A FRAMEWORK FOR SINGLE AND MULTIPLE ANOMALIES LOCALIZATION IN PIPELINES

BY

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DEDICATION

To my family.

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LIST OF ABBREVIATIONS

MEMS	:	Micro Electro Mechanical Systems
WSN	:	Wireless Sensor Networks
IoTs	:	Internet of Things
OS	:	Operating System
GIS	:	Geographical Information System
PCS	:	Projected Coordinate System
GCS	:	Geographical Coordinate System
ANNs	:	Artificial Neural Networks
NPW	:	Negative Pressure Wave
MAP	:	Middleware Application
PPA	:	Pressure Point Analysis
IS	:	Invasive Sensor
ISTS	:	Invasive Sensor with Time Stamps
R.F	:	Recalibration Factor
FP	:	Fixed Point

ABSTRACT

Full Name : SULTAN ANWAR

Thesis Title : A FRAMEWORK FOR SINLGE AND MULTIPLE ANOMALIES LOCALIZATION IN PIPELINES

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Study of pipeline network which is used to transfer gas and oil from the production sites to consumers has widened all over the globe. On the other hand, there is a colossal loss of resources due to spills and leakages caused by natural disasters, human sabotage, and wear and tear of pipeline infrastructure. Serious economic losses can be faced in transportation of fluid through these anomalies that may incur additional costs for the final consumer. Nuclear fluids may also damage infrastructure and cause health risks to both humans and marine life. This issue is much critical as to fulfill the energy demands of population in entire world. For this purpose, a comprehensive study of recent pipeline anomalies detection techniques is performed. We proposed an effective solution to monitor pipelines and provided a framework for anomaly localization using COOJA simulator and Geographical Information Systems that can also be used in pre-disaster management scenarios, i.e. pipelines can be maintained prior to actual leaks and spills. Timely precautionary measures can thus be taken during the pre-disaster, disaster and post disaster stages, thereby minimizing wastage of natural resources. We also compare localization accuracy with current anomaly detection and localization techniques i.e. Negative Pressure Wave (NPW) and Pressure Point Analysis (PPA).

ملخص الرسالة

الاسم: سلطان أنور

عنوان الرسالة : اطار عمل لتحديد موقع الحالات الشاذة الأحادية والمتعددة في الانابيب

التخصص : شبكات الحاسب الآلي

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لقد اتسعت دراسة شبكة خطوط الأنابيب التي تستخدم لنقل الغاز والنفط من مواقع الإنتاج إلى المستهلكين في جميع أنحاء العالم. ومن ناحية أخرى، هناك خسارة هائلة في الموارد بسبب الكميات المنسكبة والتسرب الناجم عن الكوارث الطبيعية والتخريب البشري والحروب البنية الأساسية لخطوط الأنابيب. هناك خسائر اقتصادية فادحه عند نقل السوائل في بعض الحالات الشاذة التي قد تكبد المستهلك النهائي تكاليف إضافية. وقد تؤدي السوائل النووية أيضا إلى إلحاق الضرر بالبنية التحتية وتسبب مخاطر صحية لكل من البشر والحياة البحرية. حيث تعتبر هذه مشكله حرجه لان هذه السوائل مهمه لتلبيه احتياجات السكان حول العالم للطاقة الناتجة من هذه السوائل. لهذا الغرض، قمنا مؤخرا بإجراء دراسة شاملة لتقنيات الكشف عن الحالات الشاذة في الأنابيب. واقترحنا حلا فعالا لرصد خطوط الأنابيب وتوفير إطار لهذه الحالات باستخدام برنامج المحاكاة COOJA ونظم المعلومات الجغرافية التي يمكن استخدامها أيضا في سيناريوهات إدارة ما قبل حدوث الكارثة، أي أنه يمكن الحفاظ على خطوط الأنابيب قبل التسربات والانسكابات الفعلية. ومن ثم يمكن اتخاذ تدابير احترازية في الوقت المناسب خلال مراحل ما قبل حدوث الكارثة أو بعدها، مما يقلل بالتالي من هدر الموارد الطبيعية. كما قمنا بمقارنة الدقة لتحديد آماكن الاختلالات باستخدام تقنيات الكشف عن الحالات الشاذة وتقنيات تحديد المواقع، مثل Negative Pressure Wave (NPW) and Pressure Point Analysis (PPA).

درجة الماجستير في شبكات الحاسب الآلي

جامعة الملك فهد للبترول والمعادن

الظهران- اللملكة العربية السعودية

CHAPTER 1

INTRODUCTION

Wireless Sensor Networks (WSNs) based applications are continuously improving with rapid technological advancements in Micro Electro Mechanical Systems (MEMS) [1]. Internet of Things (IoTs) which is also based on WSNs is a hot area now a days for the researchers [2] [3]. The novel advancements in wireless and control technology instigated us to work on WSNs [4]. WSNs consist of several wireless nodes that form a sensor network lead by beacon or sink node. The sensor nodes are used to sense the surrounding environment and then wirelessly communicate necessary data to the system to make certain control decisions [5]. In WSNs, Mote is a sensor device that can sense and collect data, calculate certain results and can forward the information to other motes or system independently. WSNs also consist of a system which is called Gateway that is implemented through Computer or Laptop devices to monitor overall environment. Sink node is used to connect WSNs and motes with other networks and internet as shown in Figure 1.1[6].

WSNs are being used in large amount of applications due to their cost effectiveness [7] and high demand in advance technologies. But they also have to deal with limited resources for transmission of power, data processing and energy efficiency [8]. A sensor node or mote consists of an energy source (battery), micro controller and wireless transceiver. Wireless sensor nodes are divided into three categories such as anchor or beacon node, localized node and normal node. Anchor node can detect its own location using GPS which makes it most powerful among other nodes. The location of localized node is determined through network layouts whereas the normal node is the node whose location cannot be determined [9].

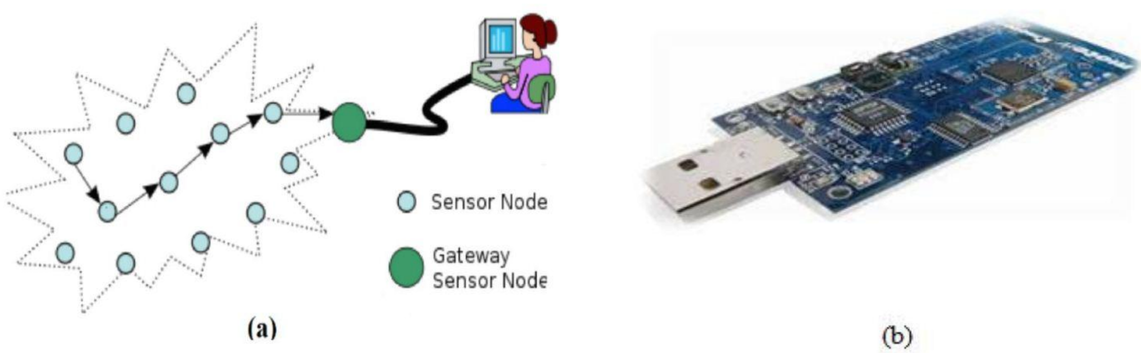

Figure 1.1: (a) WSN Structure (b) TmoteSky Sensor. [6]

1.1 Applications of WSNs

WSNs are adoptable and flexible due to which they are used in many applications related to many fields. The applications that are developed so far are divided into certain categories [10] [11] [12]. These categories are discussed in the following sections.

1.1.1 Health

In applications related to health, WSNs are used to organize drugs in healing process, diagnosing and incorporated observing of patients, tele-monitoring of human psychological problems, provide incapacitate interfaces and monitoring of medical staff and patients as shown in Figure 1.2.

Figure 1.2: Health WSN application. [7]

1.1.2 Transportation

It has become much easier to collect data of heavy traffic by deploying WSNs in potential positions or locations across the region. They are being used to collect and send the data of multiple nature in case of heavy and low traffic. They are also used to monitor violation of traffic rules in order to control the traffic in effective way. With the help of WSNs, alternate routes can be identified in case of an accident or traffic congestion as shown in Figure 1.3.

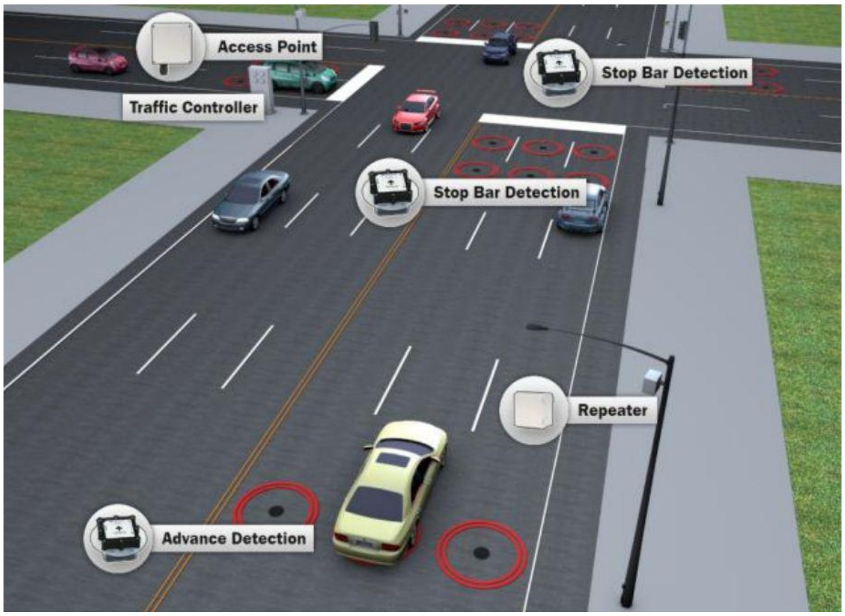

Figure 1.3: Transportation WSN application. [7]

1.1.3 Military

WSNs are significant to be used in army or military applications such as tracking, observing and restricting the enemy to ensure the safety of military installations. They have become need of an hour for several army applications as elaborated in Figure 1.4. They help to ensure military needs due to the features like self-association, internal failure adaptation, efficient and reliable communication.

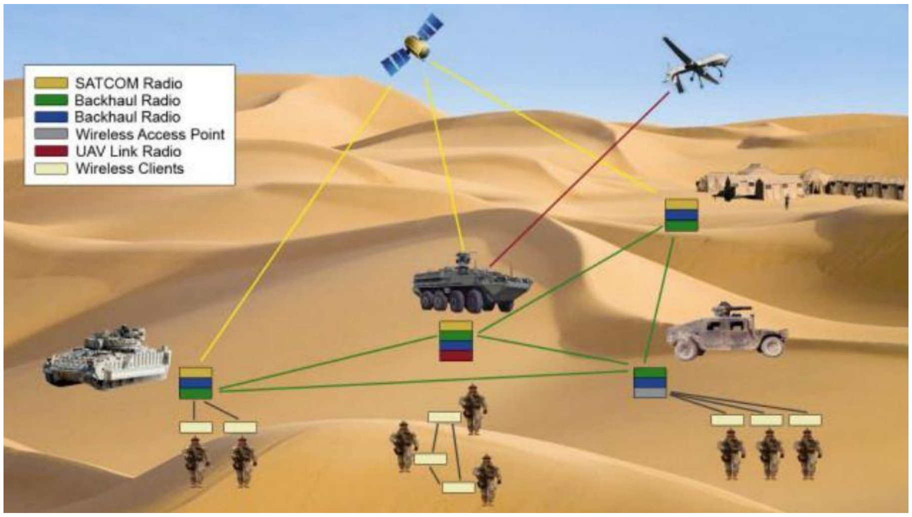

Figure 1.4: Military WSN application. [7]

1.1.4 Agriculture Sector

Applications related to agricultural sector are utilizing WSNs in order to keep track and monitor certain parameters on or off fields such as moisture, temperature, water level etc. WSNs are used to send information and alarms to system as shown in Figure 1.5.

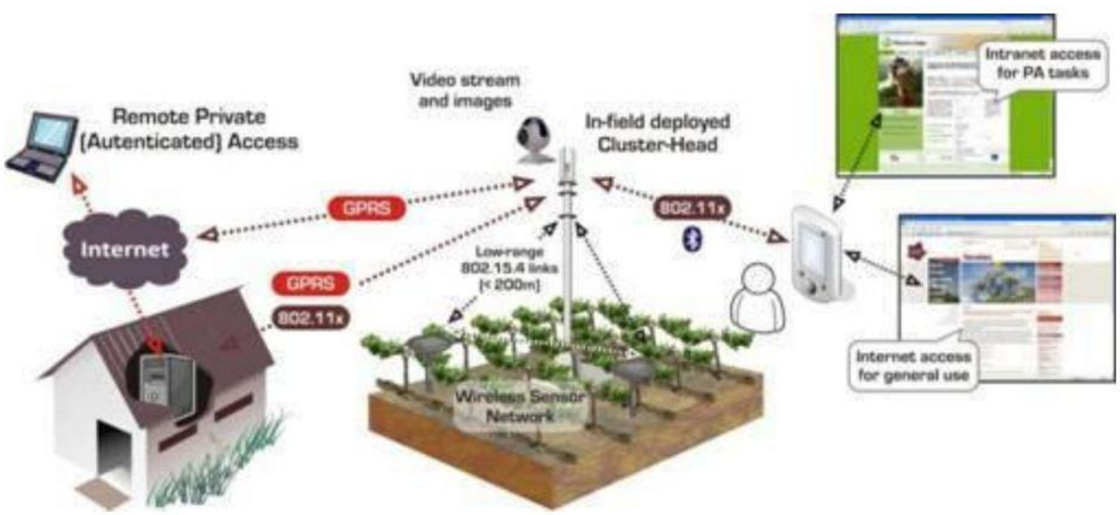

Figure 1.5: Agriculture monitoring WSN application. [7]

1.1.5 Structural Monitoring

WSNs are also used in bases and structural projects such as burrows, river banks, flyovers and bridges to examine their development. Engineers monitor and control the resources remotely using WSNs through which they can gather and analyze all the data. They can examine remote locations as well where it is difficult to go as shown in Figure 1.6.

Figure 1.6: Structural monitoring WSN application. [7]

1.1.6 Industrial Monitoring

Wired sensors are attached with wire due to which they are much vulnerable to failure and are difficult to reach in remote locations. Wireless sensors have solved this problem that can be utilized in diverse locations and applications. Commercial enterprises are now a days using WSNs broadly to examine and convey the condition of its apparatus as shown in Figure 1.7.

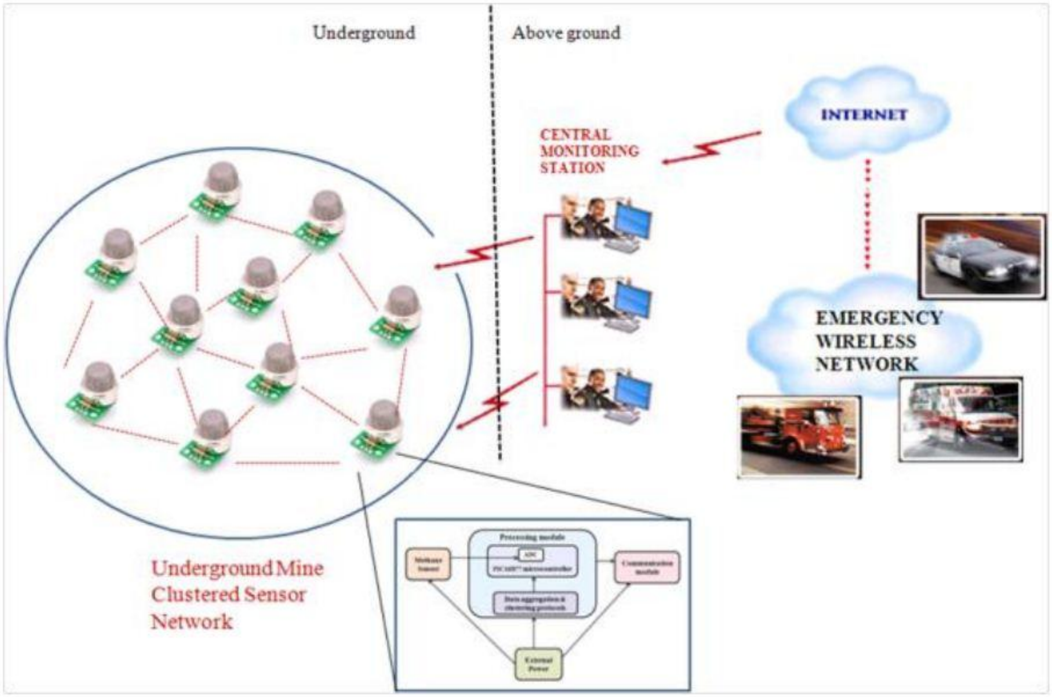

Figure 1.7: Industrial monitoring WSN application. [7]

1.2 Challenges in implementing WSNs

WSNs offer considerable range of challenges that still need to be addressed. We have listed down main challenges in deploying WSNs in various applications.

1.2.1 Operating Systems

The OS of a sensor node offers memory and other resources in a restricted manner. The issues related to the sensor node operating system are as follows:

- The data collected from the adjoining domains is to be computed by the sensor node. Sensor node will process, compute and control the data by utilizing the limited resources offered by the operating system. Consequently, limited resources will provide limited data management and functionality.

- The Operating System not only provides basic and simple level network administration but also supports multi hop routing. It provides simple programming model which is critical for complex computations.
- Consumption control of battery power is much essential in sensor node for which the built in components are necessary for this purpose. Battery power of motes cannot be energized according to the needs due to small size, low prices and their deployment in remote locations. So the operating system must be robust enough to accommodate all applications keeping in view energy efficiency of a sensor node. Many operating systems that include Nano Qplus, Mantis OS, Tiny OS and Contiki have been introduced so far keeping in view above mentioned challenges [13-15].

1.2.2 Communication

Efficient work of WSNs depends on reliable wireless transmission which is much difficult to obtain or foresee its behavior. There are various issues related to WSNs communications that are mentioned below:

- Local signal processing and low duty cycling is implemented in sensor nodes that are expected to provide extra working lifespan by utilizing lesser energy.
- Signal strength must be good enough so that the deployed sensing should work even against natural obstructions. Therefore, wireless domain will remain strong enough even in the presence of distinct variables such as scattering, scrambling and reflection.
- The adjustment of multi hop networking is critical for sensing nodes to decrease range of transmission.

1.2.3 Localization

Localization is a process to compute locations of wireless devices in a network. Sensors' localization is a challenging task in WSNs in which sensors are deployed at random locations. In monitoring applications, they need to be localized immediately after deployment. Unfortunately, there isn't any mechanism or supporting framework for localization during their time of deployment [16, 17]. There are certain prerequisites that need to be achieved by the sensor networks during localization. [18].

- Centralized localization algorithm has such mechanism that needs large calculations for a particular sensor to determine its location in the network domain. Therefore, decentralized localization algorithms would be much resource effective and time efficient if implemented successfully.
- Localization algorithms must have certain amount of flexibility to localize the lost sensors or deal with inaccurate sensors' locations that may obtain through wrong estimations.
- It is stated in [19] that the localization efficiency can be increased through addition of more sink or beacon nodes in the domain. As mentioned above, the sink node already knows its location, so localization of other nodes is easy to estimate with the help of the presence of nearby sink node. However, this solution has certain disadvantages e.g. sink node incurs higher costs in contrast to other nodes. They may also become useless after getting the locations of nearby nodes.
- Particular equipment for sensors will be required in case of Time of Arrival (ToA) and Signal Strength (SS) based algorithm implementations.

1.2.4 Security

WSNs are much vulnerable to intrusions, therefore, numerous intrusion detection security algorithms have been developed to secure sensor domains [20] [21]. Fundamental security requirements for WSNs are listed below [22, 23]:

- Unauthorized users must be restricted at all cost to provide confidentiality to critical information in the domain.
- Verification must be implemented in order to authenticate the authorized members of network. Every sensor node must be able to verify the authentic source of information to ensure that the information is not coming from enemy. The enemy may intrude the network and send incorrect information to the legitimate nodes to destroy or hack whole network.
- Integrity of data must also be ensured in order to avoid mistaken data. Integrity of data is much critical in applications like human services inspection and contamination.

1.3 WSN Simulators

Advanced tools, communication stacks and normal operating systems cannot be used in WSNs due to limited resources. Because of this problem small operating systems are developed for such resource constraint networks. The most eminent operating systems are TinyOS and Contiki OS that are equipped with transmission stacks, simulators that can be ported to minimum equipment platform. Due to resource restriction, programming of nodes is much challenging and difficult to make battery powered nodes energy efficient [24, 25].

Real systems are emulated through a tool called simulator which is used extensively in research. The simulator makes it easy to develop and deploy sensor networks in range of fields such as computer systems, economics, biology and material sciences.

Simulator provides a software based implementation of radio system of sensor nodes. Some of the simulators have real system based radio that can also produce obstruction impacts among the nodes while certain simulators have more conceptual models.

Simulators in research work provide extra details about nodes' data, communication behavior of nodes and efficient examination of system in less time. It is also useful to reiterate the same experiment if needed within no time. More experimental control can be gained in case simulator based implementation such as ratio of packet loss, mobility and number of nodes [26].

1.4 COOJA Simulator

COOJA is a simulator which is based on Java and is developed to simulate sensor networks. Contiki OS is implemented on the network nodes. COOJA based sensor network simulation can accommodate nodes with different capabilities such as simulation equipment or on board programming. It offers large amount of simulator functions and is adaptable enough to carry out extra performance and functionality. Contiki applications can be executed on COOJA either by running the requested code for sensor node or by running application code for PC workstation [27].

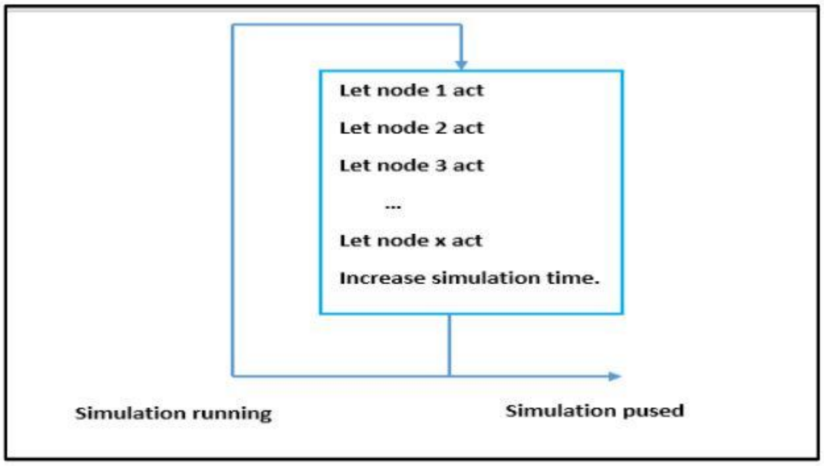

Figure 1.8: Structure of simulation loop.

1.4.1 COOJA Design Overview

Simulation in COOJA is carried out by simulating various nodes in which each node is associated by a node type. Majority of nodes perform their functions during simulation. The simulation procedure that represents simulation loop is refined when all the nodes complete their functions and the simulation time is updated as shown in Figure 1.8.

All of the nodes in COOJA have their own memory and interfaces. Their memory consists of various banks that start with particular information and address. All of the memory banks should possess data and Contiki OS information efficiently in order to forward it in less time for further computations.

