

**UNIVERSITY OF GHANA**

**COLLEGE OF BASIC AND APPLIED SCIENCES**



**HABITUATION PREVENTION IN THE USE OF ULTRASONIC FRUIT  
FLY CONTROL SYSTEMS USING THE SCARE-PATH AND  
SHEPHERDING ALGORITHM**

**BY**

**MIKE-BERG SITSOFE AFU**

**(10552681)**

**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN  
PARTIAL FULFILLMENT OF THE AWARD OF MASTER OF  
PHILOSOPHY IN COMPUTER SCIENCE**

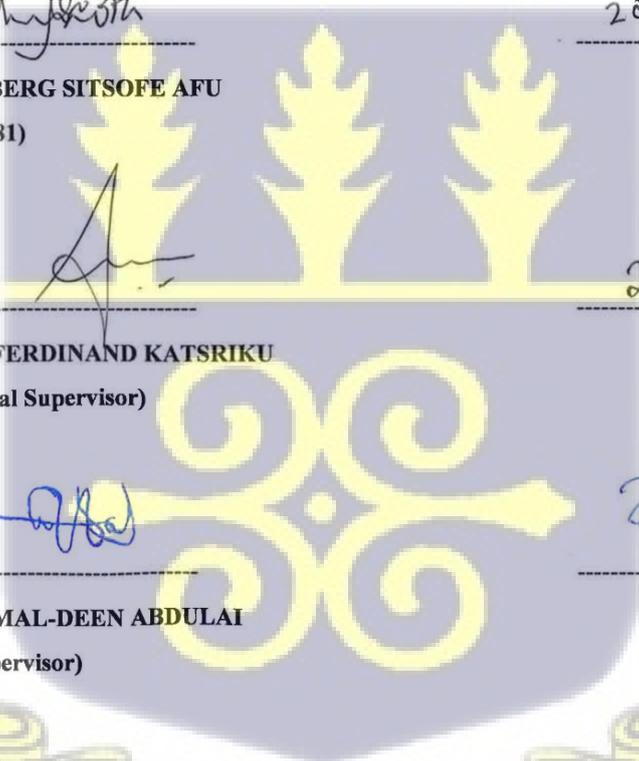


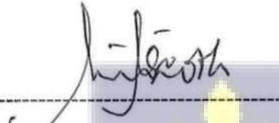
**DEPARTMENT OF COMPUTER SCIENCE**

**JANUARY, 2023**

## DECLARATION

I AFU Mike-Berg Sitsofe hereby declare that this thesis/dissertation: “**Habituation Prevention in the use of Ultrasonic Fruit Fly Control Systems using the Scare-Path and Shepherding Algorithm**” was carried out by me under the supervision of the Department of Computer Science, University of Ghana, Legon. And that no previous submission on this topic has been made to this University or any other institution for any award. Related works by others have been duly acknowledged by references to the authors.



 ----- <b>MIKE-BERG SITSOFE AFU</b> (10552681)	20 / 11 / 23 ----- <b>DATE</b>
 ----- <b>PROF. FERDINAND KATSIKU</b> (Principal Supervisor)	20 / 11 / 23 ----- <b>DATE</b>
 ----- <b>DR. JAMAL-DEEN ABDULAI</b> (Co-Supervisor)	20 / 11 / 23 ----- <b>DATE</b>

  
INTEGRI PROCEDAMUS

## DEDICATION

I dedicate this work to the Almighty God who has been with me throughout this journey, and to my friend, work colleagues and family for the continues and relentless support.



## ACKNOWLEDGEMENT

I extend my deepest gratitude and goodwill to my supervisors, Prof. Ferdinand Katsriku and Dr. Jamal-Deen Abdulai. Their contributions in form of guidance, advice and corrections brought me this far. I also thank the staff of the Department of Computer Science, and my colleagues who urged me on through my tough times, God bless you.



