ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

AFRICAN RAILWAY CENTER OF EXCELLENCE

"Availability and reliability improvement of Signalling Equipment through Remote Condition Monitoring: Point Machines"

A Thesis in Masters of Science in Railway Engineering (Traction and Train Control)

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**Availability and reliability improvement of Signaling Equipment through Remote Condition Monitoring: Point Machines**' presented by **Stanley Andrew Mbewe**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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I certify that research work titled "**Availability and reliability improvement of Signaling Equipment through Remote Condition Monitoring: Point Machines**" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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Abstract

For the past decade, sensing technologies have emerged and expanded rapidly. Due to the sensor devices becoming cheaper, condition monitoring systems have become an option as a management tool. These systems are designed and deployed in structure health monitoring, vehicles, machinery and even wild life preservation systems. These cheap sensors together with the recent advances in networking technologies such as wireless communication and mobile ad hoc networking coupled with the technology to integrate devices has brought the emergence of wireless sensor networks (WSNs).

Wireless sensor networks (WSNs) can be used for monitoring the railway infrastructure such as bridges, rail tracks, tunnels and track signalling equipment as well as vehicle health monitoring like chassis, bogies and wheels. Condition monitoring especially in remote areas reduces human inspection requirements through automated monitoring, in essence it majorly reduces maintenance costs through detecting faults before they escalate which then improves reliability, availability and safety.

In this thesis, a WSN for condition monitoring of railway point machines is researched. The point machine is selected for monitoring after data analysis of signalling devices failure rates at Addis Ababa light rail transit.

A dynamic website application is developed to monitor and manage the information coming from the sensor nodes wireless transmission. The collected data is stored using a database management service. The system uses open source tools which makes it possible to keep the cost low to justify the savings in maintenance costs.

Keywords: *Condition monitoring, WSN, Railway signalling, sensors, Reliability, Availability*

Table of Contents

List of Figures

List of Tables

Glossary of Terms / List of Abbreviations

Term	Explanation / Meaning / Definition
AALRT	Addis Ababa Light Rail Transit
AAP	Aerostat acoustic payload
ADC	Analog to Digital convertor
APS	Ad Hoc Positioning System
ATC	Automatic train control
BSN	Body sensor networks
CDMA	Code division multiple access
DPM	Dynamic power management
EDR	Ethio-Djibout Railway
FPGA	Field Programmable Gate Array
GPS	Global Positioning System
GUI	Graphical User Interface
ISM	Intelligent sensor modules
LCC	Life cycle cost
MEMS	Microelectromechanical systems
MFCC	Mel-frequency spectrum coefficients
OCC	Operations Control Centre
PPS	Precise positioning service
RAMS(S)	Reliability, Availability, Maintainability, Safety (Security)
RDAU	Remote data acquisition units
RT	Recovery Time
SDT	Soldier detection and tracking
SHLM	Self-healing land mines
SPS	Standard positioning service
STCP	Sensor Transmission Control Protocol
SVM	Support Vector Machines
UT	Up Time
WPAN	Wireless personal area networks
WSN	Wireless Sensor Network
WT	Waiting Time

1 Introduction

1.1 Overview

Signalling is a vital aspect of railway transport operations. The signalling systems have evolved from man based to automation in the past decades. The growing complexity of equipment and systems, as well as the rapidly increasing cost incurred by loss of operation as a consequence of failures, have brought to the forefront the aspects of *reliability, maintainability, availability,* and *safety* with *security* (RAMS(s)) [1] in the railway industry. The proper coordination between on board and wayside equipment is crucial. Since the failure of signalling equipment like a point machine can cause disruption of the operations, early detection of anomalies in the equipment is important. This can be achieved by condition monitoring of the signalling equipment along the tracks using wireless sensor networks.

Condition monitoring sensors detects and points out irregularities in infrastructure before major damages occur. It is common in many railway condition monitoring systems to be equipped with alarms that apply thresholds to electrical sensor readings. This does not ensure early detection of faults and they have a tendency of producing false alarms and missed failures [2]. Wireless sensor networks (WSN) would bring about collective data that can be processed together while many sensors connect to controllers and processing stations directly. This is important because many network applications require hundreds of sensor nodes often deployed in remote and inaccessible areas as is of the case of the areas [3] the railway tracks passes through. Integrated data processing provides means to have an overall picture of the system and come up with decisions using the overall condition trends of the equipment [4].

Therefore in railway signalling systems, [27] WSN monitoring can be used to;

- ✓ maintain process tolerances;
- ✓ verify and protect machine, systems and process stability;
- ✓ detect maintenance requirements;
- ✓ minimize downtime;
- ✓ prevent failures and save businesses money and time;
- ✓ Request maintenance based on the prediction of failure rather than maintenance running to a standard schedule or being requested following an actual failure.

This research thesis is about the development of a WSN for condition monitoring and sensing of wayside signalling equipment in remote locations. The research will tackle different combinations of sensors, microcontrollers, software and systems that can maximise the monitoring process while minimizing maintenance and inspection costs as well as the down time due to equipment faults.

Figure 1 depicts the proposed system in a nutshell. Where sensor nodes planted along the track on the signalling equipment send the data wirelessly to a base station represented as a server that stores the data in a database. This information can then be retrieved anytime through desktops, laptops or mobile phones. An alert is sent to a responsible officer if the readings is beyond a set threshold.

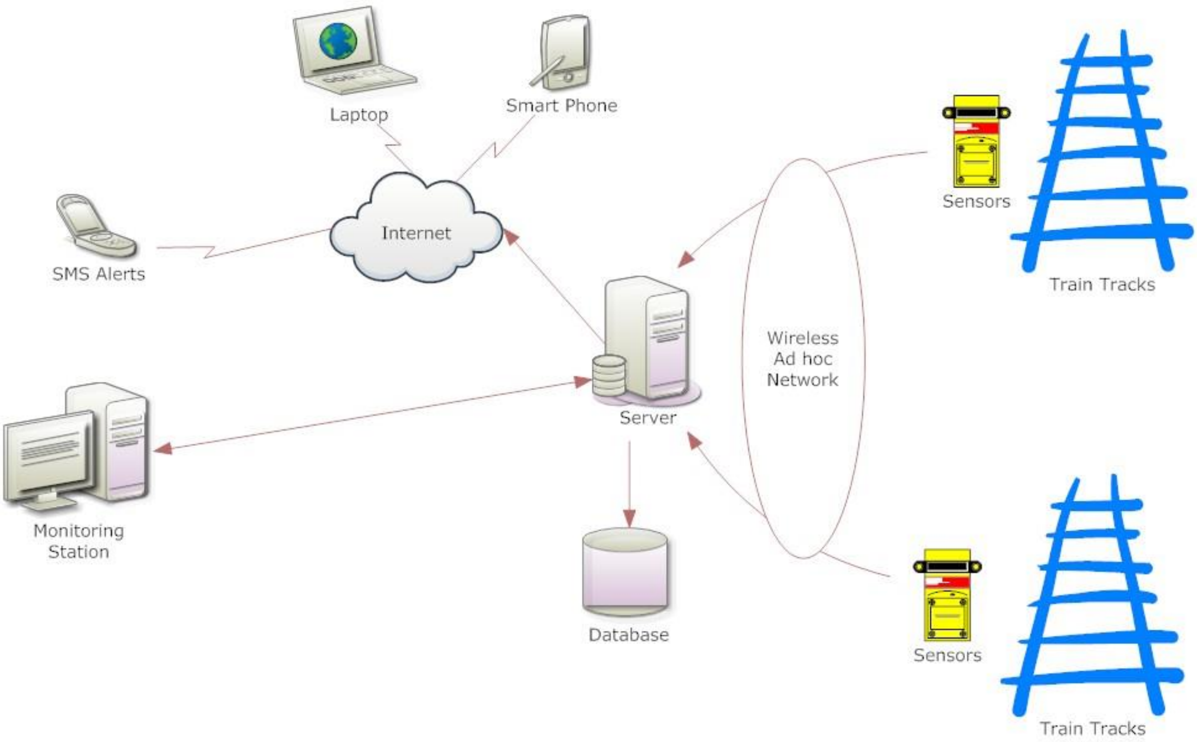

Figure 1. Illustration of proposed system.

1.2 Statement of the Problem

Most African railway corporations have their railways running through remote areas due to land ownership issues and to avoid noise pollution in residential areas. This means that wayside signalling equipment have to be installed in the remotest of areas. For the case of SIEMENS MOBILITY, a signalling company working for central east African Railways, the technicians drive and sometimes take trains to access the equipment in the remote areas for inspection and Maintenance. This is done monthly to ensure RAMS(S) of the system.

When there is a fault identified that needs approval from the supervisors before working on it or a fault that requires a specialist, it means travelling back to the office to report then travel back to the site to work after approval is granted. The time delay is very costly in operations as well as time cost in travelling back and forth which minimizes the availability of the equipment.

To curb the problem of time delay in decision making for maintenance purposes which costs the railway company money a WSN can be developed to monitor the condition of the delicate signalling infrastructure and send that recoded data to the operations control centre (OCC) for prompt decision making. [5]

In the figure 1 above, we have sensors that are mounted on the signalling equipment along the tracks sensing a critical aspect of the equipment to determine its health. These sensors wirelessly send the current condition of the device to a server that can be accessed from anywhere in the world or upon request for decision making. [6]

1.3 Purpose and Objectives

The purpose of the research is to explore the use of condition monitoring of railway signalling equipment through the use of wireless sensor networks to improve the availability and reliability of the said signalling equipment.

The general aim of the thesis is to research about a sustainable, low cost signalling equipment condition monitoring system using wireless sensor networks for remote sensing and inspection to improve maintenance and hence availability of the system. This general objective can be split down to the specific objectives to be achieved as listed below;

- ✓ Learn the current best inspection and maintenance methods
- ✓ Learn about the existing condition monitoring systems that are using WSNs
- ✓ Determine the signalling equipment that has the highest failure rate in Ethiopia Railway Company and Malawi Railway companies.
- ✓ Learn the critical parts of the signalling equipment that require frequent attention
- ✓ Learn about the different types of sensors in the market that can be utilised in monitoring
- ✓ Find the optimum wireless network among the existing networks that can be utilised in monitoring
- ✓ Do a cost benefit analysis of the designed WSN compared to the current monitoring methods
- ✓ Identify open source tools for system architecture
- ✓ Simulate the condition monitoring system
- ✓ Build a prototype of the condition monitoring system depending on availability of time and resources.

1.4 Research Questions

The following research questions have been formulated;

- ✓ What are the issues and challenges in the existing railway signalling systems in the availability, reliability and maintenance aspect?
- ✓ What are the current maintenance procedures being used in Ethiopia and Malawi railway companies?
- ✓ What are the failure rates of various signalling equipment?
- ✓ How does it take for an equipment to become available after a failure?
- ✓ How can state-of-equipment data and information help to improve to improve the dependability of railway signalling systems?
- ✓ How can sensor networks be safely incorporated in railway signalling systems?

1.5 Scope and Limitations

The research will tackle different combinations of sensors, processors, software and systems that can maximise the monitoring process while minimizing maintenance and inspection costs as well as the down time due to equipment faults. The areas of study will be the Ethiopian Railway Companies and Malawi Railway Companies. In Ethiopia the companies to be involved are AALRT and EDR. In Malawi the company to be involved is SIEMENS Mobility. The research also depends on finding the vital signalling equipment to be monitored as determined from the data to be collected from companies to narrow down the work to suit the time frame.

Limitations related to the research must be acknowledged as listed but not exhausted below;

- ✓ The research focuses on the said areas and the data is specific to the said companies.
- ✓ The data analysis will be to a particular range of time on a specific railway corridor.
- ✓ The study will focus more on the corrective maintenance procedures and performance.
- ✓ The research is based on maintenance data documents and interviews. Since the documents are manually recorded, human error is expected to affect the quality of the data.
- ✓ Since personal inspection of the maintenance is very unlikely, the unrecorded data will not be used. Only recorded data is considered.
- ✓ Simulation and prototype development will depend on availability of resources from the university.

1.6 Related Works

Radio is only one slice of the broad array of energy we call the electromagnetic spectrum. Radio signals require a lot of power because, unlike messages running through a wire, they decay in an accelerated fashion [7]. There has been intensive research to come up with wireless networks that consume less power to be utilised in WSN. One example is the ZigBee mesh networks that are designed with the inverse square law in mind. Rather than using big batteries to generate the large amount of power needed to send a signal over a great distance, each radio needs only small amounts of power to go a short distance to its nearest neighbour in the network. By adding nodes to the network, great distances can be traversed without any node needing access to large amounts of energy [7]. Some literature that are utilising WSN for condition monitoring in railway systems are outlined below;

F. Zhou et al in [8], designed a condition monitoring system of the point machines to measure the measure the shift in the switching gap and condition of the point machine parts. They use load cells, position sensors and others utilising analogue to digital converter (ADC) board for signal conditioning and signal scaling. From the analogue board the signals are sent to field programmable gate array (FPGA) for ADC control and data precondition before sending the data to the processor board which is a Pentium 166MHz on a PC-104 form factor, running the condition monitoring application under the real-time operating system VxWorks monitor measuring channels. The processor, among other tasks, Detect train events on-line and generate train event record files and reports, Generate ASCII log file giving time-stamped messages of all activities and Provide http, ftp and telnet services for local or remote access, with full security features [8]. This enables a java based Web interface used for condition monitoring. Despite the system looking all clean and nice, it poses the advantages of bringing in more maintenance work since it utilises high end components that require more attention and power hence the need for more robust field components.

WSNs are utilised in railway infrastructure health monitoring by Jaime Chen et al in [9]. They use the WSN to collect information about the structural health and behaviour of the infrastructure when a train travels along it and relays the readings to a base station. The base station uses the next train(s) as a data mule to upload the information. The information is then processed on the train which does not have the limitations of a sensor node. They use PS-QUASAR a middleware for WSNs offering a high level simple programming model based on publish/subscribe paradigm [9]. All nodes in the network are aware of the existing subscribers and can become publishers. The application scenario consists of a WSN deployed on a railway bridge and sink nodes deployed on the trains, passing through, which will collect the information sensed by the bridge such as vibrations and strain. The authors claim a 100% data collection reliability is achieved at a sensing rate of 2Hz [9]. Despite claiming that the power consumption during the data collection is relatively low, 1.950mW and 1.832mW for head nodes and normal nodes, respectively. They do not specify the type of sensors to be used. They did not also consider the influence of the train speed on the performance of the sensors.

A WSN integrating the advanced microcontroller with GSM using services as GPRS through the password secured webpage without the need of any special application or software is designed in [10]. They use GSM SIM 800 module and Zigbee for communication media between various sensor nodes. ARM7 microcontroller is used as the brain and programming is done in embedded c language and software used for the programming is KEIL. The webpage coding is written in html. They use piezoelectric sensors to sense vibrations in the rail structures, load cell to measure deformations, temperature sensor to sense temperature diffractions in equipment and an accelerometer to measure both static acceleration, such as gravity and dynamic acceleration resulting from shock or motion that allows the device to be used as a tilt sensor [10]. The values read are sent to microcontroller at base station. After processing, microcontroller will update data on webpage. The data can be accessed using cell phone or personal computer. Wireless sensor network provides continuous and near real-time data acquisition and autonomous data acquisition. The system sounds simple and cheap to be deployed but the authors do not specify how the sensors are mounted on the equipment and what equipment temperature are the temperature sensors measuring. They also did not include a database where the measured data can be kept for future reference.

Jonguk lee et al in [11] design a Fault Detection and Diagnosis of Railway Point Machines by Sound Analysis. The system enables extracting mel-frequency spectrum coefficients (MFCCs) from audio data with reduced feature dimensions using attribute subset selection, and employs support vector machines (SVMs) for early detection and classification of anomalies. Structure of the system is shown in figure 2 below.

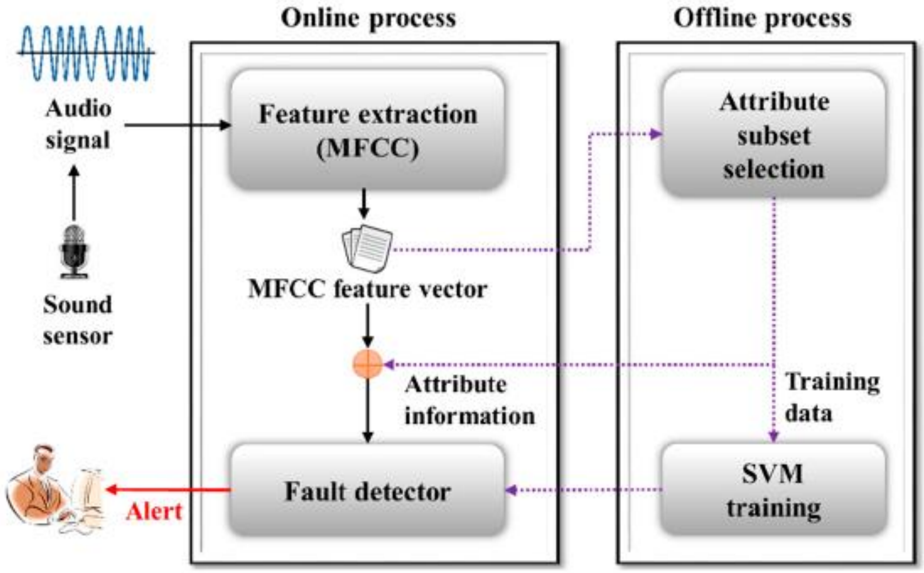

Figure 2 Point Machine monitoring through audio signals [18]

Using an audio sensor, audio data were collected from an NS-AM-type railway point machine at Sehwa Company in Daejeon, South Korea. Using sound analysis software and a filters for back ground noise, they were able to have two experiments; one for fault detection with the whole data set, the other for fault classification only using the data labelled as faulty. They were able to distinguish faults due to Ice obstruction, Ballast obstruction and Slackened nut on the switch blades. They claim that the combination of MFCC and SVM identified and classified the sounds of railway faults with accuracies of 94.1% and 97.0% respectively [11]. This system can be utilised with a WSN and information retrieved remotely on the respective faults. However, the authors do not consider how the sensor system behave when a vehicle is passing through it. And sound effects in terms of hazard weather conditions which may distort the readings.

Eduardo Canete et al in *Sensor4PRI: A Sensor Platform for the Protection of Railway Infrastructures* [16] design a WSN for infrastructure protection to be integrated into a slab track system in order to carry out both installation and maintenance monitoring activities. The worked on an experiment that was part of Fastrack [17] funded by the Spanish Government's FEDER program. In both the slab installation and maintenance monitoring phases, the communication module used is Digi's Xbee PRO S5 with a frequency of 868 MHz. The sensors deployed in the system are used to obtain acceleration, inclination and distance information. They are divided into groups controlled by a cluster head or coordinator that reports the information to base stations located in the passing trains. Figure 3 below depicts their system. They design the system to retransmit as little information as possible in order to extend the life of the devices in terms of energy consumption. They use the Arduino MEGA as the microcontroller claiming that it offers a good balance between capabilities and energy consumption at a reasonable price. They opt to us rechargeable batteries and solar panels as a power source compared to piezoelectric and Peltier cell sources which the concluded to be inadequate after experiments. The system was built and able to transmit data but the data is accessible only when a train passes through which means of the data is critical nothing can be done until it is too late.

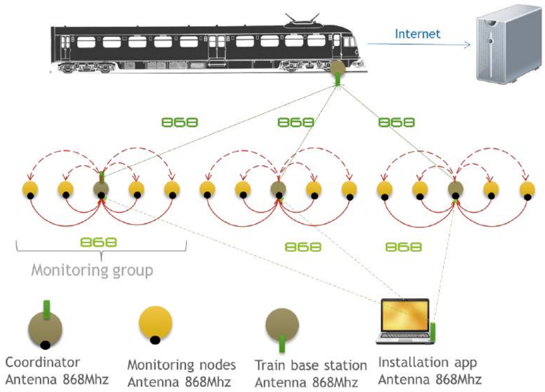

Figure 3 Train based infrastructure monitoring [16]

1.7 Thesis Outline

The remainder of this thesis is organized as follows;

Chapter 2. Theoretical framework, provides the framework used in the research.

