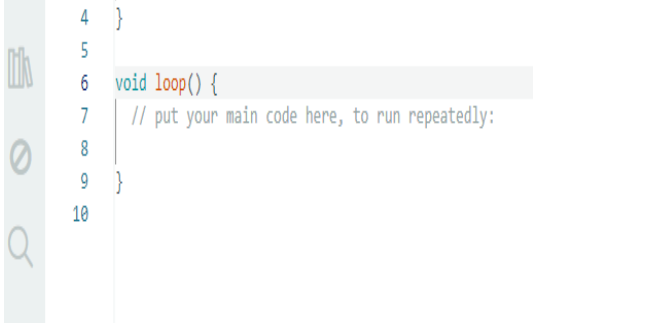
<p>19.</p> <p>Setup:</p> <p>Initialize LCD Display</p>	<pre> if (now - lastReport >= REPORT_INTERVA L_MS) { ... } </pre>	<p>Turns on LCD backlight and shows “Pipeline Monitor” welcome message.</p>	
<p>20.</p> <p>Loop:</p> <p>Read GPS Data</p>	<pre> bool gpsValid = false; double lat = 0.0, lng = 0.0; if (gps.location.isValid()) { gpsValid = true; lat = gps.location.lat(); lng = gps.location.lng(); } </pre>	<p>Continuously reads serial GPS data and feeds it to TinyGPS++ parser.</p>	

<p>21. Main Loop – Read and Reset Flow Pulses</p>	<pre>noInterrupts(); unsigned long upCount = pulsesUp; unsigned long downCount = pulsesDown; pulsesUp = 0; pulsesDown = 0; interrupts();</pre>	<p>Safely reads and resets pulse counters to prevent race conditions.</p>	<pre>CPP noInterrupts(); unsigned long upCount = pulsesUp; unsigned long downCount = pulsesDown; pulsesUp = 0; pulsesDown = 0; interrupts();</pre>
<p>22.Main Loop – Calculat e Flow Rates</p>	<pre>double upFlowLpm = pulsesToLpm(upCou nt, interval); double downFlowLpm = pulsesToLpm(downC ount, interval);</pre>	<p>22. Compute s upstream and downstream flow in liters per minute.</p>	<pre>Virtual Terminal Monitor serial started on pins 10(RX)/11(TX). GPS (hardware serial) at 9600. Section B Vandal:NO Up(L/m):0.00 Down(L/m):0.00 Section B Vandal:NO Up(L/m):0.00 Down(L/m):0.00 Section B Vandal:NO Up(L/m):0.00 Down(L/m):0.00 Section B Vandal:NO Up(L/m):0.00 Down(L/m):0.00 GPS FIX -> Lat: 6.333125 Lon: -5.995948</pre>

<p>23:</p> <p>Main Loop – Read Vibration Sensor</p>	<pre>bool vandal = (digitalRead(VIB_PI N) == HIGH);</pre>	<p>Checks for vandalism or pipe tampering.</p>	
<p>24:</p> <p>Main Loop – Check GPS Validity and Coordinates</p>	<pre>bool gpsValid = gps.location.isValid() ; double lat = gpsValid ? gps.location.lat() : 0.0; double lng = gpsValid ? gps.location.lng() : 0.0;</pre>	<p>Verifies GPS fix and retrieves current latitude and longitude.</p>	

<p>25. Main Loop – Read Section Buttons</p>	<pre>uint8_t buttons = readSectionButtons();</pre>	<p>Displays info for pressed sections or cycles between multiple buttons.</p>	
<p>26. Main Loop – Handle Multiple Button Presses</p>	<pre>if (pressedCount > 1) { ... }</pre>	<p>Ensures the display cycles through all pressed sections if more than one button is pressed.</p>	

<p>27.</p> <p>Main Loop – Display Section Info if Button Pressed</p>	<p>displaySectionOnLCD(*s, vandal, upFlowLpm, downFlowLpm);</p>	<p>Shows leakage detection, coordinates, and flow for the selected section.</p>	
<p>28:</p> <p>Main Loop – Display General Flow and GPS if No Button Pressed</p>	<p>displayFlowsOnLCD(upFlowLpm, downFlowLpm, statusStr, lat, lng, gpsValid);</p>	<p>Displays overall pipeline flow, GPS status, and vandalism alert if no section button is pressed.</p>	