## ABSTRACT

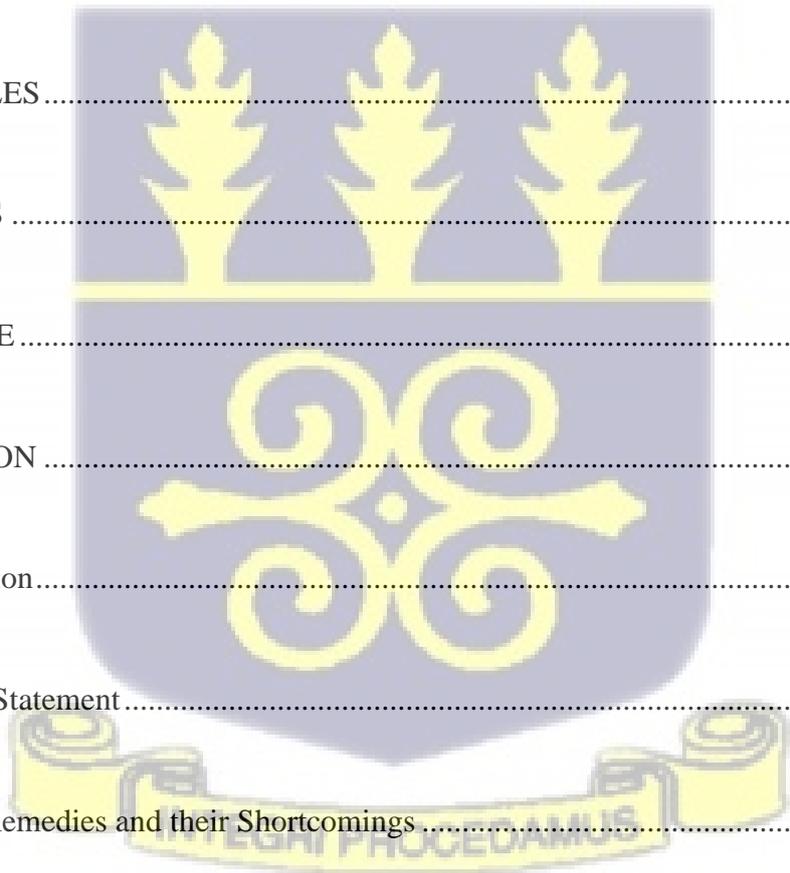
The cultivation of mangoes has emerged as a significant cash crop in Ghana, driven by both domestic and international demand. However, farmers face a significant challenge in the form of fruit fly infestations. Current mitigation strategies include the use of rubber bags to protect flowering plants and the application of pesticides. The former can sometimes reduce yield if the bag is not removed correctly or at the appropriate time to facilitate pollination. The latter is increasingly discouraged due to environmental concerns.

In response to these challenges, we propose an ultrasonic control method for fruit flies. However, continuous ultrasonic broadcasting can lead to habituation, rendering the method ineffective over time. To overcome this, we introduce the "listen before broadcast" technique, supported by our novel "scare-path and shepherding" algorithm. This approach involves a sensing node that detects incoming fruit flies based on the frequency of their wing flaps and other physical or behavioural characteristics. The sensing method is inspired by the high-clutter prey identification strategy employed by foraging bats.