Chapter 3. Research methodology, describes how the research was performed and gives the reasons.

Chapter 4. System design, describes how the system was design from hardware to software and sensors.

Chapter 5. Results and discussion, summarises the results of the research as described in the appended papers.

Chapter 6. Conclusions, summarises the conclusions extracted from the results and links them to the defined research questions, synthesises the contribution of the thesis and suggests further work.

2 Theoretical Framework

2.1 RAMS in Railway

Reliability, availability, maintainability and safety (RAMS) in railway systems were defined in 1999 in the standard called EN 50126. The goal of the standard was to make sure the railway system achieves a defined level of rail traffic in a given time under safe conditions. (X1) In the document, the following are the definitions of the respective terms;

- ✓ Reliability is the probability that an item can perform a required function under given conditions for a given time interval.
- ✓ Availability is the ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external resources are provided.
- ✓ Maintainability is the probability that a given active maintenance action, for an item under given conditions of use, can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources.
- ✓ Safety is the freedom from an unacceptable risk of harm.

This standard helps the quality of the transport service by identifying the factors that influence RAMS of railway system and managing the said factors. It also performs a risk analysis for various phases of the system life cycle and link the tasks to the authority responsible. The standard also support an audit process to provide a basis for the railway authority and the railway support industry to agree and implement an audit plan for the railway system. The figure below shows the factors influencing railway RAMS as taken from the standard.

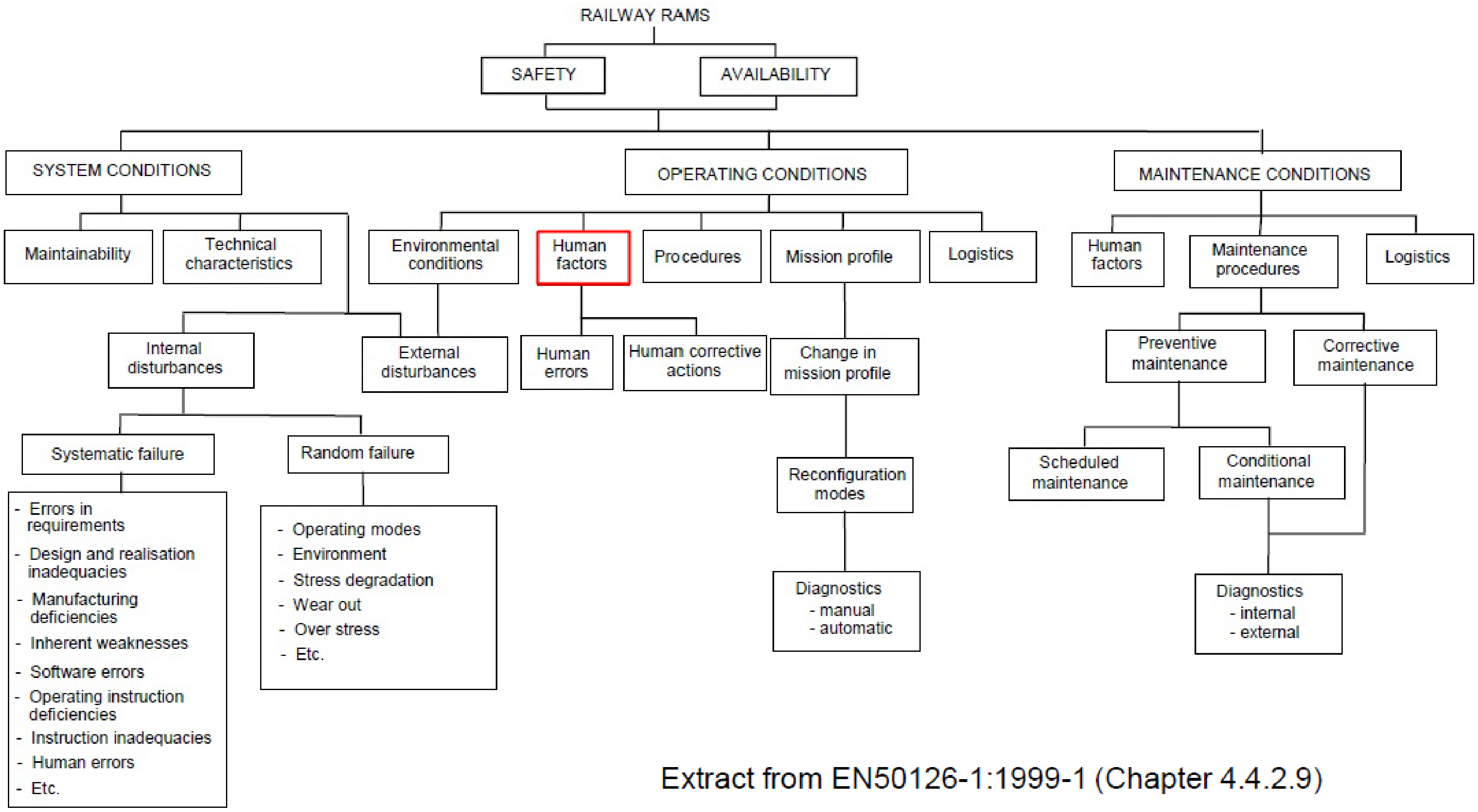

figure 4. Factors influencing RAMS in railway. (EN 50129)

The standard provides guidelines to establish mechanisms and procedures for the effective control of the influencing factors. EN 50126 introduces a system life cycle which is a sequence of phases, each containing tasks. The tasks cover the total life of a system from initial concept through to decommissioning and disposal. The life cycle provides a structure for planning, managing, controlling and monitoring all aspects of a system, including RAMS. The life cycle concept is fundamental to the successful implementation of EN 50126 and helps to deliver the right product at the right price within the agreed time scales. The standard gives a lot of control in the establishment of requirements by the customer or the regulatory authority. And finally the standard provides a guideline in determining the life cycle cost (LCC). This includes the investment, operating and maintenance costs. This process of estimating the LCC is helped by the use of the European Standards.

It is important to note that in calculating the costs for preventive maintenance the following are not considered;

- ✓ Time for organizational, admin, or logistics processes
- ✓ Time for filling up operating supplies
- ✓ Time for emptying wastewater tanks
- ✓ Technical waiting times and setup times
- ✓ Time for disposal
- ✓ Time for exterior and interior vehicle cleaning

2.2 Wireless Sensor Networks

Wireless Sensor Network have become the most standard services employed in commercial and industrial applications, because of its technical development in a processor, communication, and low-power usage of embedded computing devices. [13]The WSN is built with nodes that are used to observe the surroundings using different sensing techniques like temperature, humidity, pressure, position, vibration, sound acoustic, optical, magnetic etc. **figure** below depicts a WSN. These nodes, also called motes, can be used in various real-time applications to perform various tasks like smart detecting, a discovery of neighbour node, data processing and storage, data collection, target tracking, monitor and controlling, synchronization, node localization, and effective routing between the base station and nodes.

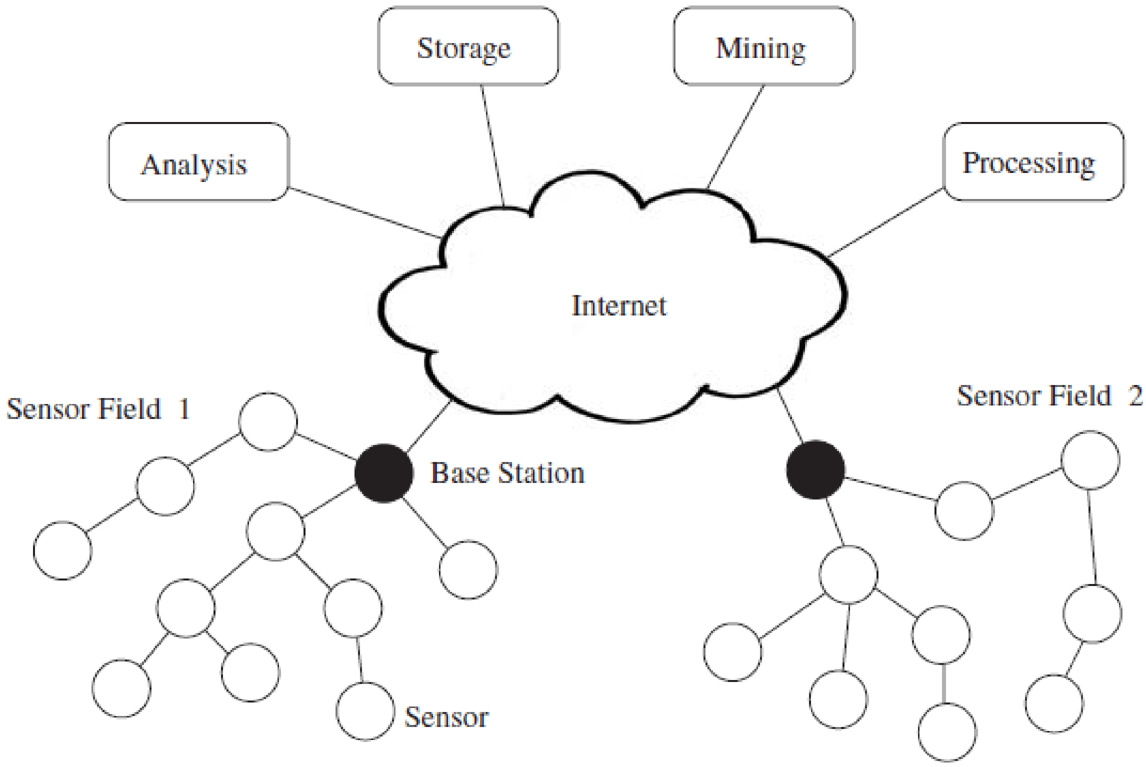

Figure 5. Wireless Sensor Network. [3]

The applications of motes in industrial are widespread. A collection of sensor nodes collects the data from the surroundings to achieve specific application objectives. The communication between motes can be done with each other using transceivers. In a wireless sensor network, the number of motes can be in the order of hundreds/ even thousands. Ad Hoc networks in the other hand, will have fewer nodes without any structure. Some devices may have access to additional supporting technologies, for example, Global Positioning System (GPS) receivers, allowing them to accurately determine their position. However, such systems often consume too much energy to be feasible for low-cost and low-power sensor nodes. [3]

2.2.1 Applications of WSNs

WSN are more diverse in applications to the real world than any other networks and their application and classified according to the goals in non-stop sensing, event detection, position sensing and more [19, 20]. The applications can be categorised into military, biological, commercial, environmental and industrial applications [21].

- ✓ Military Applications; this is the initial application of WSNs which focused on collecting information on the battlefield. Now it was improved to detecting chemical attacks and tracking enemy motion. The notable military applications [22] are such as Self-healing land mines (SHLM), Aerostat acoustic payload for transient detection (AAP) and Soldier detection and tracking (SDT).

- ✓ Biological applications; tackles the grand challenges of the biological science by allowing us observe the unobservable phenomena through WSNs. This ranges from organic to nonorganic biological organisms which requires intensive sampling over large spatial scales, even multiple times per second to provide new insights on biological processes [21]. Patient can be under surveillance and bio-medically diagnosed by the doctor from a distance which is called tele-medicine [23] where body sensor networks (BSN) is preferred for the care and monitoring of human.
- ✓ Environmental applications; these consist of the monitoring of the atmospheric parameters, underground water level, the movement of birds or animals, forest fire detection, habitat surveillance, [21] etc. This application requires the high deployment density, self-organization of the sensor nodes and low-energy consumption of the nodes. Some of the projects deployed in this application include the Great Duck Island project, SECOAS project, Foxhouse project, Sensorscope project or greenhouse monitoring [24].
- ✓ Commercial applications; these are the most widespread and involve a smart parking, vehicular telematics, security of Intra-care, event detection and structural health monitoring [21]. Of interest is WNSs applications in the field of structural health monitoring. This is used to detect the damage in civil, aerospace or other engineering systems. The structural health monitoring (SHM) [25] utilises the low-power, long-term monitoring of a structure to provide periodically or real-time its health condition. Wireless Sensor Network Architecture.
- ✓ Industrial applications; these are in a way similar to the commercial application in controlling and monitoring remotely the subject. The only difference is that the subject is strictly an industrial factory or entity. A lot of systems have been proposed and some are the automatic meter reading (AMR) system based on wireless RF, ZigBee technology and code division multiple access (CDMA) to remote metering technology such as electricity, gas and water. This application requires both periodical surveillance and real-time monitoring. Dynamic power management (DPM) with two hardware topologies ISMs (intelligent sensor modules) and RDAUs (remote data acquisition units) is implemented for such application [21].

2.2.1.1 Node Architecture

The node consists of sensing, processing, communication, and power subsystems. The designer decides on how to build and put together these subsystems into a unified, programmable node. [3] **Figure** below depicts the general node architecture. The processor subsystem is the central element of the node and the choice of a processor determines the trade-off between flexibility and efficiency – in terms of both energy and performance. There are several processors as options: microcontrollers, digital signal processors, application-specific integrated circuits, and field programmable gate arrays.

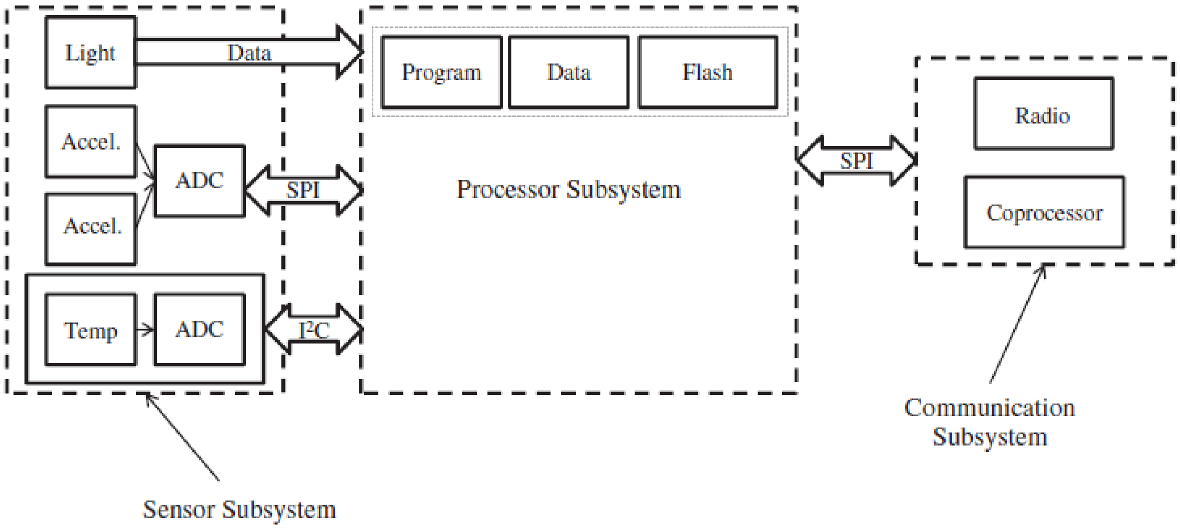

figure 6 Architecture of a wireless sensor node. [3]

2.2.1.2 System Architecture

The OSI architecture Model is followed in WSNs. The architecture of the WSN includes five layers and three cross layers. The five are application, transport, network, data link & physical layer. The three cross planes are namely power management, mobility management, and task management. These layers of the WSN are used to accomplish the network and make the sensors work together in order to raise the complete efficiency of the network.

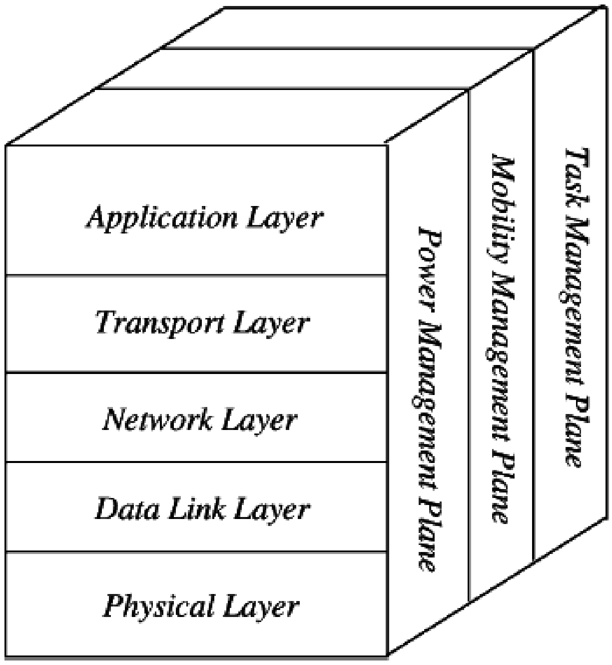

Figure 7 system Architecture

- ✓ Application Layer is liable for traffic management and offers software for numerous applications that convert the data in a clear form to find positive information.
- ✓ Transport Layer deliver congestion avoidance and reliability where a lot of protocols intended to offer this function are either practical on the upstream. These protocols use dissimilar mechanisms for loss recognition and loss recovery. The transport layer is exactly needed when a system is planned to contact other networks. A popular protocol in the transport layer is STCP (Sensor Transmission Control Protocol).
- ✓ Network Layers' main function is routing, it has a lot of tasks based on the application, but actually, the main tasks are in the power conserving, partial memory, buffers, and sensor don't have a universal ID and have to be self-organized.
- ✓ Data Link Layer is liable for multiplexing data frame detection, data streams, MAC, & error control, confirm the reliability of point–point (or) point– multipoint.
- ✓ Physical Layer provides an edge for transferring a stream of bits above physical medium. This layer is responsible for the selection of frequency, generation of a carrier frequency, signal detection, Modulation & data encryption. IEEE 802.15.4 is suggested as typical for low rate particular areas & wireless sensor network with low cost, power consumption, density, the range of communication to improve the battery life. CSMA/CA is used to support star & peer to peer topology.

In summary, WSN MAC protocols can be characterised with the consumption of Power limits for nodes with batteries, Capacity to handle with node failures, Some mobility of nodes and Heterogeneity of nodes, Scalability to large scale of distribution, Capability to ensure strict environmental conditions, Simple to use and Cross-layer design.

2.2.1.3 Node and network Management

2.2.1.3.1 Power Management

Energy is a scarce resource in every wireless device, but when it comes WSNs the problem is amplified due to the complexity of the task they carry out which include sensing, processing, self-managing, and communication [3]. In addition, a WSN consists of a large number of nodes. This makes manually changing replacing or recharging batteries almost impossible. [3] There is a lot of research investigating the contribution of renewable energy and self-recharging mechanisms, the size and number of nodes is still a constraining factor because the accommodate high-capacity power supplies[3].

Waltenegus et el in [3] suggests that the power consumption problem can be approached from two angles. One is to develop energy-efficient communication protocols (self-organization, medium access, and routing protocols) that take the peculiarities of WSNs into account. The other is to identify activities in the networks that are both wasteful and unnecessary and mitigate their impact.

The first approach requires a lot of programming which will in turn consume more power. The second approach is more practical. To achieve the second strategy, there is need to understand the how power is consumed by the different subsystems of a wireless sensor node architecture [3]. After this, a dynamic power management system can be developed following the following approaches:

- ✓ Dynamic operation modes: configuring the subsystems to operate in different power modes.
- ✓ Dynamic scaling: frequency and voltage scaling.

2.2.1.3.2 Time Synchronization

In a sensor network, each node operates independently and relies on its own clock. The clock readings, phase shifts and the gap between clocks of different sensors will in turn differ [3]. Hence, time (or clock) synchronization is required to ensure that sensing times can be compared in a meaningful way.

Time synchronisation is very important in WSNs when multiple sensors will observe the same activity. For example in railway, if we condition monitor axle counters, it is important to have the correct order of events in time to determine if the speed being measured is indeed true. Unlike wired networks, time synchronisation faces a lot of challenges in sensor networks. These challenges include [3];

- ✓ Environmental effects: differences in temperature, pressure and humidity affect drift rates of clocks differently.
- ✓ Energy constraints: WSN design make sure that time synchronization protocols do not contribute significantly to the energy consumption making the design difficult.
- ✓ Wireless medium and mobility: environmental properties like rain, fog and wind affect the wireless communication medium.