Data is fetched through interfaces from the memory to perform several functions during node simulation. For example if time changes, the interface of clock must be updated through some specific time variables that will also be updated in memory.

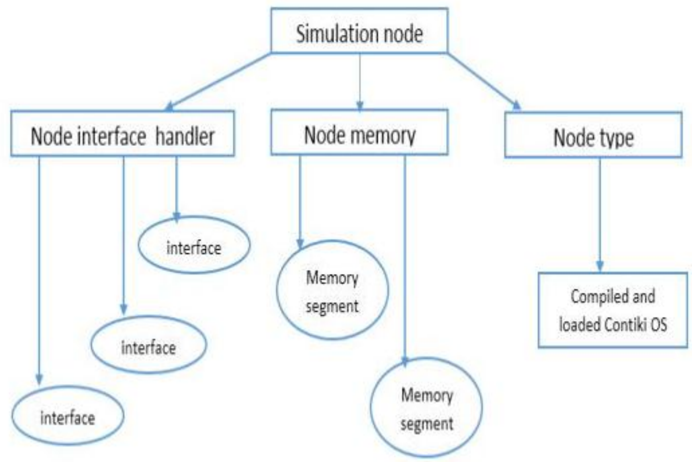

Figure 1.9: Simulated Node Architecture.

Node type is the part of Contiki OS that executes special code of a node and node itself which is explained above. All of the identical sensors are linked in Contiki OS with same stack. Node type maps address and variable names for example if there is a need to alter core time variable through clock interface, node type has to deliver the particular address of that variable. When a node performs its function, the node type then connects the node with relevant Contiki OS as shown in Figure 1.9 [28].

1.4.2 COOJA Interface

Simulated nodes are examined through a favored and fundamental approach known as COOJA interfaces. Dynamic simulation can be achieved by utilizing these interfaces that simulate all the devices and equipment. The interfaces are not only deal with the communication of node devices but they also associated with the functionality of node properties. If a node does not know its actual location than the interface of that node is called virtual interface while simulation of a moving node can be carried out through repositioning of interface. The simulation may become more efficient if the node moves over robotic arm or travel downwards.

Simulator and core, both may have COOJA interfaces. Interfaces associated with the simulator have ability to approach memory of node while the interfaces associated with core can approach the functions of Contiki OS. Regular conditions and connections lie inside the simulator and core interface. For example, radio interface of a radio transmitter exists in between core and simulator. When interfaces communicate with each other or radio information is broadcasted, they resist the framework of Contiki OS. When a node is clicked, core interface transmits radio information by enclosing it in buffer of Contiki OS in the same manner as of device driver with normal equipment.

1.4.3 COOJA plug-in

As nodes are linked together with the help of an efficient way of COOJA interfaces, the plugins are used to modify and introduce new functionality for a user in simulation. Modules can be installed at run time before they perform their actual functionality during simulation. User can make the objects of available and installed modules by simulations. Plugins can initiate their functionality as a customary Java panel by which user can easily construct graphical interfaces [27]. Plugins can be divided into four categories that are described below [29]:

- **GUI Plugin:** This plugin is used as an extra functionality if user wants to embed GUI in the system. The plugin is very useful in introducing and handling new plugins. User can get relevant data related to ongoing and advanced simulations easily with the help of Graphical User Interface as shown in Figure 1.10. In GUI based module, plugin may work fine even after the removal of ongoing simulation.

- **Simulating Plugin:** Simulation dependent module that works as a parameter when it is implemented. The plugin has to be deleted if there is a need to delete simulation while the plugin is made automatically when a new simulation is formed. A significant advantage of this plugin is, it shows the data related to current dynamic simulation that is simulation status, nodes position, nodes kinds and number of nodes.
- **Node Plugin:** A node dependent plugin that needs to be simulated. The plugin would be removed with the removal of plugin. Node behavior is monitored through plugin. It can also monitor the variable which is used to create the node and can halt the simulation considering predefined variable estimation.
- **Dynamic Plugin:** Dynamic plugin is the plugin which is not enrolled as above mentioned plugins. COOJA supports the plugins that are enrolled and unenrolled in accordance with the requirements of ongoing simulations. Simulation may add more than one plugins by using dynamic plugins on its own for which wireless medium is a better case. Visual interface is usually insufficient as radio medium can enroll more than one plugins by itself. Some of the useful plugins with extra advantages are implemented in COOJA such as simulation control, monitoring of mobile nodes and output log for radio traffic monitoring [29].

1.5 Motivation

Study of pipeline network which is used to transfer gas and oil from the production sites to consumers has widened all over the globe. On the other hand, there is a colossal loss of resources due to spills and leakages caused by natural disasters, human sabotage, and wear and tear of pipeline infrastructure. Serious economic losses can be faced in transportation of fluid through these anomalies that may incur additional costs for the final consumer. Nuclear fluids may also damage infrastructure and cause health risks to both humans and marine life. This issue is much critical as to fulfill the energy demands of population in entire world. For this purpose, comprehensive study of recent pipeline anomalies detection techniques is done. We have proposed an effective solution in this thesis to monitor pipelines and provided a framework for fault localization using Geographical Information Systems that can also be used in pre-disaster management scenarios i.e. pipelines can be maintained prior to actual leaks and spills. Timely precautionary measures can thus be taken during the pre-disaster, disaster and post disaster stages, thereby minimizing wastage of natural resources.

1.6 Research Objectives

This thesis aims to:

- Address the issues of sensing and detecting pipeline network leaks through WSNs.
- Make a comparative study between current detection and localization algorithms to assess localization accuracy.

- Propose an effective solution to monitor pipelines and develop a framework for anomaly localization in pipelines.
- Compare localization accuracy with existing techniques.

We have developed our own framework for anomaly localization using COOJA simulator. The focus of this thesis is on the accuracy of localization protocols.

1.7 Methodology

As discussed in previous sections, COOJA is an open source java based WSN simulator. It is not specialized for pipeline monitoring purposes. So we developed our own framework for anomaly localization in pipelines. It not only provides an elucidation for pipeline monitoring but also provides framework for anomaly localization with Geographical Information System. First and foremost step was to conduct an extensive literature survey of recent leak detection and localization techniques. Then propose an effective solution for pipeline monitoring. Next phase was to simulate the proposed solution. We used COOJA Simulator as a part of our framework any other simulator can be used. External Script Support (ESS) and External Modular Support (EMS) are used to give support for pipeline monitoring. ESS and EMS act as an external aid for simulator e.g. External Mobility plugin was used as EMS to aid in node mobility. Several Python Scripts were used as ESS to generate node positions. ESS was also used for controlling simulations i.e. repetitions, stop at specific time etc. After successful simulation, data is sent to Middleware Application (MAP) for further processing and calculation. MAP can do memory intense calculations for final localization results. MAP has the capability to generate GIS compatible data in order to transform anomalies and pipeline data to a real time geographical information system. Python scripts were written for final data projection using various coordinated systems. With GIS, they are two main coordinate systems. 1. Geographical Coordinate System (GCS). 2. Projected Coordinate Systems (PCS). Both coordinates provide a framework for defining real world locations. GCS mainly refers with the use of latitude and longitudes i.e. spherical coordinate system whereas PCS provides mechanism to project maps' spherical surface to a two dimensional Cartesian coordinate plane. There are hundreds of GCS and thousands of PCS available with varying parameters like units of measurement, datum, central median, spheroid of reference, shifts in -x -y directions, measurement framework (geographic/plain metric) etc. Data can thus be projected to any of GCS and PCS. Figure 1.10 shows the workflow followed to achieve our goals. Note: The path for google API is not followed in this thesis. It was Plan B, incase GIS integration fails.

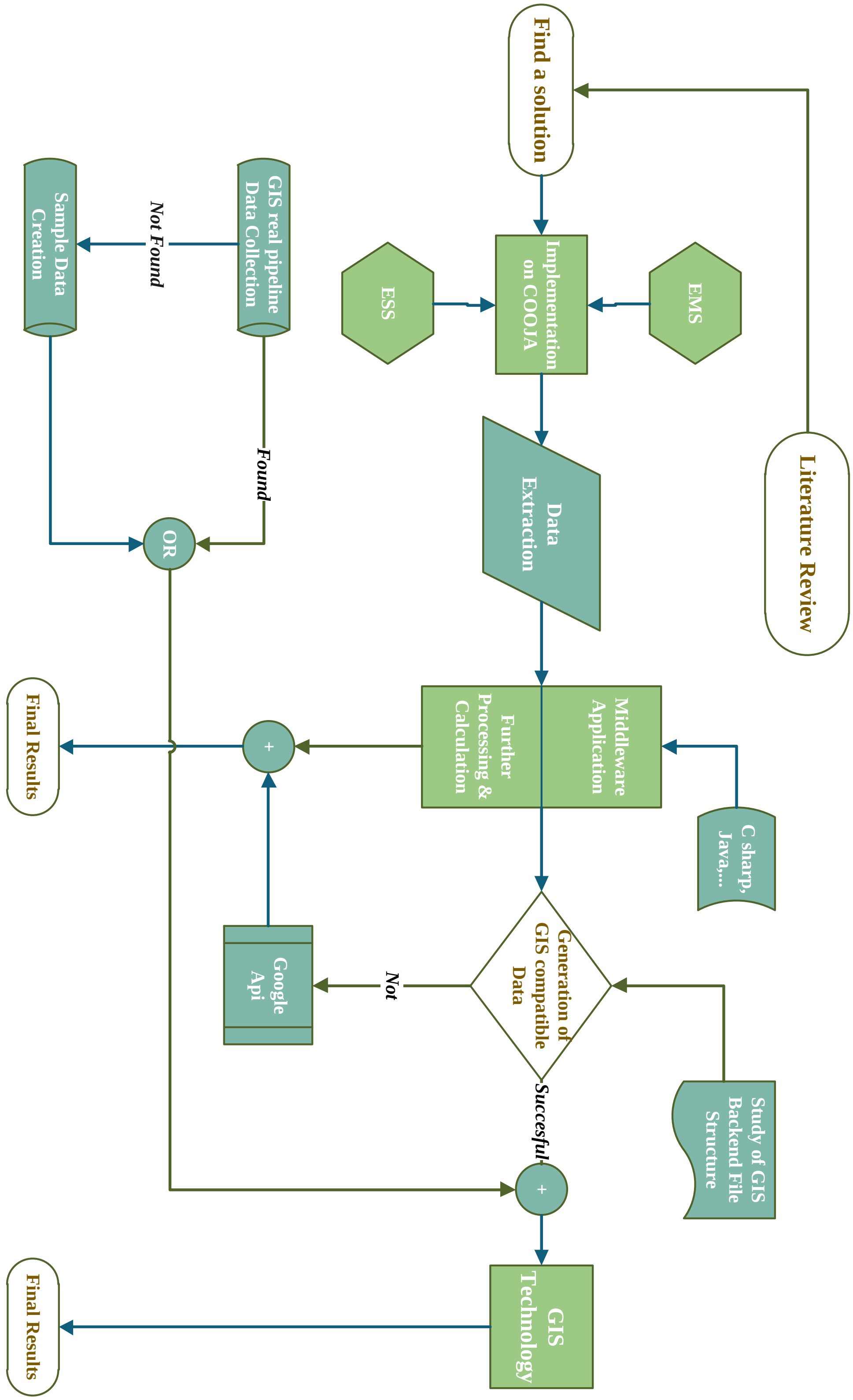

Figure 1.10: Methodology – Framework.

1.8 Thesis Outline

The thesis outline is organized as follows:

Chapter 2 has an extensive literature review, with the classification of different anomaly detection techniques, hardware and software based anomaly detection methods. Chapter 3 presents implementation and evaluation of Negative Pressure Wave (NPW) and Pressure Point Analysis (PPA) methods. In Chapter 4, Invasive Sensor with Time Stamps (ISTS) localization technique is proposed and implemented using the developed framework. In Chapter 5, NPW, PPA and ISTS are evaluated based on localization accuracy. Chapter 5 concludes with conclusion, future work and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Large amount of fluids are being transported through pipelines. They are dominant source to cover long distances. Thus anomalies in pipelines is a critical problem that may lead towards huge environmental pollution and economic losses which must be controlled in order to enhance efficiency to supply fluids from one place to another [30]. The main causes for pipeline leakages could be human carelessness, natural accidents or pipeline material and infrastructure. Mostly, the methods used for leak detection contains a maintenance personnel who use to monitor pipeline on periodic basis but one main disadvantage of this method is slow response. Due to which fluid transportation system can face more economic losses. To overcome this problem smart, intelligent and inexpensive monitoring sensors have been developed based on the technology of Micro Electro mechanical Systems (MEMS) [31]. Smart sensors consist of many sensors that consume low power and consist of actuator, communication interface, power source, memory and a processor. Wired and wireless systems have been developed for smart sensors that can be utilized according to environmental requirements to monitor leak detection in real time [32] [33] [34]. In wired systems, the data is transmitted to a control station through wire but this method is costly due to physical infrastructure, more installation complexity and time, more possibility of damage especially in underground or under water pipelining. On the other hand wireless sensors are used to transmit data through radio signals [35],[36],[37] [38] but the major issue is of power consumption [39]. Because power cannot be continued for most of the wireless sensors especially in remote areas so power is delivered in both wired and wireless sensors that are connected in hybrid mode [40].

Design and deployment of WSNs in pipeline leak detection depends upon fluid type and the environment in which pipeline is going to be placed [40]. Generally the fluid that transported through pipelines are thermal fluids, sewage, gas, oil and water. Usually the pipelines are placed inside and outside water or underground and above ground on soil [41]. Environment and fluid type in pipelines are also important factors in decision that whether the WSNs to be placed inside or outside the pipe for leak detection [42]. WSNs for leak detection are broadly classified based on communication mechanism they adopt, with one another as well as with fluid itself [43]. The sensors that are in contact with fluid are called invasive while that are not in contact are called noninvasive sensors. Vibration and acoustic sensors are non-invasive while velocity, flow and pressure transients are invasive.

2.2 Classifying leak detection techniques

Leak detection techniques can be classified into various categories as per different criteria. These criterion include: level of human dependence, number of sensors required and technological structure [44]. If classification is done based on level of human dependence then system can be classified into manual, semi-automatic and fully automatic based on number of humans involved. For number of sensors, it can be classified as gas sampling, optics, acoustic pressure and flow rate. This category contains several methods that is why they are usually divided into optical and non-optical methods

[45]. However some of the researchers categorize these methods into inferential, direct and indirect [46]. Direct methods deal with leak detection and pipeline monitoring based on visual inspection and hand held devices to measure gas diffusion, whereas Inferential or indirect method deals with leak detection based on variation of certain parameters of a particular pipeline such as pressure and flow rate.
There are two other categories of pipeline leak detection that are software based method and hardware based method in which hardware based method is very effective in leak detection and localization with the help of specially designed precise instruments. But these methods are expensive and difficult to install, therefore, there usage is limited in places with high possibility of risk such as natural disaster areas, rivers or pipelines with dangerous materials [44].

These hardware methods can be further classified into various categories based on the use of detection equipment. These methods include ultrasonic flow meters, soil monitoring, optical, vapor sampling, cable sensor and acoustic. While non-technical methods do not contain any kind of technical device rather they rely more on human or animal senses. Software based methods rely more on software. Such algorithms are used that detect leaks by continuously monitoring the state of pipeline parameters like pressure, temperature, flow rate etc. Based on their technical nature leak detection methods are classified as shown in Figure 2.1[44].

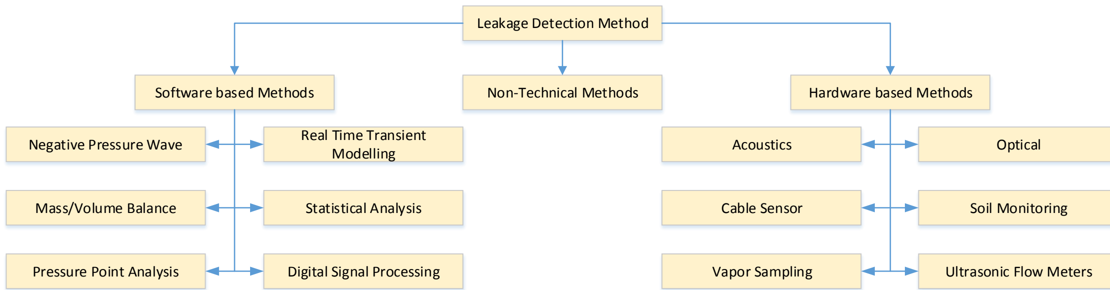

Figure 2.1: Leak Detection Methods Classification.

2.2.1 Hardware Based Leak Detection.

This section explains the hardware based method in more detail that also include recent research works and generic discussion by considering there advantages.

2.2.1.1 Fiber Optic Sensing

In this method fiber optic cable is installed throughout the pipeline to monitor leak detection. According to this method the material in pipeline gets physically connected with the fiber cable in case of leak occurrence. When material is touched with fiber cable, the cable temperature gets changed from where leak can be detected.

The method works on the principle of Optical Time Domain Reflectometry (OTDR) or Raman Effect in which the light of laser is dispersed when laser pulse is expanded throughout the fiber due to molecular vibrations. In this way the information about change in temperature is carried through dispersed light along the pipeline. Raman dispersed light consists of two components of shifted frequency that are stokes components and anti-stokes components. When there is a temperature difference in fiber cable the amplitude of anti-stokes components changes dramatically whereas amplitude of stokes components remain the same. That is why a mechanism is needed to confine stokes and anti-stokes components [47]. The low magnitude of dispersed light is a disadvantage associated with this method that can be avoided through multimode fibers of high numerical aperture. But multimode fibers do have features related to severe attenuation that is why the Raman method is only feasible for up to 10 Km distance pipeline [48].

There is another problem of Raman scattering that occurs because of thermal acoustic waves and propagation of optical signals which results in the increase of frequency shifted components. In result, the information about strain and temperature is carried through Brillion shift. On the other hand, the intensity of dispersed light is changed by Raman based method. For long term perspective, Brillion based method is more stable and accurate. Spectrum of dispersed light is shown in Figure 2.2 where the difference among Brillion and Raman based methods are demonstrated when a wavelength is transmitted in optical fiber [49].

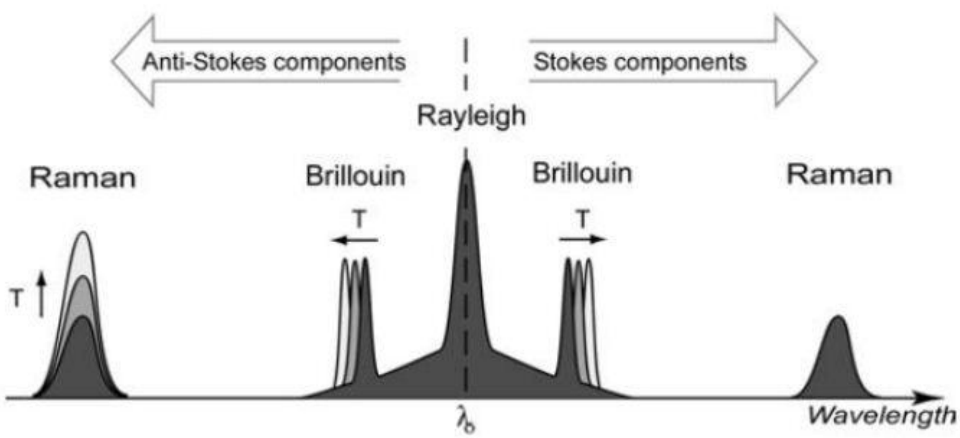

Figure 2.2: Scattered Light Spectrum Schematic Representation Of A Single Wavelength Signal Propagating in Optical Fibers. [49]

In 2002, a leak detection system containing fiber optics was laid over 55 Km pipeline in Berlin by a company named GESO. The system was operational until the reports of 2004 which also detected one leakage [48] in that time span. The major advantage of fiber optics is its power of resistance to interference of electromagnetic waves while it also has certain drawbacks that include maintenance and installation cost as well as its insensitivity towards variety of heterogeneous applications for pipeline monitoring. This method is also not suitable for existed underground pipelines because of the need of an extra excavation to find the suitable place for its installation [44].

2.2.1.2 Soil monitoring

Soil monitoring uses a nonhazardous and low cost gas tracer to be sent into the pipeline. The tracer consists of high quality volatile gas that escapes from the exact leakage point. Outer soil of pipeline is examined in case of any possible leak and its location can also be found out [50]. The method becomes reliable if more alarms are associated with the detection of small leaks but the one major disadvantage of this method is, the pipeline has to be fed with gas tracer continuously along with material to be transported which makes it much costly. Furthermore, this method is also not suitable for uncovered and pipelines without surrounding with soil.

2.2.1.3 Acoustic detection

This method detects the leaks based on sound produced at the time and place of leakage in pipelines that transport gases and fluids. Acoustic sensors are deployed outside of the pipeline than monitor and detect internal sound level and generate special baseline characteristics. The similarity in sound features is continuously monitored through acoustic sensors and when leak occurs, it produces acoustic signal of low frequency which is detected by the sensors. Leak sound features are different than normal sound so sensors detect it alarm is generated [51]. As the sound effects are stronger near leak so it becomes easy to localize the point of leak. Cross co-relation is used in general acoustic method which is used to detect and localize acoustic signals of leak. In this method, sensors are placed at both edges of pipes where the leak is likely to occur. The deployment of sensors can be carried out directly on suspected point or over road surface that is fire hydrants as can be seen in Figure 2.3.

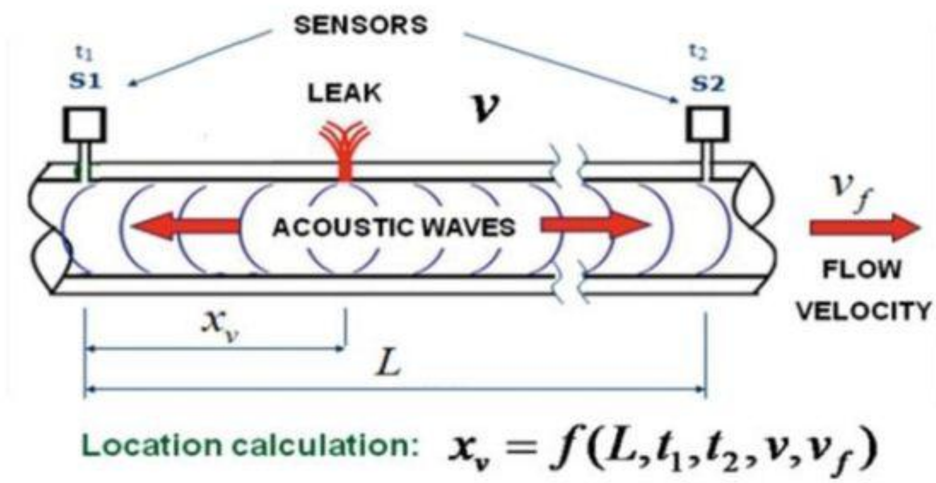

Figure 2.3: Acoustic Leak Detection.

Leak location could be found through velocity of sound propagation, sensing points distance and lagging time. Leak location could be detected through the equation below [52]:

$$d_1 = \frac{d - ct_{peak}}{2}$$

Where d is the distance among sensors, d_1 represents the distance from leak to sensor S1. c represents the velocity of propagation of sound waves and t_{peak} represents difference of time among same frequencies in each sensor. All of these parameters could be found through experiments. Leak detection efficiency and performance mainly rely on d where d should be low to gain maximum efficiency in leak localization. Higher levels of accuracy can be achieved through this technique. It's efficiency also depends upon the skills and proficiency of operator [53].