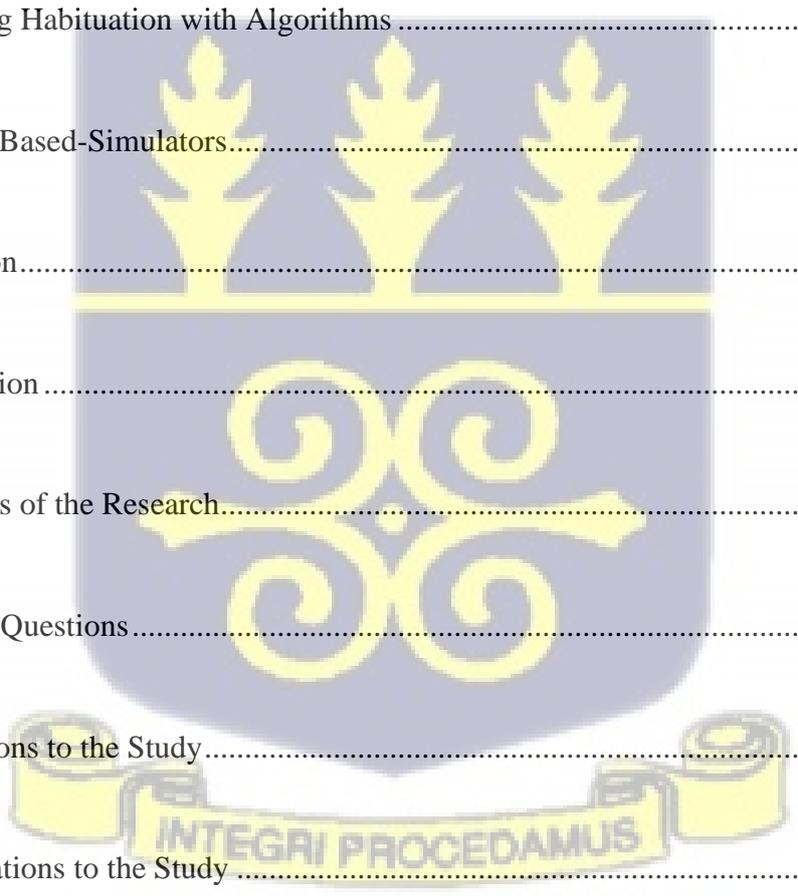
The introduction of our habituation mitigation method, combined with the scare-path and shepherding algorithm, has yielded promising results. According to our simulation data, less than 10% of fruit flies were able to penetrate the inner perimeter of a mango plantation. These findings represent a significant milestone in the ongoing research into habituation prevention, with potential applications extending beyond agriculture to the general use of ultrasonic devices for pest control.

## TABLE OF CONTENT

DECLARATION .....	i
DEDICATION .....	ii
ACKNOWLEDGEMENT .....	iii
ABSTRACT.....	iv
TABLE OF CONTENT .....	v
LIST OF TABLES .....	xii
LIST FIGURES .....	xiii
CHAPTER ONE .....	1
INTRODUCTION .....	1
1.0 Introduction.....	1
1.2 Problem Statement.....	2
1.3 Current Remedies and their Shortcomings .....	3
1.4 Application of WSNs.....	4
1.4.1 Precision Agriculture .....	5



1.4.2 Disaster Relief and crisis management .....	6
1.4.3 Medical monitoring.....	7
1.4.4 Military and defence .....	7
1.4.5 Transportation .....	8
1.4.5 Industrial Automation .....	9
1.4.5 Environmental monitoring.....	9
1.5 Solving Habituation with Algorithms .....	10
1.6 Agent Based-Simulators.....	10
1.6 Motivation.....	11
1.7 Contribution .....	12
1.8 Objectives of the Research.....	13
1.9 Research Questions.....	13
1.10 Limitations to the Study.....	14
1.11 Delimitations to the Study .....	14
1.12 Organisation.....	15
CHAPTER TWO .....	16



