UNIVERSITY OF NAIROB1

SCHOOL OF COMPUTING AND INFORMATICS

A COMPARATIVE STUDY OF INFRASOUND BASED AND IMAGE BASED WIRELESS SENSOR NETWORKS FOR HUMAN ELEPHANT CONFLICT MITIGATION.

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A Research Report Submitted to the School of Computing and Informatics in Partial Fulfillment of the Requirements of the Degree of Master of Science in Distributed Computing Technology of the University of Nairobi.

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DECLARATION

This is to certify that this research proposal submitted by me to the University of Nairobi, School of Computing and Informatics in partial fulfillment of the requirement for the award of the degree of Master of Science in Distributed Computing Technology is my original work and acknowledgement has been made in the text to all other material used.

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This is to certify that this research proposal submitted by John Mukanu Wainaina in partial fulfillment of the requirement for the award of the degree of Master of Science in Distributed Computing Technology of the University of Nairobi is a record of the candidates own work carried out by him under my supervision. The matter embodied in this research is original and has not been submitted for the award of any other degree.

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ABSTRACT

Wireless sensor networks have been widely used in scientific studies to investigate phenomenon and acquire data from otherwise hostile environments that span over large geographical areas. Elephants have been discovered to produce infrasound: - sound that humans cannot hear, that they use to communicate within the herd. Due to changes in the world today, animals have been observed to move out of their natural habitats and into human settlements in search for food while humans have also encroached into the animals' natural habitat. Due to this, cases of Human Elephant conflict are on the rise and need to be addressed. Although many technologies have been implemented to address this issue they have been reported to be inefficient for early alerting. Two technologies; image based and infrasound based have been proposed as candidates an application of Wireless Sensor Networks.

This research compared the effectiveness and efficiency of an Infrasound Wireless Sensor Network (WSN) and an Image processing based WSN for Human Elephant Conflict (HEC) mitigation by using a Multi Agent Simulation. This exploration was done by developing models for each of the technologies; Infrasound based WSN and Image processing based WSN and comparing their outputs after simulating them on a computer under the same variables.

Results were collected from the Simulations as graphs which were then exported to spreadsheets for differentiating comparative analysis. Based on the results we concluded that Infrasound based WSN for HEC is a superior technology to an Image processing based WSN for HEC. We recommend an efficiency Matrix based on the area to be covered and the detection efficiency of the sensor before any WSN is deployed while deciding on which option to implement. The research borrows from and extends existing applications of wireless sensor networks and their designs, detection and alert systems and sound engineering.

Key Words: **Infrasound, Wireless Sensor Network, Human Elephant Conflict.**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABM - Agent Based Modeling

ANSI - American National Standards Institute

CSV - Coma Separated Variables

GPS - Global Positioning System

HEC – Human Elephant Conflict

Hz - Hertz (Cycles per Second)

KHz - Kilo Hertz

IoT – Internet of Things.

RF - Radio Frequency

WSN - Wireless Sensor Networks

CHAPTER ONE

1.1 INTRODUCTION

1.1.1 Background

In October 2018, four people were attacked by elephants leading to serious injuries and hospitalization (Jacinta, 2018). Barely eight months after, another attack was reported in the same area with reports indicating that schools have had to be closed earlier than usual for fear of attacks and locals have experienced loss of livelihoods (Jacinta, 2018). In February 2015, an incident was reported where a herd of eleven elephants escaped a park near Makueni County in Kenya and trampled a woman to death (Mary, 2015). The incident led to the closure of the Nairobi-Mombasa highway as residents protested urging the Kenya Wildlife Service (KWS) to fence the park to avoid attacks in future. In the article the KWS later promised to fence off the park and set up a crisis center in the area to handle conflicts and issues of compensation. These are just some of the many similar scenarios rife in communities bordering wildlife habitats in Kenya today.

A study conducted in Laikipia County established that crop raids orchestrated by elephants happened exclusively at night (Maximilian et al, 2010). The study also found that most of the attacks happened in areas within two kilometers where elephants had been found to hide during the day in thick bushes. Elephant attacks on people have also been recorded to occur from early evening and early morning. Residents discover the elephants when they have already entered into their farms and caused damage to the crops. It is estimated that an elephant eats about 450 kilograms' a day. Due to this high food requirement and the ever reducing resources in their natural habitats elephants are finding it irresistible to raid farms in search of food and water.

Human deaths and injuries caused by elephants are on the rise as more and more elephants enter human settlements. In an effort to protect their farms humans try to chase away the elephants by either waving large branches, making loud noises by beating drums, lighting fires and even by shouting. Elephants in turn respond by either running away from the farms or fighting back. When they fight back, elephants have been reported to kill humans and in the lucky cases only injure them. Such attacks lead to trauma for the victims and even affects the society in large. There have been reported cases of curfews imposed by these mighty animals and schools being closed due to fear of attacks (Irene, 2015).

In Kenya today, several solutions have been put in place in an effort to resolve the human-elephant conflict. These include; Chilli rope fences, Chilli smoke briquettes, Noise makers, Watch towers and torches, Electric fences, and bee fences. Elephants react by keeping away from chilli and bees and this has been observed to keep away the elephants. Watch towers erected along the boundaries require volunteers to keep watch at night using torches to scare away the elephants. The electric fence has been the most successful method of keeping the elephants away. It uses electric current to give a shock to the elephant when it comes into contact with the fence. The electric fence is however expensive to set up and maintain. Some parts are not fully fenced, some parts have been vandalized and the electricity required for the fence is not always available. Due to the vast areas required to be covered the solutions above have not been fully effective.

In all the above methods the focus has been on preventing the elephants from entering into human settlements. Very little effort if any has been made at detecting and alerting relevant authorities about the elephants before they enter into human settlements. In light of this we found it necessary address the problem of early detection of elephants near human settlements.

Some countries in Asia such as India are also facing the same issue and researchers have come up with Computing Systems based solutions to mitigate Human Elephant Conflict (HEC). (Wijesinghe et al, 2011) developed the eleAlert that would detect electric fence intrusions, locate the intrusions and generate alerts to relevant officials. However, physical access to the system after an intrusion was a challenge necessitating other solutions. (Ruwini et al, 2013) developed the WI-Alert: A wireless sensor network based intrusion alert prototype for HEC. WI-Alert used detection of line of site to detect elephants. The project used Radio frequency fingerprinting as a method of detecting anomalies that would quantify the presence or absence of elephants in an area. In 2014, Sugumar and Jayaparvathy proposed an improved real time image detection system for elephant intrusion along the forest border areas. The system would compare previously taken images of elephants and compare with images captured in real time and on matching generate alerts. However, the inefficiency of the system led to yet another development. Using a wireless sensor network Ramkumar et al, 2014 developed an automated system for remote elephant tracking to reduce HEC. The system was based on seismic wave detection which on analysis would indicate the presence or absence of elephants in an area. However, due to weather conditions such as rain the system could miss the events that cause detection.

Most of the solutions that have been developed though relevant have lacked in one aspect: early detection. It is in this regard that we compare the effectiveness and efficiency of an Image based wireless sensor network and an Infrasound based Wireless sensor network for early elephant detection.

1.1.2 Problem Statement

Every application of WSN's has its own requirements and faces its own challenges due to the varying environments in which these WSN's are implemented. Previous implementations of WSN's for HEC mitigation have been done using Image processing and seismic wave detection and analysis. These solutions have been proved to work in ideal conditions. However, under not so ideal conditions the solutions have been found to be inefficient and ineffective for HEC mitigation. By inference, it is evident that in most cases these failures have been brought about by the lack of adequate information/ knowledge under which the WSN for HEC function efficiently and effectively before the solution is deployed. In light of this we found it necessary to investigate the conditions/ circumstances under which an infrasound WSN for HEC mitigation would function efficiently and effectively as compared to the earlier solutions of Image processing and Seismic wave detection and analysis.

Simply put, this research compared two WSN implementations for early elephant detection as mitigation to HEC to try and identify the most effective approach for such implementations.

1.1.3 Purpose

The goal of this study was to compare an Image based WSN and an Infrasound WSN to help identify the strengths and weaknesses of each for elephant detection as an application for Human Elephant Conflict Mitigation. Through the study we were able to develop an Infrasound based WSN and an Image based WSN models and simulate them while exposing them to different parameters that they would be exposed to in an actual implementation. Data from the simulations was used in analysis to determine the most efficient and effective alternative for elephant detection.

1.1.4 Objectives

The objective of this research project was to compare the two technologies and identify the most effective and efficient one for elephant detection in HEC mitigation under different conditions.

The research therefore sought:

1. To compare the detection capabilities of an Infrasound based WSN against an Image processing based WSN for elephant detection as an application for Human Elephant Conflict mitigation.
2. To compare the Energy consumption of an Infrasound based WSN against an Image processing based WSN for elephant detection as an application for Human Elephant Conflict mitigation.
3. To identify and propose the conditions under which either an Infrasound WSN or Image based WSN should be used.

1.1.5 Research Questions

The research questions below augmented the research problem and objective by sourcing knowledge from scientific literature and the study. The scientific literature looked into the application of wireless sensor networks. It also looked into other elephant detection strategies that have been put across and how effective they have been.

Research Question 1: What are the factors that affect the detection of elephants using elephant infrasound and images in wireless sensor networks?

Research Question 2: Between an image based WSN and an infrasound based WSN, which is a superior technology for early elephant detection for HEC?

1.1.6 Scope of Study

In this research early detection of elephants was identified as a major concern. As such two attributes were identified as key; accurateness and timeliness. Accurateness would focus on the information gotten from the system in terms of the location proximity of the detected elephants to the nearest human settlement and timeliness would focus on the speed of receivingalerts given by the system in order to allow appropriate responses to these alerts. Distance between the elephants' location and the nearest human settlement would therefore form an integral part of this research. The amount of time from the initial detection to the time an alert is displayed was also of importance in this research.

The simulation tool NetLogo was identified as an appropriate tool for the development and simulation of the envisioned model. This research focused on the application of WSN's as opposed to the internal working mechanisms of the networks which made NetLogo the preferred tool as opposed to tools mainly used for the inner functionality of the WSN's. It was also freely available as an open source tool for research and thus reduced the resources required for this research. NetLogo has also been used widely in scientific research and is thus a trusted tool in the research world (NetLogo , 2016).

1.1.7 Significance of Study

The study added onto scientific knowledge in the field of applications of Wireless Sensor Networks applications in the Internet of Things (IoT). The findings from this research will assist scientists who are involved in the design of solutions for Human Elephant Conflict mitigation in determining the best WSN to use in different circumstances.

The use of simulation also advances and confirms that Multi-agent systems can be used to study natural systems. The research is also useful for researchers who would like to use Multi-agent systems to model and simulate other phenomenon similar to this. The research demonstrated that Multi-agent systems can be used to model complex system where every component is an agent in its own respect.

1.1.8 Assumptions and Limitations

The focus of this research was on the application of Infrasound WSN's. It assumed that coupling infrasound sensors with wireless motes will produce an infrasound wireless sensor network. In light of this, this research also assumed that the protocols and algorithms developed for the WSN are fully functional.

1.1.9 Project Deliverables

The deliverables for this research were;

- Identification of the factors that affect the detection of elephants using an infrasound WSN and an image based WSN.
- Data collected from the simulations performed for the elephant detection model systems.
- An analysis and conclusions made from the data collected and analyzed.
- A detailed research project report.

- A publishable academic paper.

1.1.10 Chapter Summary

This document is organized as follows. Chapter two explores the literature review, focusing on the application of Wireless Sensor Networks using infrasound for the mitigation of Human Elephant Conflict mitigation. It also looks into the factors that affect the application of Wireless Sensor Networks and alerting systems for HEC. Finally, we look into the envisioned elephant detection and alerting system based on an Infrasound wireless sensor network. Later on in Chapter three, we discuss the methodology that was used in this research. This will focus on the tools and technique that were used, measurement metrics, data collection and data analysis to be performed during the research.

CHAPTER TWO

2.1 LITERATURE REVIEW

In this chapter we review past as well as ongoing research in the application of wireless sensor networks for HEC mitigation and research into elephant infrasound. We also look into elephant movement restriction, detection and alerting models that have been identified and discussed in previous research. Finally, we discuss the proposed elephant detection-and-alert model using an infrasound wireless sensor network by combining concepts from applications of WSN's and elephant infrasound for HEC mitigation.

The chapter has been divided into; Human Elephant Conflict and mitigation solutions, Wireless sensor networks, Infrasound, and the proposed elephant detection-and-alert model using an infrasound wireless sensor network.

2.1.1 Human Elephant Conflict

Human Elephant Conflict (HEC) has been a major problem leading to the death of elephants, damage to property, injury and even loss of life for communities living near elephant habitat. In light of this several solutions have been put forward and have been used to prevent the entry of elephants into human settlements. Studies have also identified an early detection system especially at night time and generation of alerts as the best solution to mitigating HEC (Fernando et al, 2008 and Rangarajan et al 2010). Below we discuss some of the key methods that have been used.

2.1.1.1 Non- Computing Systems Based Solutions

2.1.1.1.1 Electric Fences

This is a barrier that uses electricity to deter animals from crossing a boundary. Electric fences are used for human as well as animal control. They have been used to enhance the security of sensitive areas such as military installations and prisons. By design electric fences are not meant to cause fatalities but there are other places where lethal voltages are used.

The fence is designed as an open circuit such that when an animal touches one of the electrified wires and the ground at the same time then the circuit is completed. This means that the electric current will flow through the animals' body. The flow of current through the body causes muscle contraction in the animal that is similar to a human muscle cramp. The electric fence though having a high voltage is designed to have a very low current (amplification). The flow of current in the fence is also controlled by releases it in pulses of high voltage and very low current that is only meant to cause discomfort and not death. The current is delivered in pulsating effect to reduce the chances of a grabbing effect and to give the animal an opportunity to release the wires.