Artificial Neural Networks (ANN) based computational system and acoustic sensors are used to identify leaks. Leak is detected based on the difference of speed and amplitude of signal propagation [54]. Blesito [55] and Garcia [56] used ANN. They found promising and adaptable results. ANN is also used by Shibata [57] where the data of sound is recorded via microphones that were embedded in different locations from crash. Data collected is transformed through FFT. It is then delivered to ANN to make final decision. Zhao [57] has used NN for pipeline's pattern recognition. Acoustic sensors data is obtained and processed then passed with the help of filter to get the frequencies of 1, 5 and 9 KHz. These frequencies were used as an input to NN where neural experiments were taken place with the help of pipeline's database being in health and weak conditions. This method is useful for up to 100 meter pipelines but as distance increases, one has to attach more microphones along the pipeline which makes is more costly. A real time leak detection system was proposed by Avelino [58] who used sonic technology to employ wavelet transform for feature extraction and then NN is used for analysis and decision making for leaks in pipelines. The system used, consist of GPS, piezo resistive sensors and 32 bit DSPs. Piezo resistive sensors have high level of sensitivity and their mechanism depends on difference between electrical resistance of material because of the change in mechanical stress. These sensors were attached to both sides of pipeline to deliver the ability to detect fall of pressure due to leak occurrence. The decomposition of wavelet was applied after extraction of processed signals from sensors. In the end wavelet decomposition output was given to NN for decision making. As leak detection is based on fall of pressure in pipeline so the phases in which pressure is stable or increase were ignored. Obtaining the optimal sampling rate was a challenge in this experiment. They used 100 Hz, 200 Hz, 500 Hz and in the end managed to get 1 KHz of sampling rate. Prominent recognition in this work is the ability to differentiate among pump switching and leak detection. However this method is not suitable for long pipelines and does not offer leak localization.

Acoustic Detection technique has one major advantage in terms of feasibility of continuous monitoring of pipeline for leakage detection. Leak's size and location can also be determined through this method [44]. Whereas, vehicular pump and valve noises affect efficiency of this method as they will also be detected at sensor ends. In terms of cost, large numbers of sensors need to be installed on pipelines which also limit its feasibility to cover long distance pipelines.

2.2.1.4 Liquid or Vapor sensing tubes

In this method a vapor or liquid sensing tube is installed along the whole pipeline for leakage detection. This tube is filled with air while being in atmospheric pressure. Whenever leak occurs the liquid inside pipeline gets in contact with the tube and then penetrates inside. An air column with fixed speed is injected in tube to examine the concentration distribution in it. Gas sensors are deployed in sensing tube ends. The level of gas concentration increases with increase in leak substance which indicates the size of leak.

An electrolyte cell is deployed along the detected line. An accurate gas volume is transmitted into the tube through electrolyte cell. The gas and air travel from the entire length of sensing tube. The test gas generates an end peak when it passes from the detector. End peak indicates the entire length of sensing tube. Leak localization can be determined by computing ratio of end peak arrival and leak peak arrival [48]. This method is shown in Figure 2.4.

The disadvantage of this method is its low response time for leak detection. Also the cost of installation in long pipelines is very high due to which it is not suitable in terms of practical implementations. This method is also very complex to be adopted for above ground applications as well as for deep sites.

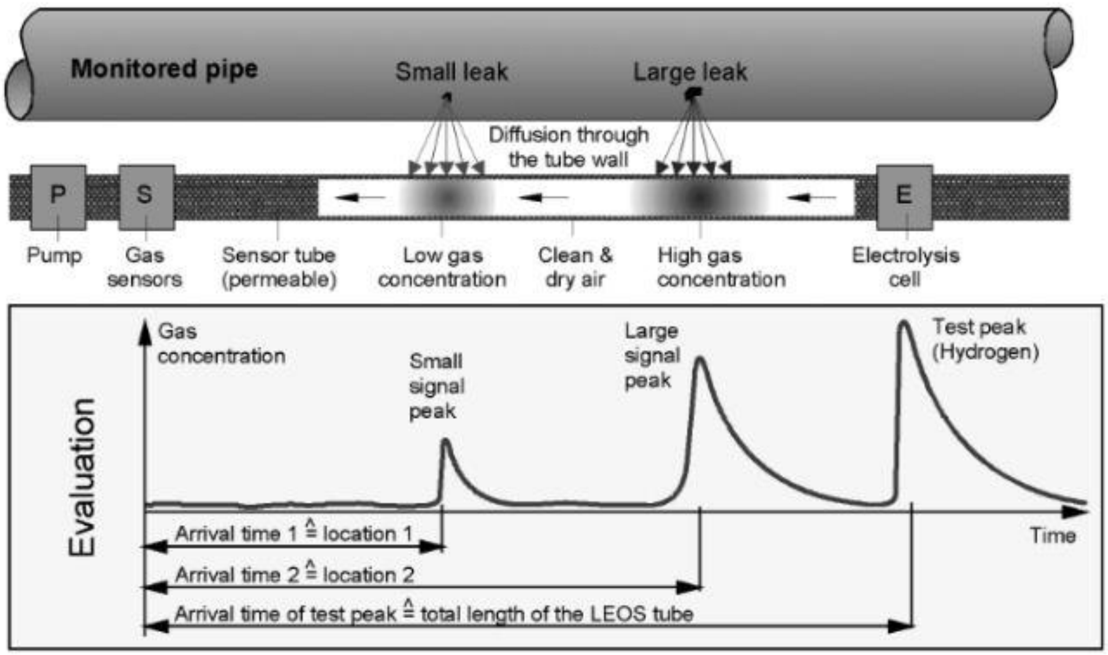

Figure 2.4: Vapor Sensing Tube Detection and Localization.[48]

2.2.1.5 Liquid sensing cables

Along with pipelines, these cables are installed that show changes in energy pulses. The changes occur because of impedance differentials and the energy pulses that are safe are sent via cables. As energy pulses passes through the cable, reflected energy map is saved in the memory and reflections are turned back to monitoring unit. The electrical properties are changed when liquid inside pipeline makes the sensor cable wet in case of sufficient leakage. This variation would become the cause for reflection at that point and leak is localized through this variation. The lag between reflected pulse and input pulse is used to calculate time of localization [48]. This method is suitable for short pipelines and for multiple leakge detection and localization.

2.2.2 Software Based Methods

Software based methods are briefly explained. General discussion, merits and demerits of recent research work for these methods is also described in this section.

2.2.2.1 Negative Pressure Wave Method

In this method, pressure is dropped when leak occurs. This is because of the unexpected reduction in the density of liquid at the location of leak. Consequently, the source of pressure waves travels outwards from leakage point in the opposite direction of leak. The fluid pressure is noted down after and before the leak occurs and the wave generated by this leakage is named as negative pressure wave. The signal of pressure reduction is measured by pressure sensors that are deployed in terminal ends, when the negative pressure wave moves towards pipeline section terminal ends. This is achieved due to the arrival of wave at the terminal ends that becomes the cause for inlet pressure drop and then drop in outlet pressure. Various negative pressure time differences are obtained at the terminal ends because leak can occur at any point on the pipeline. With the help of measured time differences obtained through pressure sensors deployed on the two sides, the point of leak, negative pressure wave velocity and length of pipeline section can be determined [59, 60].

In Figure 2.5the distance is considered as L, negative pressure wave velocity is represented as v, natural gas velocity in pipeline is depicted as u, the distance between upstream sensor and leak location is x and time is represented as t1 and t2 for the detection of wave through two sensors. Pipeline gas velocity is negligible when compared with negative pressure wave velocity and hence can be ignored [59, 61, 62]. But the authors in [63] have kept the pipeline gas velocity in consideration. Therefore, relationship among time variable and length can be established by considering pipeline gas velocity, because this relationship affects transmission of negative pressure wave inside the pipeline [63].

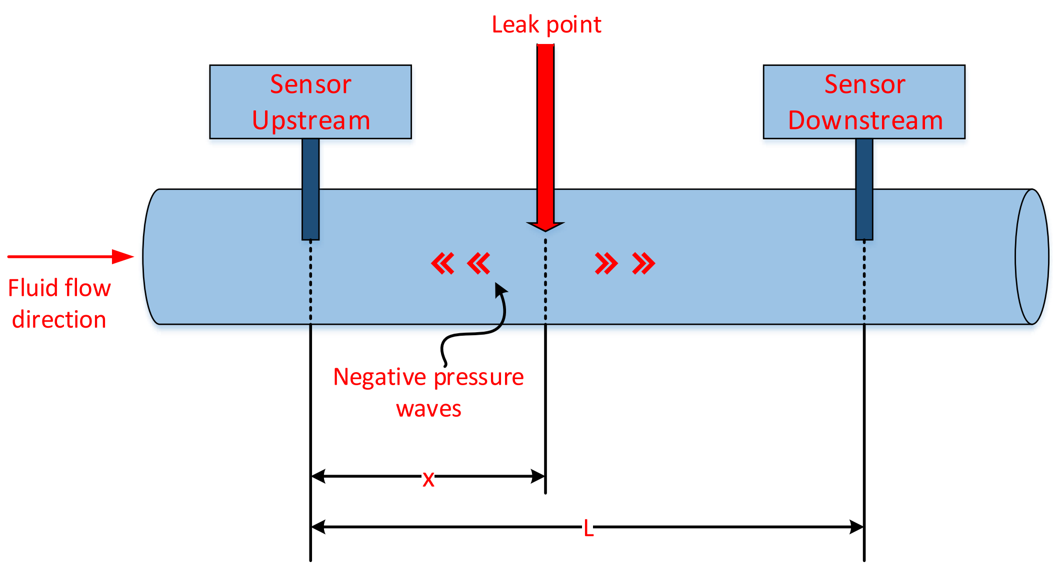

Figure 2.5: A Schematic of the negative pressure wave method [61].

Distance *x* between sensor and leak point can be determined through Equation 1 [63].

$$t_1 = \frac{x}{(v-u)}$$

$$t_2 = \frac{(L-x)}{(v+u)} \quad (1)$$

$$\Delta t = t_1 - t_2$$

Equation 2 is known as formula for general leak localization. *Hou et al.* [63] and *Shuqing et al.* [64] demonstrated a customized form of general leak localization

$$x = \frac{1}{2v}[L(v-u) + \Delta t(v^2 - u^2)] \tag{2}$$

Equation 2 has a common restraint that it considers pipeline natural gas velocity u and negative pressure velocity as constant [63, 64]. Whereas v and u depend on specific heat capacity, density, pressure and temperature of surrounding atmosphere. Equation 3 provided by [63] shows the updated version of equation 2.

$$u, v = \sqrt{\frac{\frac{Z^2RT}{P^2m}}{1 + \frac{ZDC}{PEe}}} \tag{3}$$

Where,

Z = gas compression factor

R = constant (8.3143 J/(mol.K))

T = gas temperature

P = gas pressure

m = molar gas value

D = pipeline diameter

C = coefficient for pipe restraint

E = elastic modulus for material of pipe

e = wall thickness of pipe

Formula of these velocities can be determined using hydraulic and thermal analysis. Leak localization is presented in equation 4 in which negative pressure wave and natural gas velocities are considered as variables.

$$t_1 = \int_0^x \frac{1}{v(x) - u(x)} dx$$

$$t_2 = \int_0^L \frac{1}{v(x) + u(x)} dx \quad (4)$$

$$\Delta t = t_1 - t_2$$

Numerical methods are used to calculate t1 and t2 as u(x) and v(x) are difficult to compute and equation 4's definite integrals are unmanageable integrals [63, 64]. Compound Simpson is a numerical method which is used for the rough estimation of definite integrals. This method is used by Hou et al. [63] to compute equation 4's variable integrals.

Compound Trapezoid is another method for estimating definite integrals, this method is used by Shuqing et al. [64] to compute integrals. The difference among both works is, Hou et al. [63] have used gas velocity in their experimental by considering it non negligible while Shuqing et al. [64] have not used gas velocity.

Tian et al. [61] have demonstrated the technical challenges that occur in leak detection and localization in Negative Pressure Wave Method (NPWM). They have suggested that accuracy and reliability can be increased in three areas that include reduced rate of false alarms, adaptive thresholding and quality of data. Quality of data decreases with data missing and duplication. Interpolation algorithms are used to solve the problem of data missing by repopulating the data while the problem of data duplication is solved through data processing to get rid of redundant data. Noise can also be eradicated through filtering methods.

Anomalies in slope curve of pressure transducers can be precisely detected through adaptive thresholding [61]. Adaptive thresholding is much suitable method instead of using constant threshold because the slope keeps changing in various working conditions. Statistical Process Control (SPC) [65] is proved to be an effective method for adaptive thresholding.

High false alarm rate is another challenge in NPWM that occurs because of pressure drop at transducers due to normal transient of pipeline. Sometime large pressure drop may occur due to these transients (that include opening and closing of pump valves) than drops caused due to leakage [61]. That is why such techniques need to adopt solutions that decrease the rate of false alarms. Examples of these techniques are discussed below:

- Composition of NPW method and other leak detection techniques for cross validation [66].
- Flow balance method can be integrated with flow meters to solve the problem of high rates of false alarms in NPWM [59, 61, 62]. Only pressure analysis is not sufficient to determine the cause for negative pressure waves that can be due to leak or due to pipeline's transient behavior. Therefore, NPW technique can be made more effective by hybridizing it with flow balance method in which ultrasonic sensors are deployed at both edges of pipeline as shown in Figure 2.6 [62]. The flow meters unceasingly calculate the signal of gas flow at the outlet and inlet of pipeline. No meaningful difference is generally recorded

among the flow readings in normal process. However, downstream flow will decrease and upstream flow will increase during leak occurrence. Hence the differential rate of flow becomes substantially large. Thus, by analyzing pipeline operation's normal transient, a decision can be taken for a specified differential threshold value and an alarm goes on when this value surpasses the threshold.

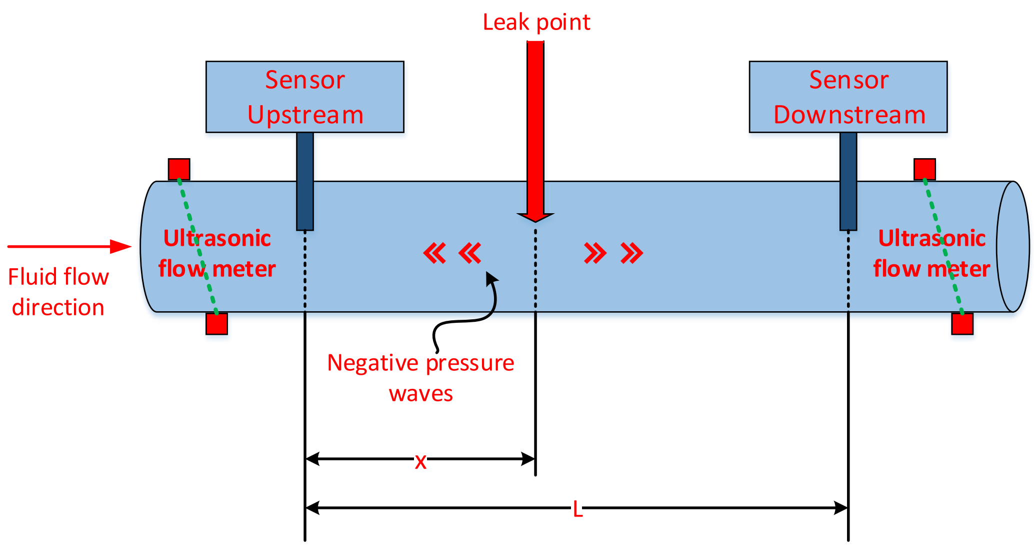

Figure 2.6: Negative Pressure Wave Method with flow meters.

- Pattern machine algorithms are the other technique through which false alarms can be reduced. This technique is useful as mostly, in case of leak, the pressure drop curve have various oscillations while there is a smooth drop curve in case of pump pressure. In this way we can discriminate that either pressure drop is due to normal pipeline transients or due to leak.
- More than one pairing of sensors can also decrease rate of false alarms [61].

Accuracy of leak localization can also be affected by inefficient time synchronization of upstream and downstream sensors that are used for monitoring purposes. Accurate Time Synchronization was obtained by Ma et al. with the help of GPS [59] which is very critical in locating leaks because only a little time deviation in monitoring may come up with a large error of localization [61].

There is a very effective computational tool known as wavelet transform which is used for image and signal processing applications. It can also be used for decreasing noise of the signal [67]. Wavelet transform has such characteristic of time localization through which it has become an excellent choice to examine non-stationary phenomenon. Due to this property, limited time Fourier transform is also solved by wavelet transform by examining non stationary signals [68]. These analysis are focused on various frequency ranges of original signal because wavelets that are also called frequency range components are decomposed into time domain signal. Wavelet transform is used to break down signal in high and low frequency ranges because desired signals attain from pressure sensors have low frequency as compared to noise. This is the reason why noise signal is separated from desired signal so that analyses should only be focused on useful data [61-64].

ATMOS wave is a kind of NPWM that has the ability to estimate leakage size [69]. NPWM can also be employed by generating premeditated transient pressure waves through regularly opening and closing of valves [70, 71]. The leak is detected and localized by the reflection of pressure waves. This method does not include any mathematical model and calculation and thus easy to use. Also this method does not require any system hardware and is more suitable for sudden, quick and small leaks. For non-sudden leaks, leaks go undetectable due to the low intensity of negative pressure waves and not able to get detected by the sensors deployed at terminal ends. This method is not very efficient for lengthy pipelines as it offers very low accuracy [72].

2.2.2.2 Mass Balance Method

The mass balance method is very simple which is based on process of mass conservation [73, 74]. Rate of line pack variable and Input and output mass flow rates are disturbed in case of leakage occurrence through which leak can be detected [75, 76]. Actual amount of gas in distribution system and pipeline is defined by line pack variable. When volume of fluid entering and leaving the pipeline exceeds a threshold level then alarm is raised. This method is describe by Liu et al. [77] and the difficulties in implementations are also addressed. They have also pointed out that process variables that include flow rate, pressure and temperature can be used to get mass or volume. A hybrid mass balance method is presented by Rougier et al. [78] that hybridize mass balance method with probabilistic method. But probabilistic method requires considerable amount of computational power whereas mass balance method is very easy for implementation on already constructed pipelines. It also offers low cost implementation by giving the advantage of using already available instrumentation over the pipeline [44, 79]. But the performance depends on measuring instruments' accuracy, frequency to obtain balance measurements and leak size. The major drawback of mass balance method is that, it cannot perform real time small leaks detection which results in loss of plenty of fluid before an alarm is raised. One more disadvantage of mass balance method is, it is much sensitive to be affected by random dynamics and disturbances that occur in pipeline time to time. Hence, to avoid high rates of false alarms during transient period of pipeline, threshold values are necessary to be adaptive. This method needs an additional localization method to localize the leak which it cannot perform alone.

2.2.2.3 Pressure Point Analysis

Pressure Point Analysis (PPA) is one of the significant methods to detect leakages in pipelines [79]. It requires continuous pressure measurement in whole pipeline at different locations. Whenever a mean pressure value is recorded to be below a threshold level, a decision for raising an alarm is made through statistical analyses of measurements. Mathematical derivations are presented by Bin Md Akib et al. [80] to compute pressure before and after occurrence of leak. These derivations show relation among pressure and temperature with leak and are time efficient for collection of samples and evaluation purposes. Actual leakage point can be located by using temperature and pressure drop. This method offers low cost and is easy to maintain because it only needs pressure signals that are delivered through detection points. This method is also suitable for underwater and cold environments. It also has the ability for to detect small leak which other methods cannot [44, 79]. On the other hand, it is unreliable for leak detection and localization in transient flows which limits its functionality in several applications.

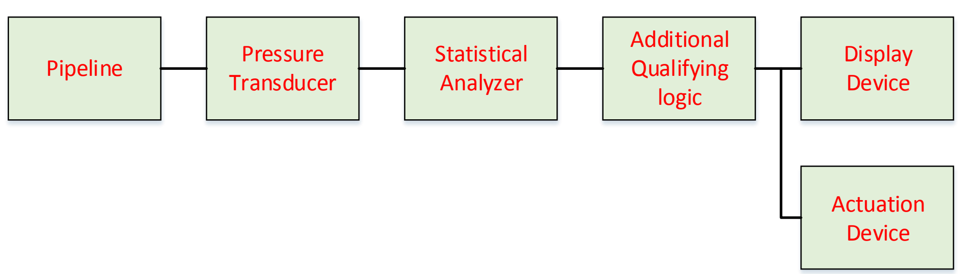

Figure 2.7: Block diagram of PPA method for leak detection.

Hydraulic pressure is converted to electrical signals through pressure transducer as presented in Figure 2.7 [81]. Pressure readings that are collected from each point on pipeline are analyzed statistically through statistical pressure analyzer whereas false alarms are obstructed through additional qualifying logic block. Display device displays results that are analyzed by analyzer. Then actuator devices are responsible to perform corrective measures on pipeline in case of leakage [81].

2.2.2.4 Real Time Transient Modeling

The method of Real time transient modeling consists of models of pipe flow that are generated to make use of equations such as state of fluid equation, energy and mass equations and equation of conservation of momentum. In this method, flow values are measured and estimated for leak detection. Rate of false alarm is reduced by constant monitoring of transient events and noise levels. An observer is designed by Billmann et al. [82] with fiction adaptation that creates a different output than the output obtained from measurement whenever leak occurs. The leak can then be detected by this difference.

Another method was proposed by Verde et al. [83], the method is based on model of discretized and linearized pipe flow on a bank of observers and a grid of N-node. The observers are designed in such manner that in case of leak, except one all of other observers are reset. The location of idol observer is obtained through which the leak localization is carried out and output of other observers can provide the quantity of leak. Hauge et al. [84] and Aamao et al. [85] proposed a detection system that based on hyperbolic one dimensional nonlinear first order partial differential equation, which uses an observer having an adaptive Luenberger-Type. This method needs large instrumentation to collect real time data which makes it a costly one but this method is capable of finding small leaks as of below 1 % of pipeline flow [86]. On the other hand, because of the complexity, this method is only operated by an expert.

2.2.2.5 Statistical Methods

This method does not require any mathematical model to be developed that is why it is a simple method for leakage detection in gas pipelines [44]. The measured parameters that include pressure and flow rate are examined in this method at different point over the pipeline. Alarm is raised based on a substantial change in flow rates and pressure when system faces some specific patterns [87]. Parameter variance is analyzed during the time of calibration and after that leak thresholds are obtained when there is no leak in various conditions. To ignore high rates of false alarms, tuning is required which is a time consuming task [88]. One of the limitations is, if there is any leak detected during calibration period than it will affect the collection of preliminary measurements which will result in bad behavior of the system. As a result, it cannot detect initial leak unless its size big enough that goes beyond the threshold level. This method has capability to detect tiny leaks at the rate of 0.5% flow as mentioned by Zhang et al. [88] as leak location can also be estimated through this technique. This method is also robust, easily adapted and deployable in various pipeline infrastructures but this method is much costly in terms of implementation and leak volume is also difficult to analyze.