Synchronization protocols for WSNs have and are being further developed. Below are some of the protocols out there [3];

- ✓ Reference Broadcasts Using Global Sources of Time
- ✓ Lightweight Tree-Based Synchronization
- ✓ Timing-sync Protocol for Sensor Networks
- ✓ Flooding Time Synchronization Protocol
- ✓ Reference-Broadcast Synchronization
- ✓ Time-Diffusion Synchronization Protocol
- ✓ Mini-Sync and Tiny-Sync

2.2.1.3.3 Localization

Since WSNs are often deployed in an ad hoc fashion, their location is not known. Location is necessary for services such as intrusion detection, inventory and supply chain management, and surveillance [3]. It is also important for sensor network services that rely on the knowledge of sensor positions, including geographic routing [14] and coverage area management.

Most sensor networks rely on a subset of nodes that know their global positions. These anchor nodes are then used by all other nodes to perform localization. This techniques is known as anchor-based. Localization techniques are based on range measurements, that is, estimations of distances between several sensor nodes [3]. This technique, requires sensors to monitor measurable characteristics such as received signal strengths of wireless communications or time difference of arrival of ultrasound pulses. The ranging techniques include time of arrival, Time Difference of Arrival, Angle of Arrival and received signal strength [3]. With these, localization can be done through Triangulation, Trilateration, Iterative and Collaborative Multilateration and GPS-Based Localization [3] which includes standard positioning service (SPS) and precise positioning service (PPS).

Range-free techniques estimate node locations based on connectivity information instead of distance or angle measurements. They do not require additional hardware [3] and can be deemed as a cost-effective alternative to range-based techniques. The different approaches in this technique include Ad Hoc Positioning System (APS), Approximate Point in Triangulation, and Localization Based on Multidimensional Scaling. The other range-free techniques are call event-driven localization techniques which include The Lighthouse Approach and Multi-Sequence Positioning [15] which works by extracting relative location information from multiple simple one-dimensional orderings of sensor nodes.

2.2.1.3.4 Security

The CIA security model of security address Confidentiality, Integrity, and Availability as the main services. The concept of network security looks at all policies, mechanisms, and services that afford a computer system or network the required protection from unauthorized access or unintended uses [3]. In this work, the webserver designed will have 2 layers of authentication to prevent unauthorised users getting access to the sensor data being stored.

3 Research Methodology

3.1 Research Strategy

The aim of the thesis affects the operation and maintenance of the railway network by adding in a new component. The research is somehow of exploratory nature. An exploratory orientation gives fundamental knowledge and understanding of an area of interest and provides input which allows the narrowing down of future research [26].

The study scope of this research covers the Ethiopian and Malawian railway signalling maintenance and management practices. The proposed models are validated using sub-cases of a specific railway corridor during a determined period of time. The data for this research have been derived from the corrective maintenance database, documents and unstructured interviews. In line with the case study approach, the maintenance records are studied while establishing boundaries on the research due to limitations of time. Hence, the corrective maintenance data used in this study is from a specific location during a limited amount of time.

The strategy in the research is divided into two parts. The first part is gathering the maintenance data of all the signalling equipment in a specific corridor. This data will be aggregated to select which item is critical and will require monitoring to improve the availability and reliability of the system. Then the selected item will be assessed to determining the parameters to measure. The second part is the WSN model. This will include system specifications, software development and hardware considerations that will maximise operation and minimise the total cost of the system. To achieve this, it will involve comparing the strengths and weaknesses in different combinations of materials in creating a WSN for condition monitoring, comparing the strengths and weaknesses in different combinations of open source tools that can be used to build the system since the resources available will not allow proprietary tools.

3.2 Data collection and Analysis

For the case of Ethiopia, maintenance work orders were gathered and processed from the corrective maintenance database of the Signal and Communication manager. The data comprise work orders from January 2018 until December 2018 for the AALRT corridor. This is a fully operative railway line; the signalling system ATC supervises and controls the network. Form the interviews with the manager, the line has been operative with no major changes so the data gathered in the work orders deal with maintenance and not design changes or failures. The information recorded was enormous but we only consider the parameters that give more information about the failures. It is important to mention that the data in the work orders was completed by different technicians and hence had a lot of differences on similar faults. The data was recorded looking at the quality of the data recorded for each parameter in amount of data and quality of information. The signalling in consideration was the axle counters, point machines and signals.

In the analysis of the data, three scenarios were considered;

- ✓ Up time (UT); the time the system fully operational
- ✓ Waiting time (WT); the time between when a failure occurs until the corrective action commences. This time covers opening of the work order to arrival of the failure location.
- ✓ Recovery time (RT); time the corrective action is performed and the work order is closed.

To help in selecting the equipment to monitor for the research, the data gathered was analysed and tabulated in table 1 below. The table is simplified to show the item, number of failures and the time it takes to recover or maintain the item.

Table 1 AALRT Signalling maintenance data for 2018

Item Description	Number of Failures in 2018	Average Recovery Time
Axle Counter	540	1 min
Point Machine	96	50 min
Signal Filaments	348	5 min

The data in the table below shows that the axle counter had the highest failure rate. Almost every day of the year not less than 2 axle counters would fail. However, the database showed that the failures were minor and only needed a button reset or key reset to fix. On investigation we found that the faults were design errors in the axle counter source code. The counter would get suck at red showing that there is a train in the block even when the train had moved out hence needing a reset.

The point machine faults are less compared to the others but they were the most severe taking longer time to fix. The faults included power supply failure to the machine which initiated a manual lock, information of state and position of switch not showing to signals, and the closing gap being split and not closed completely and lastly the voltage regulator alarm fault. The split fault took more time to fix because a diagnosis to determine if the problem is mechanical ore electrical has to take place first.

The signal filament faults were minor but occurred more than those for the point machines. The faults were overcurrent from supply causing breakers to trip and sometimes destroying the transformers and filament replacement if more than 25% of the LEDs break down.

The time to recover the faults were those recorded by the technicians beginning from the time the start the job on the signalling equipment to the time the finish. This time does not include the time taken to arrive at the fault location. To calculate the average recovery time of the year, the following formula was used;

$$Average\ Time = \frac{Sum\ of\ fault\ recovery\ times\ per\ fault}{total\ number\ of\ faults}$$

Looking at the average fault recovery time results, we see that the point machine has the highest average time taken to recover a fault meaning that a point machine fault was the one that rendered the line unavailable for the longest time during the year. Hence, in our quest to improve the availability and reliability of Signalling Equipment through Remote Condition Monitoring, we select this item as the one to monitor.

3.3 Point Machine

Point machines are there to switch the track between two alternative routes. Sometimes called switches or just points, they have always been an essential component of railway networks and their failure significantly affects train operations [48]. Their reliability and availability directly affects the quality and safety of the rail service as already seen from the data gathered at AARLT. The principle and operation of the points comes in the action of moving the switch, to move the switch rails from one side to the other, the motor torque is first transferred to the clutch, then to the belt and ball-screw which converts the rotating torque to a force in the axial direction [8]. Via the crank, the force direction is rotated through 90° to drive the switch rails. The rails have two movement directions, either to the normal position ("Normal" movement) or to the opposite "Reverse" lie ("Reverse" movement). There is a third position which is the mid-way position which indicates fault in the machine. The lock blade is used to secure the switch in place, preventing slippage. Electrical contacts operated by the detect blade are used to indicate to the signalling control system that the switch blades have been successfully locked into position. The signals ahead of the point will show green if the point is normal position and red if in reverse position. Figure 8 below shows a simplified diagram of a typical electrically-driven point machine and its linkages.

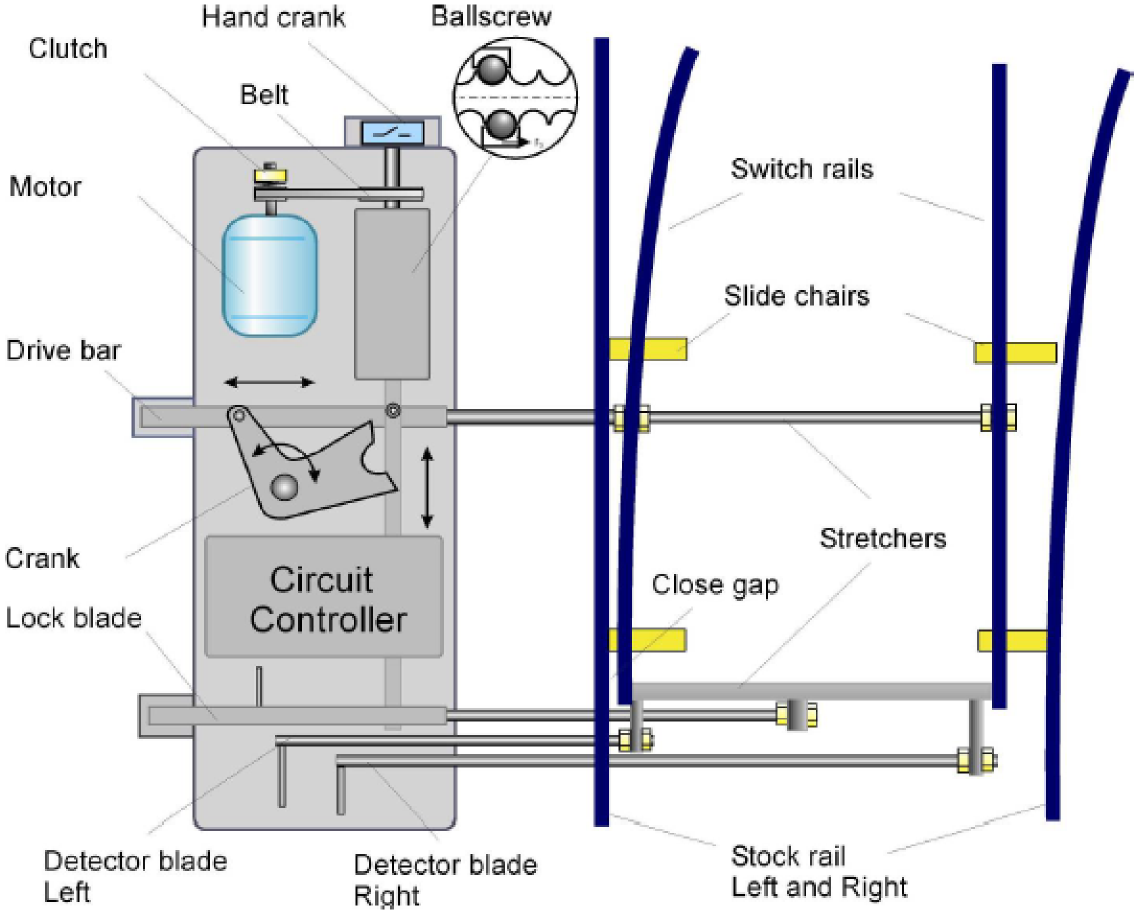

figure 8 Elecrical point machine [45]

Globally, the lock and detect mechanism have been used for decades as the basic points safety system. For the AALRT control does not permit a train to proceed until lock and detection are completed. They require that detection should succeed for a gap of 2mm or less between the switch rail and stock rail on the closed side, and that detection should fail if this gap exceeds 4mm. AALRT categorises the point failures in two categories, mechanical and circuit failure. The circuit failure is further divided into action circuit failure and indicator circuit failure [46]. The mechanical failure are grouped into three, failure to release, failure to lock and failure to completely switch. All these faults entails the inability to make detection after the points machine has operated to switch the rails, or the loss of detection due to some mechanical movement of the system [8]. As this in turn leads to a block in the signalling system, it is classed as a signalling failure. This may cause train delays and passenger inconvenience, but minimises the risk of a train passing over faulty points.

Currently, it is safe to say that the detection mechanism utilized in switches is discrete: from a signalling perspective a detection failure is usually sudden, with little prior warning. But, there is evidence of temporary losses of detection, particularly during train transits [8]. Routine maintenance is the only tool available to avoid point failure. At AALRT, the level of scheduled work varies from biweekly inspection, monthly inspection, and quarterly inspection of point machines [46]. As summarised in table 2 below. These can be turned to basic inspection or full servicing depending on the condition of the machine [47].

Table 2 AALRT maintenance schedules

Biweekly Inspection	Monthly Inspection	Quarterly Inspection
-inspect general closure of turnout to ensure no crawling of switch rail -inspect gap position both normal and reverse	-inspect the cotter by checking the opening angle -inspect the automatic shutter - inspect general closure of turnout to ensure no crawling of switch rail	-inspect cable box and guard tube -inspect the trail enable device, lead sealing and locking mark -inspect the bearing of contact heel, automatic shutter, electric motor, reducer, friction axis coupling and ball screw -inspect the grooved gear and apply or remove excess grease -inspect the push plate case and action display

The alignment of the points and the lock and detect mechanisms are tested, and adjusted mechanically during servicing. These servicing intervals have been established as a result of statistical analysis of failure events by manufacturers and railway service companies [8]. However, the failure rates imply that scheduled maintenance alone is currently not providing a satisfactory level of reliability.

From the AALRT maintenance information, we see that the common faults are mechanical hence likely to be incremental in nature. Therefore, there exist physical parameters which, if monitored, might offer evidence of the fault condition before a failure takes place. Catastrophic failures occurring without prior indication are clearly not amenable to advanced warning, and complete fault coverage is not possible [8]. Condition monitoring can only provide data for such kind of failures so that the failure mechanism can subsequently be studied in depth.

4 System Description

Lopez-Higuera et al in [26] developed a staircase of monitoring systems, where the higher the level, the higher the complexity and functionality.

- ✓ Level 1: systems detect the presence of damage without locating it.
- ✓ Level 2: provides location information.
- ✓ Level 3: system is able to grade the degree of damage
- ✓ Level 4: system can estimate the consequences of the damage and remaining service life.
- ✓ Level 5: system will comprise complex hardware, custom algorithms and software to allow the diagnosis and/or the prognosis and even to recommend the solution to a problem. This level has not been achieved so far.

Harsh conditions in railway systems requires the sensors to be carefully located to ensure their measurements are useful and do not replicate the measurements of other sensors, which can skew the distribution of the collected data [27]. The type of sensor used needs to be carefully considered to ensure the maximum value and the best quality data. For the work in this research, we aim to achieve a level 3 condition monitoring system.

4.1 Failure Data

The failure data gathered was analysed to determine the most significant fault modes and to identify which parameters should be measured in the condition monitoring system of the point machines. As cited above, from January to December of 2018 there were 96 faults recorded. These have been classified into 3 major fault categories, as shown in Table 3 below, as being related to the points proper (i.e. the track), the points machine itself, or other causes (including no fault found).

Table 3 Point machine faults

Category	Number of faults	Components
Points	16	Slide chairs, fittings, obstructions
Point Machine	58	Manual lock Point lock out of Adjustment Split Circuit controller Motor and Fuses Voltage regulator
Other	22	Tested Ok Cut-Out Blown Fuse Relay faults

Cause of a failure and its functional effect have to be distinguished in order to identify suitable signals to detect and anticipate failure. The cause of the failure is typically what a maintenance engineer will report, based upon the required corrective action [8]. On the other hand, the functional effect of the failure describes the way by which the cause induces failure/ for example; obstruction, looseness, detection or lock failure, or failure to move. It has to stated that not all possible causes of faults can be identified using automated condition monitoring. The method to be used in condition monitoring is to monitor signals which verify the proper functional operation of the points machine and associated track, rather than focussing on the development of specialised mechanisms for detecting quite specific causes of failure, each of which may reoccur with extremely low probability [8]. In other words, the method adopted will look or listen to the positive assertion that there is a good relationship between a comprehensive set of monitored signals.

Figure 9 below shows measurements that can be taken from the point machine to determine the operation and predict a failure. We assume that if all of these measurements maintain an acceptable relationship with one another, then any form of mechanical misalignment of the points is unlikely [8]. Since the motor is the like the heart of the machine, it is imperative that the voltage and current and load force are measured. These measurements together with the dynamic switch rail position, provide comprehensive data on the switch movement. In addition, we monitor temperatures machine to allow thermal expansion and contraction to be considered when measuring changes. The condition monitoring system can also be used as a maintenance management tool by monitoring case opening and closing as well as hand-crank insertion and removal which can be used to provide automated records of maintenance action for management, and for field support for maintenance engineers [56].

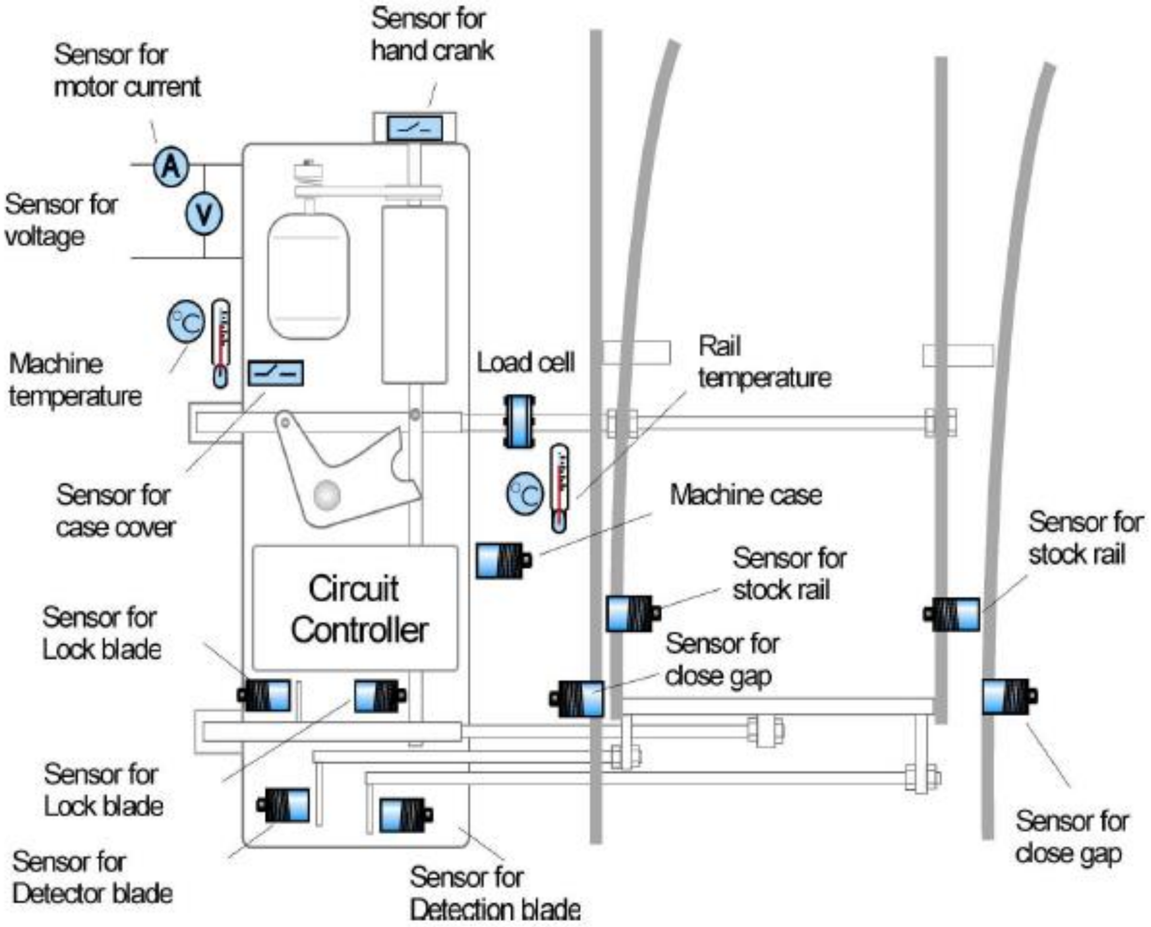

Figure 9 Point machine sensing elements [45]

Critical occasions when data has to be recorded of the health of the machine are the point machine movement, background sound and train passage time. It can be noted that large number of sensors reduces the reliability of the condition monitoring system. We need to narrow down the sensors that are shown in figure 9 to the critical ones in line with our objectives and scope.