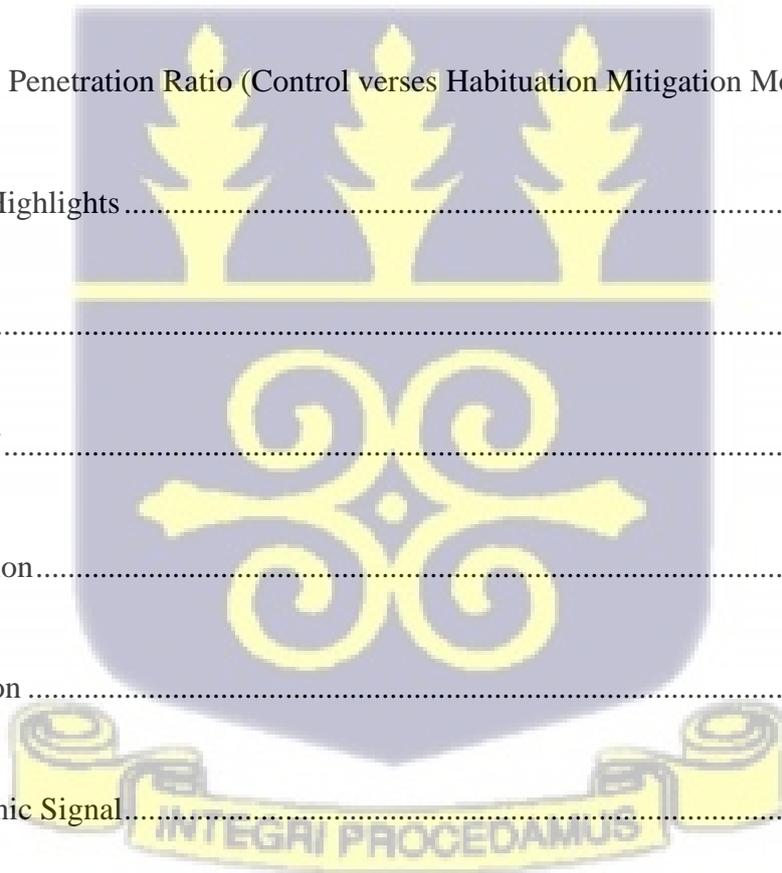
RELATED LITERATURE.....	16
2.0 Introduction.....	16
2.1 Technology and Automation in Agriculture.....	16
2.2 Wireless Sensor Network in Agriculture.....	17
2.2.1 Setbacks of Using Wireless Sensor Nodes in Agriculture.....	20
2.3 Pest Control in Crop Production – The New Paradigm.....	21
2.4 Fruit-fly Pest Control in Mango Production – Current Trends.....	22
2.5 Evolution of Insect Hearing.....	26
2.5.1 Ultrasound Avoidance Behaviour.....	28
2.5.2 Using Ultrasonic for Predator Avoidance.....	28
2.6 Detecting Ultrasonic broadcast from Flies (“The Bat Technique”).....	30
2.6.1 Perceptual problems for foraging bats.....	30
2.6.2 Signals Adapted for Specific Tasks.....	31
2.6.3 Narrowband Signals.....	32
2.6.4 Broadband Signals.....	33
2.6.5 The Masking Problem.....	33

2.6.6 Search Signals of Insect-Eating Bats .....	38
2.6.7 Other Meaningful Categorizations of Bats .....	39
2.6.8 Effect of Bat Echolocation Behaviour on Sense-Before-Broadcast Technique. ....	40
2.7 Design and Implementation of Software Algorithms .....	41
2.8 Agent-Based Model for Simulation .....	42
2.8.1 Characteristics of Agents in Agent-Based Modelling .....	44
2.8.2 Repast Symphony Simulation.....	45
CHAPTER THREE .....	48
METHODOLOGY .....	48
3.0 Introduction.....	48
3.1 Conceptual Framework.....	48
3.2 Scope of Experiment.....	50
3.2.1 Ultrasonic Devices .....	50
3.2.2 Habituation.....	52
3.2.3 Ultrasonic Communication .....	53
3.2.4 Predator Avoidance and Auditory Disturbance Ultrasonic .....	54

3.3 Theoretical Framework.....	56
3.4 Methods of Analysis .....	57
3.4.1 Simulation Steps .....	57
3.4.2 Simulation Set-up.....	58
3.4.3 Listen-Broadcast Technique .....	60
3.4.4 Scare-Path Algorithm Implementation .....	62
3.4.5 Principle of Separation.....	63
3.4.6 Principle of Cohesion.....	65
3.4.7 Principle of Alignment.....	66
3.5 Types of Data and Sources .....	67
3.6 Sample Size.....	68
3.7 Chapter Highlights .....	68
CHAPTER FOUR.....	70
RESULTS AND DISCUSSION .....	70
4.0 Introduction.....	70
4.1 The Simulation Run Results .....	70