In an animal control scenario, the electric fence has to be constructed along a defined border and runs for a great distance. In Kenya the electric fence has been adopted to control the movement of wildlife. This has been done in areas such as Aberdare National Park, Amboseli National Park, Tsavo East and West as well as Mt.Kenya National park and other wildlife habitats. Prior to this some areas such as the Ol Pajeta Conservancy had a perimeter fence to control livestock movement and frequently crop raiding elephants would break the fence (Graham et al, 2009). The fence needed an upgrade and modification to control the movement of wildlife, particularly elephants.

Several papers have discussed the effectiveness of electric fences as mitigation against HEC. Results from one such paper by Graham et al, 2009 indicates that though cases of crop raiding, fence breaking and movement outside the boundary reduced significantly. Data indicates that cases of crop raiding reduced by 43% in the year immediately after installation of the fence as compared to the year immediately before the fence installation. Although the project can be said to be a success, it was also found to have negative impacts. Elephants are known to follow traditional migratory routes that after the introduction of the fence were in accessible (Graham et al, 2009). This has greatly affected the natural life of the wildlife as their movement is now restricted. To counter this some openings were introduced in the fence to allow for movement outside the conservancy. In areas where these openings are HEC still continues to be a challenge that needs to be addressed. Graham et al, 2009 concluded that even a well-designed and properly maintained electric fence will not necessarily be a 100% effective barrier to elephants as they can and will find ways to get through even the most sophisticated fence designs (Thouless and Sawka 1995).

Some of the drawbacks in the use of electric fences are; high construction and maintenance costs, electric power requirements that are not often met, fence breakage by elephants and other wildlife and vandalism by humans.

2.1.1.1.2 Trenches

In HEC mitigation using trenches, trenches are dug along the boundary between the elephant and human habitat. The trenches have to meet a minimum specification of two meters wide by two meters deep (2m X 2m). Elephants are not able to jump and thus are confined in their habitats. Trenches have been used in Uganda (IEF, 2007) where a 20 kilometers trench was dug by the Uganda Conservation foundation. Even before the project was completed locals had reported positive results stating that elephant crop raiding had been reduced significantly in areas where the trench had already been completed.

However, as with electric fences the trenches are not a 100% solution and issues in their construction have already been identified. One of the key issues is the closure of elephant migration routes. When trenches are dug in the migration routes of the elephants then their movement is restricted causing an imbalance to the ecosystem. This solution is seen to be invasive.

2.1.1.1.3 Beehive Fences

In 2002, Vollrath and Douglas-Hamilton discovered that African elephants will avoid feeding on acacia trees that host beehives, either empty or occupied by African honey bees. King et al 2009 decided to extend the previous work of Vollrath and Douglas and did a pilot study which was successful. In showed a significant difference in crop raiding on two similar farms. One farm was fenced with a 90 meters' bee hive fence while the other was not fenced. The fenced farm experienced fewer raids as compared to the unfenced farm.

Bee hive fences are constructed along the boundary area and hives installed 8 meters apart from each other. The hives are then connected using a wire that acts as a trigger to disturb the hive whenever the wire is touched. Bees are then introduced in the hives. When the elephants want to cross the border, they touch the wire and trigger the movement of the hives, in turn this alarms the bees in the hives and they react defensively (King, 2014).

The use of beehives faces one major drawback. The fences are erected very near to human settlements. The bees in the hive if provoked can turn on people causing injury and even death at times. In other scenarios the bees may desert the hives leaving the fence unguarded. This is a challenge that is beyond human control.

2.1.1.1.4 Chilli Fences

Chilli fences comprise of both chilli rope fences and chilli smoke briquettes. Chilli rope fences are made using timber for posts, strands of sisal string and some white cloth. The white cloth is stretched and tied between the 2 strands then a mixture of ground dried hot chillies and engine grease applied to the strings and cloth. Chilli smoke briquettes are a mixture of elephant and cow dung mixed with hot chillies and a little water. The mixture is then shaped into moulds and left to dry in the sun. The briquettes are then placed in fires lit along the perimeter to create a noxious smoke that preferably blew into the direction the elephants were likely to raid from (Graham et al, 2009).

Due to weather conditions such as rainfall the chilli on the ropes can be washed away while fire in the briquettes can go off thereby rendering the system unavailable. The briquettes also introduce the risk of wild fires that could destroy the environment severely.

2.1.1.2 Computing Systems Based Solutions

2.1.1.2.1 GPS Tracking

A GPS Tracking unit is a device affixed to a target object either living such as an animal and human beings or non-living such as a vehicle or shipment container, that uses the Global Positioning System (GPS) to determine and track it and hence the target object precise location. The recorded location data can be stored within the unit and later transmitted to a computer system using a cellular, radio or satellite modem embedded in the unit. The data will show the objects movement against a map in real time or historically.

In elephant tracking the GPS tracking unit is installed on a matriarch in a heard or on a bull elephant in case of the bull herds (Venkataraman et al, 2005). Elephants live in social groupings although cases of lone bull elephants exist. The females live together with their young calves while the bulls live in their bull herds only coming together during the mating season. The matriarch is the female head of the family and wherever she goes the other elephants go. This factor makes it appropriate for the GPS Tracking unit to be installed on her. The tracking unit is also installed on one of the older males in the bull herds. With the installation of the GPS Tracking unit on each leader of a group it is easy to conclude that we can keep track of the whole herd. However, this is not the case as cases have been reported where some of the members of the herd break away, a lone elephant breaks away or in other cases the leader becomes incapacitated by death and the group moves on.

Using real time GPS Tracking we can be able to tell of the actual location of the herd by their movement. This helps in the fight against HEC by providing actual locations that can be displayed on mobile phones and other devices making the tracking easy.

GPS Tracking also has some drawbacks which make an unsuitable solution due to issues such as; (1) In a herd of about six to twelve or twenty elephants only one elephant is tagged. This implies that the location of the remaining elephants is dependent on the location of the tagged elephant and therefore one cannot be certain of the location of the non-tagged members of the herd. (2) Once a herd breaks a new tracking unit has to be installed on the new leader. The process of installing a tracking unit is dangerous both for the animal and humans and is invasive to the animal. (3) Sometimes the tracking units fail and do not transmit their location data making it impossible to track the elephants. This requires tracking the tagged animal and replacing the faulty equipment.

2.1.1.2.2 eleAlert (Wijesinghe et al, 2011)

Elephant Alert (eleAlert) was a solution developed that would detect electric fence intrusions, locate the intrusions and generate alerts to relevant officials. Sensors were installed at specific positions along the fences. When a breakage along the line would occur an alert would be sent to forest officials informing them of the location of an intrusion. However, physical access to the system after an intrusion was a challenge necessitating other solutions.

2.1.1.2.3 WI-Alert (Ruwini et al, 2013)

This is a wireless sensor network based intrusion alert prototype for HEC. WI-Alert used detection of obstruction to line of site to detect elephants. The project used Radio frequency fingerprinting as a method of detecting anomalies that would quantify the presence or absence of elephants in an area. The system faced the challenge that it was set out to use to detect elephants: obstruction of line of site. It required that the sensors be always in line of site which proved a challenge in the forest areas. It also required very many sensors to be set up. This proved costly for adoption as a solution to HEC.

2.1.1.2.4 Image Detection

(Vermeulen et al, 2013) proposed unmanned aircraft system to survey elephants, in which the elephant images were acquired at a height of 100 meters. The solution was too expensive while the flight time was too short making it infeasible. Another solution was to identify elephants based on recognition algorithms.

The system was fed with facial images of an elephant and gave the result as already identified or as new (Daberera and Rodrigo, 2010). These solutions and others such as those proposed by Goswami et al, 2012 and Ardovini et al, 2008 show reliable techniques for identification of elephants. In 2014, Sugumar and Jayaparvathy proposed an improved real time image detection system for elephant intrusion along the forest border areas. The system would compare previously taken images of elephants and compare with images captured in real time and on matching generate alerts. The system could only take photographs at a distance of 20 meters. However, the system required a lot of computing resources which led to inefficiency. The distance of capturing images was also a limiting factor to the early detection capabilities of the solution. However, in real time the capture of an elephant's front image is difficult rendering the solutions unreliable.

2.1.1.2.5 Seismic wave analysis

Using a wireless sensor network Ramkumar et al, 2014 developed the automated system for remote elephant tracking to reduce HEC. The system was based on seismic wave detection which on analysis would indicate the presence or absence of elephants in an area. The system would analyze the seismic waves perceived by the sensors and compare them with already stored waves to look for patterns. However, due to weather conditions such as rain the system could miss the events that cause detection.

2.1.2 Wireless Sensor Networks (WSN)

Several definitions that try to define Wireless Sensor Networks have been put forward. Some of them are;

A Wireless Sensor Network is a collection of nodes organized into a cooperative network (Hill et al, 2000). Each node consists of processing capability, may contain multiple types of memory, have a Radio frequency (RF) transceiver, have a power source and accommodates various sensors and actuators. Nodes communicate wirelessly and often are self-organized after being deployed (Stankovic, 2006).

(National Instruments, 2012) define a WSN as a wireless network consisting of spatially distributed autonomous devices using sensors to monitor physical or environmental conditions. The WSN system incorporates a gateway that provides wireless connectivity back to the wired world and distributed nodes.

A wireless sensor network is a small, portable, battery powered device that works under harsh environments. It consists of sensors, motes, gateway and a database server (Khanja et al, 2008).

From the definitions above we can come up with a more consolidated definition and say that a Wireless Sensor network is a system of two or more wirelessly interconnected and distributed devices known as sensor nodes that are used to automatically perceive signals and their locality in an area and transmit the perceived signals to a computer system through central gateway. The signals perceived include; sound (infrasound, audible sound and ultrasound), temperature, humidity, pressure, chemical concentrations, and radioactivity. Due to their autonomous nature they are ideal for use in harsh environments and in very large geographical areas. Below is a diagrammatical representation of a simple WSN showing the sensor nodes, gateway node and communication media used between the devices.

Figure 1. A Simple Wireless Sensor Network showing three sensor nodes, and a gateway connected to a laptop using a wired connection. The sensor nodes and gateway communicate wirelessly.

Wireless sensor networks have been used in Area Monitoring, Security monitoring, Healthcare monitoring, Environmental/ Earth monitoring as well as in Wildlife monitoring. Below we highlight some of these applications

2.1.2.1 Some areas of Application of WSN's

Applications of WSN's can be classified into the following non-exhaustive categories. As you will note, some of the applications overlap into some other categories. This is a high level classification meant to only elicit some of the fields where WSN's are being used.

2.1.2.1.1 Area monitoring and detection.

In area monitoring the WSN is deployed over a region where some phenomena is to be monitored. In a military case a WSN is used to detect enemy intrusion while geo-fencing of gas and oil pipelines is another example. In healthcare WSN's can be wearable and implanted. Wearable devices are used on the body surface or at close proximity to the user. Implants on the other hand are inserted inside the body. They are used to monitor elements such as blood pressure, breathing patterns, perspiration and body heat. All these are within the personal area of the wearer of the devices.

2.1.2.1.2 Environmental monitoring and detection.

In monitoring environmental parameters, many applications have been deployed. In most of these applications the challenge is mostly harsh weather and reduced power supply. WSN have been deployed in cities to address air pollution by monitoring the concentration of dangerous gases in the environment. WSNs have also been deployed in forests for early detection of forest fires. The nodes measure temperature, humidity and the gases produced by the fire in the trees and vegetation. Water quality monitoring has been done in dams, rivers, lakes and oceans as well as in underground water reserves using WSNs.

2.1.2.1.3 Natural Phenomena monitoring and detection.

Landslide detection is another area where WSN have been used as illustrated by Ramesh et al, 2009 in their paper. The WSN systems detects movements of soil and changes in various parameters that may occur before or during a landslide. Flood detection is another area where WSN have been used. The sensors detect the level of water in the water bodies on a real time basis. Natural occurrences such as volcanoes, earthquakes, Tornadoes and other weather elements have been and are still being monitored using WSNs.

2.1.2.1.4 Agricultural monitoring and detection.

In agriculture, WSNs have been deployed on farms to monitor parameters such as humidity, moisture, air pressure and temperature in the soil and above the soil. This has been done in green houses as well as in vast open fields. Data gathered by the WSN is even used to automate the irrigation systems that have been deployed on the farms. In the flower industry WSN’s are even used in the cut flower warehouses to monitor and control temperatures within the storage warehouses. In ranches WSN’s have been used to monitor the movement of cattle across the ranches and for easy localization.

2.1.2.1.5 Industrial monitoring and detection

WSNs are also used in industrial monitoring in machine health monitoring, data logging waste and waste water monitoring. In the building and construction industry, WSNs are used to check the Structural health of the structures through data logging over long periods of time. In cement manufacturing factories monitoring of gases is being done in an effort to monitor the safety of workers in the factories and to maintain standards.

2.1.2.2 Sensor Nodes

As we established earlier a WSN is comprised of a gateway connected to a computer system, sensor nodes and a communication channel between the nodes and the gateway and at times among the nodes themselves. The sensor nodes are a key component of the WSN as they are the main enablers of the system. The components that make up a sensor node are the Transceiver, Power source, Controller, Memory and the Sensor interface.

The transceiver is the combined functionalities of the transmitter and receiver into a single device. The possible choices of transmission media are radio frequency (RF), optical communication (laser) and infrared. Optical communication requires less energy but needs line-of-site for communication and is sensitive to atmospheric conditions. Infrared requires no antenna but is limited in its broadcasting capacity.

Radio frequency based communication is the most relevant and fits most WSN applications. WSNs utilize license free frequencies; 173, 433, 868 and 915 MHz; and 2.4GHz(National Instruments, 2012). The transceivers lack unique identifiers and their operational statuses are; transmit, receive, idle and sleep.