4.2 Sensor Designs

Sensors are devices that convert a measured mechanical or physical signal into an electrical signal. Most railway sensors are under the type of microelectromechanical systems (MEMS). MEMS are cheap and efficient small, integrated devices, or systems that combine electrical and mechanical components [28]. The design of these sensors requires a balance or trade-off between functionality and power consumption, with functionality often coming at the cost of power [27]. As already stated, condition monitoring systems for railways are often deployed in remote or inaccessible locations. Usually these locations have no wired power supply available.

Hence, the sensors must receive power from either batteries or local energy generation. The important advantage of these sensors is that that they can be produced to consume ultralow power [19]. In the railway monitoring systems, the common sensors utilised are numerous due to the complexity of the industry. Table 4 below summarises these sensors [49, 50, 51, 52, 53, 54, and 55].

Table 4 Different kinds of sensors available for monitoring

Sensor Type	**Description**
Accelerometers	Used to measure vibrations and lateral accelerations of mechanics.
Displacement Transducer	Converts linear or angular displacement into a signal that can be recorded.
Fiber-Optic	Used to measure temperature, strain or acceleration. It utilises the change in Bragg wavelength that is caused by a change in the said physical parameters.
Gyroscope	Measures the angular velocity around axes. Ideal for analysing carriages, chassis and bogies.
Inclinometer	Measures the slope angle by means of generating an artificial horizon and measuring the angular tilt with respect to this horizon
Magneto-electric	Used to analyse magnetic fields in current carrying conductors and thus monitor the current. They are passive and do not require an energy source since they are powered by induction
Piezoelectric	They generate a signal when the material is compressed. Hence, they can be used to measure strain, pressure, vibrations and shocks.
Strain Gauges	Measures stresses proportional to the strain applied to the sensor
Thermocouples	Used to monitor temperature changes of the atmosphere and equipment.
Ultrasonic	Used to measure distance changes
Audio	Used to measure sound from equipment to be analysed for anomalies

It is important to note into account the external factors that define the ambient conditions of the sensors and build them into the models. For this paper, we take 3 kind sensors to use in condition monitoring of the point machine. These will be the voltage and current sensors, load cells, temperature sensors and accelerometers to measure the vibration of the point machine when in operation.

4.2.1 Sensor Nodes

Nodes are mounted on boards which combines mobile computing and wireless communication [27]. The boards contains one or more wireless sensors, a microcontroller, transceiver, data storage (memory), and a power source. The power source size depends on the data sampling rate. The node design is shown in the figure 10 below.

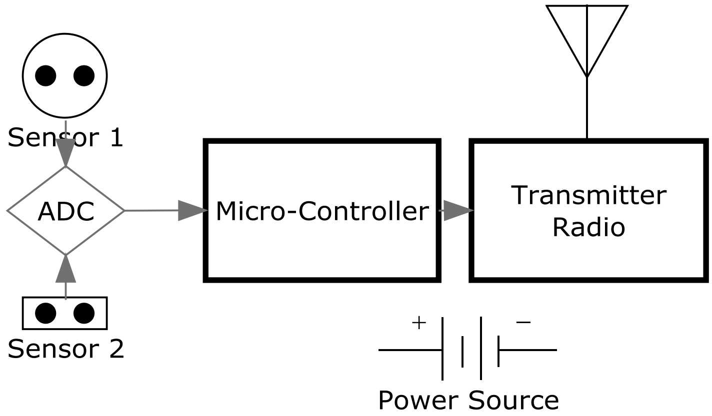

Figure 10. Sensor node.

4.2.1.1 Sensors

For the designed system, a mode on each monitored point machine shall have 3 sensors. These are vibration sensor, voltage and current sensor and temperature sensor.

4.2.1.1.1 Vibration Sensor

An accelerometer will be used to measure the vibration of the point machine whenever in operation to determine if is in good condition. The point machine has various rotating and moving equipment that require constant vibration monitoring. Hence, measuring and analysing the vibration of the machine helps to determine both the nature and severity of the defect and hence predict the machine’s failure. Thus, vibration analysis is a vital part of predictive and preventive maintenance programs that seek to reduce costs and unplanned down-time [75]. Charge-mode piezoelectric accelerometers measure shock and vibration in high temperature environments and offers dynamic range scalability. Figure 11 below shows a piezo vibration sensor that would be utilised in the solution.

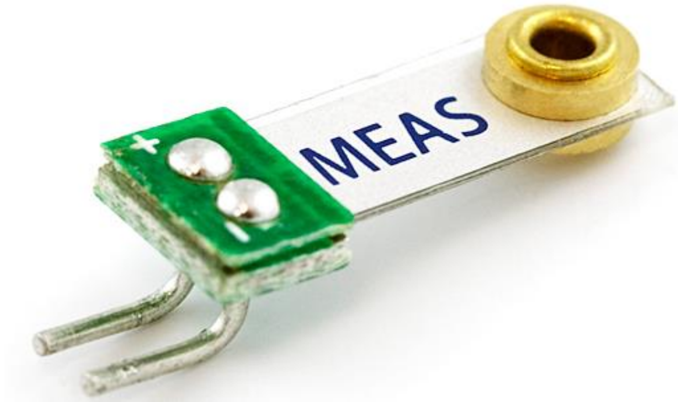

figure 11 Piezo Vibration Sensor [81]

4.2.1.1.2 Temperature Sensor

The sensor will be used for motor ambient temperature detection to detect if the motor is about to fail. The sensor module features an NTC thermistor sensor which has good sensitivity with a comparator output signal having a driving ability of more than 15mA. It provides an option to adjust the temperature distribution position detection threshold through the potentiometer adjustment. The working voltage 3.3V-5V and it uses a wide voltage LM393 comparator. The temperature detection range of the modules is 20 to 80 ° C which is sufficient for our purpose. It is almost plug and play because the output can be directly connected to the microcontroller through the microcontroller to detect high and low thereby detecting temperature changes in the environment making it easy to install. Figure 12 below shows the temperature sensor.

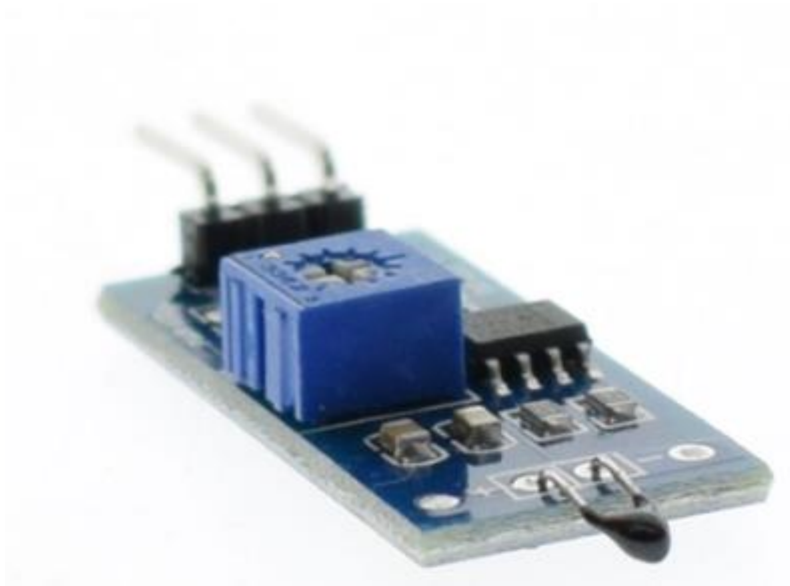

figure 12 Temperature sensor [81]

4.2.1.1.3 Current Sensor

To measure the current supplying the point machine a current sensor will be utilised. Since it is a low power sensor, it will require a step down transformer to bring the current to a proper level. The ACS715 Current Sensor Board in figure 13 below is used.

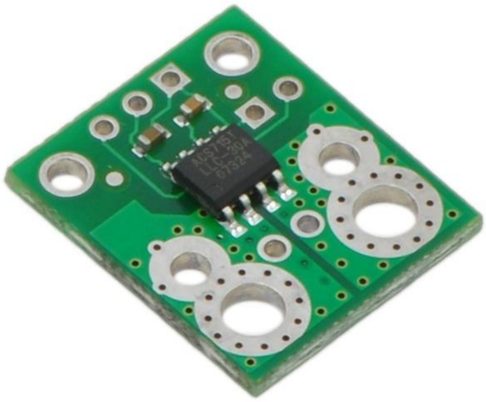

figure 13. ACS715 Current Sensor Board [81]

The sensor is designed for unidirectional input current from 0 to 30 A, but the sensor will provide meaningful feedback for currents as low as -1.5 A, and the robust IC can survive up to five times the overcurrent condition. The conductive path internal resistance is typically 1.2 mΩ, and the PCB is made with 2-oz copper, so very little power is lost in the board [81].

The use of a Hall effect sensor means that the IC is able to electrically isolate the current path from the sensor's electronics allowing the sensor to be inserted anywhere along the current path and to be used in applications that require electrical isolation. High accuracy and reliability: typical total output error of ±1.5% at room temperature with factory calibration, an extremely stable output offset voltage, and almost zero magnetic hysteresis and it has automotive-grade operating temperature range of -40°C to 150°C [81].

4.2.2 Sensor Node Power

The power problem in WSNs forms a paradox in that WSNs need to minimize energy usage yet communication needs to be maximally efficient and communication requires energy [27]. This area has received and is still under a lot attention in research. Sensor nodes usually use batteries as source energy and depending on the nature of the monitoring these batteries can last from just a few days to yeas. For example, the batteries in an accelerometer monitoring a train pantograph only lasted 20 days [30] and [31] managed to extend battery life to 1.5 years for 4 AA batteries by only waking their sensors when required and sleeping otherwise. Due to access difficulties of nodes, alternative power sources that needs to be reliable to allow the WSN to function for long periods of time with no human involvement and able to generate sufficient power have been considered.

We see that batteries are the most widely used energy sources for sensor nodes. Since the nodes are usually put in hard to reach places, battery replacements will be difficult hence the use of rechargeable batteries is preferred. In thus study we look at 4 different power sources that can be used to replenish the voltage in the batteries and make an analysis to select the one to be used in implementing the condition monitoring system.

4.2.2.1 Solar Panel

Solar panel being suitable for outdoor are the widely used means of charging sensor nodes batteries. Eduardo C et el [16] conducted a test to determine how the solar panel can behave in supplying energy to a node. The table 5 below show the technical characteristics of the solar panel and the battery used to perform our tests.

Table 5 Solar panel parameters

	Solar Panel	**Battery**
Supplier	Cooking hacks	Union-fortune
Type	Cristal	Lithium
Voltage	5V(10V Peak)	3.7V
Efficiency	17%	
Connector	JST PH-2	JST PH-2
Size	81 x 137 x 2 mm	53 x 33 x 5.7
Power	1.5 W	

They build a node with a shield Xbee Arduino containing Xbee PRO 868 and an Arduino Mega 2560 board module. The Xbee module is used to send the results of voltage from the board to a PC where the data is collected and stored. They doe 3 tests, the first does not have the solar panel and works in 10s intervals. The second has the solar panel and also works in 10s intervals. The third test is a realistic system with the solar panel and given one hour sleep modes and 10s working intervals to send the collected data. Tests one and 2 depletes the battery in 200minutes and 400minutes respectively. This shows that the addition of the solar panel doubles the operation time of the batteries.

Figure 11 below shows the results for test 3. It demonstrates how the solar panel is able to generate enough power to keep the node indefinitely on [16]. The graph shows that the battery enters a discharging at 6:00 p.m. and charging 8:24 a.m. phase depending on the way the sun's rays affect the solar panel. In both phases different stepped zones can be appreciated. These correspond to small voltage drops which occur every hour during transmission mode.

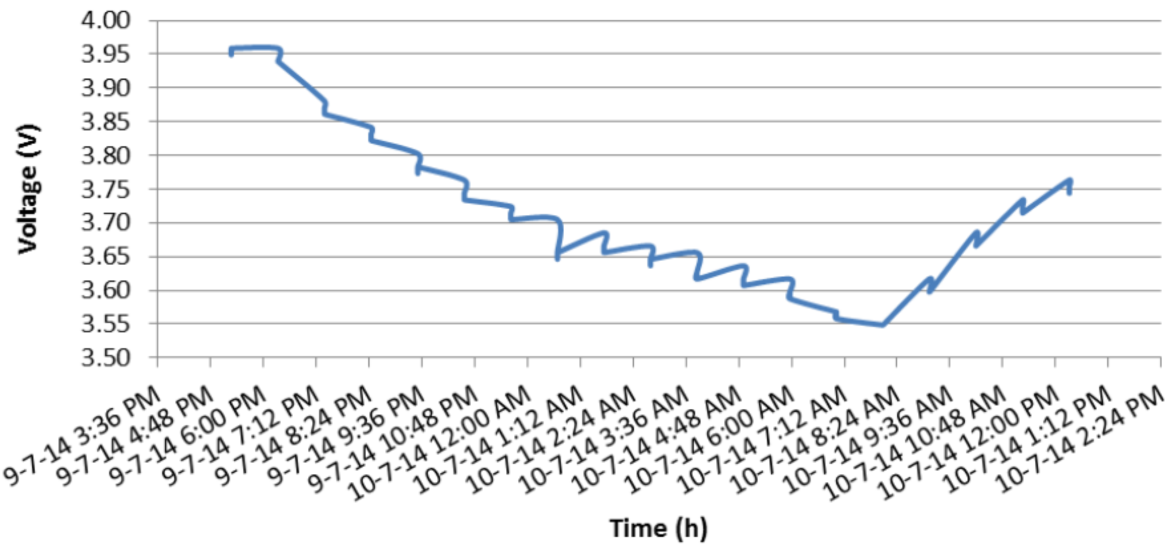

Figure 14 Solar panel voltage production [16]

4.2.2.2 Piezoelectric

In railway systems, a piezoelectric device can be used to obtain energy from the vibrations produced when trains pass over the slab track or rails. [16] Analysed 2 different models of piezoelectric devices in addition with AC to DC converters and a 200μF capacitor. The converter has two configurations SS and PN for low amplitude and high amplitude respectively. Table 6 below gives the technical characteristics of V20W and V21B piezoelectric devices from Mide.

Table 6 characteristics of piezoelectric materials

	V20W	**V21B**
Frequency ranges	75 Hz – 175 Hz	80 Hz–205 Hz
Performance data	180 Hz, 1.719 mW 130 Hz, 2.692 mW 95 Hz, 3.005 mW 75 Hz, 5.860 mW	275 Hz, 0.250 mW 175 Hz, 0.658 mW 140 Hz, 1.311 mW 105 Hz, 2.252 mW
Size	81 x 33.3 x 0.86 mm	53 x 33 x 5.7

Taking 81 s as the estimated time of a train passing through a point. Experiments for vibrations taking that particular time were conducted and the results are shown in table 7 below.

Table 7 Piezoelectric material test results [16]

Test	Box	Piezoelectric	Configuration	Voltage	Coulombs C	mAh
1	Metal	V20W	PN	2.7 V	0.00054	0.00015
2	Metal	V20W	PN	5 V	0.001	0.00027
3	Metal	V20W	SS	7.7 V	0.00152	0.00042
4	Metal	V21B	SS	5.4 V	0.00108	0.00030
5	Plastic	V20W	SS	4.4 V	0.00088	0.00024

Looking at the milli ampere per hour (mAh) rating, it shows that the use of vibration piezoelectric devices to harvest energy is currently an unviable solution [16]. However, there exist other piezoelectric systems able to generate energy from pressure [57] that are able to generate a great deal of energy (about 120 KWh per 1 km rail). These systems have a complicated and cumbersome design making it difficult to integrate into our monitoring system.

4.2.2.3 Peltier Cell

These are cells that generate energy from temperature differences. These can be really ideal for tunnels where solar panels cannot be used due to the total absence of light. In [16], they conduct experiments on a cell with the characteristics shown in table 8 below

Table 8 Peltier cell parameters

Power	**100 W**
Max Voltage	15.4 V
Connectors	Conventional
Current	10.5 A
Temperature range	66 degrees Celsius
Size	40 x 40 x 3.3 mm

Two experiments were conducted to check whether the temperature difference established between the exterior of the platform casing in contact with the concrete of the slab track and the inside of the casing will be used by the Peltier cell to generate energy. The first experiment was placed indoor to mimic a tunnel and the second experiment was placed outdoor. The highest voltages produced were 0.8 V and 2.8 V respectively. This shows that the generated voltages are insufficient to power a node. This is due to the large temperature difference that the cells require to produce a substantial voltage.

4.2.2.4 Point Machine Voltage Supply

The other option of powering the node is by taping the energy from the switch supply. The CAMTECH 143 mm throw Electric Point Machine with internal locking power supply is extended from the nearest location box through PVC insulated Aluminium conductor cable of 3 core X 10 sq. mm. or equivalent copper cable (for 110 V DC operation of point machine) and PVC insulated Aluminium conductor cable of 19 core X 1.5 sq. mm (for detection circuit) directly or through adjacent junction box. Table 9 below gives details of the Siemens Electric Point Machine;

Table 9 Point Machine parameters

Motor	**110V Split field, series wound**
Minimum Operating Voltage	60 V DC
Normal Operating Current	2.5 – 3.0 Amps
Output of Motor	0.44 KW
Operating time	3 – 4 Secs
Size	40 x 40 x 3.3 mm

From this information we can introduce a battery charger with an adapter to tap the power from the supply and charge the node battery. But this brings in bulky equipment and raises the cost of the sensor node. In addition, tampering with the point machine system is undesirable for safety reasons.

This analysis of the power supply for the node gives us the required information to select the suitable means of power for the nodes. From the results, the solar panel is most ideal to charge the node battery. It easy to mount, cheap and gives the precise amount of energy required.

4.3 Network Designs

Due to the importance of the data acquired, the network has to be carefully designed to overcome the system drawbacks in power consumption and prevent transmission errors, latency, network outages, missing data, or corrupted data.

4.3.1 Network Topology

Sensor nodes can be arranged in either an *ad hoc* or a pre-planned configuration [32]. This is determined by the requirements of the monitoring and by the physical environment. In *ad hoc* arrangement, sensor nodes are randomly placed in the monitored area while in pre-planned arrangement, sensor nodes are arranged in either a grid, optimal placement [33], 2-D or 3-D placement [32]. The process of selecting the optimum topology is tedious and the optimization is against a number of constraining factors depending on the aim of the system. A network may minimize relay nodes, may need to ensure a minimum level of service, minimize energy usage to preserve battery life, or may need to ensure accessibility of the nodes [27, 34]. The general topology choices available for WSNs in most applications are star, tree, and mesh topologies as shown in figure 12 below;

- ✓ Star Topology: there is a single base station that can send and/or receive messages to/from a number of remote sensor nodes. The remote nodes can only communicate directly with the base station but not with each other.
- ✓ Tree Topology: a hierarchy of nodes, with the root node serving client nodes that, in turn, serve other lower level nodes. Sensor nodes can communicate with their parent or with other nodes in a group within transmission range.
- ✓ Mesh Topology: any node in the network can communicate with any other node in the network that is within transmission range.