<p>29. Loop Repeats</p>	<pre>void loop() { /* repeats continuously */ }</pre>	<p>Program loops endlessly, updating readings every second.</p>	 <pre>4 } 5 6 void loop() { 7 // put your main code here, to run repeatedly: 8 9 } 10</pre>
-----------------------------	---	---	---

```
// Pipeline Section Monitor - Arduino UNO
```

```
// Monitors flow sensors, GPS, buttons for pipeline sections, vibration sensor for vandalism
```

```
// Displays info on I2C 20x4 LCD and sends debug info over SoftwareSerial
```

```
#include <TinyGPS++.h> // GPS parsing library
```

```
#include <SoftwareSerial.h> // For debug serial communication on pins 10/11
```

```
#include <Wire.h> // I2C communication library
```

```
#include <LiquidCrystal_I2C.h>
```

```
// For I2C LCD display
```

```
// ----- PIN CONFIGURATION -----
```

```
const uint8_t FLOW_UP_PIN = 3; // Upstream flow sensor (interrupt pin 1)
```

```

const uint8_t FLOW_DOWN_PIN = 2; // Downstream flow sensor (interrupt pin 0)

const uint8_t VIB_PIN = 4; // Vibration sensor pin

const uint8_t BTN_A = 9; // Button for Section A

const uint8_t BTN_B = 8; // Button for Section B

const uint8_t BTN_C = 7; // Button for Section C

const uint8_t BTN_D = 6; // Button for Section D

// ----- TIMING CONSTANTS -----

const unsigned long REPORT_INTERVAL_MS = 1000; // Report data every 1000 ms (1
second)

const unsigned long SECTION_CYCLE_MS = 1000; // Cycle button sections every 1000 ms if
multiple pressed

// ----- FLOW SENSOR CONSTANT -----

const float PULSES_PER_LITRE = 450.0; // Sensor generates 450 pulses per litre of flow

// ----- LCD CONFIGURATION -----

const uint8_t LCD_ADDR = 0x20; // I2C address of the LCD (change if needed)

```

```
LiquidCrystal_I2C lcd(LCD_ADDR, 20, 4);    // Create LCD object for 20 columns x 4 rows
```

```
// ----- SERIAL CONFIGURATION -----
```

```
TinyGPSPlus gps;                          // GPS object from TinyGPS++ library
```

```
// SoftwareSerial pins for debug output to external monitor
```

```
const uint8_t MON_RX_PIN = 10;
```

```
const uint8_t MON_TX_PIN = 11;
```

```
SoftwareSerial monitorSerial(MON_RX_PIN, MON_TX_PIN); // Debug serial at 19200 baud
```

```
// ----- PIPELINE ENDPOINTS (GPS coords) -----
```

```
const double START_LAT = 6.333134; // Start of pipeline latitude
```

```
const double START_LNG = 5.664700; // Start of pipeline longitude
```

```
const double END_LAT = 6.375555; // End of pipeline latitude
```

```
const double END_LNG = 5.678900; // End of pipeline longitude
```

```
// ----- SECTION STRUCTURE -----
```

```
// Represents a pipeline section with name, GPS location, and button pin
```

```

struct Section {

    char name;    // Section letter (A, B, C, or D)

    double lat;   // Latitude of section

    double lng;   // Longitude of section

    uint8_t btnPin; // Button pin associated with this section

};

Section sections[4]; // Array holding all 4 sections

// ----- FLOW SENSOR COUNTERS -----

// These variables count pulses from sensors; volatile because they are changed inside interrupts

volatile unsigned long pulsesUp = 0; // Pulses from upstream sensor during the current interval

volatile unsigned long pulsesDown = 0; // Pulses from downstream sensor during the current
interval

// Total pulses since start (not reset each interval)

unsigned long totalPulsesUp = 0;

unsigned long totalPulsesDown = 0;

// ----- TIMING VARIABLES -----

```

```

unsigned long lastReport = 0;    // Time when last data report occurred

unsigned long lastSectionCycle = 0; // Time when last button section cycle occurred

uint8_t cycleIndex = 0;        // Index for cycling through multiple pressed buttons

// ----- INTERRUPT SERVICE ROUTINES -----

// These functions run automatically on rising edges from flow sensors

void isrUp() {

    pulsesUp++;    // Increase upstream pulse count

    totalPulsesUp++; // Increase total upstream pulse count

}

void isrDown() {

    pulsesDown++;    // Increase downstream pulse count

    totalPulsesDown++; // Increase total downstream pulse count

}

// ----- HELPER FUNCTION: Convert pulses to Liters per minute -----