The sensor node requires power for sensing, communicating, and data processing and hence a power source is a requirement for every sensor node. Rechargeable and Chargeable batteries are the main source of power supply for sensor nodes. Some sensors are able to renew their energy by solar sources, temperature difference or vibration. The need to have a reliable power source is brought about by the challenges in regularly locating the sensors and changing batteries. The sensors are most of the time in hard to reach areas and thus a challenge to change batteries. Often three years of battery life is a requirement, so many of the WSN systems today are based on ZigBee due to its low power consumption (National Instruments, 2012). A significant amount of power is consumed when switching from sleep mode to transmit mode in order to transmit a packet.

On-chip memory and flash memory are the preferred choice of memory for sensor nodes. This is majorly because of the energy constraints of the sensor node. Flash memory is used as it is cheap and its storage capacity is ideal for this type of computing as not much storage is required. There are two categories of memory based on the purpose of storage. They are; user memory used for the storage of application related and personal data, and program memory used for programming the sensor device. Where device identification data is present program memory is used to store it.

The sensor node controller processes data, and controls the functionality of other components in the sensor node. The most common control is the microcontroller. However, other controllers such as a desktop microprocessor and digital signal processors can also be used. Microcontrollers are often used in many embedded systems such as sensor nodes because of their low cost, ease of programming, flexibility to connect to other devices and low power consumption.

Sensors produce a measureable response due to a change in a physical condition. They measure physical data of the parameter to be monitored. The analog signal produced by the sensor is digitized by an analog-to-digital converter and sent to the controller for further processing. The sensor should be small in size, consume low energy, operate in high volumetric densities, be autonomous and operate unattended, and be adaptive to the environment. Sensors are classified into three classes: Passive, omnidirectional sensors, passive narrow beam sensors, and active sensors. Passive sensors sense the data without manipulating the environment by actively probing and are self-powered. Active sensors continuously probe the environment and require a continuous energy. Narrow-beam sensors have a well-defined notion of direction of measurement.

2.1.2.3 Wireless Sensor Network Topologies

There are basically three network topologies that nodes in a WSN can be organized into. They are; Star topology, Cluster tree network and mesh networks. In the star topology each node in the WSN is directly connected to the gateway. In the cluster tree network every node connects to a node higher in the tree and then to the gateway and data is routed from the lowest node on the tree to the gateway. Mesh networks have nodes that connect to multiple nodes in the system and pass data through the most reliable path available. This setting offers increased reliability as compared to the cluster tree network (National Instruments, 2012).

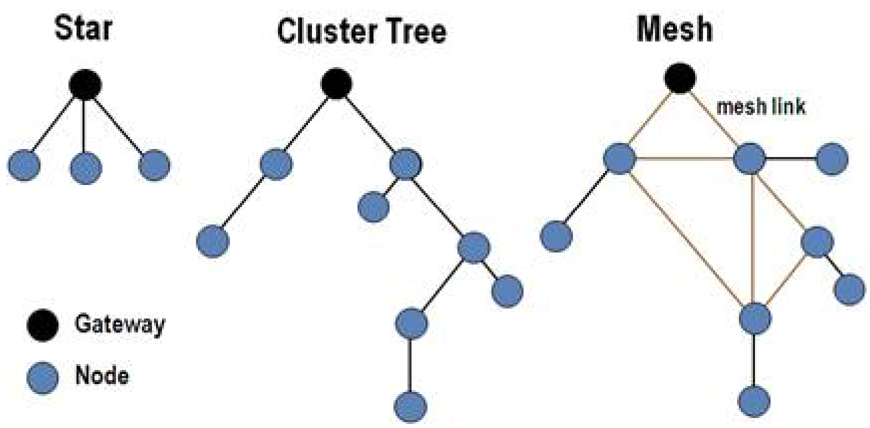

Figure 2. Common WSN Network Topologies

2.1.2.4 Infrasound

The oxford dictionary defines sound as vibrations that travel through the air or another medium and can be heard when they reach a persons or animals ear. Sound is a vibration that propagates as typically audible mechanical wave of pressure and displacement, through a medium such as air or water (Western Electric Company, 1969). In physiology and psychology, sound is the reception of such waves and their perception by the brain. Sound (a) is the oscillation of pressure, stress, particle displacement, particle velocity, propagated in a medium with internal forces such as elastic or viscous, or the superposition of such propagated oscillation. (b) Sound is the auditory sensation evoked by the oscillation described in (a) (ANSI, 2013).

The range of frequencies that can be heard by humans and other animals is described by the Hearing Range. However, it can also refer to the range of levels. There are three basic hearing ranges; Infrasonic sound, Audible Frequencies, and Ultrasonic sound. Infrasonic sound, also known as infrasound refers to sound waves whose frequency is below 20 Hertz (Hz). Audible Frequencies refer to sound waves in the range from 20 Hz to 20,000 Hz. This is the normal limit of human hearing, though studies have shown that young children can hear frequencies beyond 20000 Hz and in ideal laboratory conditions frequencies below 20 Hz (Heffner et al, 2004). Ultrasonic sound refers to sound waves with frequencies of over 20,000 Hz.

Infrasonic sound can come from many manmade and natural sources such as ocean wave activity, weather patterns, topographical features, thunderstorms, geo-magnetic earthquakes, jet streams, rocket launchings (Cook, 1969 and Procunier, 1971) and animals. It has been found to be produced by animals such as Elephants (Payne et al, 1986), Whales, and even Rhinos. Whales as well as Elephants use this sound to communicate within the herd and with other elephants over long distances (Payne, 1986). Animals such as bats and dolphins have been found to produce ultrasonic sound for communication and navigation (Novelline, 1997). Ultrasonic sound produced by ultrasonic transducers has been widely used in medical imaging and some of its industrial applications are in cleaning, mixing and to accelerate chemical processes.

2.1.2.5 How to Detect Infrasound

As we saw earlier Infrasound is sound below 20 Hz; the lower bound of the audible range. It therefore follows that equipment used to “hear” sounds that humans can perceive cannot be used to perceive infrasound. As such, special equipment is required for the perception of sound that is between 0 Hz and 20 Hz.

In order to detect infrasound equipment that is sensitive to low frequencies special equipment is required. Such equipment is composed of a microphone and a preamplifier (ELP, 2015). Infrasound can also be detected using a speaker or a micro barometer. Micro barometers are sensitive to very tiny fluctuations in air pressure that are usually caused by infrasonic sound waves making them ideal for the detection and recording of infrasound.

(Girisha and Kasun, 2009) developed the low infrasonic recording system which they tested against a group of elephants and a diesel engine for frequencies between 0Hz and 40Hz. In tests focused on the group of elephants they found that the sensor could perceive elephant infrasound in the range of 7 Hz – 22 Hz with the peak frequencies at 8 Hz to 13 Hz. The durations of the peak frequency were around 7 seconds fitting perfectly into the previously established typical elephant call durations of between 2 – 10 seconds. In tests focused on the diesel engine the infrasound frequencies perceived had a very low frequency of between 0 Hz to 1 Hz. Girisha and Kasun also go ahead to state that their equipment could be extended to be part of a Wireless Sensor Network, they justify this by specifying that sensor motes contain analogue/ digital (A/ D) converters inbuilt in them and by connecting the output of the anti-aliasing filter to the A/ D converter (input) of the mote would create an infrasound sensor node. A collection of these nodes would thus be used in a WSN.

There exist infrasonic sensors that have been developed and used in other scientific work such as in the Lofar project (2010). Their infrasound sensors are Geophones and Microbarometers that enable seismic monitoring of the earth's crust up to 5 to 10 kilometers deep.

2.1.2.6 Applications of Wireless Sensor Networks using Infrasound

Majorly WSN's that perceive Infrasound have been used in two areas; Volcano monitoring and Animal monitoring. Sensor nodes used have to be able to perceive the low frequency waves that qualify as infrasound waves.

(Geoffrey et al, 2005) developed and deployed a wireless sensors network for volcanic monitoring on Volc´an Tungurahua, an active volcano in central Ecuador. This network was based on the Mica2 sensor mote platform and consisted of three infrasonic (low-frequency acoustic) microphone nodes transmitting data to an aggregation node, which relayed the data over a 9 km wireless link to a laptop at the volcano observatory. From this research they refined and developed a larger-scale prototype in which individual infrasonic motes capture signals locally and communicate only to determine whether an "interesting" event has occurred. By only transmitting well-correlated signals to the base station, radio bandwidth usage is greatly reduced.

The Lofar project (2010), deployed a WSN perceiving infrasound using Geophones and Microbarometers as infrasound sensors that enable seismic monitoring of the earth's crust up to 5 to 10 kilometers deep. The network is distributed over the Northeast of the Netherlands and spreading over the whole country and over all of Europe. The Lofar consists of a hierarchically structured sensor system, which is a aperture synthesis array composed of phased array stations. Sensor fields form a station that select one of multiple beams (phased array); these beams are transferred over a high speed (glass fiber) wide area network to a central processing unit, which convolves data from various stations to create the aperture synthesis array. In this configuration, the Lofar system is used for deep space observation. Its base line length ranges from 100 meters (m) to 1,500 kilometers (km).

(Ramkumar et al, 2014) developed the automated system for remote elephant tracking to reduce human elephant conflict. In their design the wireless sensor network (WSN) having a geophone sensor node is placed in some remote location near the edge of the forest or railway track or road side. The sensor node picks up the seismic wave created by the elephant herd from a large distance. A group of sensor nodes or primary units is connected to secondary units or gate-way node with bi-directional transmitter and receiver and a signal processing unit to filter specific signal of particular frequency and amplitude. Signals from such multiple secondary nodes are received by a central processing unit (base station). The processing unit looks for a pattern match of incoming signals with a reference signal and if elephant presence is detected in close distance, it generates some local warnings and also sends the information to the nearby forest office with specific location codes. It can also generate mobile alerts to nearby people through GPS. However, the use of such a system was found to be inefficient as it at times misses out on events that cause a detection to occur. The weather conditions also affect the availability of the system making it unsuitable for use during rainy weather as outlined by Sugumar and Jayaparvathy in 2014.

By extending the work of Girisha and Kasun (2009) and combining it with a WSN we hope to come up with a model for an infrasound wireless sensor network for an early elephant detection and alerting system. By sensing infrasound produced by elephants at large distances from the fence the system will be able to provide alerts early enough such that the relevant parties will have enough time to respond before the elephants even arrive in the human settlements. Using detection location data, it will be easy to identify the area of detection easily making the response more effective and efficient.

2.1.2.7 Designing Wireless Sensor Networks

The design of a wireless sensor network is greatly influenced by its intended application. However, there are some common issues that affect the design of all wireless sensor networks. Below we will discuss some of these issues as outlined by Gowrishankar et al, 2008 and Gurbhej and Harneet, 2013.

Energy Consumption is one of the major issues in the design of WSN. It determines the lifetime of a WSN and depends on major operations such as sensing, communication, and processing. Most of the power is used up during communication with other nodes. Use of solar powered nodes and low power consuming communication protocols have been identified as ways of increasing the lifetime of a WSN.

Node localization which deals with the determination of actual locations of a node is another issue. In most deployments, node deployment positions are not predetermined. There are algorithms that have been developed for this issue. Use of GPS, Beacon nodes and proximity based localization are other alternatives of dealing with this issue.

To achieve optimum results then maximum coverage of the area under study must be covered. This is known as topology control. It deals with ensuring that the entire environment is covered with the sensor nodes. It has three phases; (1) Pre-deployment and development phase. (2) Post-deployment phase and (3) Redeployment and additional nodes phase. In phase one the intention is to have as many nodes as possible to cover the whole area and to place them in a way that they cover the whole environment. After deployment some nodes may fail due to hardware issues such as breakage and need to be replaced. Over time some of the sensor nodes will fail either due to lack of a power source and need their batteries replaced or due to other external factors based on their environment.

Coverage, Connectivity, Clocks and Computation: Coverage deals with how well the area of interested is monitored. The coverage configuration protocol and minimal and maximal exposure algorithms are some of the technologies used to ensure coverage. Connectivity deals with the communication from the node to the sink node. Clocks in all nodes should be synced as this helps in energy conservation. Data processing is also known as computation. It can be done at the sensor nodes or at the sink node based on the availability of resources at each node. When resources are few then it is best to perform computation at the sink node.

The processes of determining for which time period a node is in either sleep, active or standby mode is known as scheduling and is a key issue that determines energy consumption in the WSN. This issue is heavily dependent on the application of the WSN as different applications have different requirements.

Data gathering from the sensor nodes is another issue. Some WSNs collect data and store it in the sensor nodes for some time period before sending to the sink nodes. Others send the data immediately to the sink nodes after collecting it. This also depends on the requirements of the application. Data needs to be delivered to the sink nodes without loss.

The WSN needs to be fault tolerant for it to achieve its intended purpose. Hence, reliability of the WSN is a key factor in all WSN. Reliability can be summarized into three categories; (1) Packet Reliability which deals with successful transmission of all packets (2) Event Reliability which deals with successful event detection and (3) Destination Reliability which addresses sending of messages to nodes in a specific area of the network.

Security is another issue that needs to be addressed early in the design of the WSN. The WSN system should fulfill the requirements of Confidentiality, Integrity and Availability. The WSN should have high availability to achieve optimal results. A risk analysis should be performed in order to make informed decisions on how to address the security of the WSN. Again, this will be based on the intended application of the WSN.

The WSN should be scalable to allow for growth, both positive and negative. Other issues include the cost of the WSN, Environmental impact and Availability of technical skills necessary for development and management of the WSN.

2.1.3 The Conceptual Model

This research tries to counter the problem of early elephant detection and alerting of relevant authorities in the fight against HEC using an infrasound wireless sensor network. As such we have identified variables that directly relate to this. These variables are; (a) Signal source, (b) Signal source location, (c) Detection time (d) Alerting Time (e) Alert Location and (f) Notification Time.