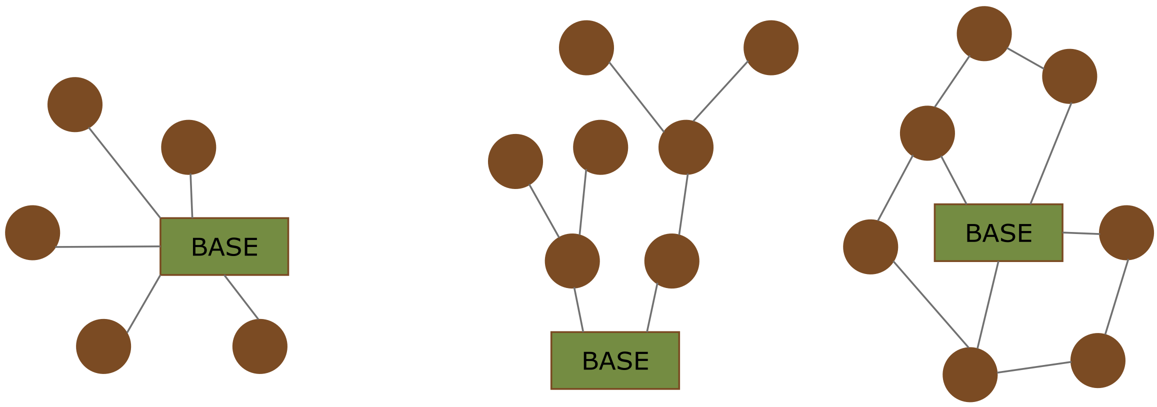

Figure 15 common network topologies

For this thesis the selected topology is star because this topology is simple; the point-to-point connection will result in fewer transmissions and fewer collisions; and, it has low communication latency which is suiting for the number of sensors that will be mounted on the point machine. In addition since the minimum length of a train station is more than 1 km, the other topologies would prove difficult to implement to create a complete connection between the 2 ends of the train station. The disadvantages of the star topology are the base station must be within transmission range of all nodes, remote nodes must increase their transmission power to overcome signal attenuation and loss, and it is not robust due to its dependence on a single base station to manage the network. But these do not affect our system since we will have at least a sing node per switch.

4.3.2 Communications Medium

In railways systems, a lot of communication techniques can be used. Short range to long range. WSNs can use technologies based on standard mobile telephony like Bluetooth, GSM, GPRS, and UMTS. They can also utilise broadband techniques such as Wi-Fi as defined in IEEE 802.11in 2007, and wireless personal area networks (WPANs) as defined in IEEE 802.15.4 and ZigBee [35] or WiMax [36] of IEEE 802.16.2 in 2004 can also be used.

ZigBee is one of the latest communication medium technologies that enhances IEEE 802.15.4 by including authentication, data encryption for security, and data routing and forwarding [7, 27]. Mobile telephony and WiFi are peer-to-peer only, whereas WPANs and WiMax can connect many devices in a mesh topology, where any node can communicate with any other node [27]. It has been noted that Wi-Fi, WPANs and WiMax allow communication at much higher speeds and bandwidths than mobile telephony and are cheaper to set up. But on the other hand, mobile telephony has better coverage and range than Wi-Fi and WPANs. Worldwide Interoperability for Microwave Access (WiMax) can operate over long distances but has a trade-off in that it will either have high bit rates or long distances but not both [27].

Global System for Mobile Communications-Railway (GSM-R) has been recently. This is an adaptation of the already established GSM telephony for railway applications designed for information exchange between trains and control centers. GSM-R comes in handy due to its low cost and worldwide availability since it is already established.

Salaberria *et el* in [37] talk of Terrestrial Trunked Radio Another which is a standard for data communication for closed user groups. This is also a technique for railways radio system. It is a private mobile telephone system and is easily deployed using a series of antennas at stations or control centers along the railway routes.

For this work, we select the ZigBee protocol as our mode of communication due to their lower power consumption, lost complexity and low cost compared to Bluetooth and WiFI.

4.3.2.1 Arduino UNO

The sensor at the nodes are built around an Arduino microcontroller. This is open source hardware. The circuit design along with PCB layout is available online. Some of the versions of Arduino available include: Arduino Uno, Arduino Leonardo, Arduino Due and Arduino Mega. In this work, we use Arduino Uno which is based on ATmega328. The package contains a 16 MHz ceramic resonator, a USB connection, a power jack and ICSP header and a reset button as shown in figure 13 below. Instead of using the FTDI USB-to-serial driver chip our Arduino features the Atmega16U2 chip programmed as a USB-to-serial converter. The Uno has been chosen due to its low power consumption, cost and easiness to configure. The other reason is that the Xbee shields for the Arduino Uno are readily available and easy to integrate.

figure 16 Arduino Uno Microcontroller [59]

This microcontroller can be powered by a USB connection, ac to dc adapter and battery (which is preferable for remote monitoring). Each of the 14 digital pins on the Uno can be used as an input or output using functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor of 20-50 kΩ. In addition, some pins have specialized purpose. Pin 0 and 1 can be used for RX and TX TTL serial data. Pin 2 and 3 can be configured to trigger interrupt. Pin 3, 5, 6, 9, 10 and 11 can be used to provide 8 bit PWM output. The six analog inputs provide a 10 bits resolution [59].

4.3.2.2 Xbee Radios

For the wireless communication between sensor nodes and the gateway or base station node, we used Xbee radios. These radios use the ZigBee network protocol. Every ZigBee network will have a single coordinator device. You can’t call anything a network until you have at least two things connected. So every ZigBee network will also have at least one other player, either a router device or an end device. Many networks will have both, and most will be much larger than just two or three radios [7]. This protocol has a data rate of 20-250 kbps and a typical range of 10-100 m which makes them ideal for wireless sensor networks.

There are 2 version of this XBee available which are known as XBee pro series1 and series2. It is important to note that they don’t work together. It’s not possible to use both versions in the same network [62]. For the design of the system here, we use the XBee pro series2 model as depicted in figure 14 below. Series 2 improves on the power output and data protocol. Series 2 modules allow you to create complex mesh networks based on the XBee ZB ZigBee mesh firmware [64].

figure 17. XBee Radio [64]

4.3.2.3 Xbee Arduino Shield

To make a sensor node the Arduino Uno microcontroller is connected with the XBee wireless module using wire and breadboard or using an add on knows as a shield. The breadboard method is very simple, cheap and straightforward but can be inconvenient for deployment. The add-ons can be attached vertically atop the Arduino board. Fortunately there is such a board available from Libelium which first attaches itself to the Arduino board and then XBee module is attached on top of it as shown in figure 15 below [65]. With this method, it is possible to directly configure XBee using XCTU as long as the Arduino is connected to a PC.

figure 18. XBee Arduino Shield [65]

4.3.3 Base Station

This is like the hub that controls the sensor nodes and acts as a gateway for data transmission to a remote server [27]. Nodes will use short range communication protocols to transmit data to the base station which it turn uses long range communication protocols to transmit the data to a server or control center. Compared to the sensor nodes, the base station has a more powerful processor and more memory which requires more power.

The low power XBee modules that will be used for wireless connectivity will makes it possible to transmit the sensed data to the gateway node at the base station. The Xbee connected to the base station is the coordinator. The XBee connected to the sensor nodes can be either router or end devices. Figure 16 below depicts the information flow from the sensor nodes to the base station [58].

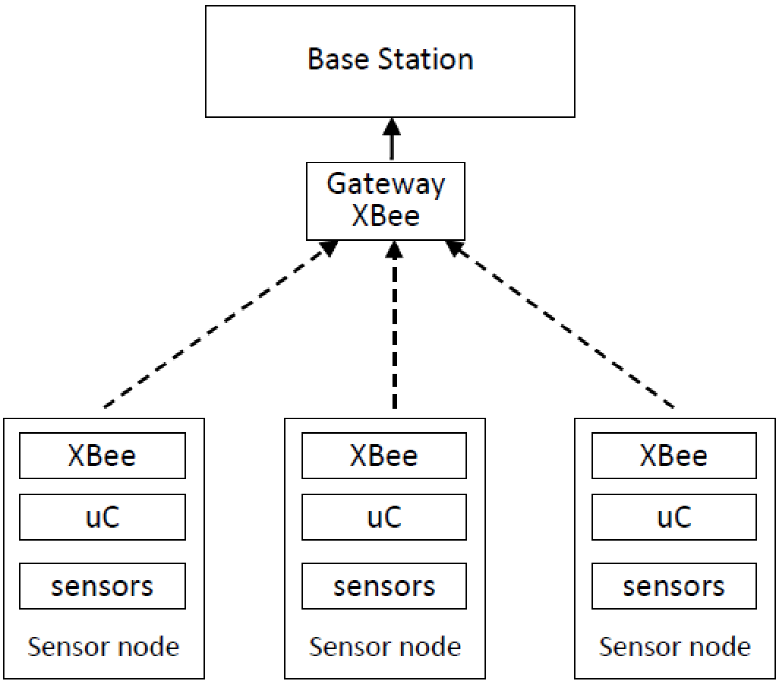

figure 19. Sensor nodes to base station configuration

Now having the data at the base station, the question is what to do with the data. In other words, how smart do we want our base station to be? The received sensor information can saved in a text file at the host computer by using a serial reader program. It can also be saved in a structured way by using a database. For convenience in our environment, our system requires to remote access. The data will be uploaded from the base station to a webserver since we cannot use the base station as a webserver as it will be located along the rail line. A developed graphical user interface (GUI) will be provided to monitor the data in real time and add or remove data from the database.

To achieve this functionalities as a base station, a question of what microcontroller to use comes in play. We consider a number of microcontrollers in market as summarised in table 10 below. The two Arduinos featured are the MEGA 2560 model which is a better quality model, bigger, with better technical characteristics and a higher cost. A key difference is that Arduino UNO has only one serial port, while the Arduino MEGA has four, making it more flexible and useful it also has four times more SRAM which is very important to allow implementing some algorithms which are important for the proposed. But, since it competes with the raspberry Pi as a base station, it is good to know that Raspberry Pi is a credit card sized computer that can be used as a desktop PC. It is small but powerful enough to do regular word processing, spread sheet analysis and other regular activities. It can also do nonstandard function like being a media server [58]. It has an Ethernet port making it easy to be turned into a server

Table 10 Microcontroller comparisons for base station

Name	Arduino UNO	Arduino MEGA	BeagleBone	Raspberry Pi3 B
Microcontroller	ATmega328	ATmega2560	AM335x	ARM1176JZF-S
Operating Voltage	5 V	5 V	5 V	5 V
I/O Pins	14 (6 PWM)	54 (14 PWM)	2 x 46 headers	25 headers
Flash Memory	32 KB	256 KB	4 GB	SD dependant
SRAM	2 KB	8 KB	512 MB DDR3	512 MB
EEPROM	1 KB	4 KB	-	-
Serial	1	4	4	4
Clock Speed	16 MHz	16 MHz	1 GHz	700 MHz

The raspberry Pi is selected because it also supports a wide range of operating system that can be easily configured with a monitor through the HDMI port. Operating systems include any unix-like compiled for ARM architectures including linux and freeBSD. Monitor, keyboard and mouse can be connected to the PI for configuration as well as troubleshooting. It can also be connected within a local area network using Ethernet cable or Wi-Fi adapter and then login using SSH client like putty [58, 61]. Figure 17 below shows the raspberry PI 3B with labelled parts.

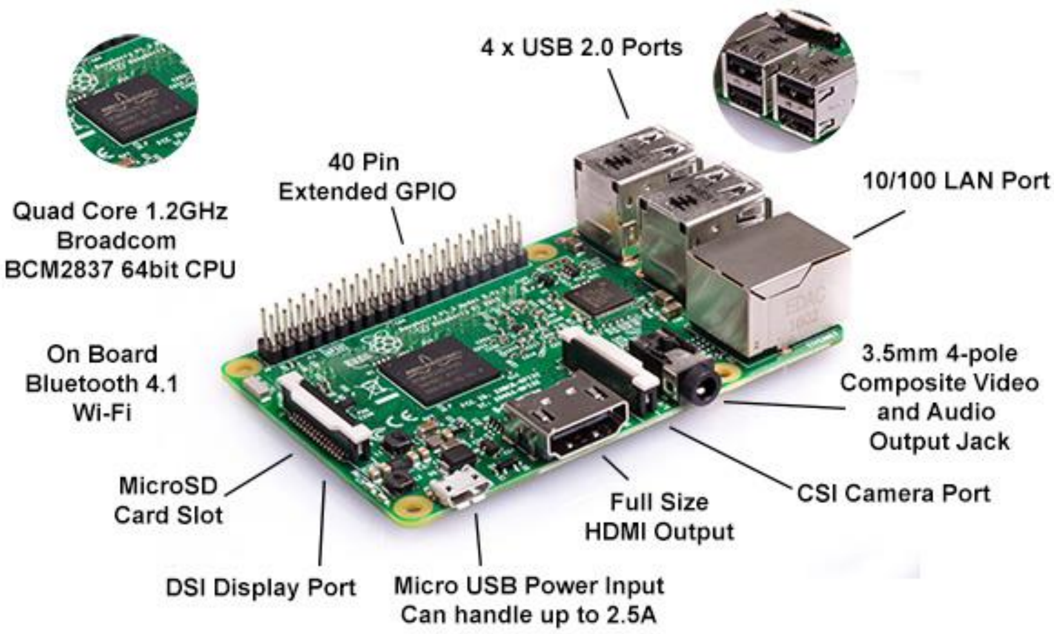

Figure 20 Raspberry Pi Microcontroller [62]

4.3.3.1 XBee Adapter Kit

To complete the base station, the gateway node XBee module that receives data from the sensor module has to be connected with the Raspberry Pi. Here XBee adapter kit are used. Using this adapter kit and a FTDI cable we can directly connect the XBee module to any PC. It's a much more cost effective choice for the gateway node. The board has 10 port socket on both side so that XBee modules can be swapped very easily. Most of the common XBee pins have been drawn out to one side. So it can be easily connected to bread board or FTDI cable. There is a 3.3V on board regulator which provides ample current to support all version of XBee. Two LEDs are also available, one of them is for RSSI and the other one is for power [58]. The adapter kit is shown in Figure 18 below.

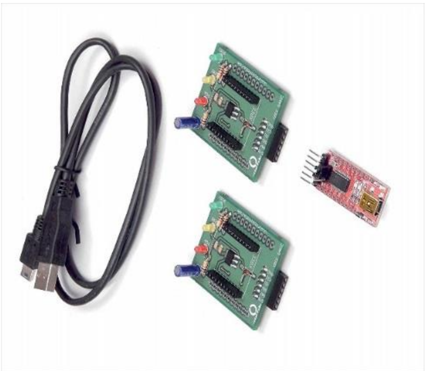

figure 21 Xbee adapter kit for the base station [66].

4.4 Monitoring System

In this aspect we have two scenarios of condition monitoring, it can be performed continuously or periodically. Continuous monitoring is the ideal kind and it detects a problem straight away but is expensive in terms of energy and careful pre-processing to ensure accurate diagnostics since the sensor data is very noisy. On the other hand, Periodic monitoring is cheaper, uses less energy, and allows time for data cleaning and filtering [27]. Depending on the type of data being acquired, there can be a problem in that the fault is only diagnosed at the next processing run. This may be acceptable for some situations that change slowly such as cracks developing in bridges but for time critical scenarios, then continuous monitoring is necessary. In railways, WSNs can be further divided into two types; the fixed network relates to sensor nodes in fixed locations such as bridges, tunnels, and special points, whereas the movable network relates to sensor nodes attached to locomotives or rail wagons [38]. For this research we focus on in the fixed monitoring category.

4.4.1 Fixed Monitoring

Until recently, inspection has been performed visually [39], but this only examined the structures superficially and intermittently, and the visual analysis needs to be interpreted by an expert, which can be subjective. In the past, fixed WSNs were simple such as attaching sensor nodes to the rails to monitor the rail temperature or low-voltage warning sensors that monitor the power supply to motors at points [40]. The output of the systems were simply binary high or low. For the temperature sensor, a rail expert with knowledge of the ambient (stress free) rail temperatures set the alarm levels for “amber” and “red” warnings. If an alarm level was reached, then the system sent an SMS alert [27]. Nowadays, WSNs provide semiautomatic or automatic analysis of the sensor data to examine structural changes and to improve the durability of structures reducing the overall maintenance costs.

Railway point machines also called switches move the track between two alternative routes to ensure the train takes the correct path or route [41, 42, 43, 44]. The points work in together with track circuits to detect and route trains. Hence, both the track circuits and the points must be fully functioning to accurately detect and route trains to ensure safe and reliable operation [27]. Point machine is a complex system and has a lot of parts hence the monitoring systems often use a variety of sensors. What we can monitor is the closing distance, motor driving force, driving current and voltage, electrical noise, temperature and state changes, current drawn by the system as a whole, and the force in the drive bar measured with a load pin. The fixed monitoring selected will be periodical with set limits to set alarms and there will be an option of the user requesting a sensor reading in real time through queries.

4.5 System Software Platform

The selected software is the open source Linux which can be installed on the Raspberry Pi. For the design the system is installed in a Ubuntu 14.04 LTS which is a Linux platform. Various tools are also used to create and mimic a web server. These are python programming language and Linux Apache MySql and PHP language together known as LAMP that creates the database engine.

4.5.1 Linux

For the base station setup, Linux is used. On the real system the Linux operating system is to be installed in the Raspberry Pi to create a small pocket computer. Linux is highly customizable as it is open source and there are a number of distributions of Linux such as Red Hat, Fedora, SuSe, Mandrake and Debian. The Raspberry Pi organization customized a new out of box software (NOOBS) which gets installed flawlessly onto the system without much prior technical knowledge. But for configuring the system, we are going to work on a laptop Linux which will act as the webserver and gateway for the base station.

4.5.2 Webserver Platform

In simple terms, Webserver is a combination of hardware and software delivering web content which can be accessed by clients or users through internet or local area network. In which communication between the server and the client takes place using Hypertext Terminal Protocol (HTTP). The hardware platform in this case is the laptop which is being used for development which will then be transferred to the Raspberry Pi.

The software part has a few options. For Linux the common ones are Apache and Niginx. The performance of a webserver depends on how many clients it can handle simultaneously and how fast it can response. Nignx is the fastest web server seen around in terms of load time and number of connections and Apache is the slower in comparison [67] especially for static pages. In the case of dynamic pages Apache is not that slow which is why it is the common choice for most developers in the world. Apache has 2 versions and the latest one is what we use here, it is called apache2.

4.5.3 Database

The system can be designed that a user receives data directly from the sensor in a text file. But data storage is required in a way that it can be manipulated and accessed systematically. That's where the database comes in. There are several database engines like MySQL [Appendix 1], SQLite, PostgreSQL which are all open source and are free to use. We use MySQL in the system because it is very highly ranked, widely used and has a lot of literature. It also has pre-installed password prompt which will act as the first layer of security.

For the database to function properly with the webserver, modules have to be added. The first module required is the “Libapache2-mod-auth-mysql” which allows HTTP authentication by apache2 against information stored in a MySQL database. The other module is “Php5-mysql” which enables access to the database from any terminal and from PHP scripts.

The tool phpMyAdmin is installed which helps the user to graphically work with MySQL and do most of the functional task like create, copy, drop, rename and alter databases, tables, fields and indexes. User can import data from CSV and SQL to the database and also can export any data from MySQL to CSV or SQL format. This graphical option is preferable compared to scripting method through the use of scripting languages like PHP, ASP, JSP, Ruby and Python which requires a lot of technical knowledge for the same task.

For database data presentation, it is simpler for use to see the trend easily in a chart form. Hence charting tools are used to plot the sensor information as real time graphs or charts using tools that are based on JavaScript and jQuery which are available for free online.

4.5.4 Python

The python language comes build in in Linux and can only be updated to latest version. Python here is used to build the controller software which would control the sensor network, send and collect data from the sensor network and save them in the created database. To be able to interact with the other parts of the system, python required extra modules and packages which includes pip module which allows the installation of other modules. PySerial module is also required since most of the data will be written through serial port or will be read through it, the pySerial module enables python to access the serial port.

The MySQL-python module enables python to communicate directly with the MySQL database. The other module is needed is the Advanced python scheduler module which helps to schedule jobs to be executed at a chosen time. Lastly, the Xbee package is also required for implementation of the XBee serial communication API. Features in XBee devices can be accessed from an application written in Python by using this package. It is imperative to know that this package cannot work without the PySerial module.

4.5.5 Arduion IDE and Xbee XCTU

These two platforms are required to configure and program the Arduino microcontroller and Xbee radions for the sensor nodes. The IDE for Arduino is open source and Programming syntax is similar to C [Appendix 2]. An Xbee package is required in the Arduino program to enable it to work with the xbee radios.