```

```

// pulses: number of pulses counted in intervalMs milliseconds

// intervalMs: time interval in milliseconds

// Returns flow rate in Liters per minute

double pulsesToLpm(unsigned long pulses, unsigned long intervalMs) {

    if (intervalMs == 0) return 0.0; // Prevent division by zero

    double liters = (double)pulses / PULSES_PER_LITRE; // Convert pulses to liters

    double minutes = (double)intervalMs / 60000.0; // Convert ms to minutes

    return liters / minutes; // Calculate liters per minute

}

// ----- HELPER FUNCTION: Build pipeline sections with GPS coords and button pins -----
-----

void buildSections() {

    for (int i = 0; i < 4; ++i) {

        double t = (double)i / 3.0; // Normalized position along pipeline (0 to 1)

        sections[i].name = 'A' + i; // Assign section name from 'A' to 'D'

        // Linear interpolation for latitude and longitude along pipeline

        sections[i].lat = START_LAT + t * (END_LAT - START_LAT);

        sections[i].lng = START_LNG + t * (END_LNG - START_LNG);
    }
}

```

```

// Assign button pin for each section

sections[i].btnPin = (i == 0 ? BTN_A : i == 1 ? BTN_B : i == 2 ? BTN_C : BTN_D);

}

}

// ----- HELPER FUNCTION: Display section info and flow on LCD -----

void displaySectionOnLCD(const Section &s, bool vandal, double upFlow, double downFlow) {

    lcd.clear();

    lcd.setCursor(0,0);

    lcd.print("LEAKAGE DETECTED");

    lcd.setCursor(0,1);

    lcd.print("SECTION ");

    lcd.print(s.name);

    // Display latitude on row 3

    lcd.setCursor(0,2);

    char latBuf[12];

    dtostrf(s.lat, 8, 4, latBuf);

```

```
lcd.print("LAT:");

lcd.print(latBuf);

// Display longitude on row 4

lcd.setCursor(0,3);

char lonBuf[12];

dtostrf(s.lng, 9, 4, lonBuf);

lcd.print("LON:");

lcd.print(lonBuf);

// Send info to debug monitor serial port

monitorSerial.print("Section ");

monitorSerial.print(s.name);

monitorSerial.print(" Vandal:");

monitorSerial.print(vandal ? "YES" : "NO");

monitorSerial.print(" Up(L/m):");

monitorSerial.print(upFlow, 2);

monitorSerial.print(" Down(L/m):");
```

```

monitorSerial.println(downFlow, 2);

}

// ----- HELPER FUNCTION: Display flows, status, and GPS info on LCD -----

void displayFlowsOnLCD(double upFlow, double downFlow, const char *status, double lat,
double lng, bool gpsValid) {

    lcd.clear();

    lcd.setCursor(0,0);

    lcd.print("PUMP:");

    lcd.print(upFlow, 2);

    lcd.print(" L/m");

    lcd.setCursor(0,1);

    lcd.print("END :");

    lcd.print(downFlow, 2);

    lcd.print(" L/m");

    lcd.setCursor(0,2);

```

```

lcd.print("STATUS: ");

lcd.print(status);

lcd.setCursor(0,3);

if (gpsValid) {

    // Display GPS latitude and longitude on the last row

    lcd.print("LAT:");

    lcd.print(lat, 4);

    lcd.setCursor(11,3);

    lcd.print("LON:");

    lcd.print(lng, 4);

} else {

    lcd.print("GPS: No fix    "); // Indicate no GPS fix available

}

}

// ----- HELPER FUNCTION: Read button states for pipeline sections -----

// Returns a bitmask where each bit represents if a button is pressed

```

```

uint8_t readSectionButtons() {

    uint8_t mask = 0;

    if (digitalRead(BTN_A) == HIGH) mask |= (1 << 0);

    if (digitalRead(BTN_B) == HIGH) mask |= (1 << 1);

    if (digitalRead(BTN_C) == HIGH) mask |= (1 << 2);

    if (digitalRead(BTN_D) == HIGH) mask |= (1 << 3);

    return mask;

}

// ----- SETUP FUNCTION (runs once when Arduino starts) -----

void setup() {

    // Start monitor serial for debug output

    monitorSerial.begin(19200);

    monitorSerial.println(F("Monitor serial started on pins 10(RX)/11(TX)."));

    // Start GPS hardware serial at 9600 baud

    Serial.begin(9600);

    monitorSerial.println(F("GPS (hardware serial) at 9600."));