From a previous section we saw that infrasound can be produced by different objects. Signal source in this research refers to the object producing the infrasound. Our model bases the detection of elephants on the infrasound that they produce in their day to day activities. It is therefore important that we detect infrasound signals only on the sensor that we deploy in the WSN. It then follows that the sensors to be used will be capturing sounds with a frequency below 20 Hz.

To perceive a signal on a sensor the signal source must be close enough to the signal sensor for it to be detected. Thus the signal source location is another key variable in this research. The location can also be said to be the distance between the signal source and the sensor. This distance will enable us to map the distance of the signal source (elephant) to the human habitat or the proximity to the boundary.

When a signal is detected on the sensor node it has to undergo processing before data is sent out to the sink node. The sink node will then send this data to a computer system which will act as an input to the alerting subsystem. The total time taken from the time a signal is received on a sensor node, processed within the WSN to the time data is received on the computer system is what we are referring to as the detection time. This time will directly affect the total time that the entire system will take from when a signal is received to the time a notification is received.

Alerting time is the time that the alerting sub system will take from the time data is availed in its database by the detection subsystem to the time a notification is presented to the user. This presentation can either be a display on a screen or a message on a mobile device.

In this research notification time was the total time since a signal is perceived on a sensor to the time a notification is received on a display or a mobile device. This time is a combination of the detection time and alerting time. It will greatly be influenced by these two.

Lastly we have the Alert location. This is the location that the detection subsystem presents to the alerting subsystem as the position on the ground where the signal was detected. This location will form part of the data presented to the users of this system so that they can respond to a specific location within the large area under consideration. The alert location was determined by the source location that was provided by the detection subsystem.

It is clearly evident that the source signal, signal distance, sensor type, light intensity and signal frequency are the independent variables while notification time, false positives, true positives and power consumption are the dependent variables. This gives us the conceptual model below.

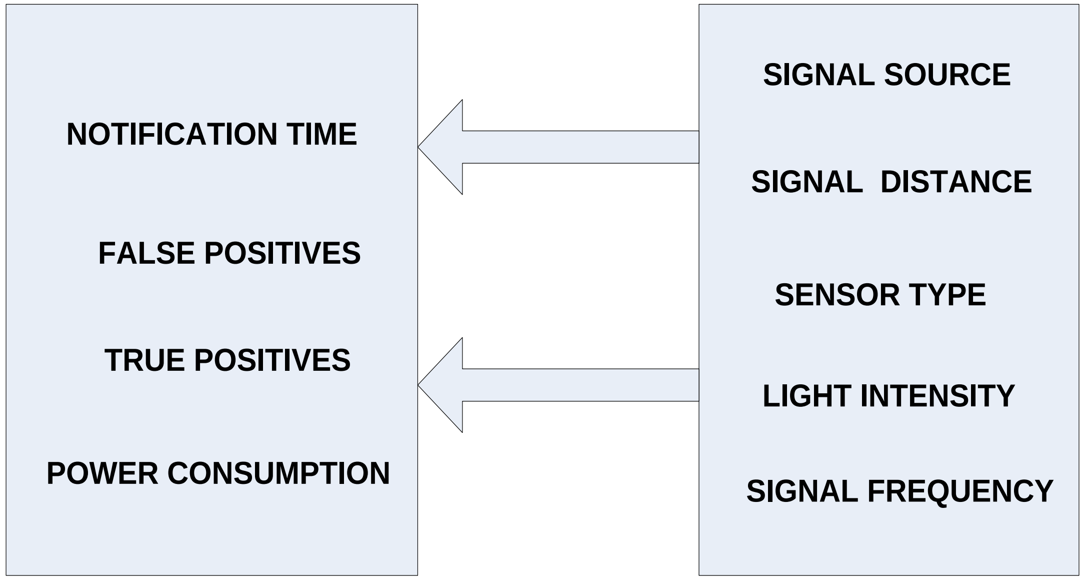

Figure 3. Conceptual Model of the Early Elephant Detection and Alert System

2.1.4 The Infrasonic Wireless Sensor Network for an Early Detection and Alert System for HEC

In this section we will describe the envisioned Wireless Sensor Network based on infrasound, its components and functionality. The solution is a combination of two previous solutions; A low cost infrasonic recording system (Girisha and Kasun 2009) and An Automated System for Remote Elephant Tracking to Reduce Human Elephant Conflict (Ramkumar et al, 2014). In their solution, Ramkumar used geophones to sense seismic waves. However in this solution we will use infrasound sensors like that developed by Girisha and Kasun as our sensing equipment. The system was made up of two subsystems (a) The detection subsystem and (b) The Alerting subsystem. The detection sub-system is composed of the infrasound wireless sensors, and the gateway connected to a computer via a wired link. The alerting subsystem on the other hand is composed of a server communicating with a mobile device, a laptop and a display screen. Users of the system are shown in the alerting subsystem as they interact with the various devices. The detection subsystem and alerting subsystems are interconnected as the detection subsystem provides input to the alerting subsystem.

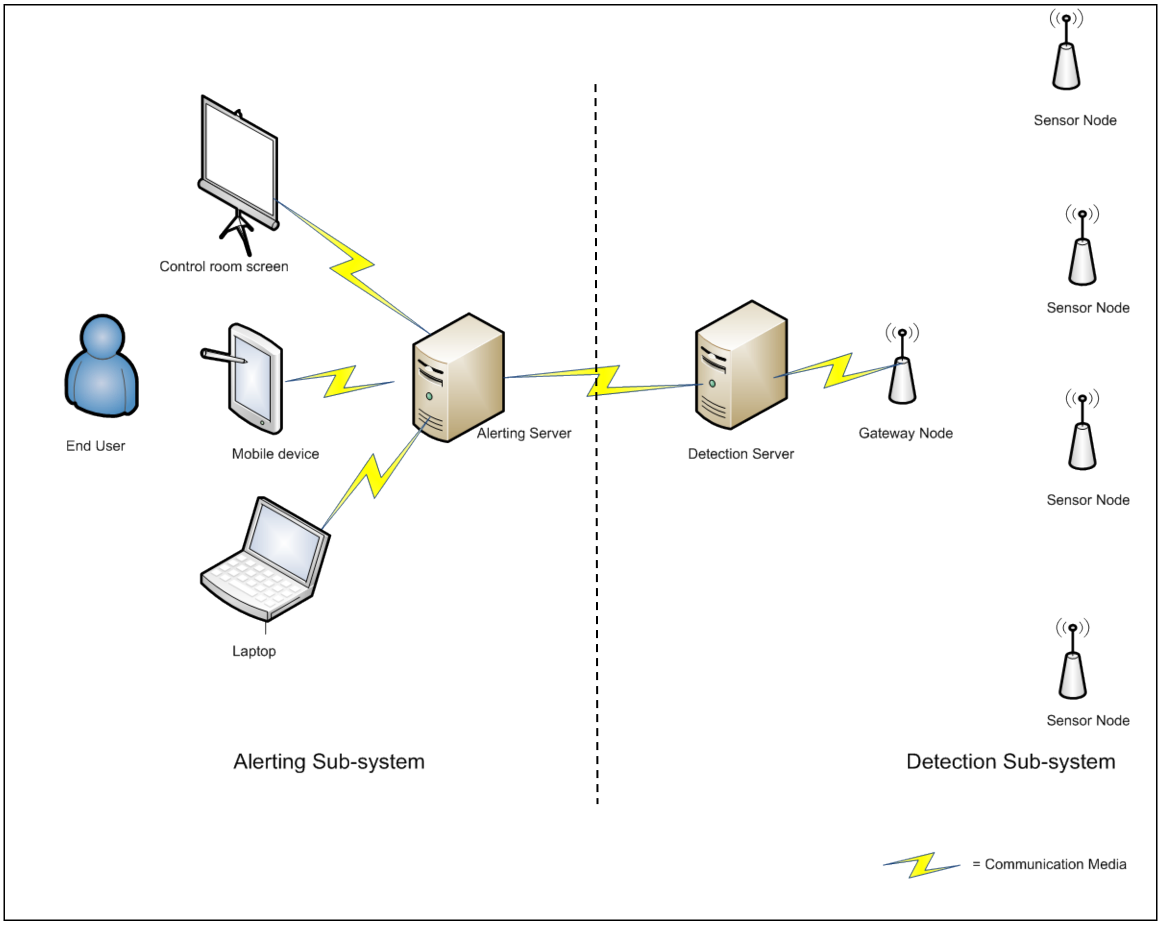

Figure 4 A diagramatical representation of the infrasound WSN for an ealry elphant detection and alerting system.

2.1.4.1 The Detection Subsystem

This is the part of the system that is responsible for the recognition of elephants near or within the human settlement boundaries. It is the Wireless sensor itself. It is made up of sensor nodes, the gateway node, communication medium among the nodes and a computer system.

The sensor nodes will be equipped with an infrasound sensor and will be placed at the boundary defined that separates human settlement from wildlife habitat. The sensors will be used to only detect the presence and absence of infrasound and not record the infrasound for purposes of storage. The sensor nodes will also contain location information that will be associated to a particular area on the map. This will therefore necessitate that instead of a random deployment of the nodes an organized planned deployment will be done. On analysis of a signal, the node will send two pieces of information in its message to the sink node; its node location and data depicting the presence or absence of infrasound. It is important to send data on the absence of infrasound as this is a sure way to confirm that the equipment is still functioning and to have a uniform data set without gaps.

From previous research on the Patterns of crop raiding by elephants, (Maximilian et al 2010) found that all incidents of crop raiding occurred exclusively at night. Other sources claim that elephants are seen in human settlements mostly when darkness starts settling in; between 1800 hours and 0600 hours. Based on these findings we propose to have our system actively listening during this timeframe. We will therefore schedule the nodes to be active between within this time in order to conserve energy. Due to constraints in power we propose to use solar charged batteries to increase the lifetime of the sensors.

The WSN is expected to utilize the most efficient protocol for communication within its nodes. Time is a key issue in this subsystem and it is expected that the WSN will process data very fast and accurately and then deliver this data to the alerting subsystem. Therefore the algorithms chosen to process data and protocols used for the exchange of data have to be efficient and accurate.

2.1.4.2 The Alerting Subsystem

The alerting subsystem is the part that is responsible for the delivery and presentation of alerts to users. It should be in sync with the detection subsystem for accurate reporting. This subsystem will consist of a display system that will have a map of the area covered by the WSN. On display screens, it will show the placement of the sensor nodes in the grid such that whenever detection occurs the alerting system displays this and points out the particular area on the grid. This will be based on the detection location information that was delivered to it. The system should also be accessible on mobile devices for use during transit.

In addition to displaying this information the system should also be able to send alerts to relevant authorities on their mobile devices. The alert should contain information on detection location and time of signal detection. This information will enable the users to respond better as they will already have an area to focus on.

The two subsystems above can be combined into a single system as shown in the data flow diagram below.

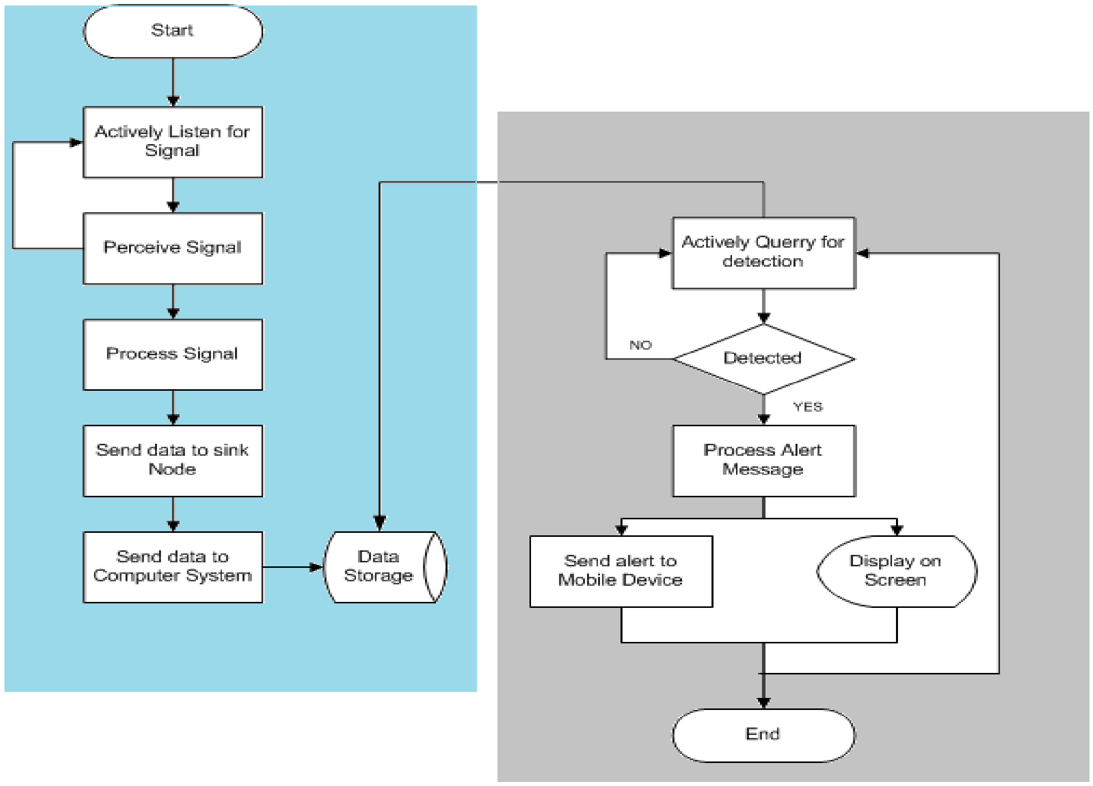

Figure 5. Combined Detection and Alert Subsystems(Detection subsystem on the right and alerting subsystem on the left)

2.1.5 The Gap

Most of the solutions that have been implemented in regards to HEC focus on preventing the elephants from moving out of their natural habitat or entering human settlements. Solutions such as watch towers are being used in a different approach to provide an early alert before the elephants enter into human settlement. However, this is not adequate and a better solution is needed to fill in this gap: early detection and alerting of relevant authorities. Other solutions have been found to miss out on detection due to interference by weather conditions or provide inefficient detection as they operate only in very short distances thus not providing detection at all or detecting when it is already too late. It is a well-known fact that it is easier to chase elephants away from farms before they enter them unlike after they have already entered the farm.