2.2.2.6 Digital Signal Processing

It is a substitute method for leak detection as the output is obtained through recognized flow alteration in the initial stage [89]. Deviations in system response are detected through the signal processing on collected measurements. Digital signal processing is much useful for the separation of original signal from noise. This method provides excellent results for liquid and gas pipelines [89, 90].

Just like statistical method, mathematical modeling is not required in Digital signal processing, anyhow the initial leak will not be detected unless its size is considerable large enough. However, this method has high installation and testing cost and considerable complex as well.

2.2.3 Recent Novel Methods

Some recent leak detection techniques are discussed in this section as most of the methods is based on hybrid techniques.

Leak detection and localization for underground pipeline is proposed by Z.Sun et al. [66] which is based on robust application of WSN. The method is especially designed for underground pipeline which is based on magnetic induction. The sensors are deployed inside or outside of the pipeline that communicate with each other in order to detect and localize leakages. Acoustic and pressure sensors are deployed at pump stations and check points on the pipeline. Pipeline division is made into several segments through check points where every segment has soil property sensors along with two check points. Flow pressure is measured by pressure sensors that send data to remote administration center during transient period. Administration center compare the measured values with steady state values and if it finds any variation that surpasses set threshold value, it immediately conveys to pressure sensors that are deployed in affected area. Then pressure sensors in that area transfer requests for the data to soil property sensors that are deployed along the segments. Collection of cumulative measurements is carried out at the processing node in multi-hop manner.

Further, other processing nodes that are deployed along the segments exchange these measurements with the help of wireless channel to verify collectively if there is any leak occurs. Processing nodes also decide the leak location. In the end the results are transferred to administration center to inform operator. The communication among processing nodes and administration center is carried out through satellite, cellular or wireless ad hoc network. With the existing wireless communication methods, communication with soil property sensors is not feasible due to high attenuation in the signals especially in case of underground pipelines [91-93]. So, magnetic induction technique is employed among soil property sensors. Sensors are targeted by magnetic wave guide through this magnetic waves are guided. Number of sensors that are required for communication can be decreased by the implementation of wave guide through relay coils. However this method deals with certain challenges such as installation of devices. As per the energy requirements of acoustic and pressure sensors, they need to be installed at pump stations. With existing pipeline infrastructure, whether pump stations exist at short intervals or not is an issue because effective detection requires sensors to be placed at small intervals. Design of collaborative algorithms for leak detection and localization is also a challenge. Such protocols are required that are considerably light to consume low power in sensors for continuous processing within the network. Charging of soil property sensors through magnetic coils is also a design limitation where it is much difficult to control and design the behavior of sleep and active modes of these sensors in real time detection. One solution for this problem is to keep few sensors active at all the time and whenever there is any indication the active sensors send command to sleeping sensors for further processing and communication. Underground magnetic induction needs to be evaluated and tested with the help of experimental work to prove its robustness.

Moreover, rapture events in pipelines are addressed by Mustafa et al. [43] with the help of real time distributed algorithms for leak detection. In this method sensors are deployed over the surface of pipeline to save them in making contact with fluid. The alarm is generated in administration center once the speed (measured through accelerometer) of fluid deviated from threshold value. This method offers much less power consumption without losing corrective identifications of actual and negative proportions which are also called sensitivity and specificity.

In this system detection process is carried out in three steps. First step deals with the sensing of pipeline's acceleration readings. Statistical data containing accelerometer media and time stamped mean readings are collected through aggregation in second step. Finally, in the third step, whenever rapture event occurs, final decision is made through back end server that exists at the end of chain.

When measurements of acceleration surpass the optimal value of threshold, it indicates the detection of damage. Detection is proved further when expected median vary from median reading. Sensing node receives interrupts from threshold unit on occurrence of any divergence. Then sensing nodes begin to evaluate median values along with sampling. The values obtained are then matched with stamped median of standard time. Damage is affirmed when deviation surpasses predetermined threshold. All of the experimental work is done in Canada over the pipeline installations at Advanced Civil Engineering Pacific. Rapture simulation is done through opening control valves all over the pipeline by installing accelerometer at the exterior side of pipeline. The model built is excellent in terms of power consumption which is designed on a past work [94]. Inaccurate readings caused by pipeline background noise are solved with the help of time stamped values. But the issue of leak localization in this method is yet to be addressed by the authors.

In another method, pipeline monitoring and control is carried out by Ivan et al. [33] which is based on pipeline structure's real time data collected through WSNs. This method is specifically deal with water pipelines with large diameter. Leak detection and localization is also carried out in this method through an algorithm based on high sampling rates obtained by vibration, acoustic and hydraulic data. The method has the ability to solve the problems that include synchronization of collected data by consuming low power, retain assertive duty cycles and high rates of data sampling. Sensors in this method collect the readings of vibration, acoustics, flow of mass velocity and pressure transients of pipeline. Pipeline can be monitored and controlled more efficiently with the help of these readings collected by sensors. This method is also capable enough to self-heal in case if some of the nodes fail. In non-invasive method, vibration sensors are used for the detection of leaks while in invasive method, poor leak localization may occur due to feasibility of installing sensors in outlet areas. The algorithm designed is very expensive in terms of computation that needs the operations of (O (N log(N)) to calculate N-Samples frequency spectrum, however, tiny leaks in water pipelines can be detected through this method. This method also has one other drawback that it needs offline processing.

Leak detection in multiphase pipelines is addressed by Meribout [95]. The method is based on secure WSNs [96] that are used for efficient and fast leakage detection. The architecture deals with the inner and outer pipeline in which the inner pipeline contains multiple fluids while outer pipeline consists of electronic devices for monitoring purposes. Leak occurrence is continuously monitored by air ultrasonic sensor from inner pipeline to outer pipeline. Bi-directional microphone is used that senses acoustics of fluid for leak localization in outer pipeline. All of the sensors are linked with WSNs that carries out transmission, signal processing and control related tasks. Reliable and secure communication protocol is also a part of this. As sensors are not placed inside the fluid so, their life period is increased with the reduction in corrosion rate. Here, outer pipeline secures and protects inner pipeline from external anomalies. The main disadvantage of this system is that it is not realizable to be implemented on existing pipeline infrastructure due its cost and design complexities.

Sportiello [40] provided a method to monitor pipelines based on wired and wireless distributed network. The system uses duty cycling to provide energy aware routing and is able to reconfigure itself in case of failure with the help of backup system governed by wireless nodes when wired nodes fail to perform. Though energy efficiency is already enhanced in the system by using duty cycling approach but it can be further enhanced by using in-network processing, data compression and aggregation schemes.

CHAPTER 3

ANOMALY DETECTION AND LOCALIZATION TECHNIQUES IMPLEMENTATION

Most of pipeline anomaly detection techniques proposed are able to detect leaks but not able to localize properly. Among the limited number of localization techniques, we choose two state of art techniques NPW and PPA which are able to detect and localize leaks and compare against our proposed ISTS technique.

3.1 Negative Pressure Wave (NPW)

In NPW method, pressure is dropped when leak occurs. This is because of the unexpected reduction in the density of liquid at the location of leak. Consequently, the source of pressure waves travels outwards from leakage point in the opposite direction of leak. The fluid pressure is noted down after and before the leak occurs and the wave generated by this leakage is named as negative pressure wave. The signal of pressure reduction is measured by pressure sensors that are deployed in terminal ends, when the negative pressure wave moves towards pipeline section terminal ends. This is achieved due to the arrival of wave at the terminal ends that becomes the cause for inlet pressure drop and then drop in outlet pressure. Various negative pressure time differences are obtained at the terminal ends because leak can occur at any point on the pipeline. With the help of measured time differences obtained through pressure sensors deployed on the two sides, the point of leak, negative pressure wave velocity and length of pipeline section can be determined.

In Figure 3.1, the distance is considered as L, negative pressure wave velocity is represented as v, natural gas/material velocity in pipeline is depicted as u, the distance between upstream sensor and leak location is x and time is represented as t1 and t2 for the detection of wave through two sensors.

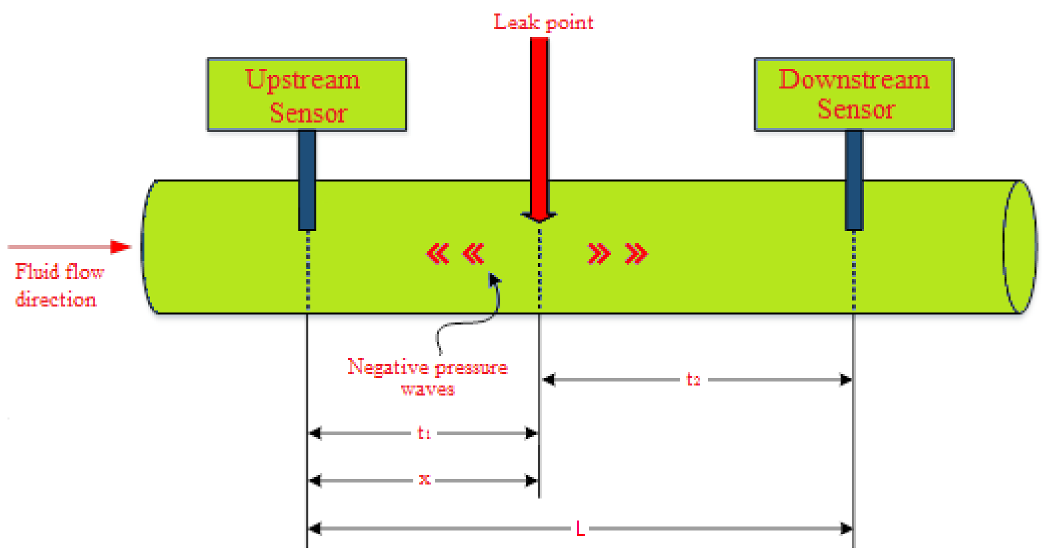

Figure 3.1: A Schematic diagram of the negative pressure wave method.

Distance *x* among sensor and leak point can be determine through Equation (3.1).

$$t_1 = \frac{x}{(v-u)}$$

$$t_2 = \frac{(L-x)}{(v+u)} \tag{3.1}$$

$$\Delta t = t_1 - t_2$$

Leaks are localized using general leak localization formula.

$$x = \frac{1}{2v}[L(v-u) + \Delta t(v^2 - u^2)] \tag{3.2}$$

3.1.1 Topology

NPW method is implemented on COOJA network simulator using Contiki OS. The topology is defined such that there is a pipeline of 5km. Every 1000 meters a sensor is deployed including the start and end. The network deployment area for NPW is 1 x 5000 meters. Each sensor acts as upstream and downstream sensors depending on the scenario. The distribution is 6 upstream/downstream sensors and an anomaly sensor (an emulator for anomalies). Anomalies can be tested at several locations in the study area. Figure 3.2 shows several upstream and downstream sensors S2, S3, S4, S5, S6, S7 (yellow colored) in the network window. S8 (pink) is an emulator for an anomaly placed at 2500 meters. There are other two sensors S1 and S9 that model the negative pressure effect which is sensed by the nearby upstream and downstream sensors i.e. by S4 and S5 in this scenario. Sensor Data is then sent to the MAP for further analysis, calculations and finalized results. Sample of MAP is shown in Figure 3.3.

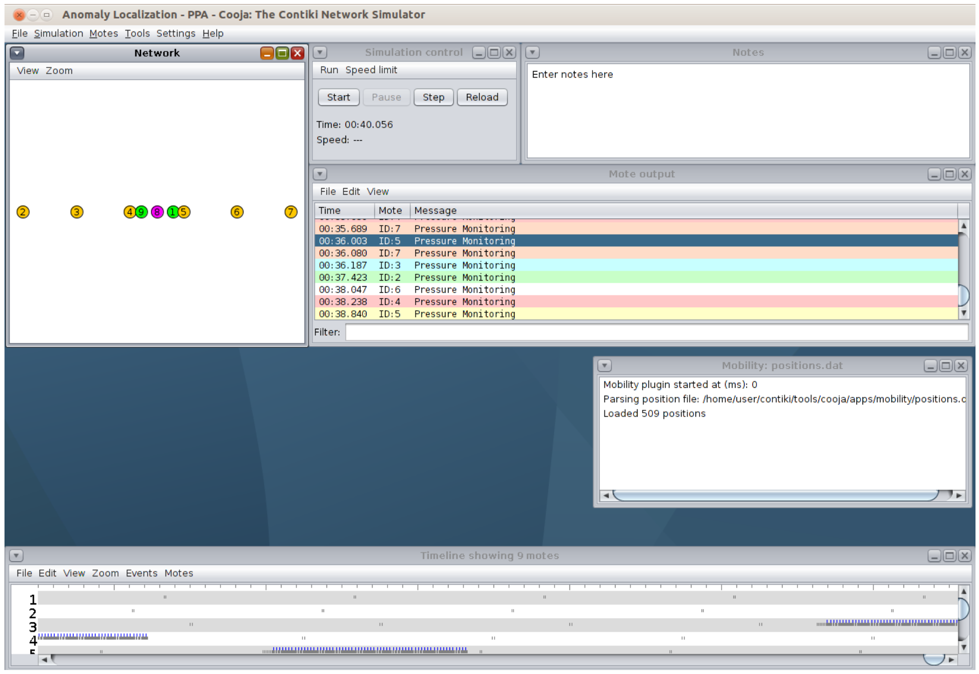

Figure 3.2: NPW – COOJA.

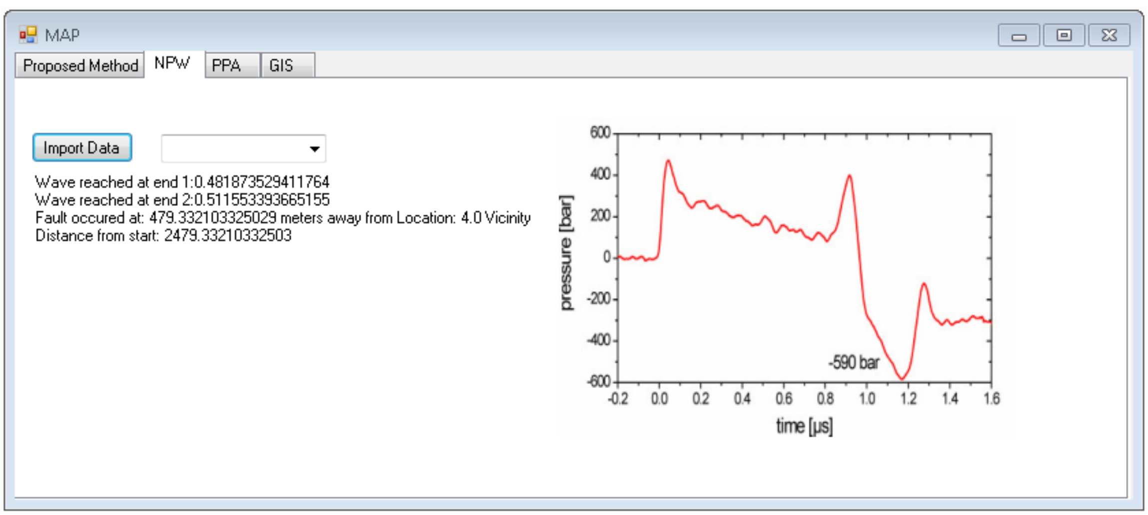

Figure 3.3: NPW – MAP Output.

It shows time t_1 taken by wave to reach end 1 (upstream sensor) is 0.482 seconds whereas time t_2 taken by wave to reach end 2 (downstream sensor) is 0.512 seconds with the occurrence of anomaly at 479.3 meters from location 4 (S4). Distance from start to the point to anomaly is 2479.3 meters.

3.1.2 Evaluation

NPW method is evaluated by analyzing the difference between the actual anomaly location and the localization accuracy achieved by the implemented algorithm as shown in Figure 3.4. NPW is analyzed and tested at 50 different locations. It can be further concluded that negative pressure wave method is not suitable for longer distances. Due to larges differences in Δt, its accuracy is highly affected. Figure 3.5 shows variance of NPW method with the ideal. Zero is taken as the reference/ideal point. Least variance is better. It can be further analyzed from Figure 3.6 that accuracy is worst up to the scale of approximately ±500 meters when the anomaly is felt close to upstream or downstream sensors.

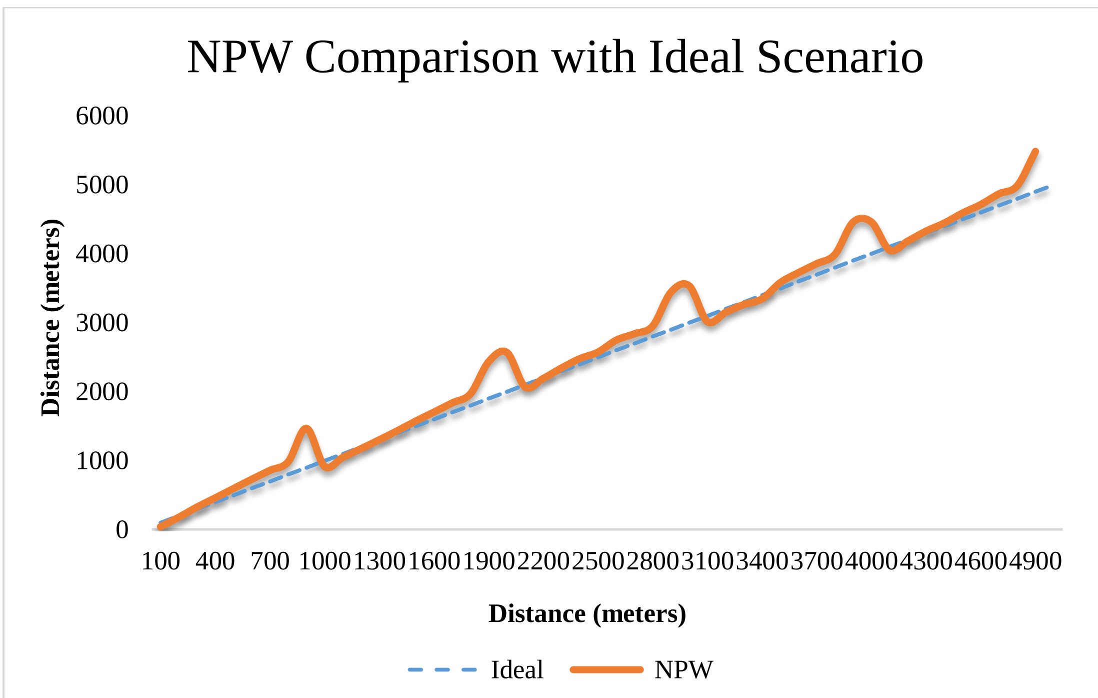

Figure 3.4: NPW - Comparison with Ideal Scenario.

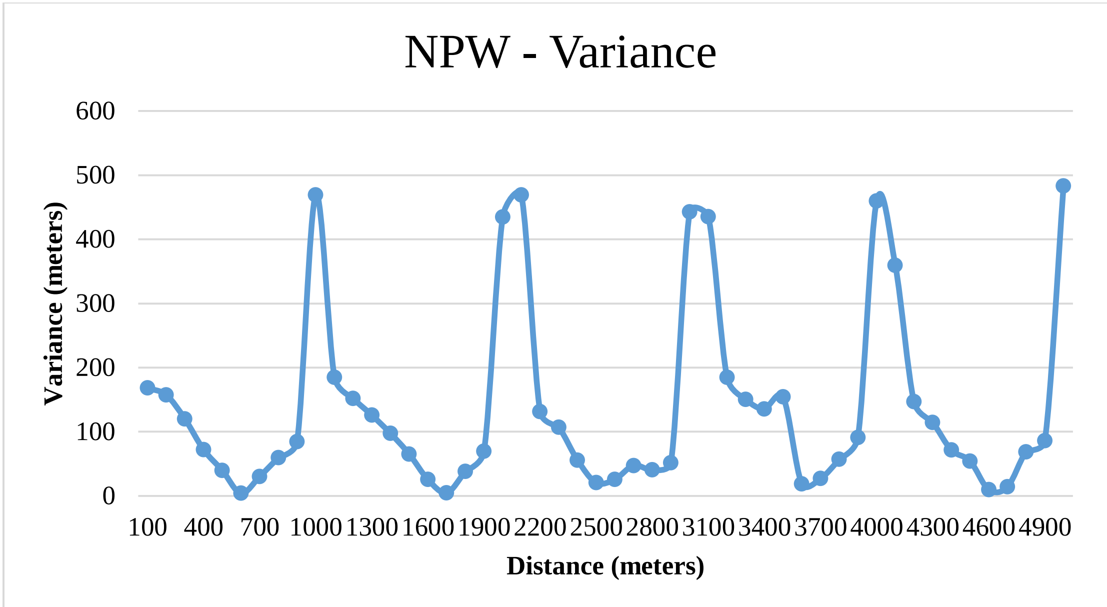

Figure 3.5: NPW – Variance.

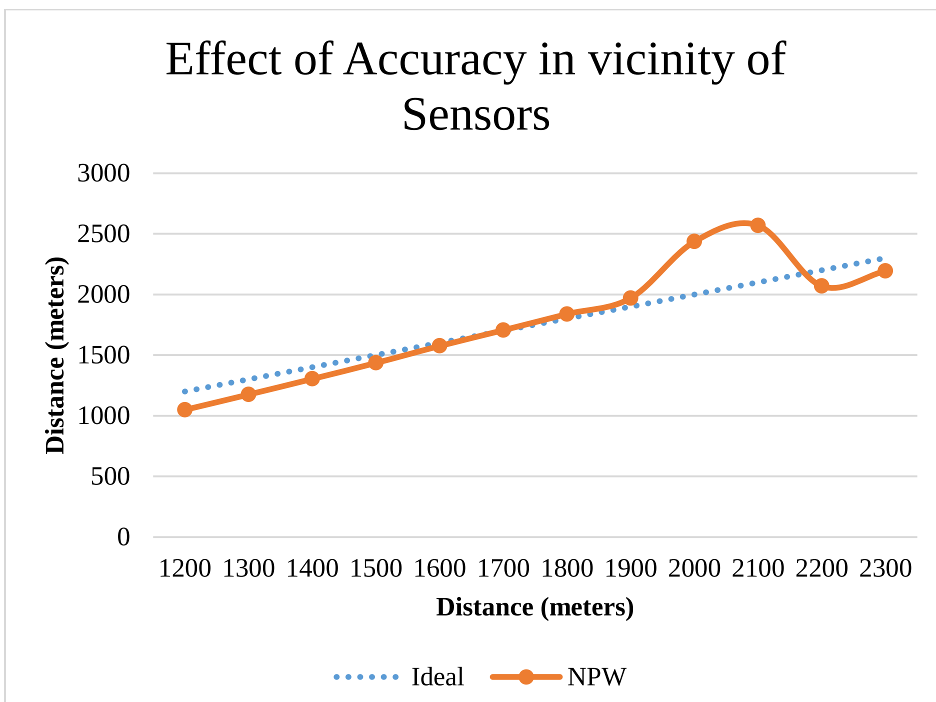

Figure 3.6: NPW - Effect of Accuracy in vicinity of Sensors.

Figure 3.7 shows percentage accuracy over a distance of 5 kilometers. NPW is also evaluated in terms of accuracy w.r.t to varying oil viscosities. Several types of oil samples are taken with varying gravities and viscosities. See

Table 3.1. It is noted that overall behavior of the curves remains the same. But noticeable differences in accuracy can be seen between different grades, especially between low grade having specific gravity 0.81, viscosity -4 cSt and extra heavy having specific gravity 0.88, viscosity 337 cSt. Figure 3.8 shows variance comparison of accuracy between light and extra heavy grade oil with '0' as a reference point.