XBee radios is require parameter to be set before first use. The software named XCTU from digi international is used to set these parameter. Using the adapter kit and the FTDI cable it is possible to connect the XBee module to any computer. PC settings of XCTU is used to test the connectivity of XBee with the computer. The baud rate can also be set from here. Terminal window in XCTU helps to see incoming and outgoing packet both in character and hex mode.

5 Results and Discussions

The nature of the work in this process brings in a lot of parts to work together, from the data collected for decision making, software and the hardware of the designed system which required different programming languages to be used. Whenever writing code, it is important that the code be thoroughly tested at different stages of development. When assembling the hardware on the other side, the same scrutiny has to be used to test the functionality of the setup. In the case that we are testing both the hardware and software there are additional challenges. Because everything must interact and function together, if things don't work as expected, it is not always readily apparent if the problem is hardware or software related. This project is an amalgamation of many different pieces and a successful deployment of the project must make sure that all those pieces fit together properly. Hence the results were taken from different stages.

5.1 Results

5.1.1 Data Retrieving

The central controller script of the system is designed with two main processes running simultaneously. Writing the received data from sensor nodes to the designated tables in the database and sending packets to sensor nodes periodically as scheduled by the scheduler. The sent packets triggers the sensor node to reply with the appropriate data as requested.

5.1.1.1 Scheduler

The scheduler is one of the most important functions of the data retrieval system. It runs periodically to get the packets sent from the sensor nodes. The period designed has to consider a number of issues to avoid running with problems. The first issue, sensor speed capacity in collecting data and receiving feedback, has to be considered. The scheduler also considers the speed the collected data is entered in the database by looking at the packet queue since each mysql query takes some time.

5.1.1.2 Packet data send and receive

The Xbee radios are designed to send packets already constructed in an API frame. The zigbee transmit request is triggered every time a packet is sent which includes a destination address. At the receiving side, all the received packages are saved in the gateway xbee inside its queue. A script routinely checks to see if there is data in the queue, if so it gets the API ID and strips the frame to acquire the information. The frame contains two data sets, one confirming that the node received a request from the gateway and the other containing the sensed data. The information is then inserted in the mysql database.

5.1.2 Sensor Node Configuration

The Xbee radio on the node is configured as a router and the radio at the gateway is configured as the coordinator by using the XCTU software as shown in the snapshot below. Most important parameter is the PAN ID. If the PAN ID of the sensor node does not match with that of the coordinator then it is not to be considered part of the wireless sensor network.

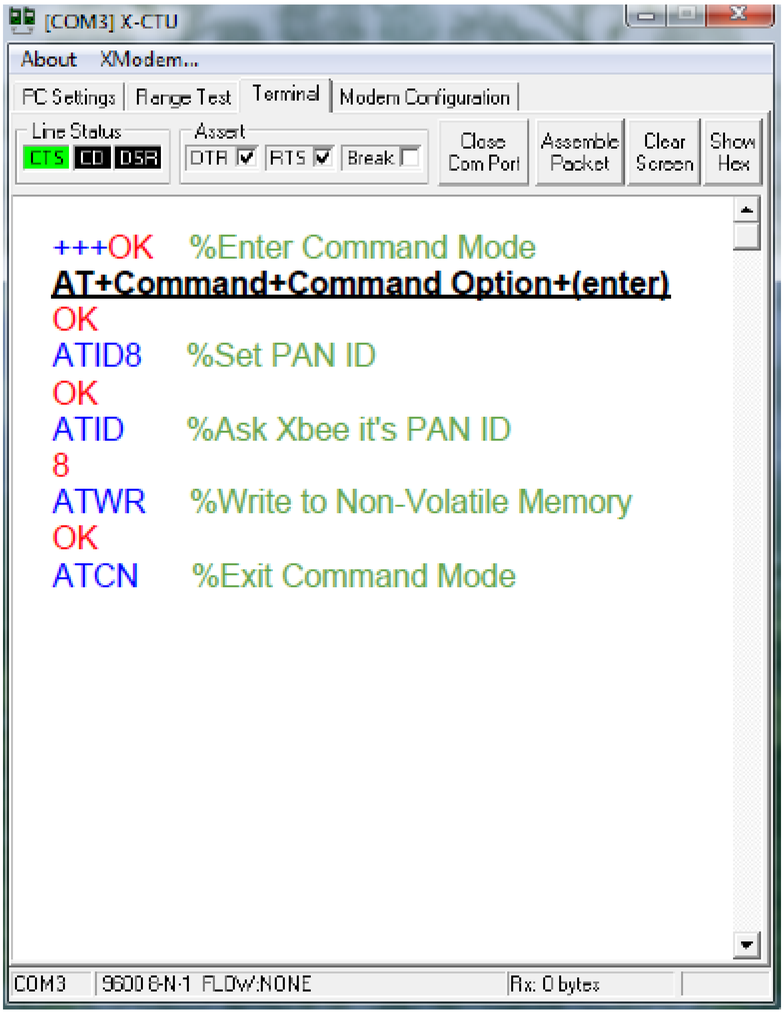

figure 22 XCTU software for configuring XBee radios

The Arduino UNO is the microcontroller on the sensor nodes and it is programmed with a C script to read sensor data and and output the results that are then transmitted over the Xbee radios to the gateway to be accessed by the python code that stores them in the database. The type of sensor used will require a particular library to be added as a driver in controlling the particular sensor.

5.1.3 WSN Simulation

Due to time and availability of the resource required to build the designed system, the WSN part of getting the data from the nodes was simulated using Network simulator library (NS). A network simulation is the implementation of a simulation that attempts to imitate the real world behaviour of a computer network or certain aspects of a computer network to analyse the captured information and transmitted data that can be used to draw conclusion or investigate characteristics of a protocol [77, 78]. NS is built using C++ and Python with scripting capability. The ns library is wrapped by Python thanks to the pybindgen library which delegates the parsing of the ns C++ headers to castxml and pygccxml to automatically generate the corresponding C++ binding glue. These automatically-generated C++ files are finally compiled into the ns Python module to allow users to interact with the C++ ns models and core through Python scripts. The ns simulator features an integrated attribute-based system to manage default and per-instance values for simulation parameters [76]. The models are defined as "abstract representations of real world objects, protocols, devices, and many more" [79] or as stated in [80] "an abstraction of reality". Then, they are aggregated into modules, which are all individual software libraries. The figures below show the results of the simulated network and the code is provided in appendix 7.

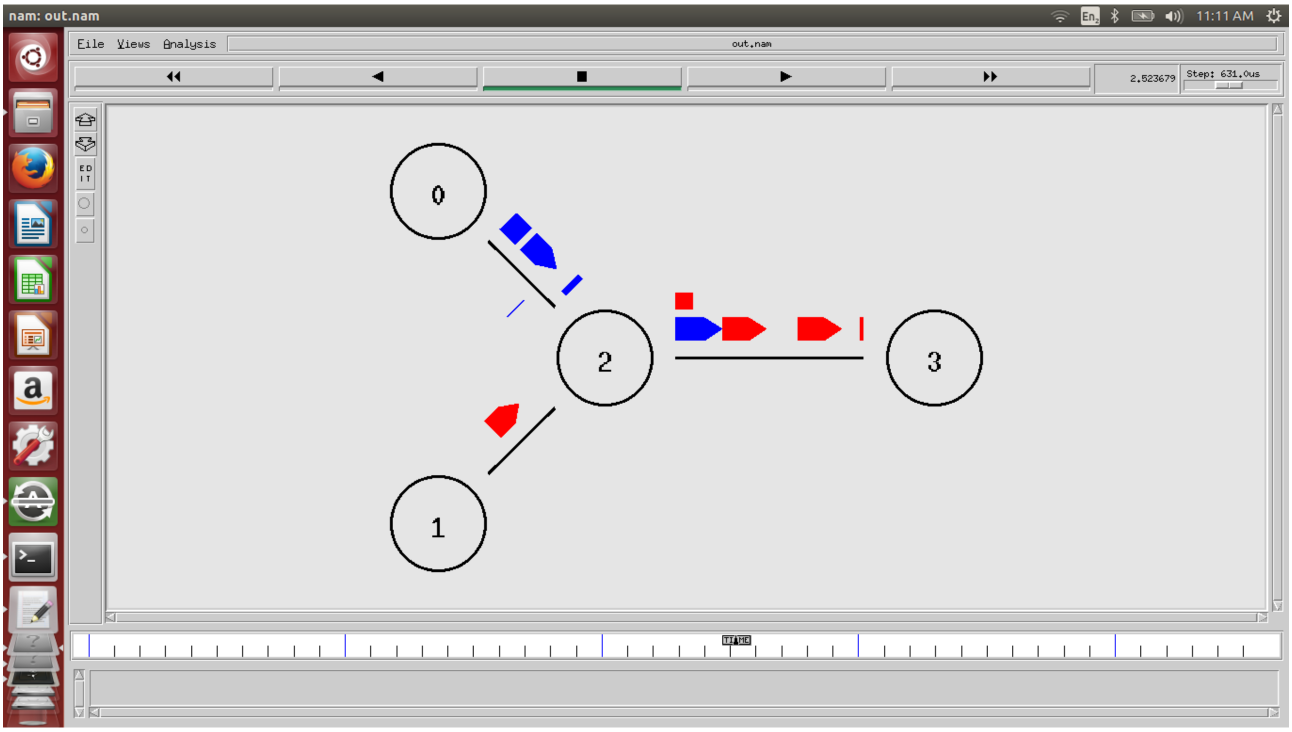

figure 23. NS simulation with 3 nodes and one coordinator as the gateway.

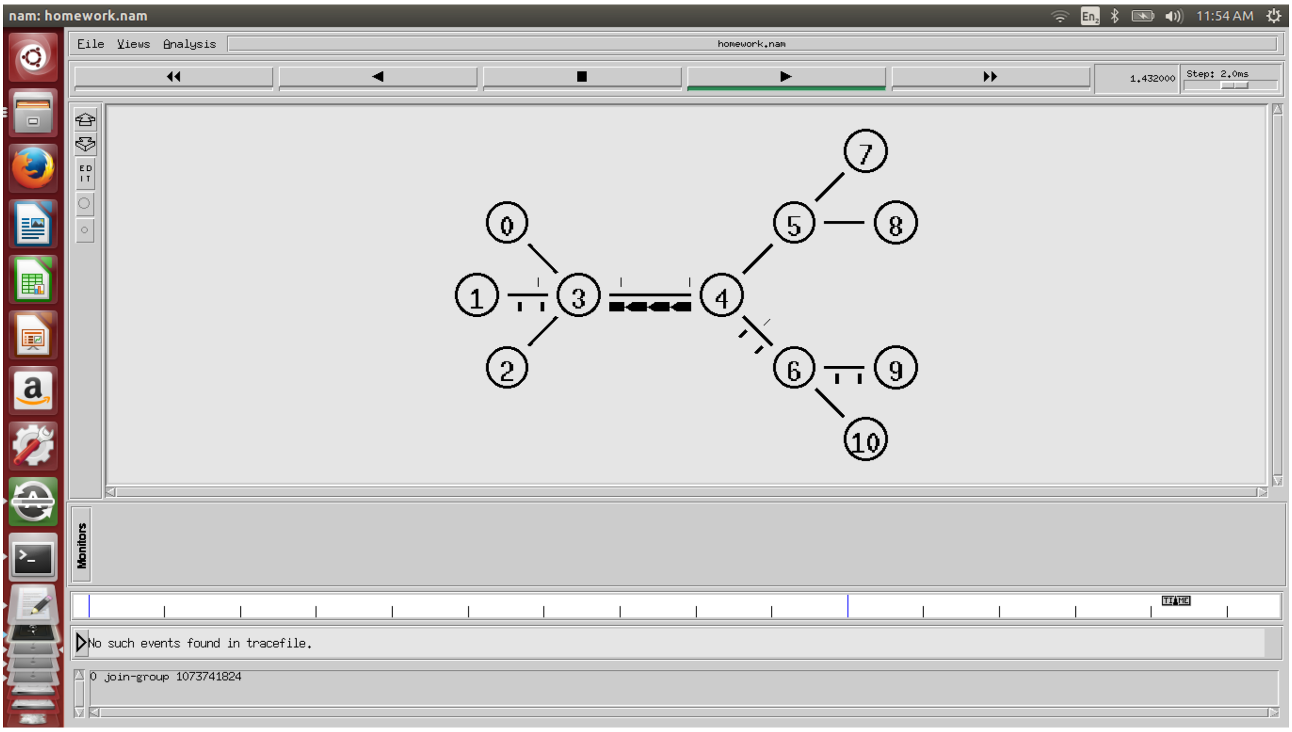

figure 24. NS simulation with 9 nodes and 2 coordinators as gateways.

5.1.3.1 Simulation limitations of NS

Despite the simulation being a powerful tool, it has its limitations. The notable limitations are outlined below;

- ✓ Credibility and validation; this is a challenge because all aspects of the reality can never be implemented in the simulation which necessitates compromises to be made in level of simulation and absence of certain aspects of the network.
- ✓ Scalability Limits; Simulation gives the flexibility of adding and removing nodes easily compared to the physical disconnections. But in NS this requires a lot of memory and computational time [75] due to its discrete event nature.
- ✓ Upper Layer Functionality; the simulation may be written for one context in which it functions flawlessly, but, if used in a different context, malfunctions completely. Some models implement every component of a network protocol, but this does not mean that every aspect of its behaviour does not differ from how the protocol would behave in the real world given the same preconditions and circumstances.

5.1.4 Local Server

The LAMP server was successfully created including apache2, MySQL and PHP as the building blocks. In the Ubuntu environment, these packages have to be installed with specific commands in the terminal and there are a few lines of the codes that have to be changed in order for the server to work. Figure 21 below shows the graphical user interface of the created database logged in as the administrator. The database shows the tables that will keep the data from the sensor nodes vial the serial through a python code. The current page shows simulated sensor values for point machine A.

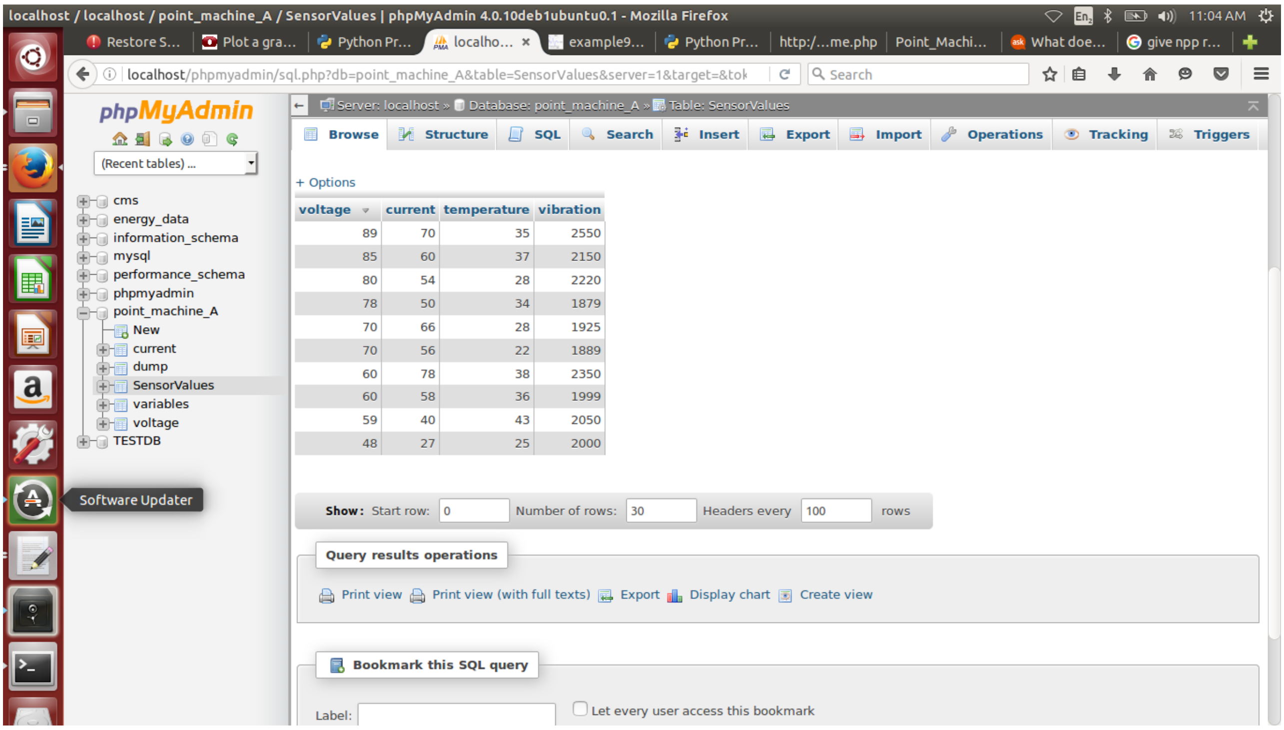

figure 25 MySQL database home page

5.1.4.1 *Server Security*

A very major concern of working with servers is unwanted visitors that can access the data without authorisation. Security to make the data in the server safe is paramount. Since LAMP is open source, security updates are always being developed so the first step in securing the system is to enable automatic updates of the server [71]. Then a firewall is enabled that stays up even after a restart.

As a precaution to fish out malicious users, a third party security tool called *fail2ban* was installed. This service is a log watch tool that scans the log files for too many login failures and blocks the IP address which is showing malicious signs. In addition, *mod_security*, a web application firewall (WAF) which can be installed as an additional module for Apache was installed. It is used to protect the web server from numerous attacks like SQL injections, session hijacking, cross site scripting, bad user agents and other attacks. [70].

Lastly, a security redundancy called .htaccess is added. This is done by editing the Apache configuration file. This is done by adding an `AllowOverride All` directive within the `<Directory /usr/share/phpmyadmin>` section of the configuration file. Then the security is implemented by creating a .htaccess file within the application directory. The contents of the file is shown in appendix 4. An addition package in apache is required to create the htpasswd utility. This package is where the users and passwords will be stored. After entering the credentialsand saving. A log in prompt pop will appear whenever the server is started as shown in figure below;

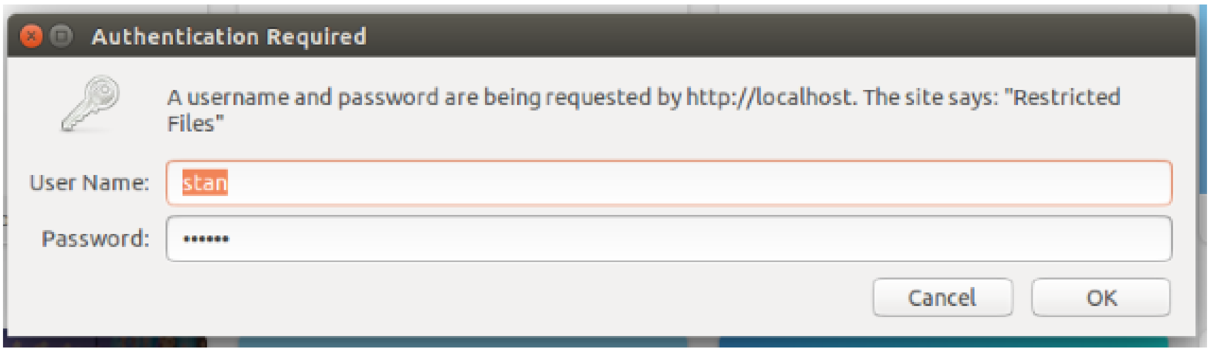

figure 26 htaccess server security.

5.1.5 HTML Web Page

Since the goal of the development was to enable remote access to the sensor network and the collected data, the HTML website is the face of the system that the users like managers and maintenance engineers will interact with to monitor the behaviour of the point machines. Initially, the computer is used to host this website which will be moved to the Raspberry Pi. The interactive page is designed as home with links to pages of the different point machines being monitored. These pages are interacting with the MySQL database as shown in figure 25 below indicating the point machine A data tables.