It is therefore necessary to determine the right technology to implement even before you implement it. This research will address this issue by putting 2 technologies side by side and recommending the better alternative when faced with a problem with similar attributes. such a study on the efficiency of a Wireless Sensor Network is a difficult task to undertake due to several factors. First, deploying or implementing an actual network may be very costly. Secondly, acquiring of licenses to conduct such studies is a daunting task. Thirdly, interacting with wild animals is a dangerous task that requires skilled personnel on how to interact with the animals. Therefore, Modeling and Simulation is a good alternative for studying and comparing the different technologies under different scenarios even before implementing them. Simulation and modeling also affords a designer to make mistakes and rectify them before deploying the actual system.

When modeling a system, its features and properties are abstracted and focus is only laid on the areas of interest in the study (Garzia et al, 1990). The model is therefore presented as a logical depiction of a system with various levels of complexity. However, the complexity is normally less complex than the actual system. Simulation is therefore simply imitating the real-world systems through a computational representation of behavior according to rules described earlier in a model. When simulating it is mandatory to only consider a limited number of characteristics and properties of interest so as to make the model more usable (Guizani et al, 2010).

2.1.6 Chapter Summary

In this chapter we looked at Wireless Sensor Networks, their design issues, Infrasound and how to detect it, and HEC mitigation solutions currently being used. Finally, we introduced the model that we hope to study in the research and explained on its envisioned mode of operation. In the next chapter we will look into the methodology to employ in the course of this research. We will discuss the tools to use as well as the measure

CHAPTER THREE

3.1 RESEARCH METHODOLOGY

This chapter focuses on the methodology for conducting the comparative study focusing on the two WSN technologies for Human Elephant Conflict mitigation. The study will employ exploration using modelling and simulation. In the study we will model the infrasound WSN and Image Based WSN for elephant detection. We will then run the simulation and collect data as the simulation output. Using the independent variables identified in Chapter 2 we will expose the two technologies to the same parameters and simulate different scenarios that occur in the real world. The results we collect from the simulation will then be analyzed to help understand how the independent variables affect the dependent variables.

The main objective of the study being to compare the efficiency of an infrasound based WSN versus an Image based WSN. We came up with a representative model of the two sensors. We then built the WSN into the model and simulated the two technologies identified to evaluate based on the results which was the more efficient technology for elephant detection. The results of the simulation formed the data analyzed.

We used secondary sources of information to develop the model. A lot of research has been done previously on areas such as the power utilization schemes, deployment schemes as well as optimization algorithms hence we found no need to reinvent the wheel. Our focus was on comparing two technologies that had been identified as suitable technologies for elephant detection and give recommendations on where each can be applied best. Modeling and simulation tools for WSN already existed and hence a tool would not be developed. As our research was focused on the application of WSN's and not the protocols therein, NetLogo was selected as the modeling and simulation tool of preference.

3.1.1 Research Design

This research followed the Comparative research design. Comparative research aims at identifying the similarities and differences between two objects and is descriptive in nature.

3.1.1.1 Problem design

From literature we established that the choice of technology for solutions for HEC mitigation is a critical pointer for the success or failure of the project. We also identified that though infrasound WSN have been used for elephant detection the solution had not been deployed on the ground but rather it had only been tested and found to be valid in a zoo setting. It is this gap that we intended to fill by giving solution designers a reference point when designing solutions for HEC. As we all work towards providing solutions we also need to provide solutions that not only address the issue but also address it with efficiency. It was therefore paramount to compare the two WSN solutions that had been identified as possible solutions and establish the similarities as well as differences in the two technologies proposed.

3.1.2 Research Instruments

To come up with a model we needed to collect data pertaining to the environment under study. We used secondary sources of data especially Journal papers to develop the models under study. After development of the models we then ran simulations to collect the results. The following scenarios were conducted for both technologies using the two sensor types :-Image based sensors and infrasound based sensors.

i. Simulation under different infrasound frequency ranges.
ii. Simulation using different signal sources.
iii. Simulation under different signal source distances.

3.1.2.1 Target Population and Sampling Technique

The focus of this research study was solutions that utilize Wireless Sensor Networks for Human Elephant Conflict mitigation. Specifically, this research focused on two solutions that employ; image based processing and infrasound based WSN by Sugumar and Jayaparvathy, 2014 and Lalith et al, 2015.

3.1.2.1.1 Simulation and Modeling

Simulation is a process of designing a model of an actual or theoretical system, executing it on a computer and analyzing the execution output. A model is a representation of an object or process typically on a smaller scale than the original. Modeling is the process of creating models that represent the actual physical environment. It involves studying and understanding the physical environment and replicating it on a computer using modeling software applications. After modeling then simulation can take place. The model is executed and the behavior of the model is observed as the output of the simulation.

Simulation and modeling is an important process of large projects as it helps in the design of how things will be done in the actual project. It helps in understanding the behavior of the system when certain factors that are expensive to test in the real world, dangerous or difficult to observe need to be studied. Such scenarios include for example how a bridge would behave in the presence of very strong winds. Using simulation engineers can vary some parameters to evaluate the weaknesses in the bridge and how varying these variables would make the bridge stronger. Other areas of simulation are in wireless sensor networks where one would want to investigate the feasibility of a certain design before developing and deploying it in the real world. Generally, Simulation and modeling affords a designer an environment to make mistakes and learn from them without having a major impact that can cause loss of life and resources. It allows one to experiment with a near similar real environment to the one under study.

There are various tools used for simulation and modeling based on the area of application. There are various tools for simulating both wired and wireless networks. Some of these tools are NetLogo , NS_2, OMNeT++, OPNET, JSim including others. Most of these tools are developed using C, C++ and Java. A key distinguishing feature of these tools is the provision of a graphical user interface (GUI) that enables the designer and audience to experience the simulated model as it would appear in real life. Tools with a GUI are more preferred and widely used.

Simulator	Developer	URL	Commercial	Language
NS_2	USC ISI	http://www.isi.edu/nsnam/ns	NO	C++, OTcL
OMNeT++	Technical University of Budapest	http://www.omnetpp.org	NO	C++, C#, Java
NetLogo	Center for Connected Learning and Computer-Based Modeling	https://ccl.northwestern.edu/	NO	Java, Scala, NetLogo
OPNET	RiverBed Technology	http://www.opnet.com	Yes	C, C++, Proto-C
JSim	UIUC	http://j-sim.cs.uiuc.edu	NO	Java, Perl, Python

Table 1 A comparison of some simulators in the market today

3.1.2.2 Modeling Technique

The research used agent based modeling. Agent-based modeling (ABM) is an approach to modeling systems comprised of individual, autonomous, interacting agents. Agent-based modeling offers ways to easily model individual agent behaviors and how behaviors affect other agents. The complex WSN system is composed of different elements that behave differently at different times making agent based modeling ideal. Each component in the model will be an Agent with its own attributes and behavior making the whole a multi-agent system.

Although the detection and alert process is a continuous process, agent based modeling would allow us to represent the system and processes as operations being performed at different points in time and at different devices. Events would trigger other events in the model and from these triggers and responses data would be generated. These data formed the backbone of this research.

3.1.2.2.1 Image based sensor model

Image based sensors detect signals by capturing images and comparing to images in a repository of images. An image The image based sensor model had the following agents; a sensor agent, elephant agents, bird agents, and land animal agents. Birds, elephants and other land animals were differentiated by using different breeds and shapes for each of the agent types. The sensor agent will also be of a different breed and shape.

3.1.2.2.2 Infrasound based model

Infrasound based sensors detect signals by listening to frequencies within the range of zero hertz to 40 hertz. As such the differentiating factor to use for this technology is the frequency of the source object. Therefore, the infrasound based sensor model had the following agents; a sensor agent, elephant agents, bird agents, and land animal agents. Birds, elephants and other land animals were differentiated by using different frequencies for each of the agent types. The sensor agent will also be of a different breed and shape.

The two models were combined in the same simulation for purposes of this comparative study. This would ensure that when the simulation is executed they were both exposed to the same conditions for the same period of time to avoid disparities in the simulation. The following is a representation of the model that was developed which shows the input parameters as signal level, signal source and distance which form our independent variables. The inputs are fed into the simulator which has been implemented with sensors and an algorithm of how the sensors react to the different parameters. After execution the simulator gives as output the false and true positives, power consumption for both sensors and the detection time for each detection.

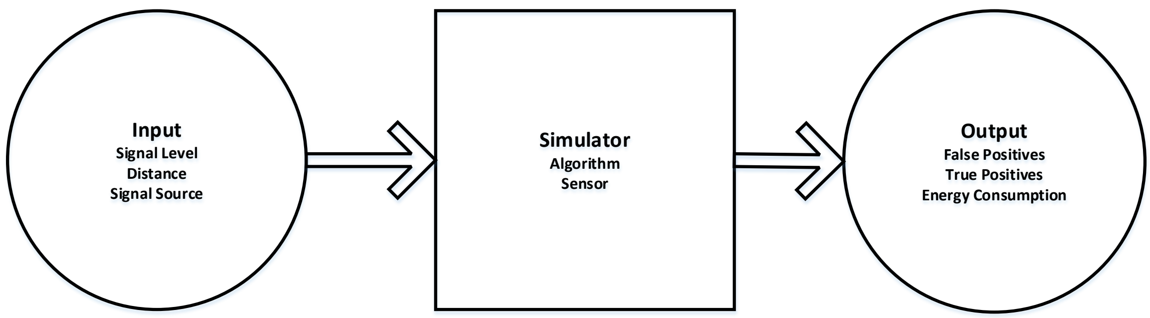

Figure 6 Simulator Abstraction showing Inputs, the Simulator and Outputs.

3.1.2.3 Modeling Tool

This research used the simulation tool NetLogo for modeling and simulation of the model. NetLogo is a multi-agent programmable modeling environment. It is used by tens of thousands of students, teachers and researchers worldwide (NetLogo , 2016). NetLogo is developed using Scala and Java and runs on the Java Virtual Machine (JVM) making it portable across different platforms.

NetLogo was also freely available as an open source tool for research and thus reduced the financial resources required for this research. NetLogo had also been used widely in scientific research and is thus a trusted tool in the research world (NetLogo , 2016). It provided a Graphical User Interface that contains objects showing the environment, generating reports and even varying variables in the environment. It is also an easy to learn and use modeling and simulation tool making it ideal for a researcher new to the field of simulation and modelling.

3.1.3 Measurement Metrics

The simulation tool: - NetLogo , identified above is capable of producing results in graphical form as well as text. The user has the freedom of selecting the type of reports to be generated and in the format of their liking. The user is also able to select the data he/ she would like to generate based on the configuration of the model developed. The following are the parameters that were measured from the simulation;

i. Image based detections. – This was the total count of recorded instances where the simulation recorded a presence of an agent that can either be or not be an elephant based on shape and breed. However, these detections would either be true or false and we therefore went further into classifying the detections as true positives and false positives. As articulated in the previous chapter, the Image based sensors work in the following way; First they detect motion and then they capture an Image. It is therefore true to state that not all motions detected by this sensor will be elephants and not all images captured by this sensor will be elephants. This therefore necessitates the need to factor in True positives and False positives.

   In the research True positives are those agents that portray the traits of an elephant as defined in the model. False positives are those that do not portray at least one of the traits of an elephant as defined in the model.

ii. Infrasound based detections. - This was the total count of recorded instances where the simulation recorded a presence of an agent that could either be or not be an elephant based on the frequency of the agent. In this case we will also had True positives and False positives.

iii. Detection Time – This was the time at which a detection was recorded by each of the sensors in the simulation. We recorded for both Image based and Infrasound based sensors.

iv. Image based sensors power consumption – This was the amount of battery power consumed from the time the simulation started to the time the simulation ended. It is calculated as Power at Start of Simulation less Power at end of simulation.

v. Infra-sound based sensors power consumption - This was the amount of battery power consumed from the time the simulation started to the time the simulation ended. It is calculated as Power at Start of Simulation less Power at end of simulation.

3.1.4 Data Analysis Methods

The simulation performed generated data in form of graphical images and text. This data was generated based on and represented events at various points in the simulation. The data would be exported to tabular form into known file systems such as Excel and Comma Separated Variables (CSV). The data would then be extracted so as to give a side by side comparison for each of the items measured. However, even without exporting the data into other file extensions the graphs in NetLogo contained both individual sensor results and combined sensor results which were interpreted easily.

This research employed the differentiating comparative analysis which aims at explaining differences. The differences obtained from the analysis then helped to achieve the objective which is to identify the most effective and efficient technology for elephant detection in HEC mitigation. As stated earlier the data that was collected would be detection time, power consumption and detections. We then further went into comparing detection time for image based sensors versus infrasound sensors, power consumption in image based sensors versus in infrasound based sensors and lastly we looked at detection in image based sensors versus in infrasound based sensors.

3.1.5 Chapter Summary

This chapter has explained on the research design to be used, data collection methods as well as analysis methods. It has also looked into the simulation that was developed based on the data collected and how the simulation will generate results for the research.

CHAPTER FOUR

4.1 RESULTS

In this chapter we describe how the simulation was setup and drill down to the agents, the environment and the scenarios that were simulated. We also look at the input variables and the different configurations that gave us the different scenarios. After scenarios were configured we delve into the execution of all scenarios under study and finally we analyzed the data which is an output of the simulation.