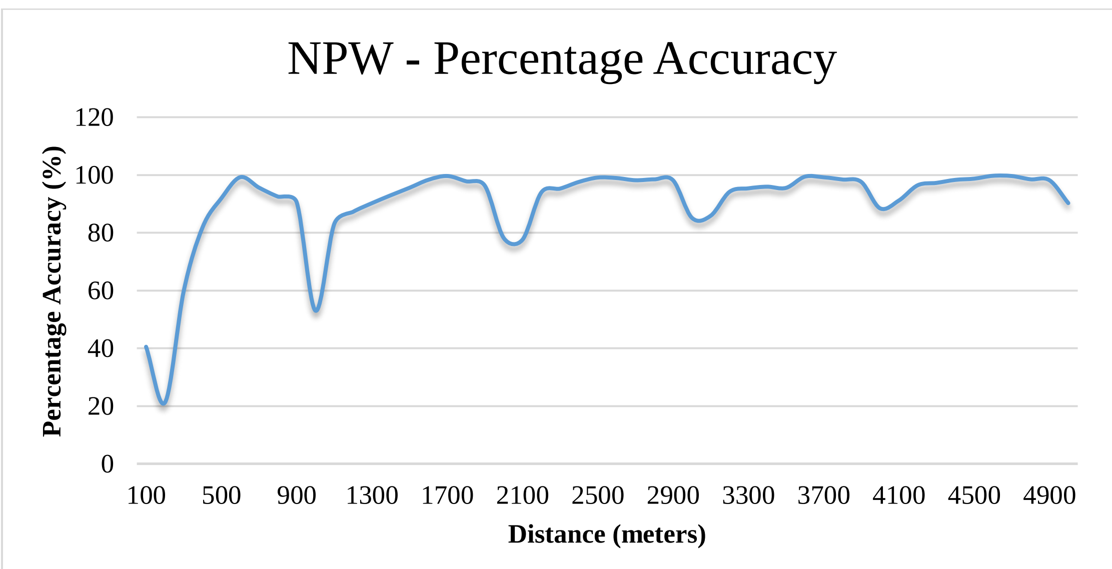

Figure 3.7: NPW - Percentage Accuracy.

Table 3.1: Oil Samples Data at 21^{o}C.

Sample	**Specific Gravity**	**Sound Velocity** *[m/s]*	**Viscosity** *centistokes[cSt]*
Light oil	0.81	1347	-4
Medium oil	0.85	1401	14
Brad Penn	0.86	1422	20
Heavy oil	0.87	1441	55
Extra heavy oil	0.88	1480	337

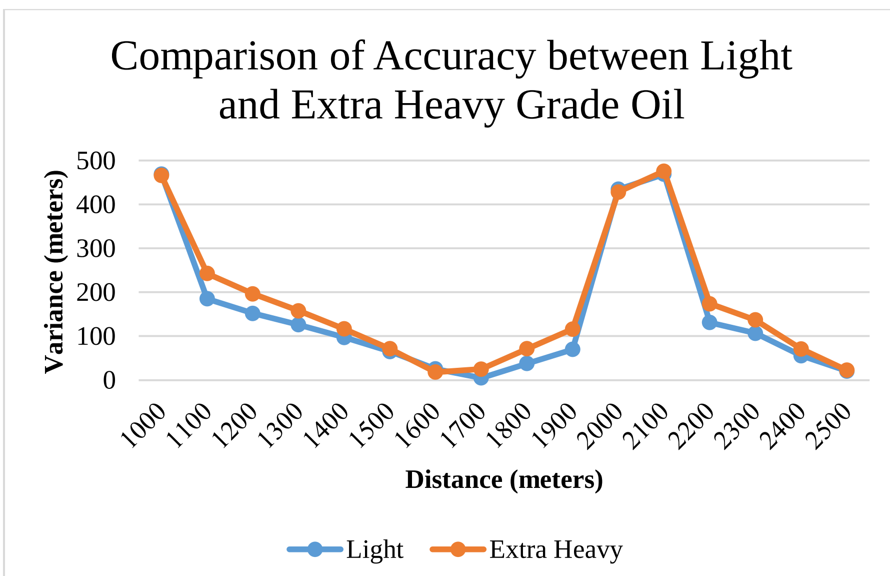

Figure 3.8: NPW - Comparison of Accuracy between Light and Extra Heavy Grade Oil.

3.2 Pressure Point Analysis (PPA)

Pressure Point Analysis (PPA) is one of the novel methods for anomaly detection and localization. Generally, it requires continuous pressure measurement in whole pipeline at different locations. Whenever a mean pressure value is recorded to be below threshold level, a decision for raising an alarm is made through statistical analyses of measurements. One of the methods is using pressure gradient model. Fluid mechanics state that, due to frictional loses steady state pressure drops linearly in a straight horizontal pipe [97]. When an anomaly occurs, we see noticeable increase in slope of the line before leak and decrease in slope of the line after leak. Anomalies can be localized by finding the intersection of two slopes.

3.2.1 Topology

PPA method is implemented on COOJA network simulator using Contiki OS. The topology is defined such that there is a pipeline of 5km. Every 1000 meters a sensor is deployed including the start and end. The network deployment area for NPW is 1 x 5000 meters. The distribution is 6 sensors (S2, S3, S5, S6, S7 - yellow) and an anomaly sensor (emulator for anomalies – S8 pink). Anomalies can be tested at several locations in the study area as shown in Figure 3.9. Data is sent to MAP for further analysis, calculations and finalized results. MAP acts as a statistical analyzer and a display device. Gradient model is also implemented in MAP and compared with data collected from COOJA. Sensors are probed for data by S1 (green). For a certain scenario, number of sensors need to be analyzed depends on the numbers of sensors probed by S1. For example, 4 sensors' data is sent to MAP with an anomaly at 1300 meters or 300 meters from location 3. Figure 3.10 shows ideal gradient model for these sensors. Figure 3.11 shows the slopes of data collected from COOJA and Figure 3.12 shows comparison with an ideal gradient model.

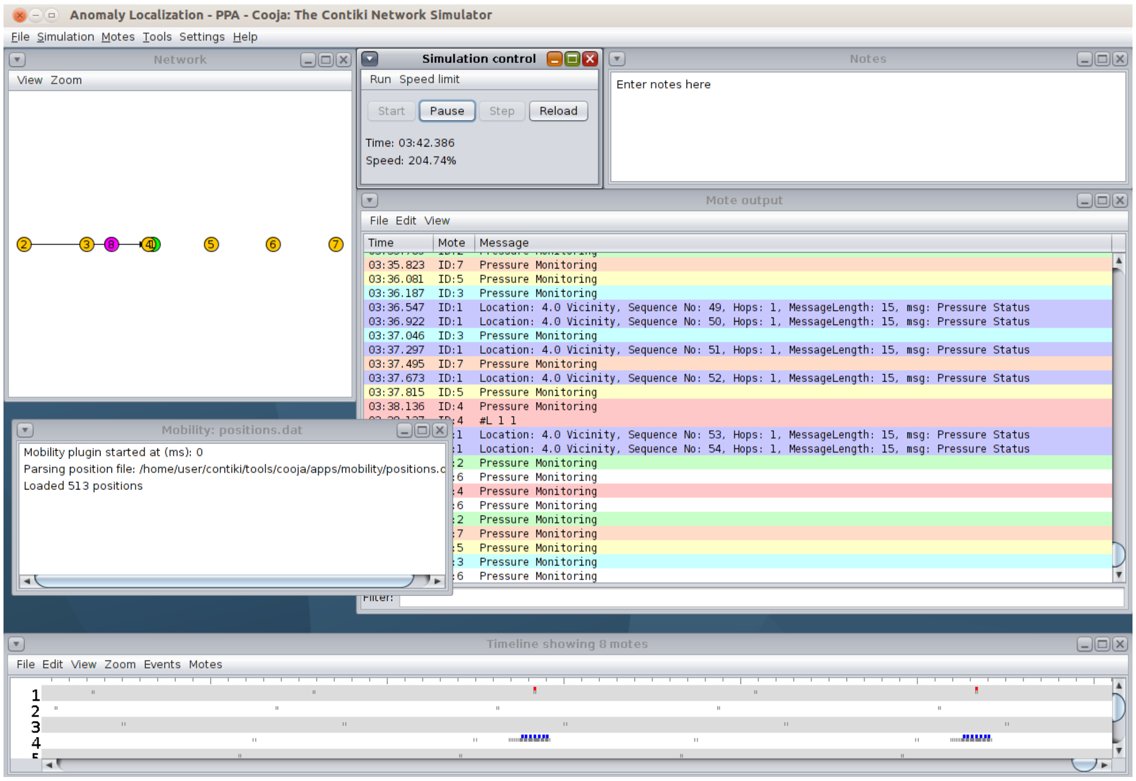

Figure 3.9: PPA – COOJA.

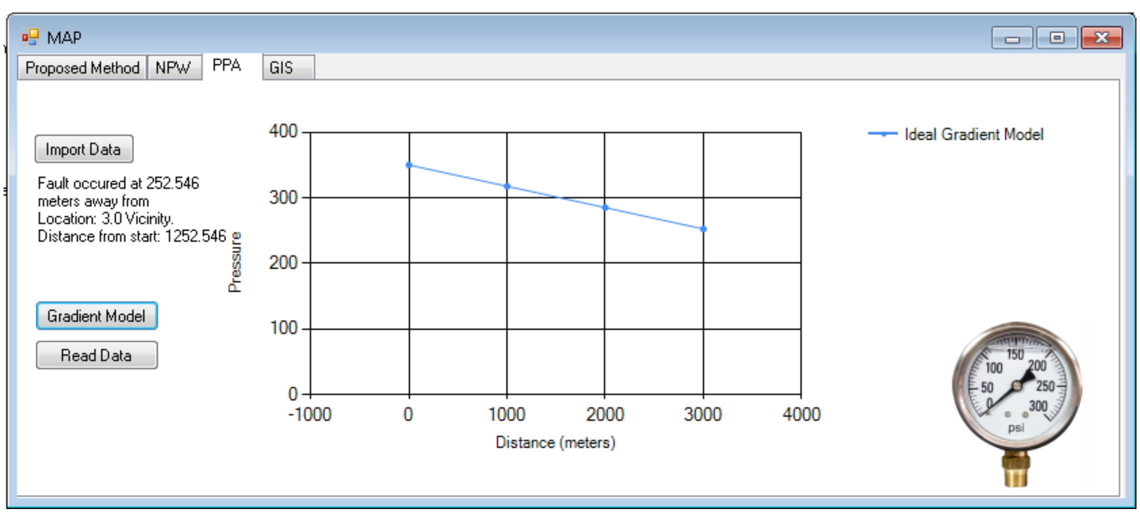

Figure 3.10: PPA MAP - Ideal Gradient Model for 4 Sensors.

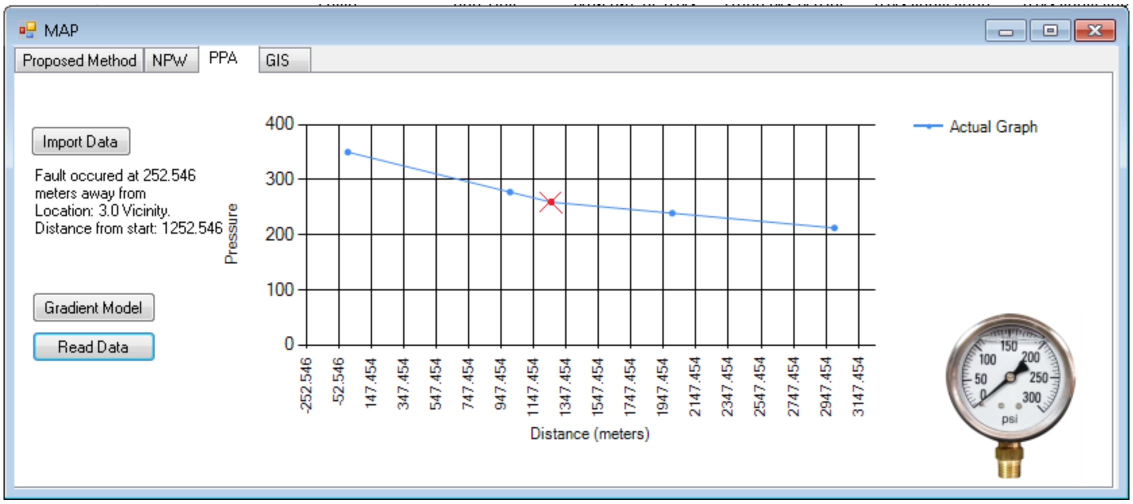

Figure 3.11: PPA MAP - 4 Sensors Data with an intersection at 1252.546 meters.

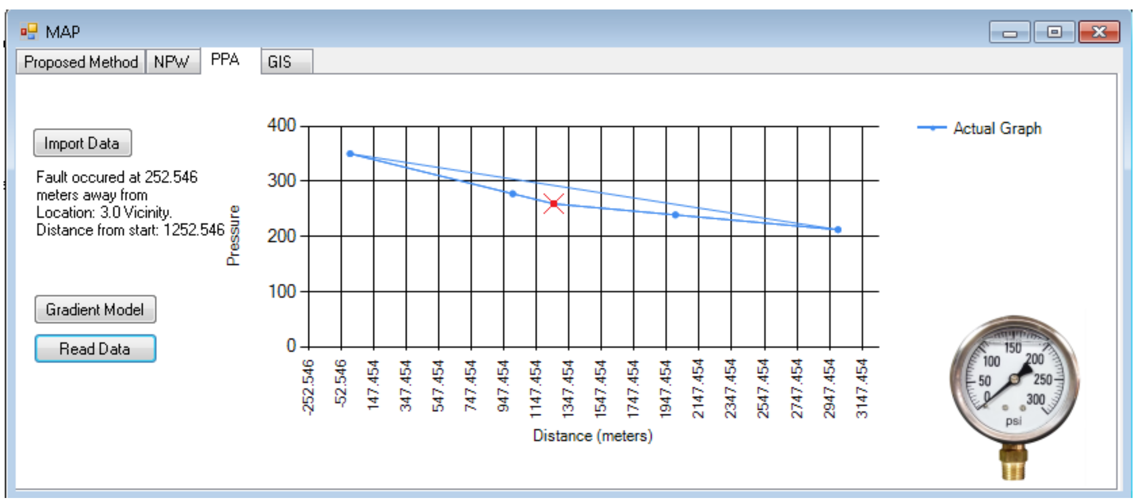

Figure 3.12: PPA MAP - Comparison with Ideal Gradient Model.

3.2.2 Evaluation

PPA method is evaluated by analyzing the difference between the actual anomaly location and the localization accuracy achieved by the implemented technique as shown in Figure 3.13 and Figure 3.14. It is analyzed and tested at 50 different locations with 160 simulations. Figure 3.15 shows variance of PPA method with the actual anomaly location. Zero is taken as the reference/ideal point. Least variance is better. It can be concluded that the points where anomalies occur in the vicinity of pressure transducers have less error in localization. This is due to the fact that effect of pressure drops due to leaks is more accurately heard nearby as compared with the pressure drops away from pressure transducers. It is observed that this method gives accuracy up to ±112.38 meters. Figure 3.16 shows percentage accuracy of PPA over a distance of 5 kilometers.

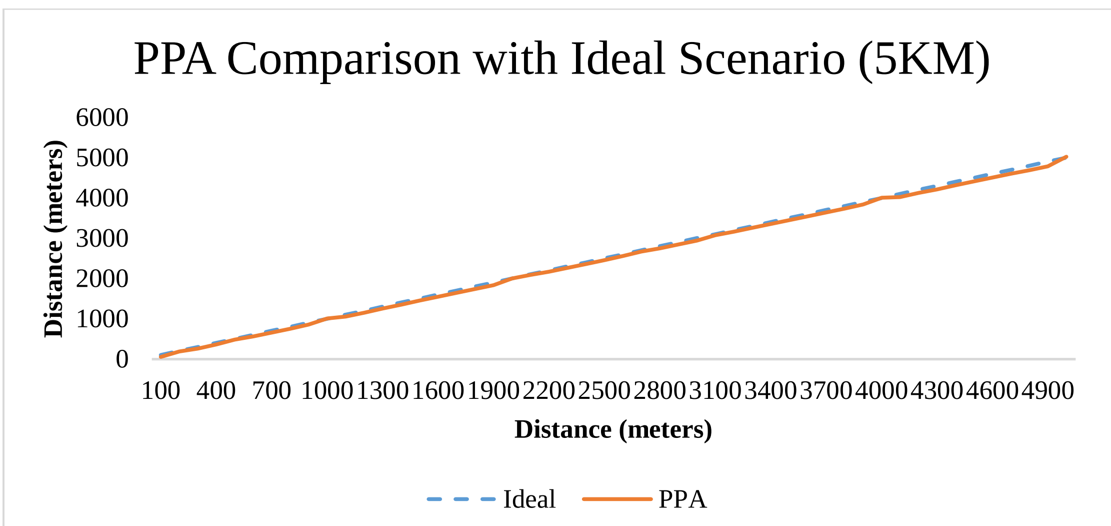

Figure 3.13: PPA - Comparison with Ideal Scenario.

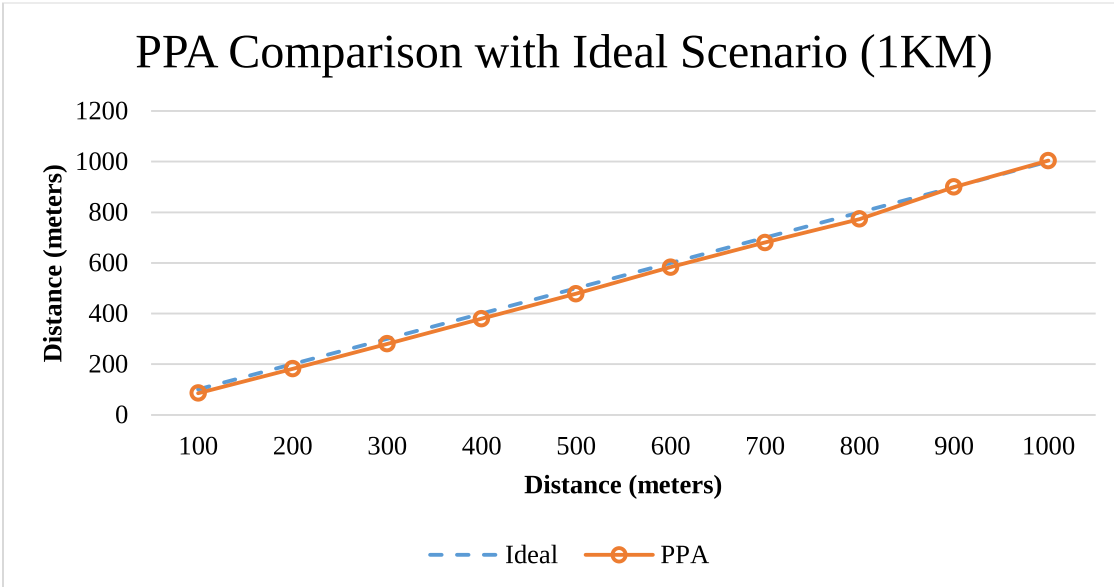

Figure 3.14: PPA - Comparison with Ideal Scenario (Short Data Sample).

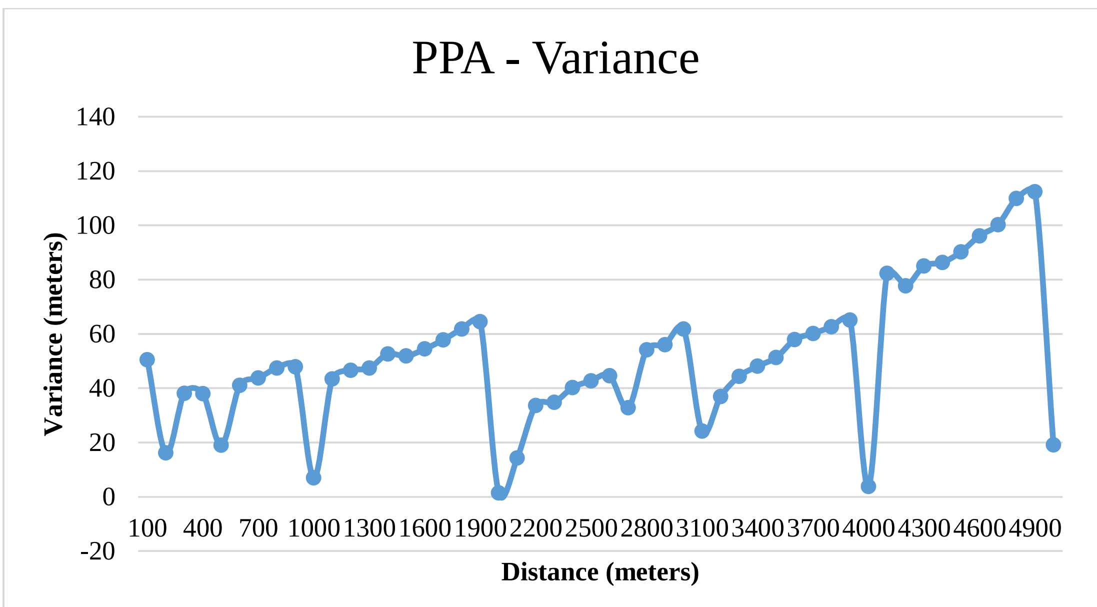

Figure 3.15: PPA – Variance.

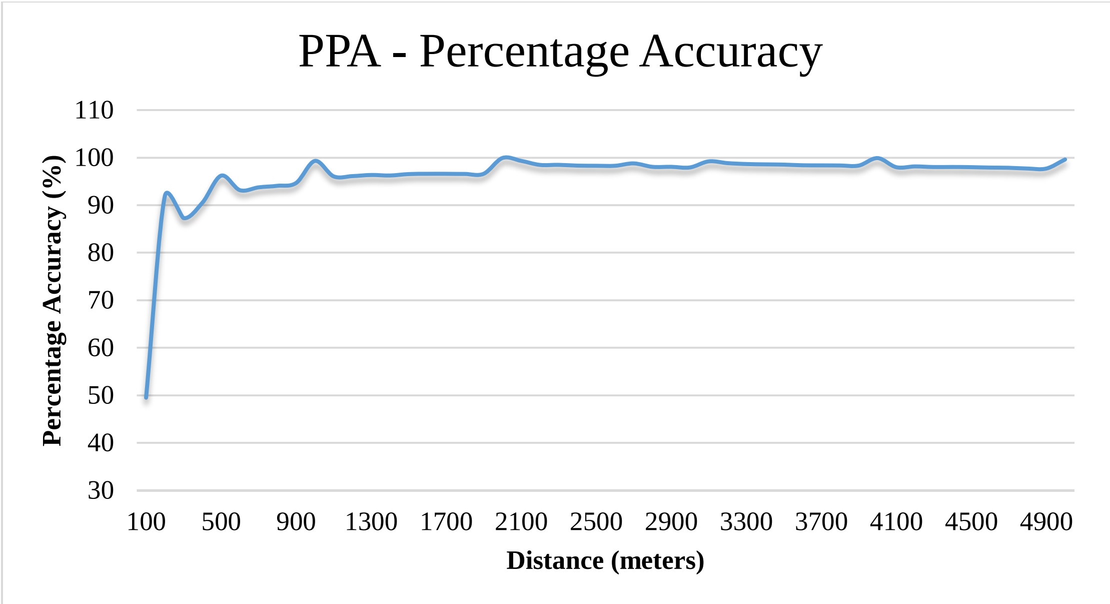

Figure 3.16: PPA - Percentage Accuracy.