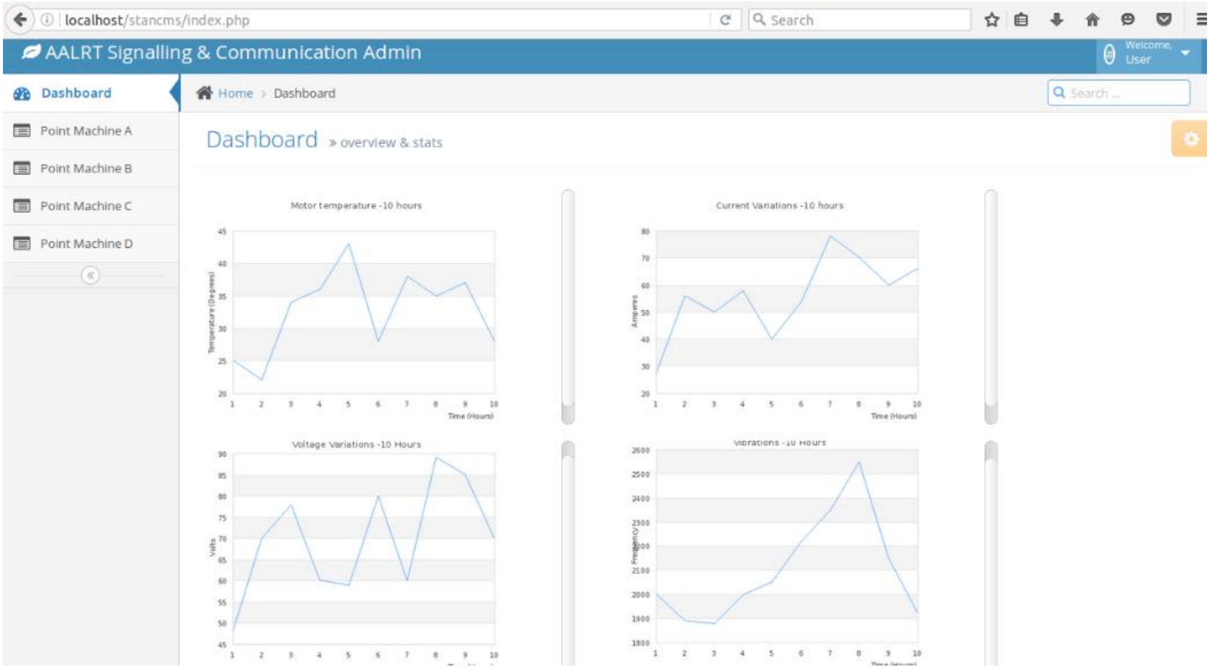

figure 27. Webpage interface of the monitoring system.

The website designed is of the dynamic type. Dynamic web pages are different from the normal web pages that are sometimes called static web pages that look the same and the content never changes unless a new page is loaded. The common types of the dynamic webpages are the database driven webpages that are utilised in this work. The web page grabs information from a database and inserts the said information into the web page each time it is loaded.

The page HOME is designed to manipulate the point machine data Table available at the MySQL database. Any changes in the point machine data table are translated into the change of destination address or payload. The other way is that the user can directly log in to MySQL from a Linux terminal and manually change the values in the table but this would require admin privileges and to physically be on site hence doing it from HTML front end is more convenient. So, front end and backend PHP script were created for this purpose in such a way so that any time submit button is selected after selecting a checkbox, a “1” will be written to the corresponding cell of the MySQL Table and the current status of the Table is displayed.

JPgraph is used incorporated in PHP scripts to give a real time plot of the trend of a parameter gathered by a particular sensor node. Here the user can select sensor node and data refresh to view the updated trend. The design is created that for each time only the data gets refreshed in the chart and not the whole page. Another link is for the admin to see the DATA which is designed to manage the storage capacity of the database. The Pi is limited to the SD card installed and can handle as much data. The DATA page displays number of lines in the database and gives options to download and remove data directly from the database. Using *jquery* (Appendix 9), the dynamic website automatically gets data from the database as it is being updated from the sensor nodes.

The vibration sensor is simulated by using a mic in place of the accelerometer to be used during deployment and the vibrations are visualised as continuous sound waves that give warnings when a certain limit of noise is reached. The noise are measured when the point machine is switching. The normal switching noise is as shown in figure 26 below. The abnormal switching noise is shown in figure 27 below. If the abnormal noise is observed it would mean that the point machine is developing a mechanical fault hence the responsible maintenance team would be notified to take action before a breakdown occurs to prevent losses. The graphs are plotted using Python module call matplotlib.pyplot library which requires a subsequent library called nampy to be installed as well [80].

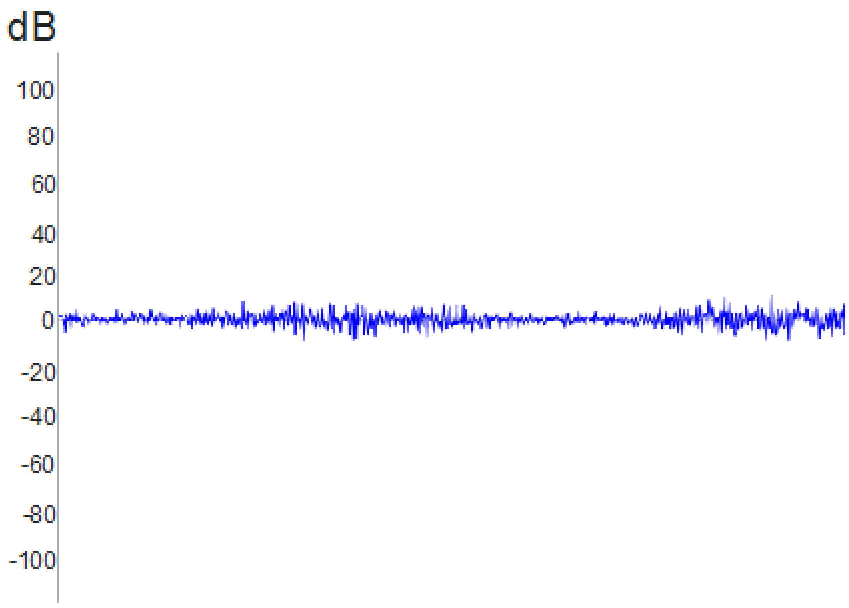

figure 28. Normal Switching Vibration Noise in dB

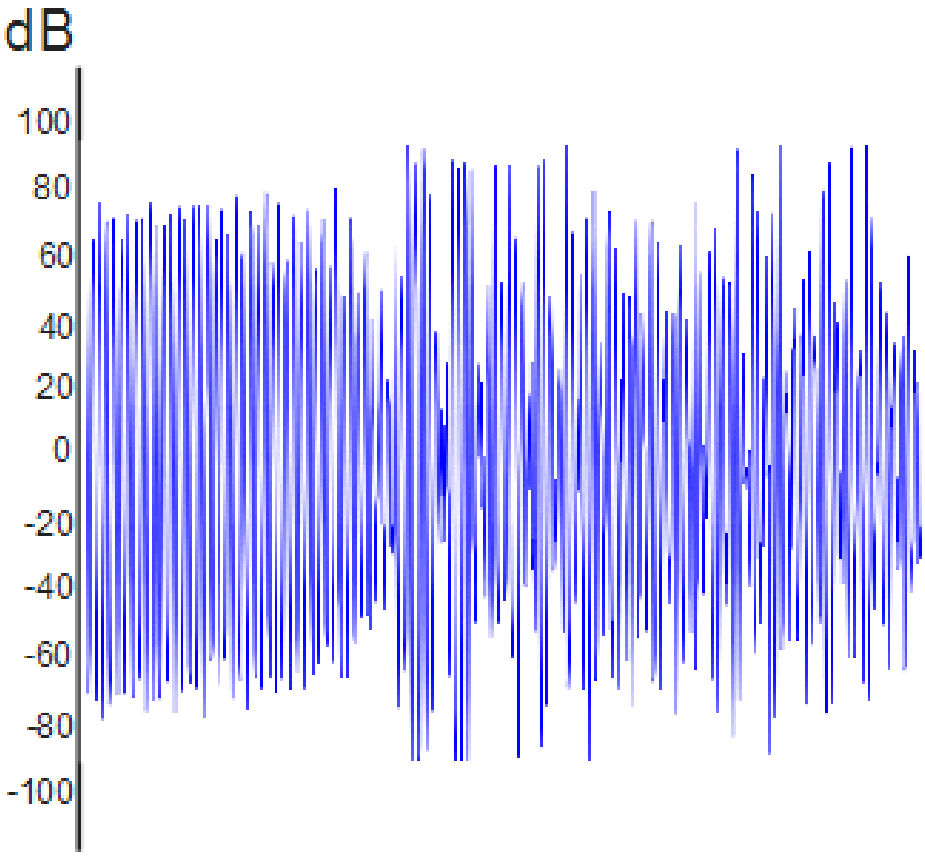

figure 29. Abnormal Switching Vibration Noise in dB

5.2 Discussions

The estimated installation of the WSN system is estimated in the table 11 below. The service cost can be estimated by looking at the parts of the system that needs frequent attention like the sensor nodes power supply. The raspberry pi computer will need updating which can be done remotely if there is internet connection.

Table 11. System Cost

ITEM	DESCRIPTION	COST
Sensors	Accelerometer for vibration sensing when switching	$3.00
	Temperature sensor to monitor the motor	$4.00
	Voltage/Current sensor to monitor the supply	$4.00
Xbee Radios (4)	To create the wireless network between sensor nodes and the base station	$80.00
Xbee Shield	Xbee-Arduino shield (3)	$24.00
	Xbee-Raspberry Pi Adapter Shield (1)	$12.00
Arduino kit (3)	To Drive sensors and read sensor Data	$45.00
Raspberry PI	The main part of the system containing the server and web interface.	$54.00
Solar Panels (4)	To power the sensor nodes. (6W)	$38.00
	To power the Raspberry PI (9W)	$57.00
Casings (4)	To hold the node and the raspberry Pi	$20.00
Lithium Rechargeable Battery	To power the sensor nodes and the Raspberry PI	$80.00
Voltage Regulators (4) (Adjustable)	For Nodes and Raspberry PI	$40.00
TOTAL		**$461.00**

Through interviews conducted with AALRT officers, the daily number of passengers is 200,000. Approximately, 25,000 per hour since it operates for 8 hours per day. With an average cost of 4 Birr ($0.14) per person per trip. We can estimate that the line generates $3,448.28 every hour if it is in full operation. From this information, the company makes the same loss whenever a point machine is at fault since the average time to fix a point machine is 1 hour. This indicates that deploying the WSN to look out for the faults and prevent breakdowns is a major saving on the revenue cost that the faults bring to the company. A payback of the cost of installing the system is paid in a single instance the system prevents a breakdown.

It is however important to note that condition monitoring devices are always seen as an unnecessary cost, until failure occurs. There is always a “we should have known” saying when things get worse. By monitoring the condition of the point machines through WSN, trends in the behaviour can be understood and failures predicted giving the technician time to take preventive measures.

One good example is monitoring the vibration of the point machine when operating. Knowledge of the vibration tendencies and history can give an indication of any anomalies. The use of wireless condition monitoring based preventative maintenance tool cannot be emphasized enough.

Basically, the cost of building a remote condition monitoring system for trend analysis in a remote area is substantially high because we do not want to monitoring system to add maintenance burden to the monitored item. Hence, care must be taken to have a quality installation for a long run balancing cost and reliability of the system. Luckily enough, Industrial wireless technologies offer alternatives that can lower costs and improve reliability. It is therefore the designer’s job to select suitable technologies because choosing the best technology and wireless hardware is critical to installing a successful system.

5.2.1 Cost justification

The obvious cost cut in WSN condition monitoring compared to cable condition monitoring is the exclusion of the cables. Depending on the location of the monitored item, cable system can get extremely expensive that I does not cut cost compared with physical monitoring by humans. Wireless condition monitoring results in a lower cost surveillance program with more frequent data collection, increased safety, and lower spare parts inventories. The other benefit is that facilities are able to run leaner because they will have more confidence in their ability to avoid downtime.

The low cost of condition monitoring sensors also reduces both the installation and operating costs. With monthly or quarterly route running on the monitored point machines, companies can prevent many failures and provide an acceptable cost justification to management. In addition to the costs, WSNs provide more frequent readings for better identification of short time-to-failure situations. This is a more technical way to justify costs for many predictive maintenance practices compared to relying on some intuition, fudge factors, and an experienced practitioner or consultant.

Research has shown that many facilities account for unplanned downtime with excess production capacity. In petrochemical and petroleum refining plants, up to 15% of production capacity is required to account for unplanned maintenance. For typical heavy process industries like the railway systems, unplanned downtime costs can represent 1- 3% of revenue, potentially

33-50% of profits annually [71]. Hence, usage of condition monitoring sensors can provide up-to-date machine condition so that unscheduled downtime can be significantly reduced.

Some of the notable justifications of the system are outlined below;

5.2.1.1 Ease of Implementation

Advantages of sensors that are used to implement wireless sensor networks include their plug and play connectivity, intelligence to assist with start-up and maintenance, ease of expansion and their long life. Taking in consideration that capital cost is not the only major cost faced in a project, the advantages eases on installation costs, training, documentation, spare parts, and cost of production losses. Ease of installation and ease of maintenance of the WSNs is a major key since it means it is easier to maintain and implement than a wired system.

5.2.1.2 Ease of Installation

The work required to install say 50 wired condition monitoring system along a line can involve a lot of material and labour which would make it not viable to most managers since the cost would be very high. A wireless network on the other hand would require only the gateway to be considered and build the sensor nodes can be deployed at ease as far as they are configured to communicate.

5.2.1.3 Cost

In recent years, the range of sensing technologies has expanded rapidly, whereas sensor devices have become cheaper. This has led to a rapid expansion in condition monitoring of systems, structures, vehicles, and machinery using sensors. Key factors are the recent advances in networking technologies such as wireless communication and mobile ad hoc networking coupled with the technology to integrate devices [27]. Continued advances will gradually open the door for sensors further up the complexity continuum to migrate toward this model. Competitive pressures continue to force industrial end-users to seek new strategies for streamlining operations. Hence, integrated wireless sensor systems represent a promising tool as their costs continue to drop.

It is estimated that the installed cost of a wireless system should be only one-tenth of today’s installed cost in the future. In the long term, many sensors will be integral components of the production equipment, and their costs will be incorporated into equipment costs. Sensors at either end of the complexity spectrum, however, will continue to be offered separately on the market [71]

5.2.1.4 System Functionality

Once configured, a wireless sensor network is pretty much self-configuring in that it recognize all components in the system and is able to organise itself effectively provided no hardware failure is involved. This minimizes demand on the users. With the inclusion GPRS on the sensor nodes, the system becomes self-located [72] reducing costs that are associated with book keeping activities. Current research in the functionality of wireless sensors is geared towards providing wireless sensor networks that are self-configuring. For the long term, the goal is to create self-commissioning systems with advanced, embedded computing and communications solutions. These advanced systems will increase ease of use to the point that they perform autonomously [73].

5.2.2 Wireless Network Reliability

The objective of the research was to improve the reliability and availability of the point machines through condition monitoring. It will be useless and ludicrous if the condition monitoring system itself is unreliable. One major challenge regarding the deployment of wireless networks is dealing with the unpredictable nature of signal propagation. This is a major problem when obstacles are involved in the path of the signals. In our case, the XBEE radios are deployed in the open space were the point machines are located. The radios have a wide range and do not need line of site to work as far as the peer radio is in range.

Security reliability of the wireless network is a bit tricky. The disadvantage is that they violate the physical security model that is so effective in wired local area networks. This necessitates additional mechanisms to implement proper access control and accountability. With no inherent access control, the wireless links extend their connectivity beyond physical boundaries, making the networks available in adjacent locations where coverage was not intended. When left unprotected, these wireless links make networks vulnerable to misuse and attacks. The ZIGBEE network however, provides a means of protection in form of API ID. Every radio in the network must have its ID registered in order for it to send and receive data packets in the system. This in itself is secure unless the malicious user has really bad intentions to access the data and manipulate it.

6 Conclusion and further Research

6.1 Conclusion

The system to remotely monitor the condition of the point machines has been a success. A web interface to control and collect the sensor data from the WSN is successfully designed. The system is a prototype with the client side completely build in the server at the gateway and the data collection side simulated since access to the point machine and to the required sensors and radios was restricted. Nevertheless, the system can be fine-tuned and modified to fit industrial level standard and applied in the field incorporated with the already existing SCADA system.

The raspberry PI, a very small computer, makes the system cheap to build and implement since only the designed purpose of the system utilises the computer capacity. This further cuts down the cost of the monitoring system. Other advantage is that it is power efficient hence environment friendly.

With the use of open source tools, the project has been shared and is publicly available. This will allow any programmer to improve and make modifications. Hence, the system will be further developed to provide robust condition monitoring as better ways of building the system are discovered.

6.2 Further Work

The system requires more testing in terms of reliability before it can be adopted and tested on the point machines. Even though the Raspberry Pi is very unlikely to crash since it is handling a small task, a separate study still has to be performed for the long term reliability test under various loads. More services can be added to generate and provide performance data for XBee network. Information such as fail rate, round trip time for a successful reception from a sensor node, available battery level for each sensor node are also very crucial and can be generated and added to be displayed on the web pages or upon request to give an idea whether the system is running healthy or not. Below are some further improvements that can be added to make the system robust;

6.2.1 Power Consumption

Since the practical side of the research has focused much on the client side by developing a gateway and web server to retrieve the collected data, the node has not been entirely covered. The most important part is the power consumption at the nodes. We opted to use solar to power up the nodes which proves to be insufficient at times. A lot of research has been done in finding the optimum power sources to power up WSN nodes and more work has to be done in this particular application. The power consumption can also be applied to run the raspberry Pi to make the system totally indecent from the monitored system power supply. This will require a reliable power source to ensure that the system is always up and running.

6.2.2 Alarms

The monitoring itself has a human factor in that the engineer has to be alert to note the change in values. This human might miss some important deviations that can lead in machine failure. Hence, adding an alarm to notify via SMS, email or just making noise when a threshold has been reached would be very helpful.

6.2.3 Error checking

Errors are expected in the transmission of the data from the nodes to the gateway. In this work since this part was simulated, we did not have a chance to encounter these errors and devise a way to check that they actually exist. An error checking code can be added in the system to alert the users of errors of any. For a small deployment these errors may not be an issue but as the system is adapted and deployed at large scale and in adverse environments, the errors can be enormous and the error check checking code will be very important.

6.2.4 Data Download

The raspberry Pi has an Ethernet port allowing it to connect to the internet. Making it less costly compared to those other deployment that utilise cell signal coverage. This gives the users access to the data everywhere in the world which is even cheaper than having to go on manually collecting the data. This is the main option of viewing and downloading the data for analysis.

Furthermore, an interesting option available that involves a messenger queue service called MQTT can be utilised. This is a very lightweight service specifically designed to run on low-power devices. It works on top of the TCP/IP protocol designed for connections with remote locations where a small code footprint is required [69] just like our scenario. MQTT can also run on a laptop or cell phone. With an MQTT server running on the coordinator node at the gateway, we could theoretically approach our sensors with something like a smartphone, running an MQTT client, and functioning as a wireless hotspot. The Pi would then connect to the hotspot and transfer any queued data.

6.2.5 Integration with Company Database

For now the system is developed as a standalone item. This may be great because it gives it its independence. However, it may be simpler if the data was integrated with the company database. This may simplify the analysis of the point machine trends in comparison with other equipment. To do this however, security measures have to be taken before introducing the system to public domain. Separate user group has to be created so that tasks like modification of configuration or database maintenance strictly belong to the administrator. Most company servers these days are being connected to cloud servers making the data available even when the system is completely out of service.

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8 Appendix

1. MySQL

   This is a database management system. To add, access, and process data stored in a computer database, you need a database management system such as MySQL Server. Since computers are very good at handling large amounts of data, database management systems play a central role in computing, as standalone utilities, or as parts of other applications.

   MySQL databases are relational meaning that they store data in separate tables rather than putting all the data in one big storeroom. The database structures are organized into physical files optimized for speed. The logical model, with objects such as databases, tables, views, rows, and columns, offers a flexible programming environment. You set up rules governing the relationships between different data fields, such as one-to-one, one-to-many, unique, required or optional, and "pointers" between different tables. The database enforces these rules, so that with a well-designed database, your application never sees inconsistent, duplicate, orphan, out-of-date, or missing data.