4.1.1 Simulation Setup

The simulation was composed of agents acting in an environment under different scenarios. We look at each of these below;

4.1.1.1 Agents

There were different agents in the simulation each with its own behavior and properties. This gave us a Multi-Agent simulation where the different agents interact and respond differently allowing us to study each independently. There were two different sensor agents which comprise of the two sensor technologies; infrasound sensor agent and image based sensor agent. There were Elephant agents that had been configured to have elephant properties especially focusing on the variables under study. We also had other agents that are some of the animals that would typically be found in this environment. These animals included birds, humans, wolves and sheep.

There were; Two sensor agents of color blue and shape flag, Three elephant agents of color red and shape cow, Three wolf agents of color magenta and shape wolf, and Three bird agents of color yellow and shape bird.

4.1.1.2 Environment

The environment in study borrowed from the studies done by Ramkumar et al, 2014 and Sugumar et al, 2014 in which they used a single sensor node in each of their studies. Each of the sensor nodes has a given sensory radius and for purposes of the study they had been configured to be at the same location using the x,y coordinates. This would allow us to do a like for like comparison especially when looking at the distance and time of detection. The simulation had been configured to run in a 33 by 33 NetLogo units' world.

The image based sensor had a sensory radius of 12.5 NetLogo units and the image based sensor had a radius of 0.25 NetLogo units. The two types of sensor agents were both set to start with an equal energy level that was consumed as the simulation progressed. The white area shows the detection region that was covered by the Infrasound based sensor. To achieve an equal comparison we also ensured that each patch within the infrasound based detection region is also covered by an image-based sensor. From this setup we got 489 imagebased sensors and 1 infra-sound based sensors. The area outside of the detection region is shown in black. The agents move freely within the environment and the world wraps both vertically and horizontally. Figure 7 below shows the NetLogo world at setup.

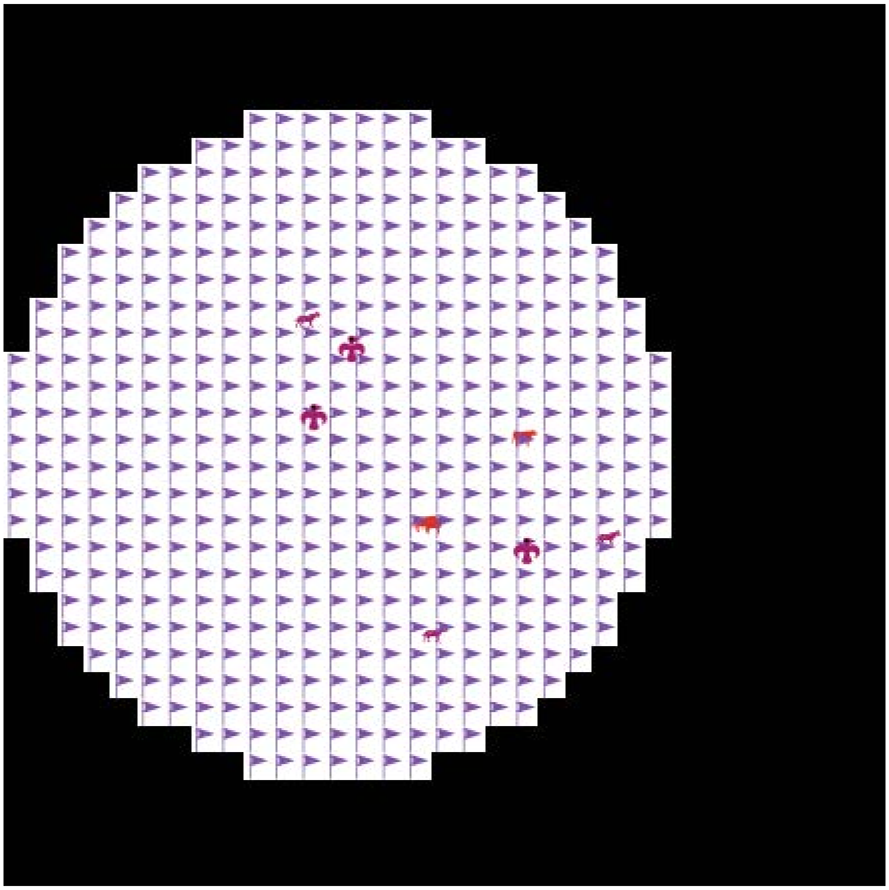

Figure 7The Simulation Environment at SetUp

The simulation will look into the following scenarios;

Scenario One – Image based detection. Elephant detection when using an image based sensor.

Scenario two – Infrasound based detection. Elephant detection when using an infrasound based sensor.

In all scenarios the stimuli sensors was both elephants and non-elephants.

4.1.2 Input Parameters

The following variables were watched and collected from the simulation; image based detections, infrasound based detections, power consumption on the image based sensor, power consumption on the infrasound based sensor and false detections within the two sensor radii.

The input parameters configured in the simulator were frequency and shape of the agents. The location would be randomly generated variable anywhere within the NetLogo world (environment).

The results would be plotted onto graphs which will then be exported into CSV format.

4.1.3 Discussion

4.1.3.1 Simulation Execution results

This section details the results collected from the simulation based on the scenarios identified previously.

4.1.3.1.1 World View During Simulations

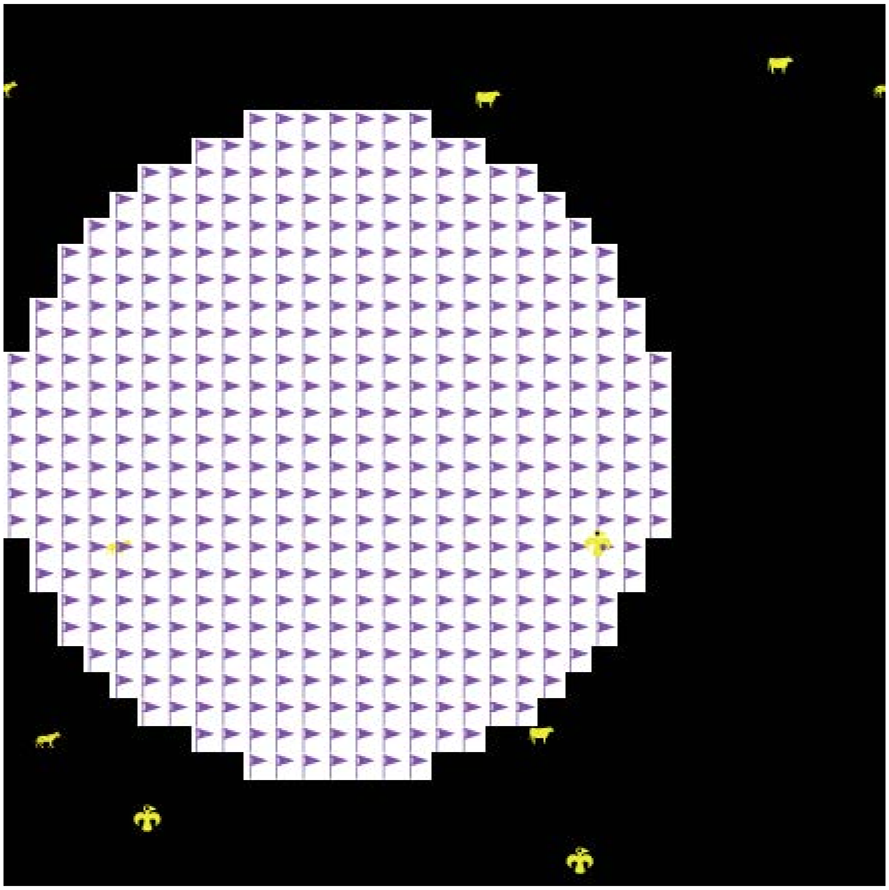

Figure 8NetLogo World View during the Simulation

Figure 8 above shows the view of the NetLogo world during the simulation. As explained previously elephants are in the shape of a cow and whenever they enter the detection area their color changes to green when in the infrasound sensor range and black when in the image based sensor range. Any animal outside of the detection region changes its color to yellow and any non-elephant animal within the detection range also changes its color to yellow.

4.1.3.1.2 Scenario One

4.1.3.1.2.1 Detection

Figure 9Detections by the Image Based Sensor

Figure 9 above shows the detections made by the image based sensor for. You will notice a red line and a green line. The red line shows the false positives captured by the image sensor while the green line shows the true positives captured by the sensor. This sensor as explained previously captures all images based on motion detection that triggers the capture of an image. The images are then submitted to the central processing unit for analysis to check on whether they are elephants or not.

4.1.3.1.2.2 Power Consumption

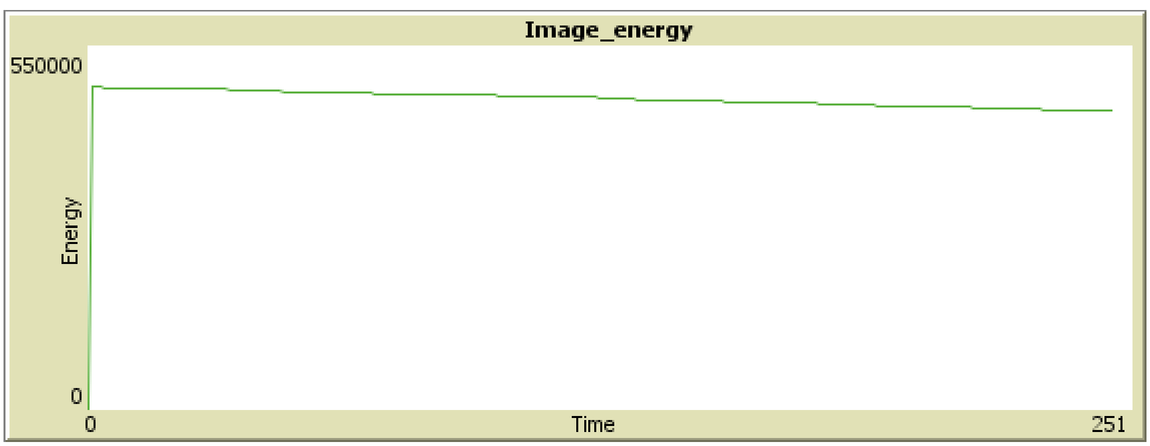

Figure 10Power Consumption by the image based sensor

Figure 10 above shows the power consumption of the image based sensor. The sensor consumes 0.4 units of power when capturing an image and consumes 0.1 units when idling. In the simulation we had 489 image based sensors that gave us a combined energy of 489*1000 = 489000 units. This number of sensors explains the reason for the high value of energy in the image based sensor graph. Due to the non-filtered nature of this sensor you will notice that it consumed power consistently as long as an object was within its range.

4.1.3.1.3 Scenario Two

4.1.3.1.3.1 Detection

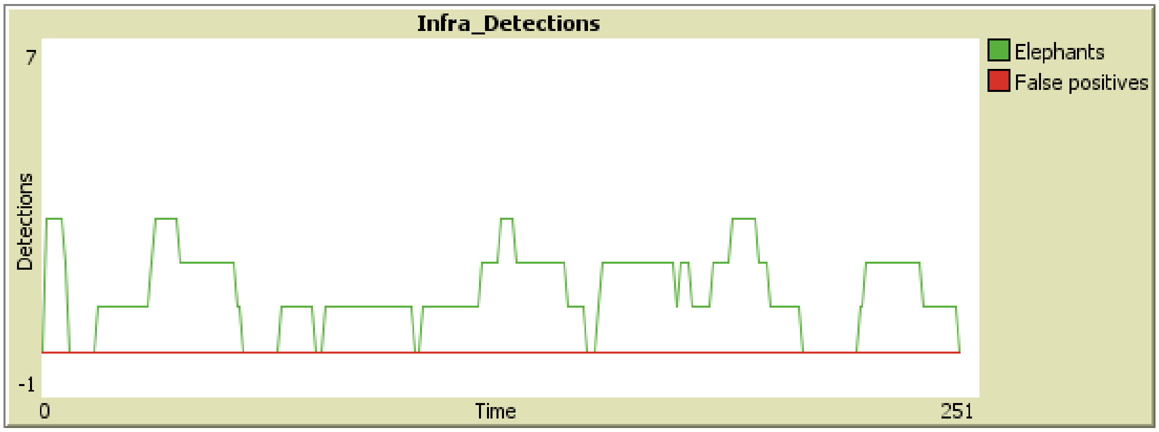

Figure 11Detections by the Infrasound Based Sensor

Figure 11 above shows the detections made by the infrasound based sensor. Similar to the image based the red line shows the false positives captured by the image sensor while the green line shows the true positives captured by the sensor. You will notice that the false positives captured by this sensor do not exist. (The graph reads zero). As explained previously in chapter three elephants are the only land mammals know to communicate at frequencies below 40 hertz and as such no other agents were configured to have frequencies below 40 Hertz. This in turn eliminates them from the captured signals as our infra-sound sensor could not capture frequencies above 40 Hertz.

4.1.3.1.3.2 Power Consumption

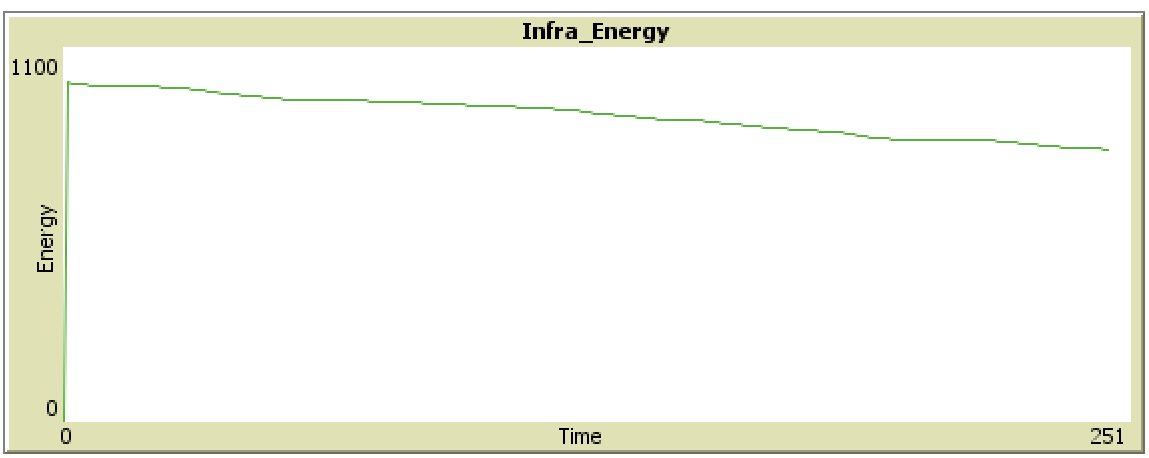

Figure 12Power consumption by the Infrasound Sensor

Figure 12 above shows the power consumption of the infrasound based sensor. The sensor consumes 0.6 units of power when capturing a signal and consumes 0.1 units when idling. Due to the filtered nature of this sensor you will notice that it consumed power only when an object was within its range and this explains the low utilizations that seem almost flat in some instances.