CHAPTER 4

Invasive Sensors with Time Stamps (ISTS) Algorithm

4.1 Algorithm Description

In this section, we propose Invasive Sensors with Time Stamps (ISTS) algorithm, a novel technique for anomaly detection and localization following our own framework defined in 1.7. ISTS technique is implemented on COOJA simulator. It localizes anomalies not only after an anomaly or a group of anomalies has occurred but also works well in pre-disaster management scenarios. Careful precautionary measures can thus be taken before actual disaster occurs. Anomalies ($\Delta1$, $\Delta2$, $\Delta3$ … Δn) are localized by using special type of invasive sensor (IS) attached along with a depth gauge. Several sensors are installed on various fixed locations on a pipeline known as FP's i.e. FP1, FP2, FP3 ... FPn). These sensors can communicate at the backend server. Data is continuously being updated. Anomalies are localized by using reference of FP's. The IS moves from one FP to another. During its journey, it maintains its clock and takes pipeline thickness readings using the depth gauge. Wherever the thickness drops below preset threshold, it records its clock (T1), average accelerometer reading (A_1) in its memory element. When it passes any FP, FP sensor shares its location id (L1, L2, L3, … , Ln) and IS replies back with data collected during the last interval with the current clock readings (T_n, T_{n+1}, T_{n+2}, … T_{n+k}) and average accelerometer readings (A_n, A_{n+1}, A_{n+3}, …, A_{n+k}). See Figure 4.1.

Anomaly Location $\Delta1$ is calculated as

$$\Delta 1 \;= \left(\frac{A1+\sum_{n=n}^{k} An}{k+1}\right) \times \{\Delta T_1\} \tag{4.1}$$

$$\text{Where } \;\Delta T_1 = \left(\frac{\sum_{n=n}^{k} Tn}{k}\right) - T_1 \tag{4.2}$$

Similarly Anomaly Location Δ2

$$\Delta 2 \;= \left(\frac{A2+\sum_{n=n}^{k} An}{k+1}\right) \times \{\Delta T_2\}$$

$$\text{Where } \;\Delta T_2 = \left(\frac{\sum_{n=n}^{k} Tn}{k}\right) - T_2$$

For Anomaly Location Δi

$$\Delta i \;= \left(\frac{Ai+\sum_{n=n}^{k} An}{k+1}\right) \times \{\Delta Ti\} \tag{4.3}$$

$$\text{Where } \;\Delta Ti = \left(\frac{\sum_{n=n}^{k} Tn}{k}\right) - Ti \tag{4.4}$$

$$i \in \{(1),(1,2),(1,2,3),\ldots maximum\ number\ of\ feasible\ anomalies\}$$

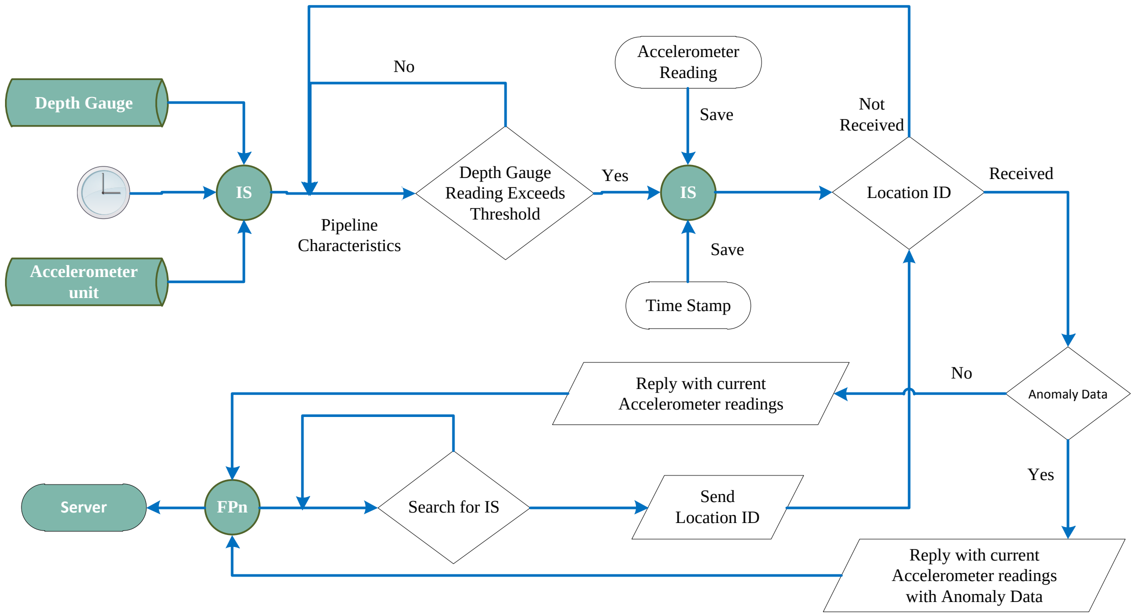

Figure 4.1: ISTS - Block Diagram.

Scenario 1: Single Anomaly

Figure 4.2 shows a scenario where we have only one anomaly (L8 pink) between locations L4 and L5. L2, L3, L4, L5, L6 and L7 are FP's. L1 (green) is the invasive sensor moving from L4 -> L5. FPs L2, L3 and L4 will share their respective ids with no data from IS (node 1) except the accelerometer reading. Nodes information and data exchanges are shown in Mote Output window where last crossed FP (L4) has shared its location with IS and in reply got accelerometer reading. Other FP's L2, L3, L5, L6, L7 including L4 are still waiting for patrolling sensor (IS) to share their respective locations. After successful data exchanges, irrelevant data is removed from the memory for garbage collection. Figure 4.3 shows MAP output of this scenario where anomaly is localized at 688 meters from location 4.

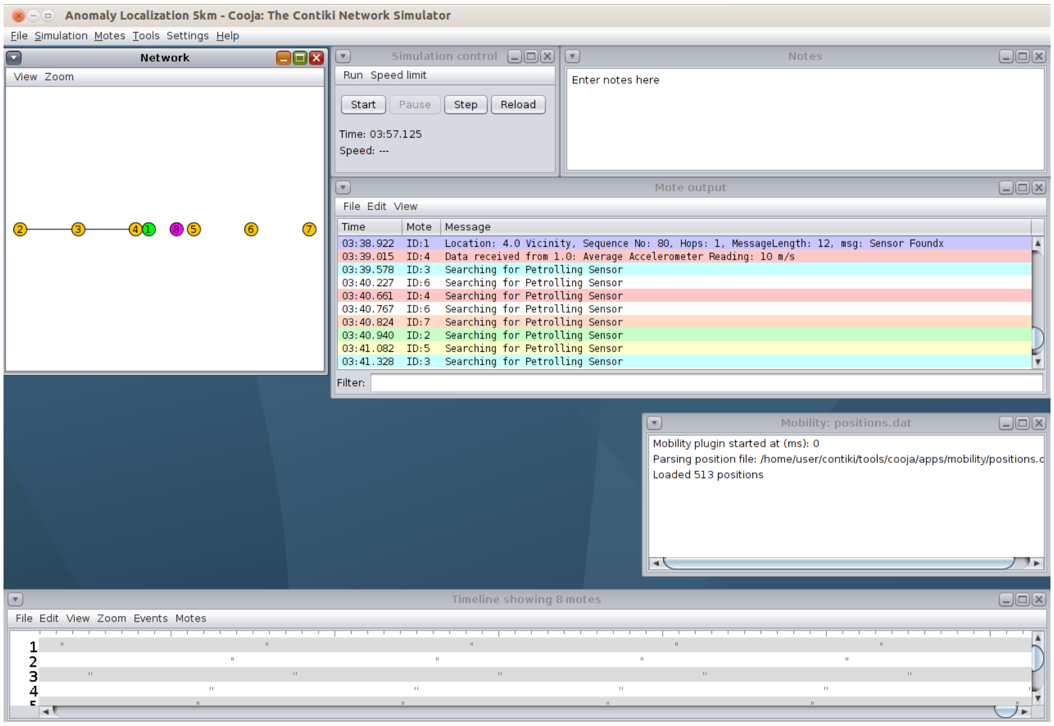

Figure 4.2: ISTS – COOJA – Scenario 1.

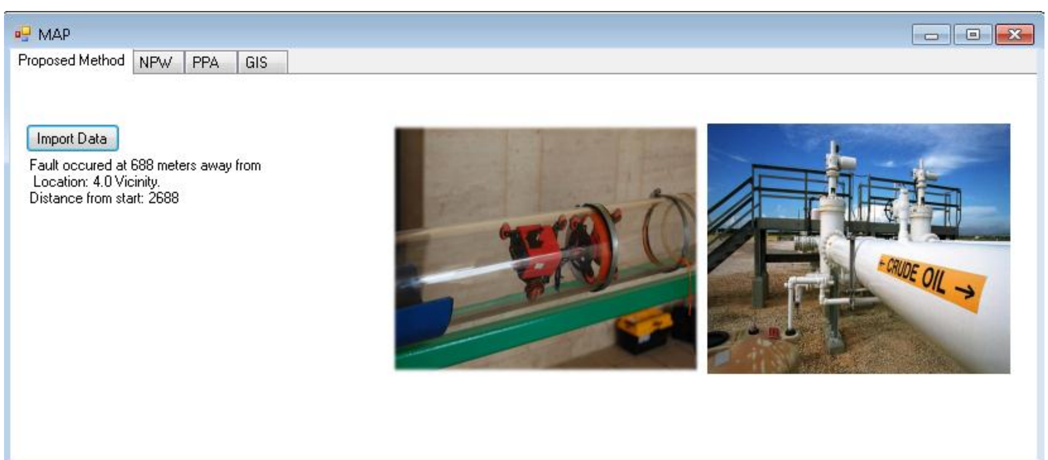

Figure 4.3: ISTS – MAP Output – Scenario 1.

Scenario 2: Anomalies between different pair of FP's.

ISTS is also capable of detecting and localizing multiple anomalies. Figure 4.4 shows a scenario where we have two anomalies: one anomaly L8 (pink) between Locations L3 and L4 and another anomaly L9 (pink) between L4 and L5. L2, L3, L4, L5, L6 and L7 are FP's. L1 (green) is the invasive sensor moving from L5 -> L6. Nodes information and data exchanges are shown in Mote Output window where last crossed FP (L5) has shared its location with IS and in reply got accelerometer readings with data collected during the last phase from L4 to L5. Other FP's L2, L3, L4, L6, L7 including L5 are waiting for patrolling sensor (IS) to share their respective locations. Figure 4.5 shows MAP output of the scenario where one anomaly is localized at 484 meters from location 3 and another at 479 meters from location L4.

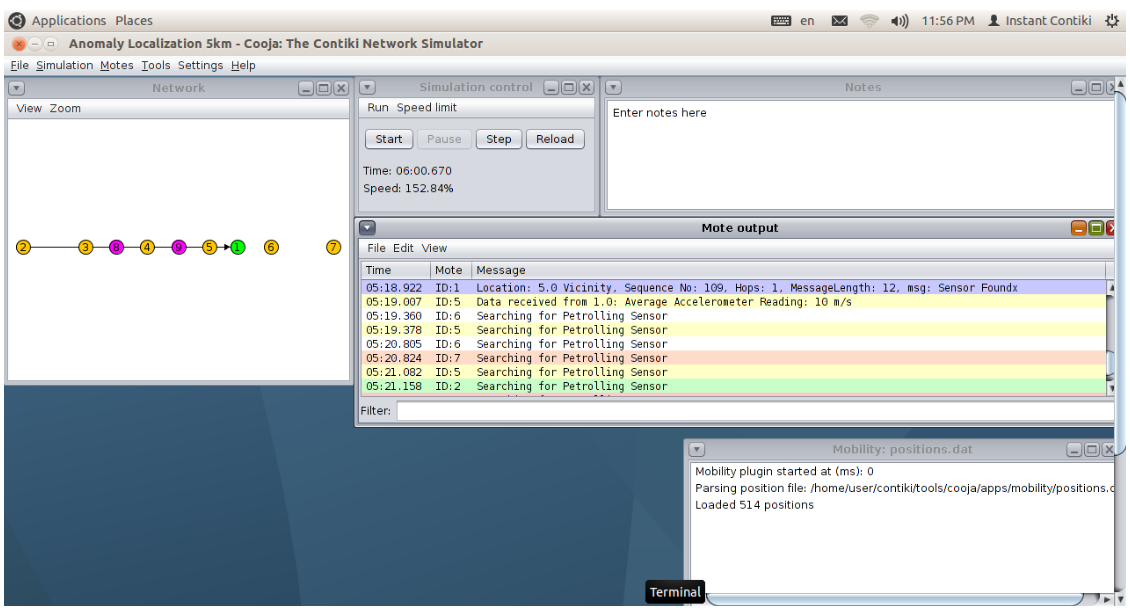

Figure 4.4: ISTS - COOJA - Scenario 2.

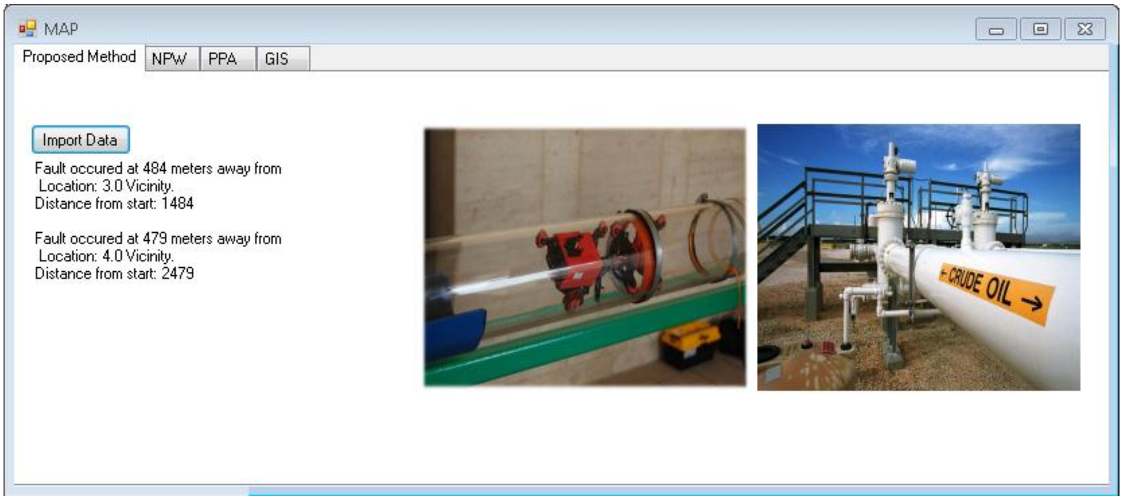

Figure 4.5: ISTS - MAP Output - Scenario 2.

Scenario 3: Multiple Anomalies between single pair FP's.

ISTS is capable of detecting and localizing multiple anomalies. Taking a scenario when multiple anomalies occur within a single pair of FP. Figure 4.6 shows a scenario where we have two anomalies L8 (pink) and L9 (pink) placed at 300 meters and 700 meters from Location L3 respectively. L2, L3, L4, L5, L6 and L7 are FP's. L1 (green) is the invasive sensor moving from L3 -> L4. Nodes information and data exchanges are shown in Mote Output window. Last crossed FP (L4) has shared its location with IS and in reply got accelerometer readings with data collected from L3 to L4. Other FP's L2, L3, L5, L6, L7 including L4 are waiting for patrolling sensor (IS) to share their respective locations. Figure 4.7 shows MAP output of the scenario where both anomalies are localized: one at 287.3 meters and another at 687.3 meters from location L3.

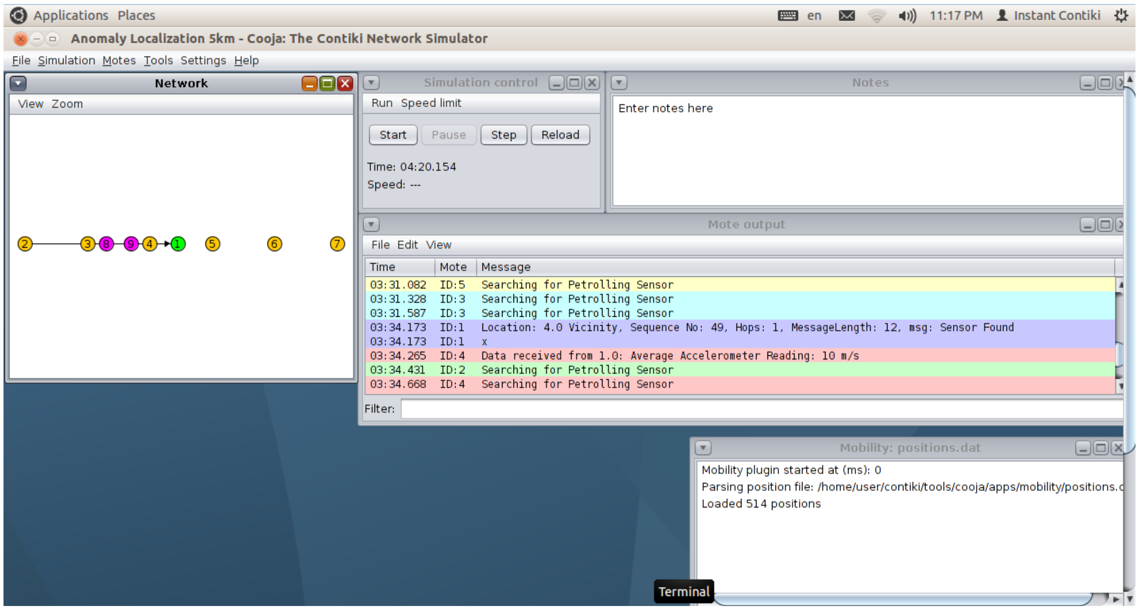

Figure 4.6: ISTS - COOJA - Scenario 3.

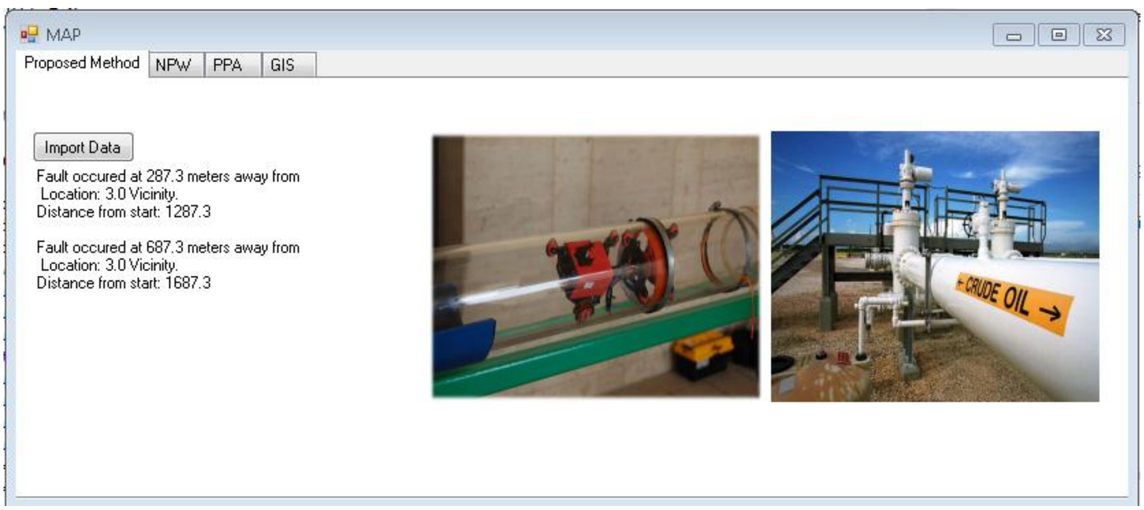

Figure 4.7: ISTS - Map Output - Scenario 3.

4.2 GIS Integration

GIS Technology is a system of software and hardware that supports capture, manipulation, management, analysis and display of Geographic Information. It's an enormous technology that maximizes the efficiency of decision making and planning similarly like today ERP systems are for Business. It provides a platform for extensive spatial analysis for researchers and decision makers with new flexibilities and research directions. GIS plugin in our MAP application can be used to project sensors, pipeline and anomaly data to a real time Geographical Information System for further analysis. GIS compatible files are generated. Then using python scripts point and line features are created and projected using specified projection system. For details about projection systems refer to Section 1.7. Currently this MAP version supports locations only in Decimal Degrees. To generate GIS compatible anomaly data, any of the three algorithms must be run once. Figure 4.8 shows layout of MAP's GIS plugin.

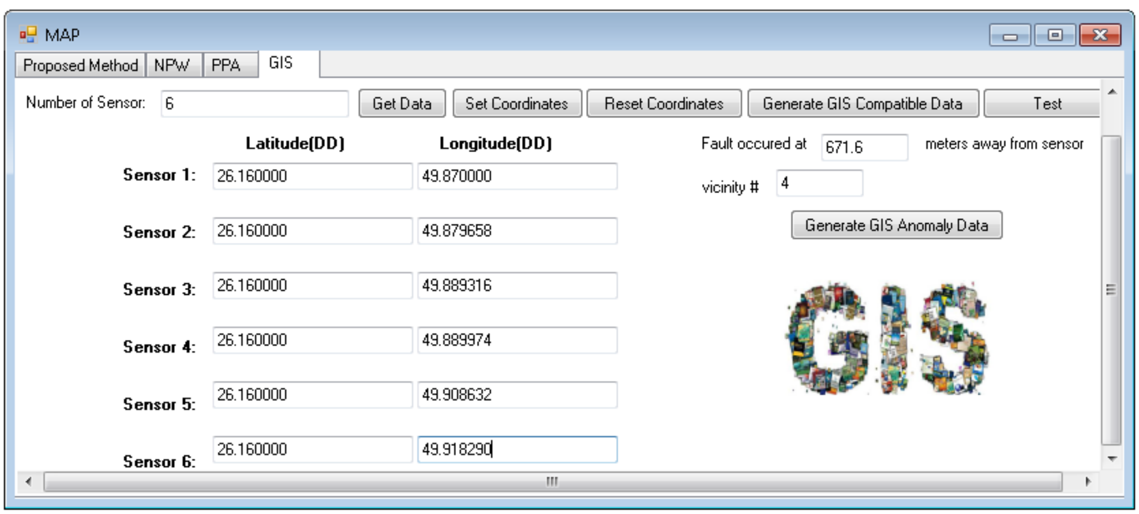

Figure 4.8: MAP – GIS Plugin.

The block diagram of the framework followed to attain integration is shown in Figure 4.9. It shows that GIS area of MAP requires field coordinates of sensor or pipeline, with localization data as an input to the system using any of the techniques (NPW, PPA, ISTS). Sensors' point features and Pipeline line features are generated using

'GIS Compatible Data' button. Similarly anomaly point features are generated using 'Generate GIS Anomaly Data' button under the condition that at least any of the three algorithms must be run once. With the help of python scripts data is then projected to GIS Technology.