   The SQL part of "MySQL" stands for "Structured Query Language". SQL is the most common standardized language used to access databases. Depending on your programming environment, you might enter SQL directly (for example, to generate reports), embed SQL statements into code written in another language, or use a language-specific API that hides the SQL syntax.

   SQL is defined by the ANSI/ISO SQL Standard. The SQL standard has been evolving since 1986 and several versions exist. In this manual, "SQL-92" refers to the standard released in 1992, "SQL:1999" refers to the standard released in 1999, and "SQL:2003" refers to the current version of the standard. We use the phrase "the SQL standard" to mean the current version of the SQL Standard at any time.

   MySQL software is Open Source which means means that it is possible for anyone to use and modify the software. Anybody can download the MySQL software from the Internet and use it without paying anything. If you wish, you may study the source code and change it to suit your needs. The MySQL software uses the GPL (GNU General Public License), http://www.fsf.org/licenses/, to define what you may and may not do with the software in different situations. If you feel uncomfortable with the GPL or need to embed MySQL code into a commercial application, you can buy a commercially licensed version from us. See the MySQL Licensing Overview for more information (http://www.mysql.com/company/legal/licensing/).

The MySQL Database Server is very fast, reliable, scalable, and easy to use. If that is what you are looking for, you should give it a try. MySQL Server can run comfortably on a desktop or laptop, alongside your other applications, web servers, and so on, requiring little or no attention. If you dedicate an entire machine to MySQL, you can adjust the settings to take advantage of all the memory, CPU power, and I/O capacity available. MySQL can also scale up to clusters of machines, networked together.

MySQL Server was originally developed to handle large databases much faster than existing solutions and has been successfully used in highly demanding production environments for several years. Although under constant development, MySQL Server today offers a rich and useful set of functions. Its connectivity, speed, and security make MySQL Server highly suited for accessing databases on the Internet.

The MySQL Database Software is a client/server system that consists of a multithreaded SQL server that supports different back ends, several different client programs and libraries, administrative tools, and a wide range of application programming interfaces (APIs). [82]

2. C Programming language

   C is a general-purpose, imperative computer programming language supporting structured programming, lexical variable scope, and recursion, while a static type system prevents unintended operations. By design, C provides constructs that map efficiently to typical machine instructions, and has found lasting use in applications previously coded in assembly language. Such applications include operating systems, as well as various application software for computers ranging from supercomputers to embedded systems.

3. Data logging

By using pySerial, which reads directly form the serial port and was a complete solution, the data coming from the gateway Xbee is retrieved. The simple line below in python does the job

```
import serial

ser = serial.Serial('/dev/ttyACM0')

ser_bytes = ser.readline()
```

Where '/dev/ttyACM0' is the port the radio is connected.

To display a plot of the data in real time, a tool is used and the scrip is as below;

```
import serial
import time
import csv
import matplotlib
matplotlib.use("tkAgg")
import matplotlib.pyplot as plt
import numpy as np
ser = serial.Serial('/dev/ttyACM0')
ser.flushInput()
plot_window = 20
y_var = np.array(np.zeros([plot_window]))
plt.ion()
fig, ax = plt.subplots()
line, = ax.plot(y_var)
while True:
   try:
           ser_bytes = ser.readline()
           try:
               decoded_bytes                                =
float(ser_bytes[0:len(ser_bytes)-2].decode("utf-8"))
              print(decoded_bytes)
         except:
           continue
         with open("test_data.csv","a") as f:
              writer = csv.writer(f,delimiter=",")
               writer.writerow([time.time(),decoded_bytes])
          y_var = np.append(y_var,decoded_bytes)
```

```
        y_var = y_var[1:plot_window+1]
        line.set_ydata(y_var)
        ax.relim()
        ax.autoscale_view()
        fig.canvas.draw()
        fig.canvas.flush_events()
except:
        print("Keyboard Interrupt")
        break
```

4. HTAccess Security file

Create the file by doing; `sudo nano /usr/share/phpmyadmin/.htaccess`

Within this file, we need to enter the following information:

```
AuthType Basic
AuthName "Restricted Files"
AuthUserFile /etc/phpmyadmin/.htpasswd
Require valid-user
```

- **AuthType Basic**: This line specifies the authentication type that we are implementing. This type will implement password authentication using a password file.
- **AuthName**: This sets the message for the authentication dialog box. You should keep this generic so that unauthorized users won't gain any information about what is being protected.
- **AuthUserFile**: This sets the location of the password file that will be used for authentication. This should be outside of the directories that are being served. We will create this file shortly.
- **Require valid-user**: This specifies that only authenticated users should be given access to this resource. This is what actually stops unauthorized users from entering.

To create the authentication file; `sudo apt-get install apache2-utils`

5. XBEE and ZIGBEE

Zigbee It is a technical standard for communication protocols using small, low power, digital radios for personal area networks (PAN), IEEE International Standard 802.15.4, typically operating at 2.4 GHz. Its target market is low power applications with infrequent data transmission needs. Xbee is Digi International's in house Zigbee communication module brand. Figure gives the full catalogue of zigbee products.

XBee® Family Features Comparison

Protocol	Product	Certified Regions	Frequency	Positioning	RF Line of Sight Range	Transmit Power	Receiver Sensitivity	Form Factor	MSRP	RF Data Rate	Programmable Variant	Hardware
IEEE 802.11	XBee® Wi-Fi	US, CA, EU, AU, JP	2.4 GHz	Low-power serial to Wi-Fi b/g/n	N/A	+16 dBm	-93 to -71 dBm	Through-hole, SMT	$35.00	1 to 72 Mbps	N/A	S6B
IEEE 802.15.4	XBee® 802.15.4	US, CA, EU, AU, BR, JP	2.4 GHz	Low-cost, low-power multipoint	300 ft / 90 m	0 dBm	-92 dBm	Through-hole	$19.00	250 Kbps	N/A	S1
	XBee-PRO® 802.15.4	US, CA, AU, BR	2.4 GHz	Extended-range multipoint	1 mile / 1.6 km	+18 dBm	-100 dBm		$32.00	250 Kbps	N/A	S1
		US, CA, EU, AU, BR, JP	2.4 GHz	International/"J" variant	2500 ft / 1 km	+10 dBm	-100 dBm		$32.00	250 Kbps	N/A	S1
Multipoint Proprietary	XBee-PRO® XSC	US, CA, AU	900 MHz	Long-range multipoint for North America	9 miles / 14.5 km	+24 dBm	-107 to -109 dBm	Through-hole	$39.00	10 Kbps or 20 Kbps	N/A	S3B
	XBee-PRO® 868	EU	868 MHz	Long-range multipoint for Europe	25 miles / 40 km	+25 dBm	-112 dBm		$45.00	24 Kbps	N/A	S5
ZigBee® PRO Feature Set	XBee® ZB SMT	US, CA, EU, AU, BR, JP	2.4 GHz	Surface mount, low-cost, low-power, ZigBee PRO Feature Set, EM357	4000 ft / 1.2 km	+8 dBm	-102 dBm	SMT	$17.50	250 Kbps	32 KB Flash / 2 KB RAM	S2C
	XBee-PRO® ZB SMT	US, CA, AU, BR	2.4 GHz	Extended-range, surface mount, ZigBee PRO Feature Set, EM357	2 miles / 3.2 km	+18 dBm	-101 dBm		$28.50	250 Kbps	32 KB Flash / 2 KB RAM	S2C
	XBee® ZB	US, CA, EU, AU, BR, JP	2.4 GHz	Through-hole, low-cost, low-power, ZigBee PRO Feature Set, EM250	400 ft / 120 m	+3 dBm	-96 dBm	Through-hole	$17.00	250 Kbps	N/A	S2
	XBee-PRO® ZB	US, CA, AU, BR	2.4 GHz	Extended-range, through-hole, ZigBee PRO Feature Set, EM250	2 miles / 3.2 km	+18 dBm	-102 dBm		$28.00	250 Kbps	32 KB Flash / 2 KB RAM	S2B
		US, CA, EU, AU, BR, JP	2.4 GHz	International/"J" variant	5000 ft / 1.5 km	+10 dBm	-102 dBm		$28.00	250 Kbps	32 KB Flash / 2 KB RAM	S2B
ZigBee® Smart Energy Public Profile	XBee® SE	US, CA, EU, AU, BR, JP	2.4 GHz	Low-cost, low-power, ZigBee PRO Feature Set	400 ft / 120 m	+3 dBm	-96 dBm	Through-hole	$17.00	250 Kbps	N/A	S2
	XBee-PRO® SE	US, CA, AU, BR	2.4 GHz	Extended-range ZigBee PRO Feature Set	2 miles / 3.2 km	+18 dBm	-102 dBm		$28.00	250 Kbps	N/A	S2B
		US, CA, EU, AU, BR, JP	2.4 GHz	International/"J" variant	5000 ft / 1.5 km	+10 dBm	-102 dBm		$28.00	250 Kbps	N/A	S2B
DigiMesh® Proprietary	XBee-PRO® 900HP	US, CA, AU, BR	900 MHz	Extended-range peer-to-peer mesh, sleeping routers	9 miles / 14.5 km	+24 dBm	-101 to -110 dBm	Through-hole	$39.00	10 Kbps or 200 Kbps	32 KB Flash / 2 KB RAM	S3B
	XBee® 865/868LP	India, EU	865 MHz or 868 MHz	Low-power RF module for India (865 MHz) or Europe (868 MHz) with DigiMesh	2.5 miles / 4 km	+12 dBm	-101 to -106 dBm	SMT	$23.00	10 Kbps or 80 Kbps	32 KB Flash / 2 KB RAM	S8
	XBee® DigiMesh® 2.4	US, CA, EU, AU, BR, JP	2.4 GHz	Low-cost, low-power peer-to-peer mesh, sleeping routers	300 ft / 90 m	0 dBm	-92 dBm	Through-hole	$19.00	250 Kbps	N/A	S1
	XBee-PRO® DigiMesh® 2.4	US, CA, AU, BR	2.4 GHz	Extended-range peer-to-peer mesh, sleeping routers	1 mile / 1.6 km	+18 dBm	-100 dBm		$32.00	250 Kbps	N/A	S1
		US, CA, EU, AU, BR, JP	2.4 GHz	International/"J" variant	3200 ft / 1 km	+10 dBm	-100 dBm		$32.00	250 Kbps	N/A	S1

figure 30 Xbee products

6. NS2 simulation code for the sensor data movements.

To run this simulation in linux you first install ns2 software in terminal and then copy the code in the terminal or type it. At the end of the code the command $ns run will execute the simulation.

```
#Create a simulator object
set ns [new Simulator]

#Define different colors for data flows (for NAM)
```

```
$ns color 1 Blue
$ns color 2 Red

#Open the NAM trace file
set nf [open out.nam w]
$ns namtrace-all $nf

#Define a 'finish' procedure
proc finish {} {
        global ns nf
        $ns flush-trace
        #Close the NAM trace file
        close $nf
        #Execute NAM on the trace file
        exec nam out.nam &
        exit 0
}

#Create four nodes
set n0 [$ns node]
set n1 [$ns node]
set n2 [$ns node]
set n3 [$ns node]

#Create links between the nodes
$ns duplex-link $n0 $n2 2Mb 10ms DropTail
$ns duplex-link $n1 $n2 2Mb 10ms DropTail
$ns duplex-link $n2 $n3 1.7Mb 20ms DropTail

#Set Queue Size of link (n2-n3) to 10
$ns queue-limit $n2 $n3 10

#Give node position (for NAM)
$ns duplex-link-op $n0 $n2 orient right-down
$ns duplex-link-op $n1 $n2 orient right-up
$ns duplex-link-op $n2 $n3 orient right

#Monitor the queue for link (n2-n3). (for NAM)
$ns duplex-link-op $n2 $n3 queuePos 0.5
```

```
#Setup a TCP connection
set tcp [new Agent/TCP]
$tcp set class_ 2
$ns attach-agent $n0 $tcp
set sink [new Agent/TCPSink]
$ns attach-agent $n3 $sink
$ns connect $tcp $sink
$tcp set fid_ 1

#Setup a FTP over TCP connection
set ftp [new Application/FTP]
$ftp attach-agent $tcp
$ftp set type_ FTP


#Setup a UDP connection
set udp [new Agent/UDP]
$ns attach-agent $n1 $udp
set null [new Agent/Null]
$ns attach-agent $n3 $null
$ns connect $udp $null
$udp set fid_ 2

#Setup a CBR over UDP connection
set cbr [new Application/Traffic/CBR]
$cbr attach-agent $udp
$cbr set type_ CBR
$cbr set packet_size_ 1000
$cbr set rate_ 1mb
$cbr set random_ false


#Schedule events for the CBR and FTP agents
$ns at 0.1 "$cbr start"
$ns at 1.0 "$ftp start"
$ns at 4.0 "$ftp stop"
$ns at 4.5 "$cbr stop"
```

```
#Detach tcp and sink agents (not really necessary)
$ns at 4.5 "$ns detach-agent $n0 $tcp ; $ns detach-agent
$n3 $sink"

#Call the finish procedure after 5 seconds of simulation
time
$ns at 5.0 "finish"

#Print CBR packet size and interval
puts "CBR packet size = [$cbr set packet_size_]"
puts "CBR interval = [$cbr set interval_]"

#Run the simulation
$ns run
```

7. Python script to insert sensor data into the database

```
import mysql.connector
from mysql.connector import Error
from mysql.connector import errorcode
    try:
       connection=
mysql.connector.connect(host='localhost',
database='point_machine_A',user='****',password='*')
records_to_insert=,
sql_insert_query = """ INSERT INTO python_users
(voltage, current, temperature, vibration)
                           VALUES (%s,%s,%s,%s) """
       cursor = connection.cursor(prepared=True)
       #used executemany to insert 3 rows
       result  = cursor.executemany(sql_insert_query,
records_to_insert)
       connection.commit()
       print (cursor.rowcount, "Record inserted
successfully into python_users table")
    except mysql.connector.Error as error :
        print("Failed inserting record into
python_users table {}".format(error))
    finally:
        #closing database connection.
```

```
        if(connection.is_connected()):
            cursor.close()
            connection.close()
            print("connection is closed")
```

8. PHP script to read and plot data from the database to display on the website in real time.

```
<?php
require_once
('/var/www/test/jpgraph/src/jpgraph.php');
require_once
('/var/www/test/jpgraph/src/jpgraph_line.php');
$servername = "localhost";
$username = "****";
$password = "*****";
$dbname = "point_machine_A";
// Create connection
$conn = new mysqli($servername, $username, $password,
$dbname);
// Check connection
if ($conn->connect_error) {
    die("Connection        failed:        "        .
$conn->connect_error);
}
$sql = "SELECT * FROM SensorValues ORDER BY time DESC
LIMIT 10";
$result=mysqli_query($conn,$sql);
$number_rows=mysqli_num_rows($result);
//echo $number_rows;
$n=0;
if ($result->num_rows > 0) {
    // output data of each row
    while($row = $result->fetch_assoc()) {
        //echo "V: " . $row["value"];
$myarray[$n]=$row["temperature"];
$n++;
    }
} else {
    //echo "0 results";
}
foreach ($myarray as $data){
```

```
        //echo $data;
    }
    $conn->close();


    $ydata = $myarray;
    // Create the graph. These two calls are always
    required
    $graph = new Graph(450,350);
    $graph->SetScale('textlin');
    $graph->title->Set('Motor temperature -10 hours');
    //$graph->title->SetFont(FF_ARIAL,FS_BOLD,12);
    $graph->xaxis->title->Set("Time (Hours)");
    $graph->yaxis->title->Set("Temperature (Degrees)");
    // Create the linear plot
    $lineplot=new LinePlot($ydata);
    $lineplot->SetColor('blue');
    // Add the plot to the graph
    $graph->Add($lineplot);
    // Display the graph
    $graph->Stroke();
    ?>
```

9. JQuery

   jQuery is a fast, small, cross-platform and feature-rich JavaScript library. It is designed to simplify the client-side scripting of HTML. It makes things like HTML document traversal and manipulation, animation, event handling, and AJAX very simple with an easy-to-use API that works on a lot of different type of browsers. The main purpose of jQuery is to provide an easy way to use JavaScript on your website to make it more interactive and attractive. It is also used to add animation.

10. Python code to sense and plot Switching vibration Noises

```
#!/usr/bin/env python3
"""Plot the live microphone signal(s) with matplotlib.
Matplotlib and NumPy have to be installed.

"""
import argparse
import queue
```

```
import sys
def int_or_str(text):
    """Helper function for argument parsing."""
    try:
        return int(text)
    except ValueError:
        return text
parser = argparse.ArgumentParser(description=__doc__)
parser.add_argument(
    '-l', '--list-devices', action='store_true',
    help='show list of audio devices and exit')
parser.add_argument(
    '-d', '--device', type=int_or_str,
    help='input device (numeric ID or substring)')
parser.add_argument(
    '-w', '--window', type=float, default=200,
metavar='DURATION',
    help='visible time slot (default: %(default)s ms)')
parser.add_argument(
    '-i', '--interval', type=float, default=30,
    help='minimum time between plot updates
(default: %(default)s ms)')
parser.add_argument(
    '-b', '--blocksize', type=int, help='block size (in
samples)')
parser.add_argument(
    '-r', '--samplerate', type=float, help='sampling rate of
audio device')
parser.add_argument(
    '-n', '--downsample', type=int, default=10, metavar='N',
    help='display every Nth sample (default: %(default)s)')
parser.add_argument(
    'channels', type=int, default=[1], nargs='*',
metavar='CHANNEL',
    help='input channels to plot (default: the first)')
args = parser.parse_args()
if any(c < 1 for c in args.channels):
    parser.error('argument CHANNEL: must be >= 1')
```

```
mapping = [c - 1 for c in args.channels]  # Channel numbers
start with 1
q = queue.Queue()
def audio_callback(indata, frames, time, status):
    """This is called (from a separate thread) for each audio
block."""
    if status:
        print(status, file=sys.stderr)
    # Fancy indexing with mapping creates a (necessary!) copy:
    q.put(indata[::args.downsample, mapping])
def update_plot(frame):
    """This is called by matplotlib for each plot update.
    Typically, audio callbacks happen more frequently than
plot updates,
    therefore the queue tends to contain multiple blocks of
audio data.
    """
    global plotdata
    while True:
        try:
            data = q.get_nowait()
        except queue.Empty:
            break
        shift = len(data)
        plotdata = np.roll(plotdata, -shift, axis=0)
        plotdata[-shift:, :] = data
    for column, line in enumerate(lines):
        line.set_ydata(plotdata[:, column])
    return lines
try:
    from matplotlib.animation import FuncAnimation
    import matplotlib.pyplot as plt
    import numpy as np
    import sounddevice as sd
    if args.list_devices:
        print(sd.query_devices())
        parser.exit(0)
    if args.samplerate is None:
        device_info = sd.query_devices(args.device, 'input')
```

```
        args.samplerate = device_info['default_samplerate']
    length = int(args.window * args.samplerate / (1000 * args.downsample))
    plotdata = np.zeros((length, len(args.channels)))
    fig, ax = plt.subplots()
    lines = ax.plot(plotdata)
    if len(args.channels) > 1:
        ax.legend(['channel {}'.format(c) for c in args.channels],
                  loc='lower left', ncol=len(args.channels))
    ax.axis((0, len(plotdata), -1, 1))
    ax.set_yticks([0])
    ax.yaxis.grid(True)
    ax.tick_params(bottom=False, top=False, labelbottom=False,
                   right=False, left=False, labelleft=False)
    fig.tight_layout(pad=0)
    stream = sd.InputStream(
        device=args.device, channels=max(args.channels),
        samplerate=args.samplerate, callback=audio_callback)
    ani = FuncAnimation(fig, update_plot, interval=args.interval, blit=True)
    with stream:
        plt.show()
except Exception as e:
    parser.exit(type(e).__name__ + ': ' + str(e))
```