```

```
// Initialize LCD and show welcome message
```

```
lcd.init();
```

```
lcd.backlight();
```

```
lcd.clear();
```

```
lcd.setCursor(0,0);
```

```
lcd.print("Pipeline Monitor");
```

```
delay(1000);
```

```
lcd.clear();
```

```
// Setup pipeline sections with GPS and buttons
```

```
buildSections();
```

```
// Set button pins as inputs
```

```
pinMode(BTN_A, INPUT);
```

```
pinMode(BTN_B, INPUT);
```

```
pinMode(BTN_C, INPUT);
```

```
pinMode(BTN_D, INPUT);
```

```

// Set flow sensor pins as inputs and attach interrupts

pinMode(FLOW_UP_PIN, INPUT);

pinMode(FLOW_DOWN_PIN, INPUT);

attachInterrupt(digitalPinToInterrupt(FLOW_UP_PIN), isrUp, RISING);

attachInterrupt(digitalPinToInterrupt(FLOW_DOWN_PIN), isrDown, RISING);

// Set vibration sensor pin as input

pinMode(VIB_PIN, INPUT);

}

// ----- MAIN LOOP FUNCTION (runs repeatedly) -----

void loop() {

// Feed all incoming GPS serial data into TinyGPS parser

while (Serial.available() > 0) {

char c = Serial.read();

gps.encode(c);

}

```

```

unsigned long now = millis();

// Check if it is time to report (every REPORT_INTERVAL_MS)

if (now - lastReport >= REPORT_INTERVAL_MS) {

    unsigned long interval = now - lastReport;

    lastReport = now;

    // Temporarily disable interrupts to safely read and reset pulse counters

    noInterrupts();

    unsigned long upCount = pulsesUp;

    unsigned long downCount = pulsesDown;

    pulsesUp = 0;

    pulsesDown = 0;

    interrupts();

    // Calculate flow rates in Liters per minute for upstream and downstream

    double upFlowLpm = pulsesToLpm(upCount, interval);

```

```

double downFlowLpm = pulsesToLpm(downCount, interval);

// Read vibration sensor state (detect vandalism if HIGH)

bool vandal = (digitalRead(VIB_PIN) == HIGH);

// Get GPS data validity and coordinates

bool gpsValid = gps.location.isValid();

bool gpsUpdated = gps.location.isUpdated(); // New GPS fix just arrived

double lat = gpsValid ? gps.location.lat() : 0.0;

double lng = gpsValid ? gps.location.lng() : 0.0;

// Read section buttons pressed as bitmask

uint8_t buttons = readSectionButtons();

if (buttons != 0) {

    // If any section buttons pressed, prepare list of those pressed

    Section* pressedList[4];

    uint8_t pressedCount = 0;

```

```

for (int i = 0; i < 4; ++i) {

    if (buttons & (1 << i)) pressedList[pressedCount++] = &sections[i];

}

if (pressedCount > 1) {

    // If multiple buttons pressed, cycle through them every SECTION_CYCLE_MS

    if (now - lastSectionCycle >= SECTION_CYCLE_MS) {

        lastSectionCycle = now;

        cycleIndex = (cycleIndex + 1) % pressedCount;

    }

} else {

    // Only one button pressed, reset cycle index to 0

    cycleIndex = 0;

}

// Display info for currently selected section

Section* s = pressedList[cycleIndex];

displaySectionOnLCD(*s, vandal, upFlowLpm, downFlowLpm);

```

```

} else {

// No section buttons pressed, display general flows and GPS status on LCD

char statusStr[20];

if (vandal) strcpy(statusStr, "VANDALISM!");

else strcpy(statusStr, "OK");

// If GPS just updated, print new fix to debug monitor

if (gpsUpdated) {

monitorSerial.print(F("GPS FIX -> Lat: "));

monitorSerial.print(lat, 6);

monitorSerial.print(F(" Lon: "));

monitorSerial.println(lng, 6);

}

displayFlowsOnLCD(upFlowLpm, downFlowLpm, statusStr, lat, lng, gpsValid);

}

}

```

}

4.3.1. Code Summary

- i. Setup initializes all hardware: serial ports, LCD, buttons, sensors, interrupts.**
- ii. Interrupts count pulses from flow sensors in the background.**
- iii. Loop: Reads GPS data continuously.**
- iv. Every second, calculates flow rates.**
- v. Checks vibration sensor for vandalism.**
- vi. Checks which section buttons are pressed.**
- viii. Displays info on LCD:**
- ix. If button(s) pressed: show section-specific info.**
- x. Else show flow rates + GPS + status.**
- xi. Sends debug info over SoftwareSerial.**