Figure 4.10 shows the sample GIS output for ISTS Scenario 1 explained in previous section 4.1, where anomaly was localized at 2688 meters from start. Black point features are the sensor locations. Red point feature is an anomaly location in real time geographical location. Similarly, GIS Outputs for ISTS Scenarios 2 and 3 explained in previous section 4.1 are also shown in Figure 4.11 and Figure 4.12

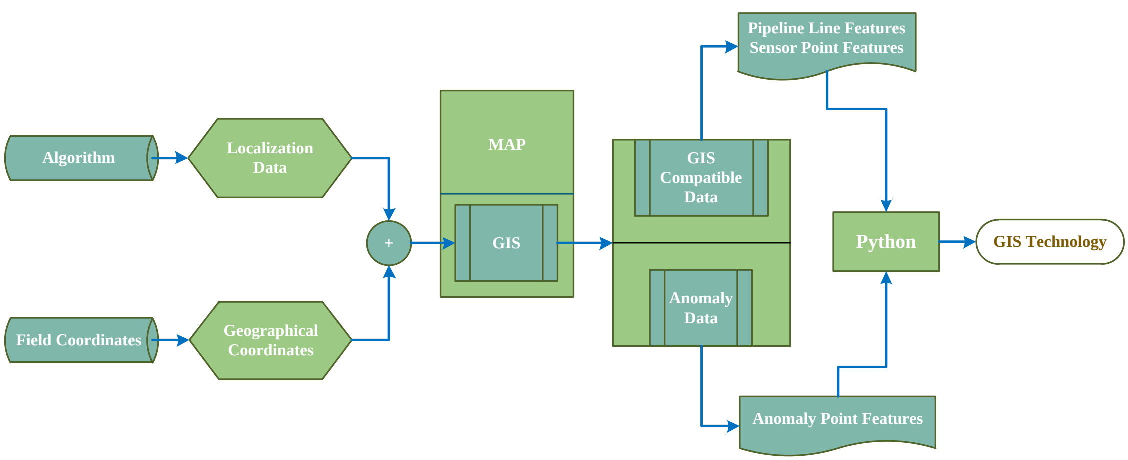

Figure 4.9: MAP - GIS Integration Flow Diagram.

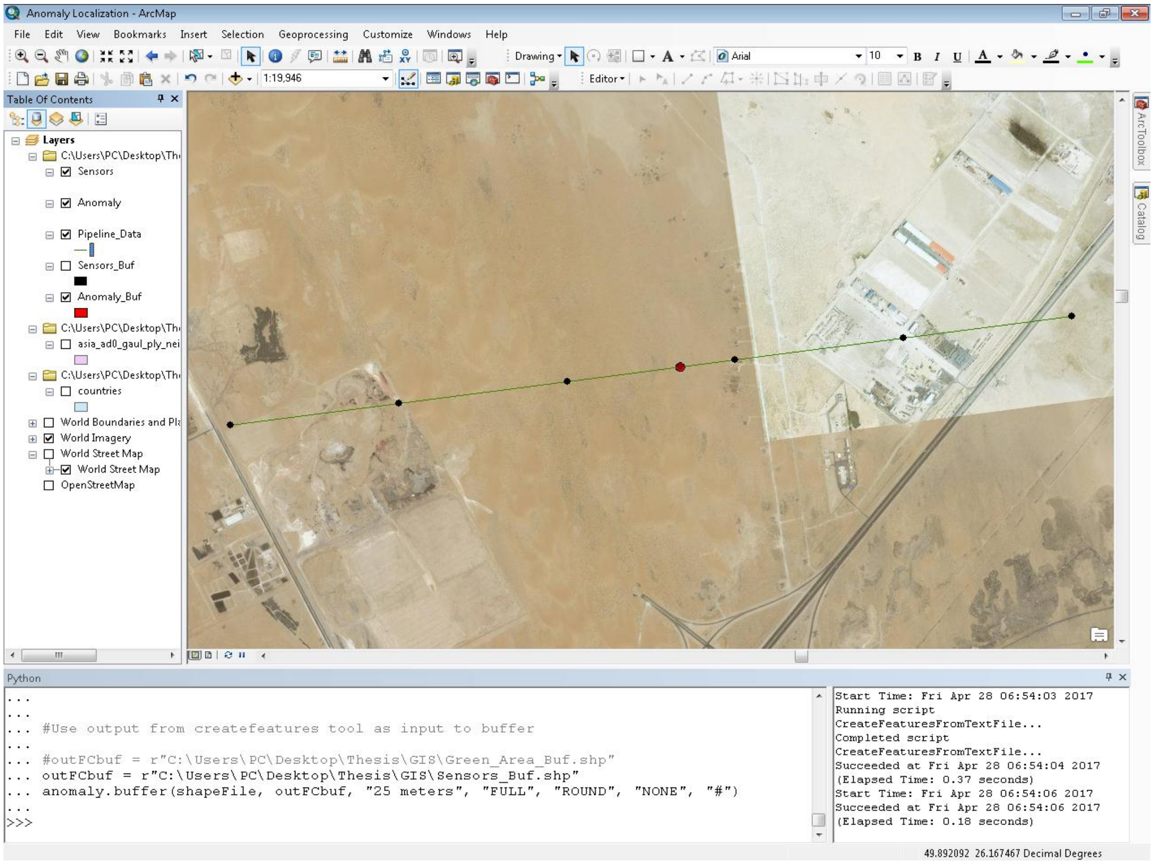

Figure 4.10: ISTS – GIS Output – Scenario 1.

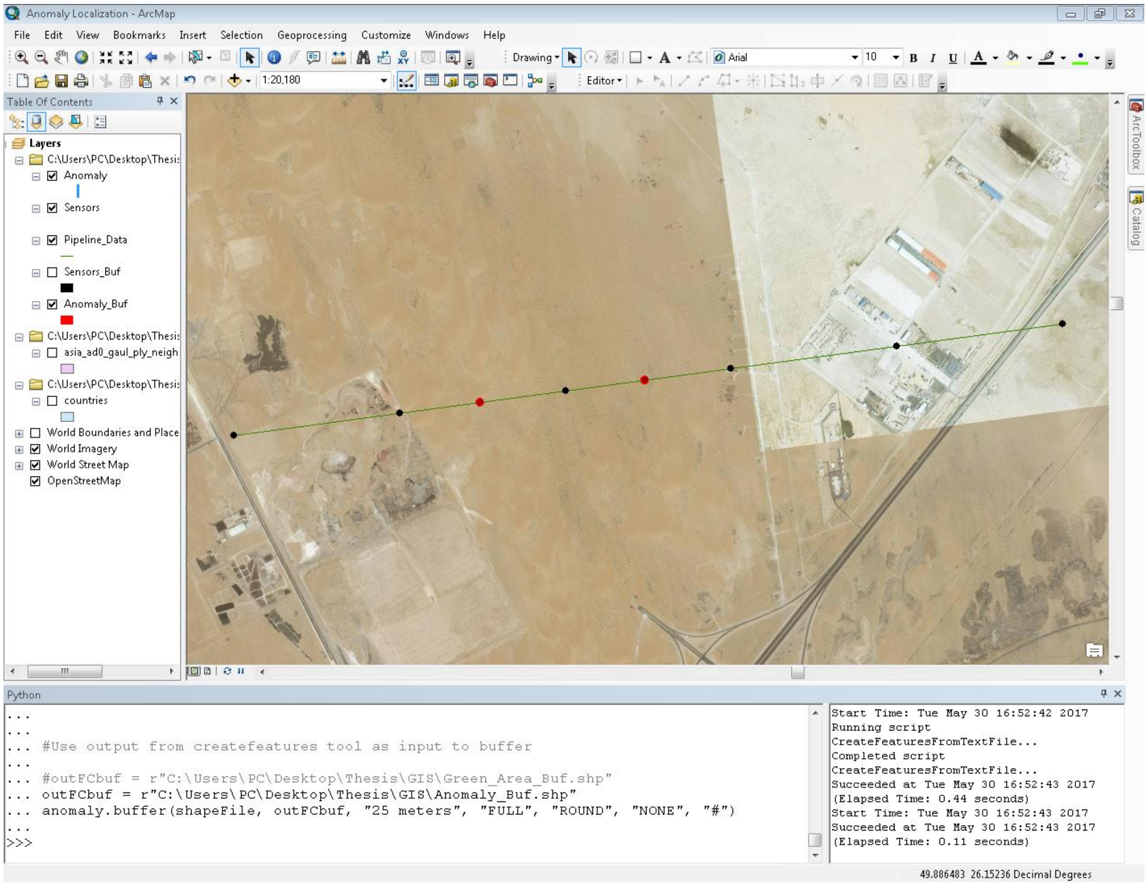

Figure 4.11: ISTS – GIS Output – Scenario 2.

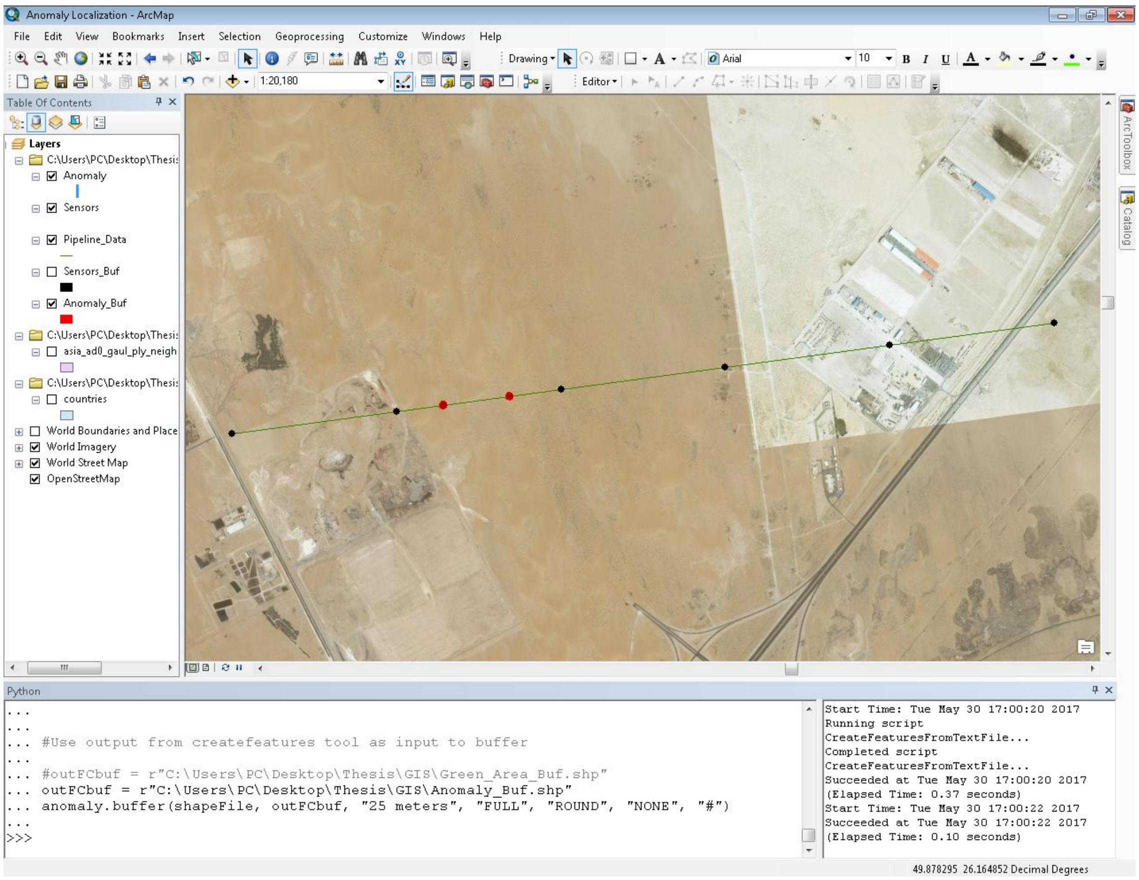

Figure 4.12: ISTS – GIS Output – Scenario 3.

4.3 Evaluation

ISTS algorithm is evaluated by analyzing the difference between the actual anomaly location and the localization accuracy achieved by the implemented algorithm as shown in Figure 4.13 and Figure 4.14. It is tested at 50 different locations. Figure 4.15 shows variances of ISTS algorithm with the actual anomaly location. Zero is taken as the reference/ideal point. Least variance is better. It is observed that this method gives accuracy up to ±46.8 meters.

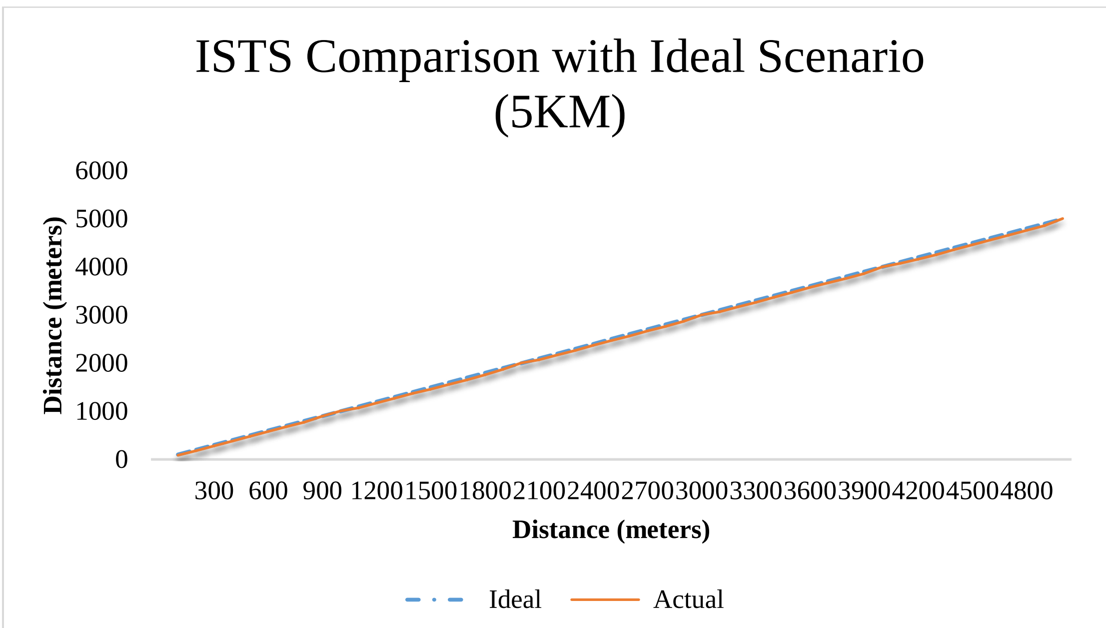

Figure 4.13: ISTS - Comparison with Ideal Scenario.

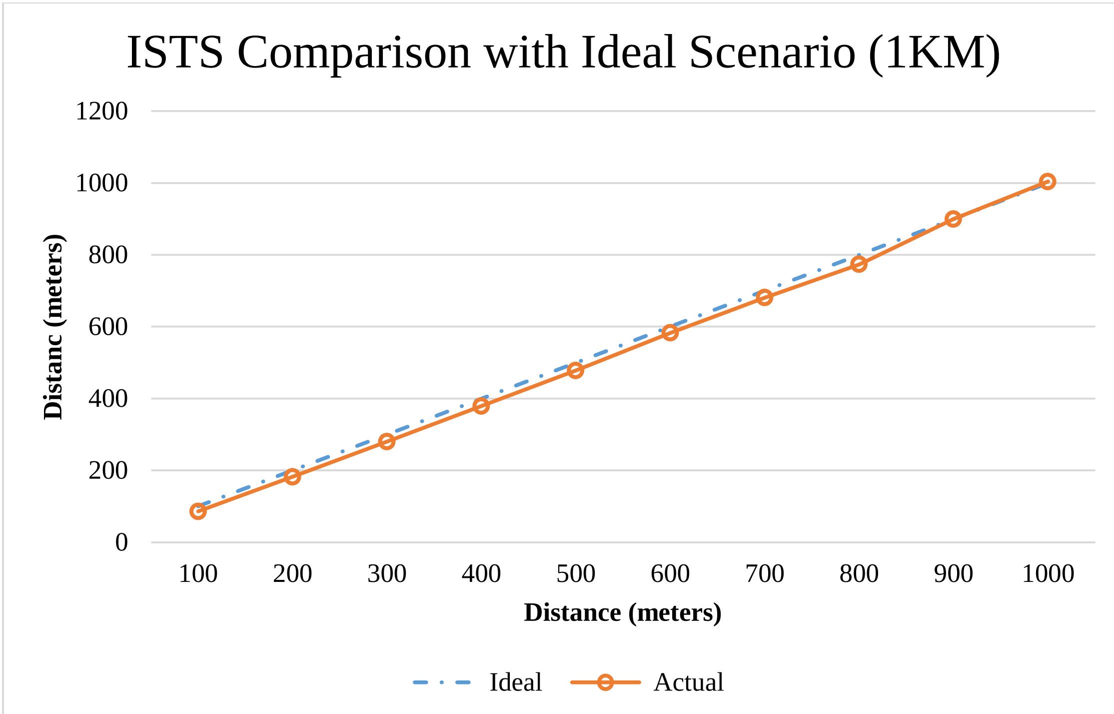

Figure 4.14: ISTS - Comparison with Ideal Scenario (Short Data Sample).

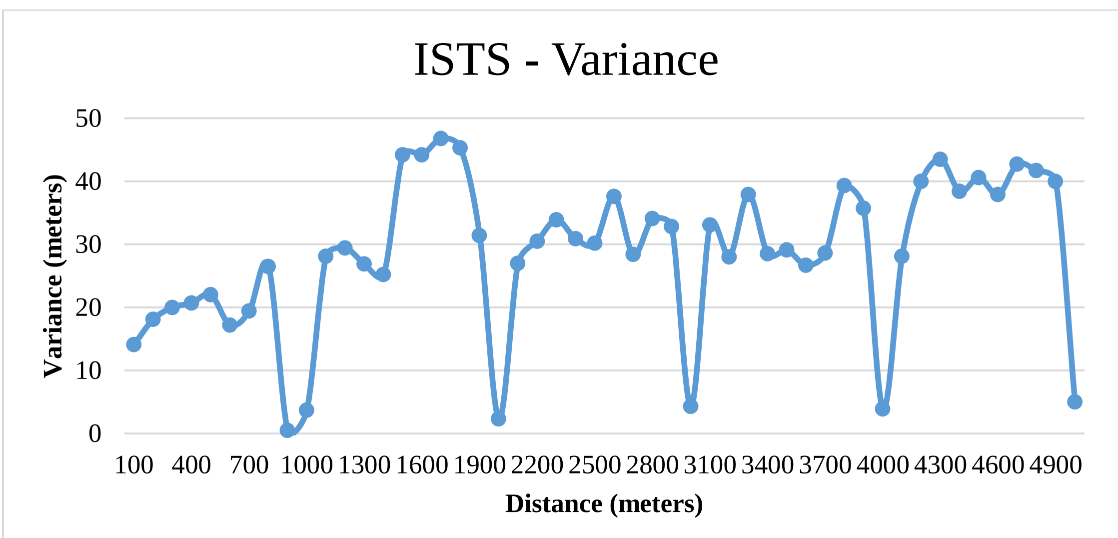

Figure 4.15: ISTS – Variance.

After several experiments, it was observed that errors in localization were shifts with a constant value. Thus, localization accuracy can be improved further by introducing a constant Recalibration Factor (R.F). Thus final equation of algorithm becomes

$$\Delta i \ = \left(\frac{A1+\sum_{n=n}^{k+1} An}{k+1}\right) \times \{\Delta Ti\} + R.F \qquad (4.5)$$

$$\text{Where } \ \Delta Ti = \left(\frac{\sum_{n=n}^{k+1} Tn}{k}\right) - Ti \qquad (4.6)$$

For a specific implementation, RF will be calculated after experiments. Figure 4.16 shows the improved version of ISTS where overall localization accuracy is increased by 50%

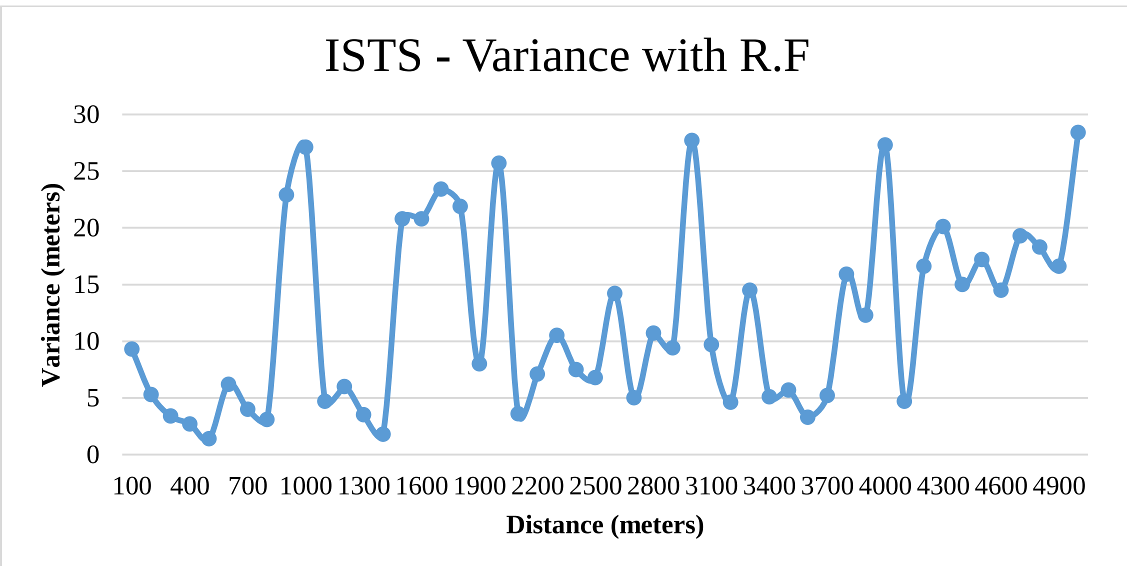

Figure 4.16: ISTS - Variance with R.F.

Figure 4.17 shows comparative variances of ISTS with R.F and without R.F. It is observed that, localization error in the vicinity of sensors is increased in contrast with the older version. But overall localization accuracy is improved from ±46.8 meters to ±23.4 meters. Figure 4.18 shows percentage accuracy of ISTS over a distance of 5 kilometers.