4.1.3.1.3.3 Animal Distribution in Detection Range

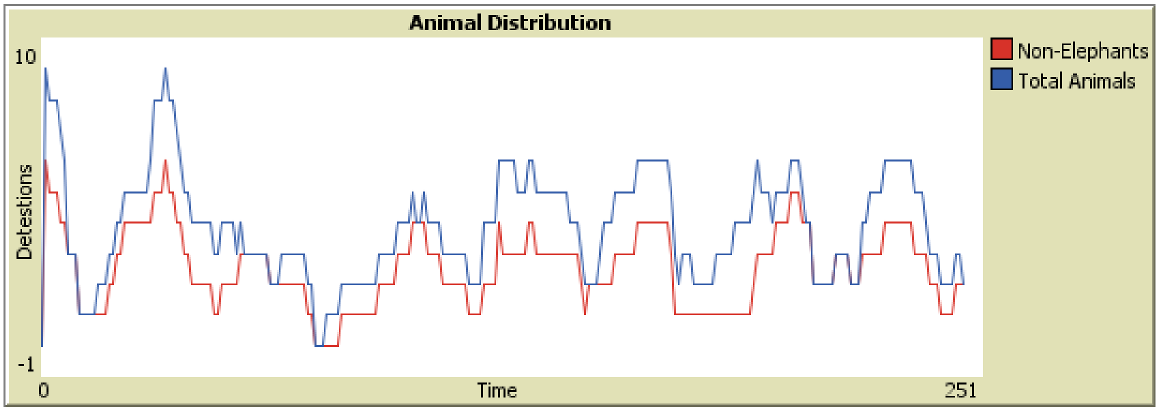

Figure 13Animal Distribution within the Detection radius

Figure 13 above shows the distribution of all animals in the detection radius. The blue line shows the number of animals within the detection radius and the red line shows the total number of animals that are not elephants in the same detection radius at the same time. The difference is the number of elephants captured within the detection radius either by the infrasound based sensor only or both the infrasound sensor and image based sensor.

4.1.3.1.3.4 Power Consumption, Image based sensor Vs Infrasound based sensor

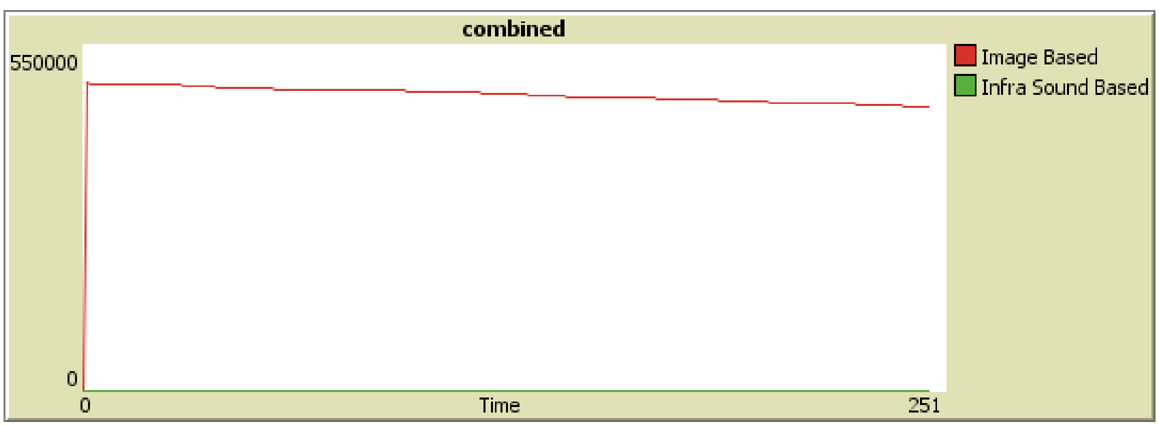

Figure 14Power consumption of the Image based Sensor vs Infrasound based Sensor

Figure 14 above shows the consumption of power by both the image based sensor shown in red and the infrasound based sensor shown in green. You notice the difference as explained above in total power of the image based sensor vs the infrasound based sensor which almost appears to be at zero. However, the infrasound based sensor was only one with 1000 units versus the combined image based power of 489000 units. It is good to remember that the infrasound based sensor actually consumes more power than the image based sensor for a single signal capture and that the infrasound based sensor covers a larger detection radius than the image based sensor.

4.1.4 Analysis

4.1.4.1 Critical Analysis

The purpose of this study was to identify the efficiency of each of the two solutions deployed on a largescale in order to be able to make a better decision on which technology to apply. In an actual deployment the area to be covered influences a great deal on the number of nodes to be deployed. It is therefore very important to consider this before any deployment. The diagram below; - Figure 15 gives a pictorial view of a sample area to be covered and the detection radius of each sensor node. Though not to scale the ratio is 1:50 for imagebased sensor to the infrasound based sensor.

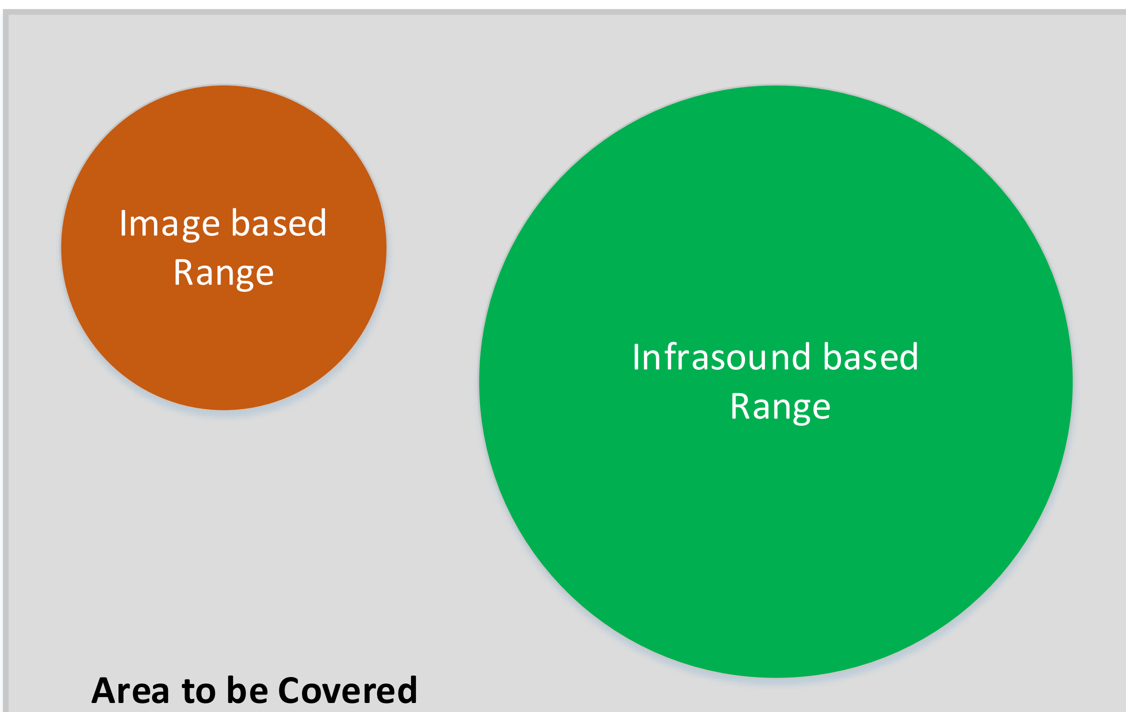

Figure 15Area to be covered vs detection radius

The brown area shows the detection radius of an image based sensor while the green sows the detection radius of the infrasound sensor. The area to be covered is the rectangular region shaded gray. If the two solutions were to be deployed on the same area, we would get the setups below.

4.1.4.1.1 Nodes for an Image based setup and Infrasound based setup

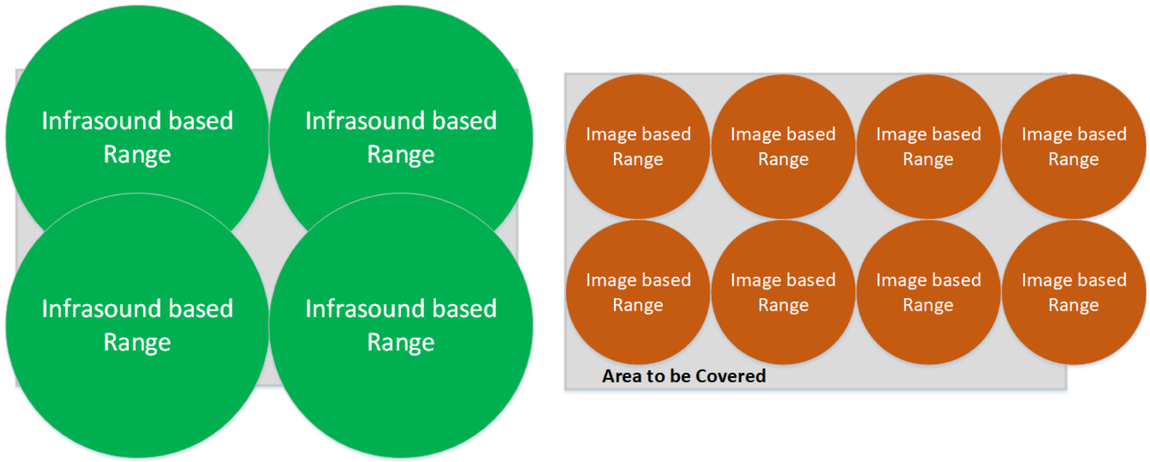

Figure 16Nodes required to cover the same area based on detection radius

Figure 16 above shows a side by side view of the sensors and their detection radius given the same area to be covered. For the same area to be covered one would ideally need 4 infrasound based sensor nodes and 8 image based sensor nodes if the radius of detection was at 1:2, However our radius of detection is at 1:50 which gives us the table below. The table below shows the number of nodes for the two setups side by side for a 1KM^2 area.

Area in Square M	Image based		Infrasound based	
	Radius m	Nodes Required	Radius m	Nodes Required
1000000	12	83334	600	1667
1000000	24	41667	1200	834
1000000	48	20834	2400	417
1000000	96	10417	4800	209
1000000	192	5209	9600	105

Table 2Nodes required for each setup by varying the detection radius

From table 2 above it is evident that the radius of detection has a very high impact on the number of nodes required for the same area to be covered. Bearing in mind that infrasound sensors have more than twice the radius of detection compared to image based sensors it is evident that we can reduce the number of nodes required by four times what is required for an image based setup. Table 3 below shows the ratio of nodes for the areas in table 2 above. Even by varying the detection radius for the sensors it shows a ratio of 98:2 as long as the radius of the infrasound sensor is twice the radius of the image based sensor.

RATIO	
infra	**image**
0.980388	0.019612
0.980377	0.019623
0.980377	0.019623
0.980331	0.019669
0.980241	0.019759

Table 3The ratio of Nodes for each setup by varying the detection radius

4.1.4.2 Efficiency

In thsis study we looked at efficiency as the amount of true positives registered given the amount of energy consumed.

Efficiency(E) = {True Positives(TP)/ Energy consumed(En)} *100

From the simulation data we collected we have the following data in table 4 below showing the true positives, false positives and total power consumption for each.