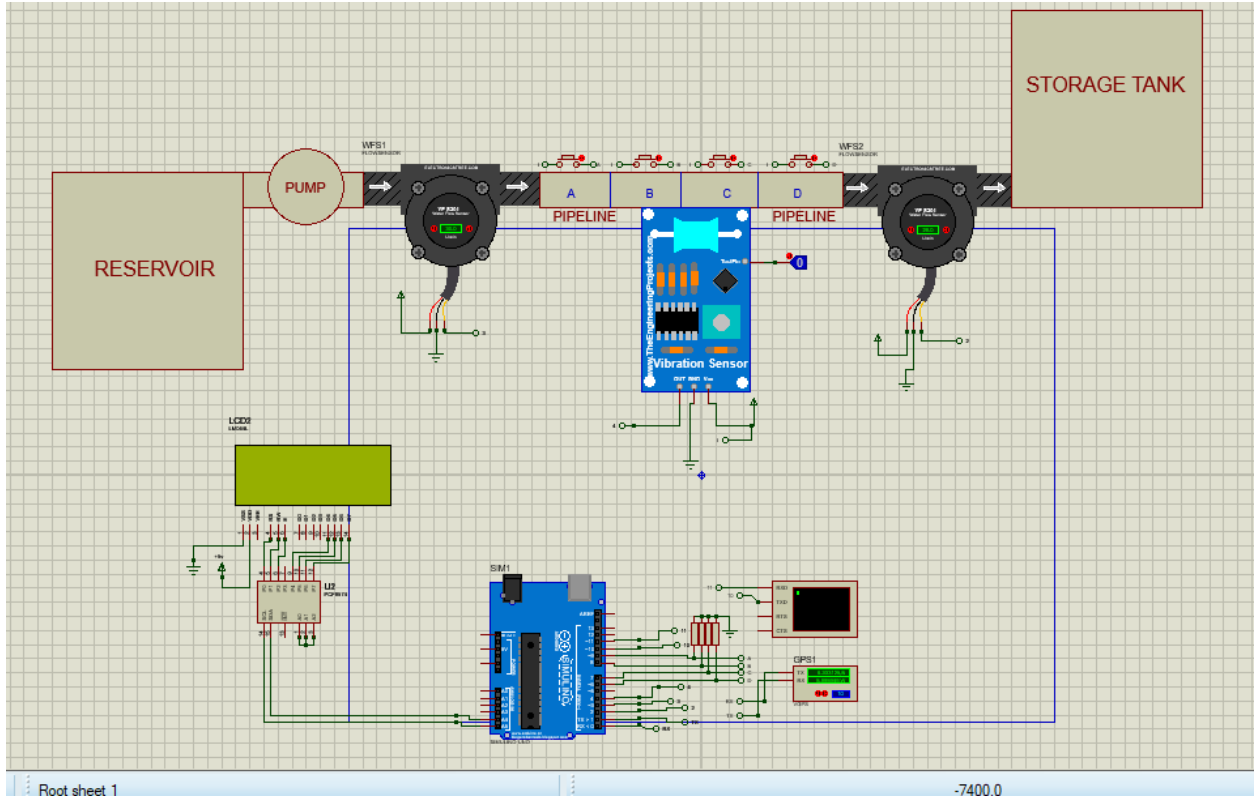


Fig 4.3.2 Simulation setup.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

4.1. CONCLUSION

A hybrid system capable of effectively monitoring liquid pipelines against third party interference has been designed and implemented. This works by incorporating different monitoring methods like flow monitoring, location detection using a GPS sensor and acoustic monitoring making the system more effective. This way, swift response can be gotten by any means pipelines are interfered with. The flow monitoring works by detecting abnormal flow rates in the pipelines and sensing an alert via the buzzer.

However, flow monitoring is most effective when there is a significant impact on the volume of the liquid in the pipeline. Acoustic monitoring provides this system with a more effective means of monitoring against third party interference as it instantly sets off an alarm when the noise in and around the pipeline is different from the normal ambient pipeline sound.

In cases where damage has already been done to the pipeline, the GPS monitoring helps us get to exact location of impact and can lead to culprits being apprehended.

4.2. LIMITATIONS

The main limitations of the developed system include:

1. Maintenance of this monitoring system is hectic and has to be carried out by trained experts only.
2. Due to changes in environmental conditions, false alarms might be given off at times.
3. This system is electricity dependent. Although a battery is used as a secondary source of power, its life is limited and system becomes battery dependent when there is power failure.

4.3. RECOMMENDATIONS

After completion and testing of the project, the following recommendations have been made in order to improve system efficiency.

1. A steady source of power should be worked on.
2. This system should be continuously upgraded as technology advances everyday.
3. Maintenance should be carried out regularly to ensure optimal system performance.

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