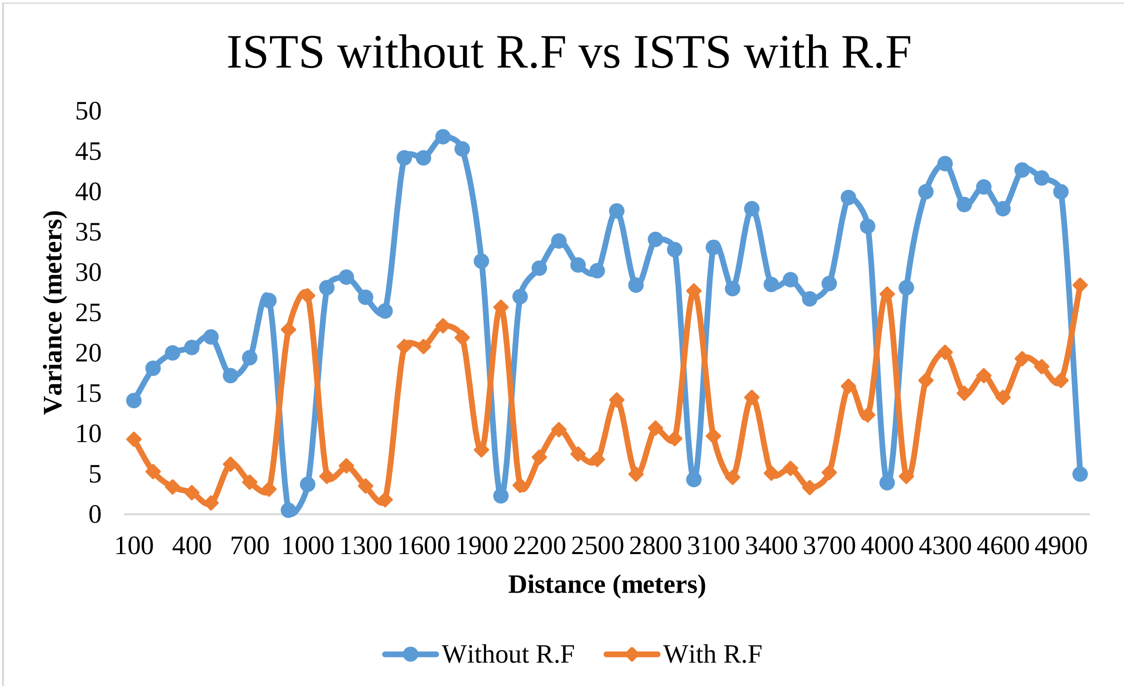

Figure 4.17: ISTS - Comparison of Variances with R.F and without R.F.

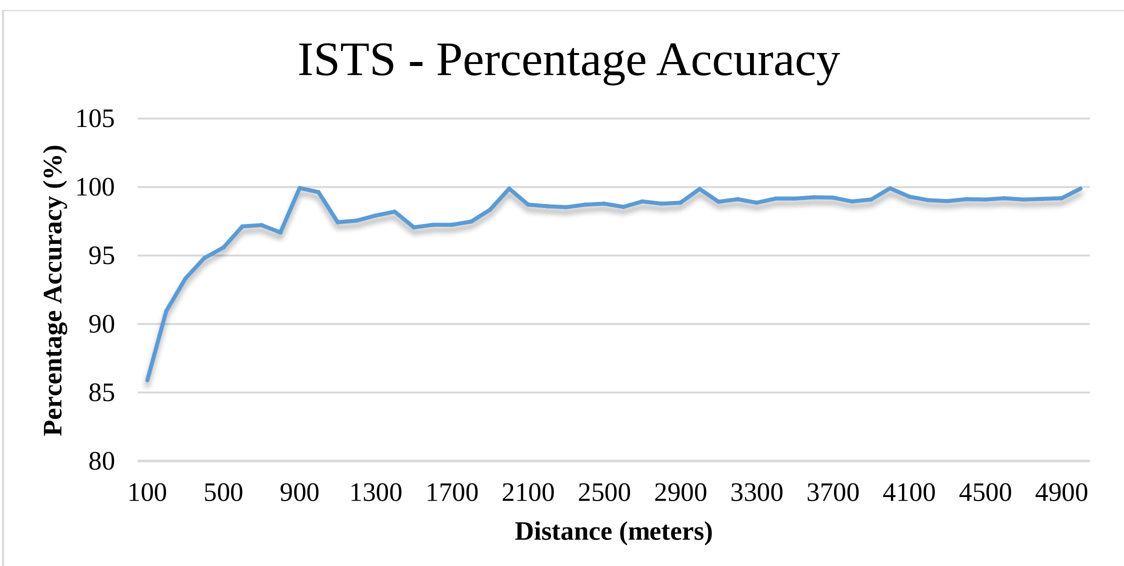

Figure 4.18: ISTS - Percentage Accuracy.

CHAPTER 5

RESULTS AND CONCLUSION

In this thesis, we simulated and evaluated Negative Pressure Wave (NPW) and Pressure Point Analysis (PPA) in terms of accuracy and compared them against our proposed technique, ISTS. Figure 5.1 shows the comparison of ISTS algorithm without RF against the other two techniques – NPW and PPA. Figure 5.2 shows the comparison of ISTS algorithm with RF against the other two techniques – NPW and PPA. In terms of accuracy, ISTS algorithm supersedes the other two. Its accuracy is not affected by pipeline transient flows and type of material. Time synchronization is also not an issue as the clock is maintained by IS. Moreover, with scheduled monitoring, preventive measures can be taken before an actual anomaly/disaster occurs with zero fluid loss. This is not possible with the other two techniques. However, on the other hand, it incurs high implementation costs on existing pipeline infrastructure. Whole pipeline infrastructure needs to be redefined. In addition, design of IS sensor is also a challenge, which is left for future work. The design of IS and pipeline infrastructure should be such that it can be deployed and evacuated from several locations along the pipeline. They are called as deployment units. The distance between two deployment units depend on the energy capabilities of IS i.e. how far it can move. IS is also supposed to be moved at constant speed. Small variations in speed will not affect localization accuracy due to averaging accelerometer reading parameters taken at anomaly location. In case of failure due to huge variations in speed between two FP's – FPx and FPy, ISTS will still be able to detect anomalies but with the increase in localization error. The maximum realizable localization error is the area of pipeline between FPx and FPy. ISTS is flexible enough to re-localize itself when it crosses any FP. The localization accuracy of anomalies will not be affected for upcoming anomalies after FPy. However, hybrid detection and localization techniques can be used in case ISTS fails. The other design requirements that IS should have is a clock. Depending on the design of IS, in case stepper motors are used for motion, clock ticks can be updated with the ticks of stepper motor. Memory elements are also required to store anomaly data. An Accelerometer unit, that can measure current speed and also able to calculate average speed since last reset. A depth gauge unit, which takes continuous pipeline thickness readings. Finally, design should be flexible enough to support varying pipe sizes.

On the other hand, PPA and NPW incur low implementation cost but are unreliable in anomaly localization and detection for transient flows. With PPA, occurrence of multiple anomalies at different locations at the same time instant cannot be detected or localized. However, at different time instants, localization is possible under the condition that system should be re-stabilized and starts adhering pressure gradient profile Pipeline Gradient profile is also affected by the natural curves and turns of pipe. Pipeline should be straight and horizontal. With NPW, time synchronization is also a critical factor because only a little deviation in time may come up with a large localization error. It cannot localize multiple anomalies that occur at the same time. Multiple anomalies occurring at different locations within a range of single pair of upstream and downstream sensors cannot also be detected. However, multiple anomalies occurring at different locations within a range of different upstream and downstream sensor pairs can be detected and localized. If negative wave is somehow missed or not able to reach at the end sensors, there is no way to detect this anomaly later on. With ISTS method, occurrence of multiple anomalies at different locations at the same or different instants of time can be detected and localized.

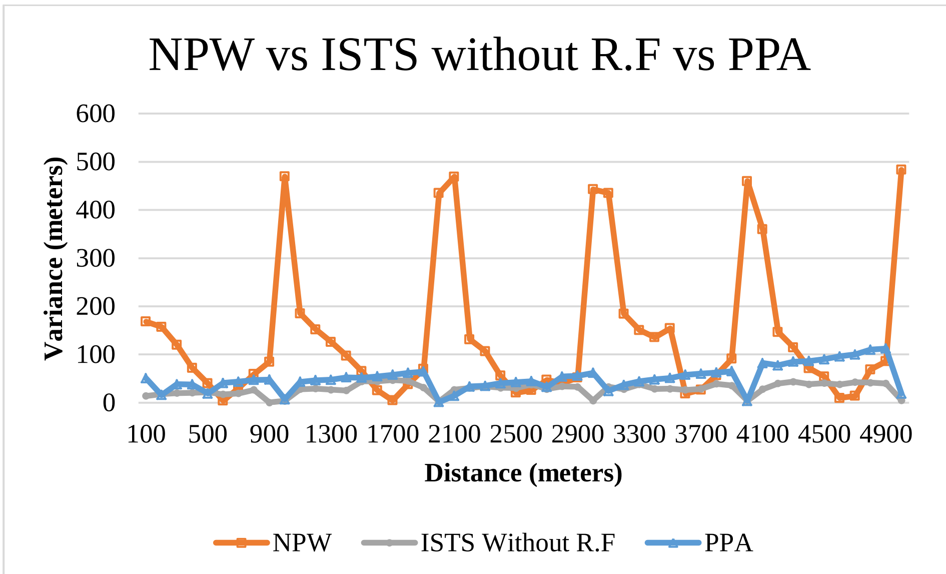

Figure 5.1: Variance comparison of ISTS without RF, NPW and PPA.

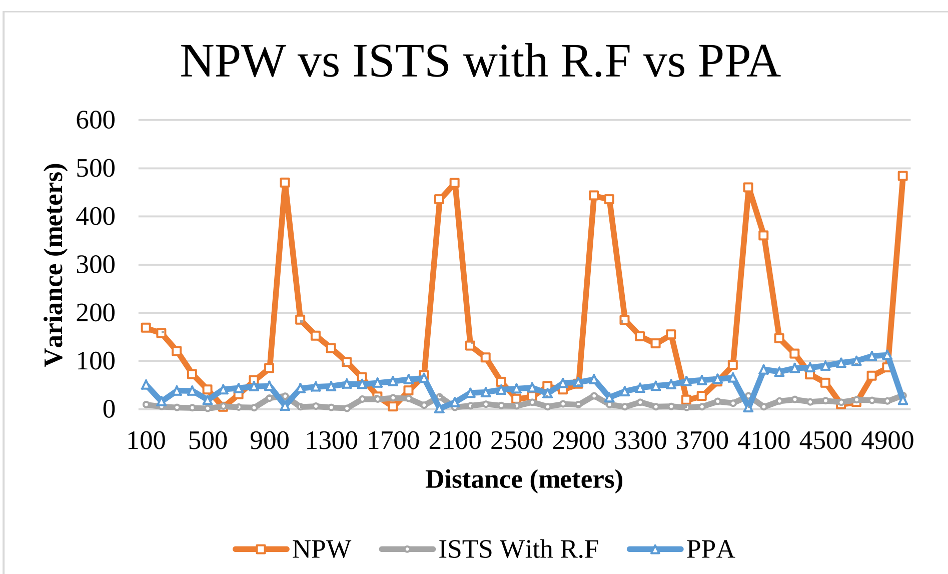

Figure 5.2: Variance comparison of ISTS algorithm with RF, NPW and PPA.

Figure 5.3 shows the average accuracy of the ISTS, PPA, NPW algorithms with light and extra heavy grade. PM with R.F outperforms all with the average accuracy of 11.976 meters.

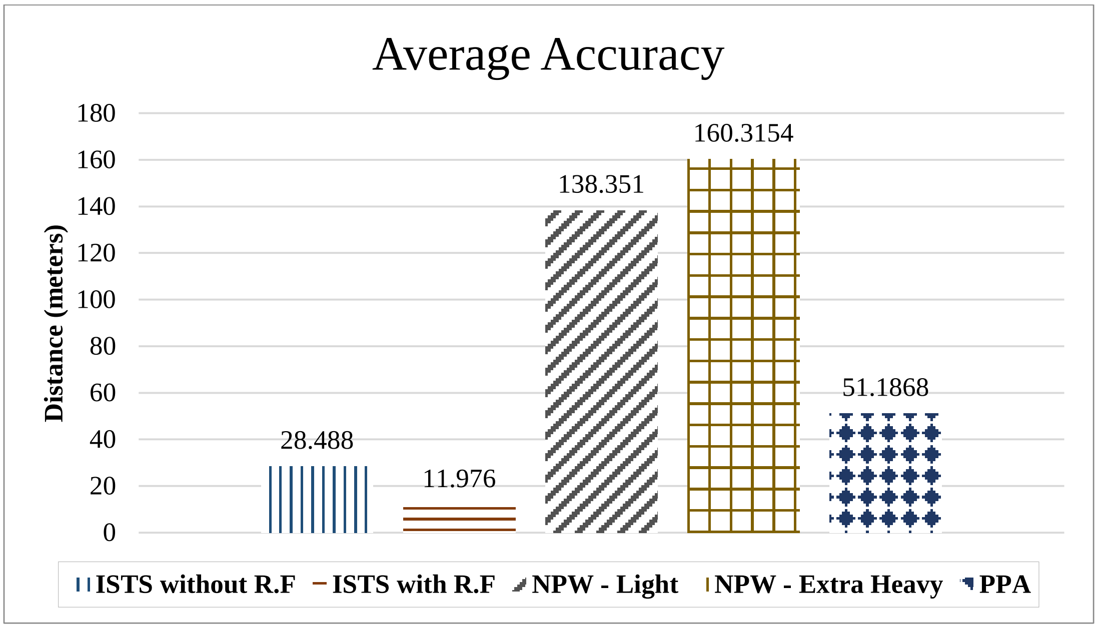

Figure 5.3: Average accuracy of all techniques.

Figure 5.4Figure 5.3 shows the confidence intervals for ISTS, PPA and NPW. These confidence intervals are calculated based on the difference in accuracies on the data set of 50 samples. With 95% confidence, it can be concluded from the figure that accuracy results of techniques will never overlap each other. NPW results may overlap because NPW light and NPW heavy belong to same class with difference in grade of oil. Area of NPW heavy grade oil overlapped by light grade oil light is 10.25%. It means there is probability of 0.1 that results of NPW heavy will match with the results of NPW light. Similarly there is 0.13 probability of getting better results than NPW light. On other hand, most of the area of NPW heavy is higher than NPW light. It can be concluded that there are 73% chances of getting bad localization results when using heavy grade oil as compared with light grade oil. This also proves that for NPW type of the material is also an important factor that affects localization accuracies.

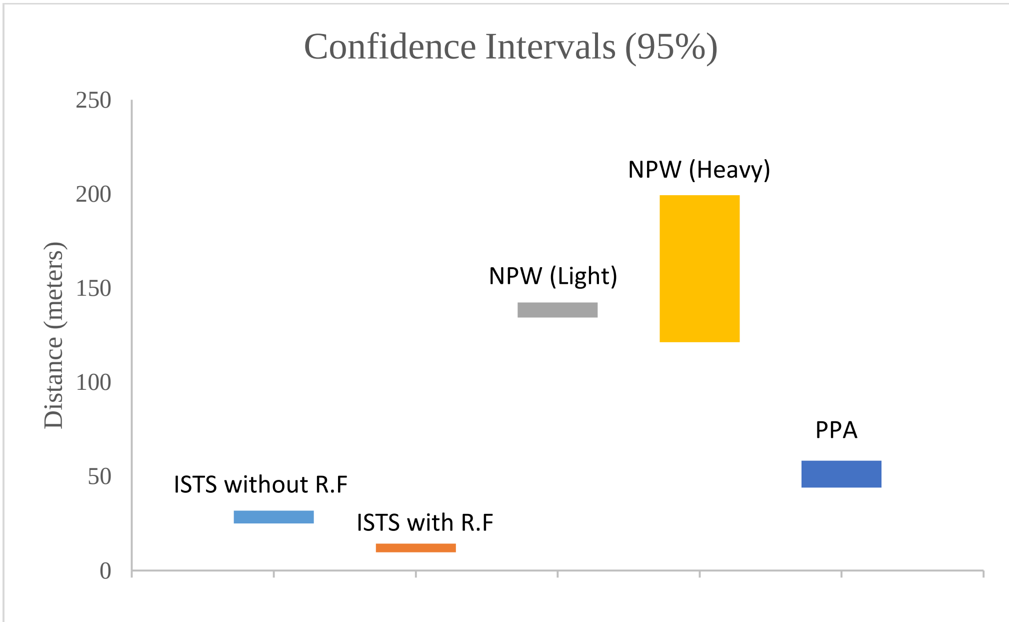

Figure 5.4: Confidence Intervals

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Vitae

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Being an Engineer and Researcher, I want to offer my services for the success of a well reputed organization & also to tackle all the challenges of the organization with a positive & ambitious attitude by doing the maximum hard work to achieve the specified goals.

Qualification Summary:

- Familiar with different network environments and programming languages with proven ability to learn new and complex products, technologies, solutions, and problems.
- Experience in all stages of network development lifecycle (NDLC).
- Information analysis, Technical understanding and management, Quality management.

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King Fahd University of Petroleum & Minerals (KFUPM), Dhahran, Saudi Arabia
Master of Science (M.Sc.)
Computer Engineering (Specialization Computer Networks)
CGPA: 3.6/4.0

Core Courses: Computer Networks, Network Design, Client Server Programming, Network Management, Network Security.

Graduate Thesis/Final Year Project

A Framework For Single And Multiple Anomalies Localization In Pipelines

2009-2013

COMSATS Institute of Information Technology (CIIT), Pakistan
Bachelor of Science (B.Sc.)
Electrical Engineering (Specialization Computer Engineering)
CGPA: 3.45/4

Core Courses: Power Distribution & Utilization, Web Engineering, Data Communication & Computer Networks, Object-Oriented Programming, OS Concepts, Computer Organization and Architecture, Algorithms & Data Structures, Microprocessor Systems and Interfacing, Entrepreneurship.

Undergraduate Thesis/Final Year Project

SystemC Modelling of Java Virtual Machine

Extensive study of

- Java Virtual Machine
- Java Optimized Processor (JOP)
- SystemC Modelling.

Succesfully wrote the ILS to simulate the JOP's bytecodes at Instruction level.

Hardware and Software Skills:

Technical Softwares:

Microsoft Visual Studio, ArcMap GIS, NetBeans, Eclipse, PSpice, Matlab, Packet Tracer, GNS, ISE Xilinx, Proteus, Cygwin

Programming Languages:

GW Basic, Assembly, C, C++, Java, VHDL, HTML, Java Script, CSS, AJAX, Python, .NET, Cake PHP Framework, SQL, NodeJS

Operating Systems:

Windows, Linux.

Designing Skills:

Microsoft Office suite, AutoCAD

Networking Skills:

MCSE, CCNA, Network design, Security and Management, Packet Analysis. Client Server Programming.

Experience:

Research Assistant at KFUPM **September 2014 - onwards**

King Fahd University of Petroleum and Minerals, Dhahran, KSA

- Assisting Dr. Abdul Aziz Yaqoob Al Barnawi in his reasearch work
- Grader with Dr. Muhammed Y. Mahmoud in his DLD course.
- Embedded Systems Lab (22-416) Organization and Cataloguing with Dr. Ahmad Khayyat
- Grader with Dr. Ahmad Mulhem in Object Oriented Programming
- COE Courses Analysis and Comparison with IEEE/BOK 2016 and Study of "Education Gap between Labour Market and Education System in KSA" with Dr. Mayez and COE Chairman Dr. Ahmad Mulhem

- Documents Control, Management and Logging under Dr. Ahmed A Al-Dharrab (Assistant Dean)
- COE Research Data Management and Analysis with COE Chairman Dr. Ahmad Mulhem and Dr. Baroudi.

Security Camera Troubleshooting visit **October, 2016**

Mo'sasa Taha Hussain Al-Jasim Trading Est.

Troubleshooting visit in Obagi MediSPA Company **28th April, 2016**

King Faisal Road - Expo # 2 Block B Opposite of Blue Tower

Security Camera Installation and Configuration **May, 2015**

Mo'sasa Busainah Ali Al-Marhoon - Opposite Corniche

Intern Assistant with DCO in PTCL **June, 2014 – July 2014**
Wanniyan Exchange, Gujranwala, Pakistan

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National Engineers Training Services (NETS), Lahore

Projects Completed

- Application of GIS for Security and Natural Hazards in Pakistan.
- A Comprehensive Study on Cloud, Server Level Security and Its Defensive Measures
- Server Based Network Management by creating virtual environment of an entire network using Windows Server, Active Directory, GNS3, MS Visual Studio and Virtual Box.
- Establishing the communication among various Wireless Sensor nodes by developing different communication protocols in Contiki Simulator to perform various tasks.
- Development of Network Performance Monitoring tool using SNMP to monitor network traffic and generate corresponding data charts.
- A survey and study of Traffic Redundancy Elimination Techniques in data distribution of Computer Networks.
- SystemC modeling of JAVA Virtual Machine (B.Sc FYP).
- Designing of intelligent path detecting robot using SPP.
- Designing & implementation of an intelligent path detecting robot via PIC microprocessor.
- Designing of 8-bit RISC micro-processor on VHDL.
- Designing & implementation of a 2-bit up & down counter with pause & reset buttons.
- Demonstration of multi-threading in Android Phones.

- Making of a blog using Web Engineering Skills and Techniques. (Cake PHP, SQL Yoq, Pagination, Login, Logout, User Authentication, Authorization, AJAX, CRUD Operations).

Publications:

- **Sultan Anwar**, Abdullah Al Mamun, and Hassan Ali. "A Defensive Measure of Cloud Server Security with Brief Solution." IJCTT vol29 (2015).
- Hassan Ali, **Sultan Anwar** "A comprehensive study of advancement of Electrical Power Grid and Middleware based Smart Grid communication platform". OMICS International (2016).
- Abdullah Al Mamun, Hilal H. Nuha, **Sultan Anwar**, and Hassan Ali "Slight Heterogeneity in Multicore Architecture: An Experimental & Comparative Study" IJSER 6:10, 1235-1238 (2015).
- Hassan Ali, Abdullah Al Mamun, and **Sultan Anwar** "All Possible Security Concern and Solutions of WSN: A comprehensive Study". IJCST vol6:4 64-74 (2015).
- Abdullah Al Mamun, **Sultan Anwar**, and Hassan Ali "4G and 5G Mobile Communication Networks: Features Analysis, Comparison and Proposed Architecture". IJCST (2016).
- Abdullah Al Mamun, Hassan Ali, and **Sultan Anwar** "Redundant Network Traffic Elimination Techniques: A comprehensive Survey" IJCTA vol6 (9) 915-925 (2015).
- Abdullah Al Mamun, Hassan Ali, and **Sultan Anwar** "Development of Monitoring Tools for
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- Mamun, A., Tareq R. Sheltami, **Sultan Anwar** "Performance Evaluation of Routing Protocols for Video Conference over MPLS VPN Network". World Academy of Science, Engineering and Technology, International Science Index, Computer and Information Engineering, (2015), 2(6), 1406.

Awards & Honours:

- Qualified for cash scholarship in NTS by scoring top position from COMSATS.
- Certificates for managing and participating different technical workshops
- Certificates for arranging and attending different workshops on leadership and inter-personal skills

Activities:

- Member of Pakistan Engineering Council (PEC) – Registered Engineer
- Member of Instrumentation, Systems & Automation Society (ISA).

- Registration Assistance for registration activities in KFUPM from 2015 to 2016
- Worked as a Part of Beta Software Testing Team for added services in KFUPM portal.

Interpersonal Skills

- Developed good Communication skills by designing and delivering multiple presentations
- Worked well as independently and as a team member in various technical and non-technical societies
- Learned how to adapt new concepts and handling of multiple responsibilities through different posts in many technical societies
- Proven skill in managing complex project schedules

Interests:

- Network Management, Security
- Software Analysis & Testing
- Geographical Information Systems (GIS)
- Wireless Sensor Networks
- Mobile App Development

Extra-Curricular Activities:

- Listening and Attending Islamic Lectures.

References:

References will be provided on demand.