	Image Based Sensor	**Infrasound Based Sensor**
True Positives (TP)	56	332
False Positives (FP)	621	0
Energy Consumption (En)	12300.2	223.8

Table 4True positives, False positives and Power consumption for each technology

4.1.4.2.1 Image based sensor efficiency

E = {56 / 12300.2} * 100 = 0.46%

E = 0.46%

4.1.4.2.2 Infrasound based Sensor Efficiency

E = {332 / 223.8} * 100 = 148.34%

E = 148.34%

4.1.4.2.3 Sensor Lifetime

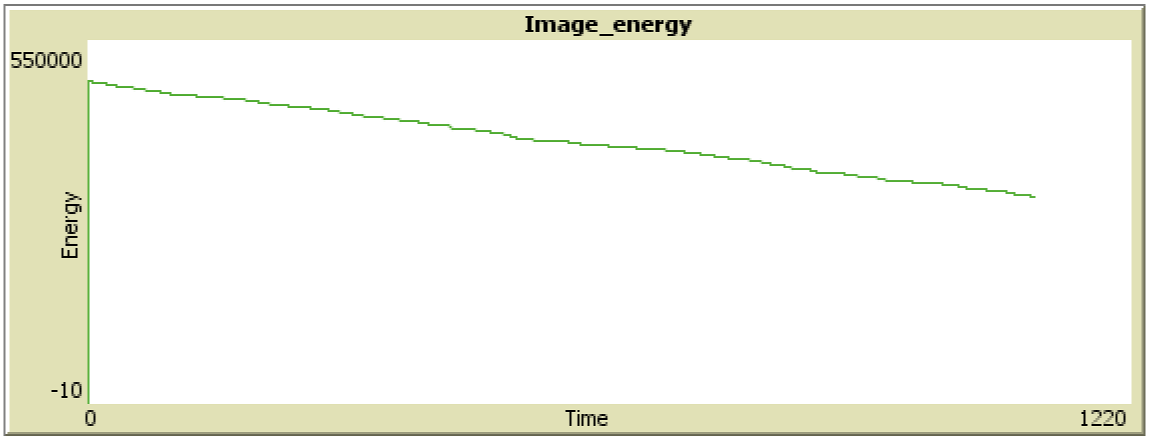

Figure 17Image based Sensor Energy consumption till the infrasound sensor died-off

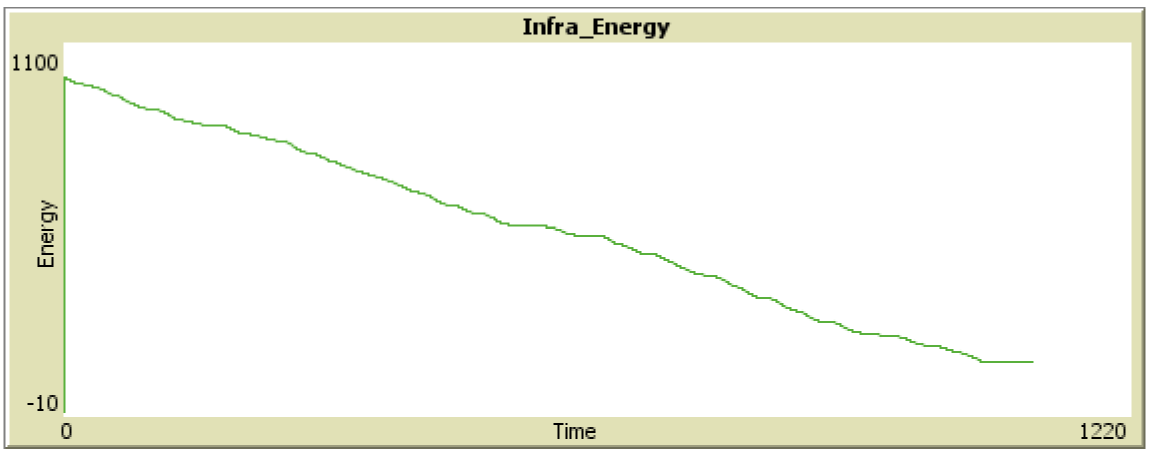

Figure 18InfraSound based Sensor Energy consumption till the infrasound sensor died-off

Figure 17 and 18 above shows the graph of both sensors showing remaining energy when one of the sensors is unable to sense any longer. By the time the Infrasound based sensor "dies off" due to low energy the Image based sensor has only utilized about a third of its energy. It still has about 538 units of energy left as shown in Table 4 below;

Time	Image Based Sensor Energy Remaining	Infrasound based sensor Energy Remaining
1053	322935.6	149.2

Table 5Remainaing Energy when one sensor is unable to sense any longer

4.1.4.3 Summary

In summary by looking at the detection radius, Energy utilization and the number of detections we have gotten this summary. Table 5 below shows the area coverage efficiency and detection efficiency of the two sensors.

Efficiency	Image Based Sensor	Infrasound Based Sensor
Area Coverage Efficiency	2	98
Detection Efficiency	0.46%	148.34%
Energy Utilization Ratio	199	1

Table 5Summary of area coverage efficiency, detection efficiency and Energy Utilization Ratio

CHAPTER FIVE

5.1 CONCLUSION AND RECOMMENDATION

In this chapter we look at the conclusions gotten from the study, make recommendations and point out areas that can be studied in future. It is key to note that this study was purely exploration and used a comparative analysis and therefore generalizations cannot be made as it only looked into two case studies.

The field of IoT is growing and the application of WSN for HEC has just begun. This study offered us a platform to study how IoT can be applied to solve real world problems and it goes ahead to prove how the use of multi-agent systems can be used during the design phase of such projects to help in decision making.

5.1.1 Conclusion

By analyzing the output from the simulation which formed the data and results from this study it was shown that infrasound based sensors have a higher efficiency than image based sensors. It was also shown that an infrasound based sensors has a higher detection rate of true positives and it has a higher detection range efficiency as well.

Although infrasound based sensors consumed more power during signal detection and energy is only utilized when a positive signal is identified it has been shown that over time they consume more energy. The image based sensors utilized a lot of energy because of the false positive detections and the number of sensors that were deployed to cover the whole area.

From this study we established battery power was a common factor that affected the detection of elephants when using either technology. Other factors were specific to the technology. To begin with, the following factors affected the detection of elephants using image based sensors; signal source distance, the angle of image capture, the database of images, and light intensity. On the other hand, factors affecting infrasound sensor based elephant detection were; signal source distance and the signal source.

This study concluded that between Image based WSN and Infrasound based WSN, Infrasound based WSN are more efficient in terms of area coverage and detection efficiency and hence a more superior technology for early elephant detection for HEC. It is also key to note that the infrasound based sensor has a shorter battery life than an image based sensor.

5.1.2 Recommendation

Based on the results of this research we recommend an Efficiency matrix when designing WSN that looks at both area coverage efficiency and detection efficiency. From the research detection efficiency far outweighed area coverage efficiency. We believe that area coverage efficiency affects the cost by dictating the number of nodes to deploy and with the advances in technology we foresee a day where the technology will be affordable regardless of the technology.

We also recommend a pro-active monitoring of battery power and management of the same to ensure that at no time does the battery go below the required operating requirements. Solar powered batteries have been proposed as a way to re-charge the battery. Power utilization is also an area that needs to be looked into to reduce as much as possible and thus increase the lifetime of the WSN. Image based sensors were identified to have relatively short detection ranges, as such the issue of early detection can be challenged as to how early they are able to relay the detection and whether the time of detection allows for a proper reaction. Sensors need to have a larger detection range that would address this issue. The central processing unit also needs to have a very up-to-date database of images to reduce the chances of false negatives. AI algorithms that can be trained over time have been proposed as an even better analysis technology. Opening up the system to allow contribution of images from external sources even gives the system a larger dataset of images to work with. The cameras used to capture images need to be able to capture in even low intensity light to be able to capture legible images that can produce better matches.

As explained earlier infrasound based sensors are majorly affected by two factors when detecting elephants; - the signal source distance and the signal source. Infrasound can be detected over very large distances and therefore any sound with such frequencies is registered as a detection. We recommend the use of sensors with variable detection ranges so as to avoid alerts that may never suffice as dangerous. On signal source we recommend the use of not only signal frequency range detection but also filtering based on the unique patterns produced by each object that produces infrasound. This will allow the solution to be deployed even in areas where multiple sources of infrasound can be experienced.

We further recommend future study into the areas we have highlighted below.

5.1.3 Future Study

We conducted a test whereby we set the energy consumption and detection range for both sensors to be the same. The results showed a different scenario as below which speaks to the optimizations that can enhance the solution.

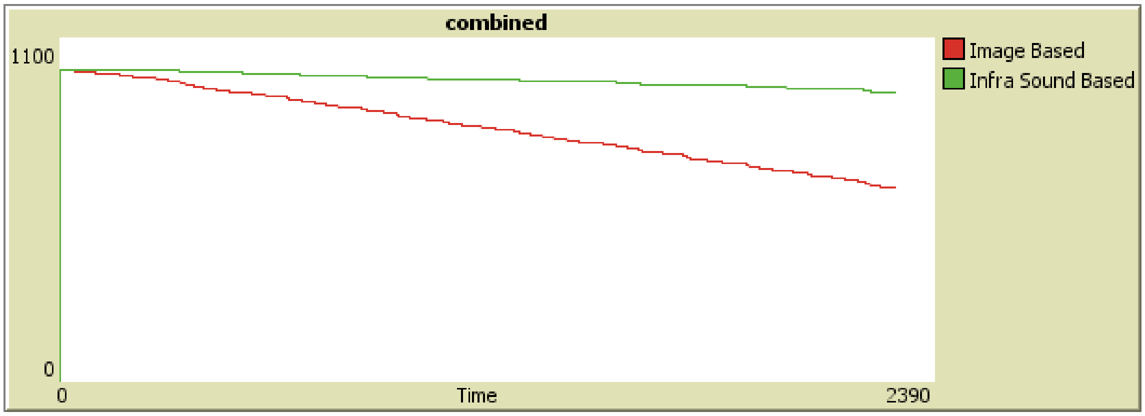

Table 6Combined Remaining Energy on both sensors when Detection range and sensor energy consumption is same

Unlike in the setup before this setup shows a trend whereby the image based sensor “dies-off” faster than the infrasound based sensor.

The field of IoT is on a high growth rate that has been accelerated by advances in technology that has led to cheaper components and high availability of these components. There are several areas of study that can be taken from this study. They include; (1) The effects of Node deployment on efficiency of infrasound sensor networks. (2) The optimization of sensor nodes in high ambient noise environments. (3) Optimization of motion sensor triggers as a signal capture activator mechanism.

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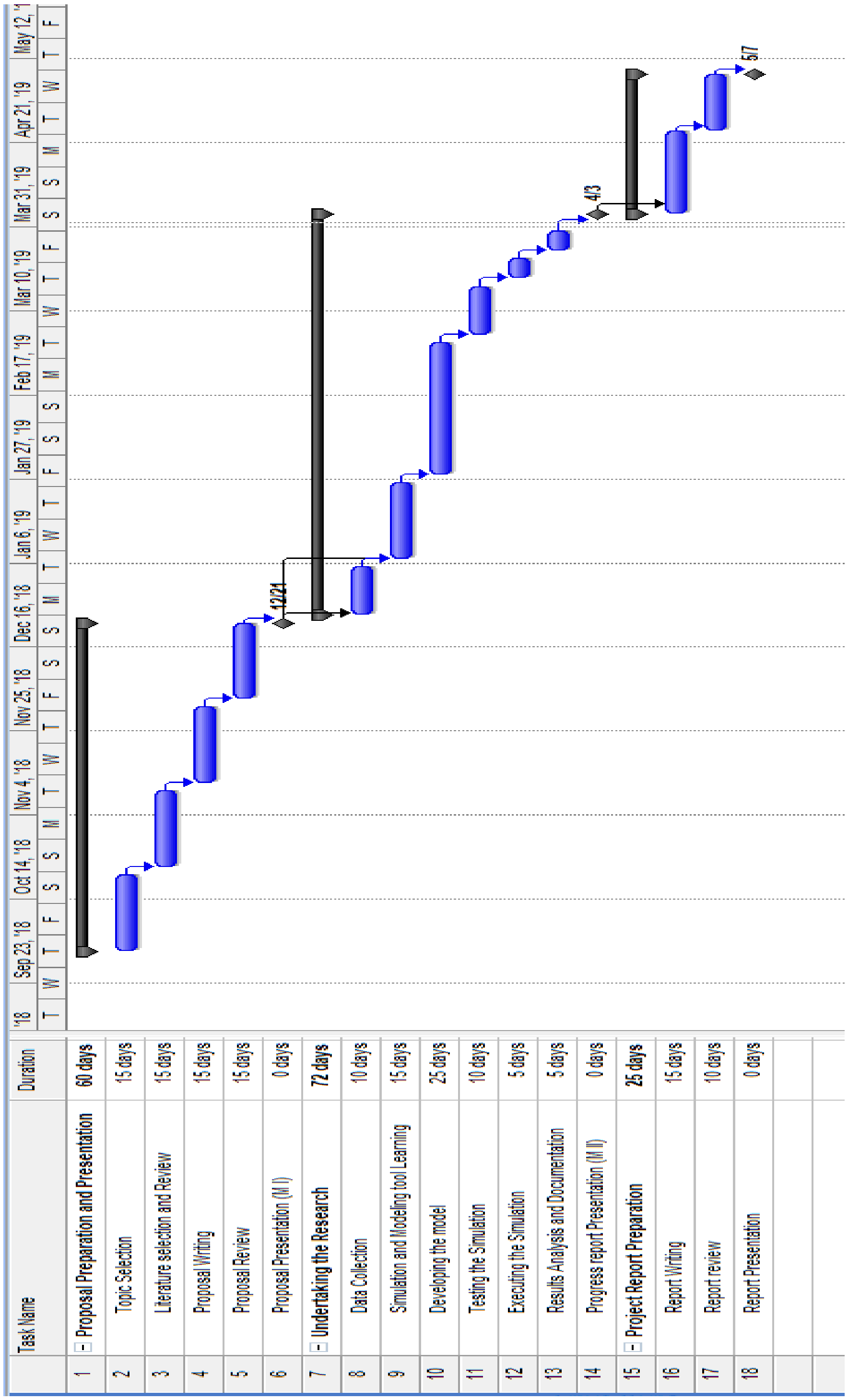
APPENDIX I: PROJECT SCHEDULE



APPENDIX II: PROJECT BUDGET

	Expense	**Amount**	
	Stationery & Printing	10,000.00	
	Transport Charges	15,000.00	
	Data Charges	18,000.00	
	Report Binding	6,000.00	
	Miscellaneous	10,000.00	
	Total	**59,000.00**	

APPENDIX III: DATA COLLECTED FROM THE SIMULATION

The following data items were collected from the simulation and were used for analysis.

Image_Energy.csv Infra_Energy.csv

Image_Energy.csv contains the energy level at each NetLogo time unit for the image based sensor.

Infra_energy.csv contains the energy level at each NetLogo time unit for the infrasound based sensor.

image_detections.csv Infra_detections.csv

Image_detections.csv contains the number of true positives and false positives detected at each NetLogo time unit by the image based sensor.

Infra_detections.csv contains the number of true positives and false positives detected at each NetLogo time unit by the image based sensor

Animal Distribution.csv combined.csv

Animal Distribution.csv contains the number of animals detected at each NetLogo time unit within the detection radius.

Combined.csv shows the energy levels at each NetLogo time units of each of the sensors combined into one spreadsheet.