4.1.1 Configuration Condition of Controlled Experiment.....	71
4.1.2 Controlled Experiment Simulation Results .....	72
4.1.3 Habituation Mitigation Model Simulation Results .....	73
4.2 Listen and Broadcast Ratio .....	75
4.3 Results Based on Communication, Avoidance and Disturbance Broadcasts .....	76
4.4 Results Based on the Comparison of Listen/Broadcast Ration with Fruitflies Penetration over time .....	78
4.5 Fruit flies Penetration Ratio (Control verses Habituation Mitigation Model).....	79
4.5 Chapter Highlights .....	80
CHAPTER 5 .....	81
CONCLUSION.....	81
5.0 Introduction.....	81
5.1 Conclusion .....	82
5.1.1 Ultrasonic Signal.....	82
5.1.2 Ultrasonic Signal Sensing using WSNs.....	83
5.1.3 Ultrasonic Signal Broadcasting using Array of Audio Nodes .....	83



5.1.4 Habituation.....	84
5.1.5 Scare-path and shepherding algorithm.....	84
5.2 Recommendation .....	85
References.....	86
APPENDIX.....	100



## LIST OF TABLES

Table 1: Scare-Path Process Table..... 62

Table 2: Controlled and HPM Simulation Configuration Table..... 71



## LIST FIGURES

Figure 1: <i>Bactrocera invadens</i> laying eggs in a mango fruit. ....	23
Figure 2: Devastating Effects of Fruit fly .....	24
Figure 3: A variety of insects with auditory organ adapted for hearing bats .....	27
Figure 4: Search and approach signals of foraging bats. (a–e) Signals of bats that captured a flying insect at the end of the sequence. (f, g) Signals of bats that gleaned insects from a surface at the end of the sequence, (f ) out of continuous search flight and (g) after the prey has been detected from a perch. In all sequences the increase in repetition rate and the reduction of sound duration indicate the switching from search to approach phase. Note the distinct terminal phase in bats that captured flying insects (a–e).....	32
Figure 5: Schematic diagram of the masking situation for a bat foraging near vegetation and emitting signals with a duration of 6 ms. The prey echo overlaps the emitted signal when the insect flies in the signal-overlap zone, and it overlaps the clutter echoes when it flies in the clutter-overlap zone. No overlap occurs when the insect flies in the overlap-free window. At a distance of 2 m the overlap-free window is closed, and for the given signal duration the bat has reached the minimum gap size where overlap-free echolocation is impossible .....	35
Figure 6: Schematic diagram of the input into the auditory system of bats that forage in different clutter situations. The emitted pulse and the returning insect echo are depicted in black. (a) In uncluttered space, the pulse echo–pair is far from clutter echoes. (b) In background-	

cluttered space, the pulse–echo pair is followed by clutter echoes (depicted in white). (c, d) In highly cluttered space, the target echo is buried in overlapping clutter echoes. Sound duration and envelope form correspond to search signals typical for the different spaces: (a) QCF signal of an open-space forager; (b) broadband FM–QCF signal of an edge and gap forager; (c) broadband FM signal of a narrow-space “FM” forager; (d) long CF–FM signal of a narrow-space “CF” forager; the echo shows amplitude modulations, or glints, created by the beating wings of an insect. .... 37

Figure 7: Examples of various search signals and their associated habitat types. Note that bats may leave their preferred space for a less-cluttered space but not the reverse. (a) *Tadarida teniotis*, (b) *Pipistrellus pipistrellus*, (c) *Pteronotus macleayii*, (d) *Myotis myotis*, (e) *Trachops cirrhosus*, (f) *Rhinolophus ferrumequinum*..... 39

Figure 8: Concept Flow-chart ..... 49

Figure 9: Communication Broadcast in the inner-perimeter ..... 54

Figure 10: Predator Sound Broadcast Outer-Perimeter ..... 56

Figure 11: Fruitfly (Agent) Simulation steps ..... 58

Figure 12: The mango tree Agent Model ..... 59

Figure 13: The fruitfly Agent Model ..... 60

Figure 14: Listen-Broadcast Diagram ..... 61

Figure 15: Separation in flocking implementation: ..... 64

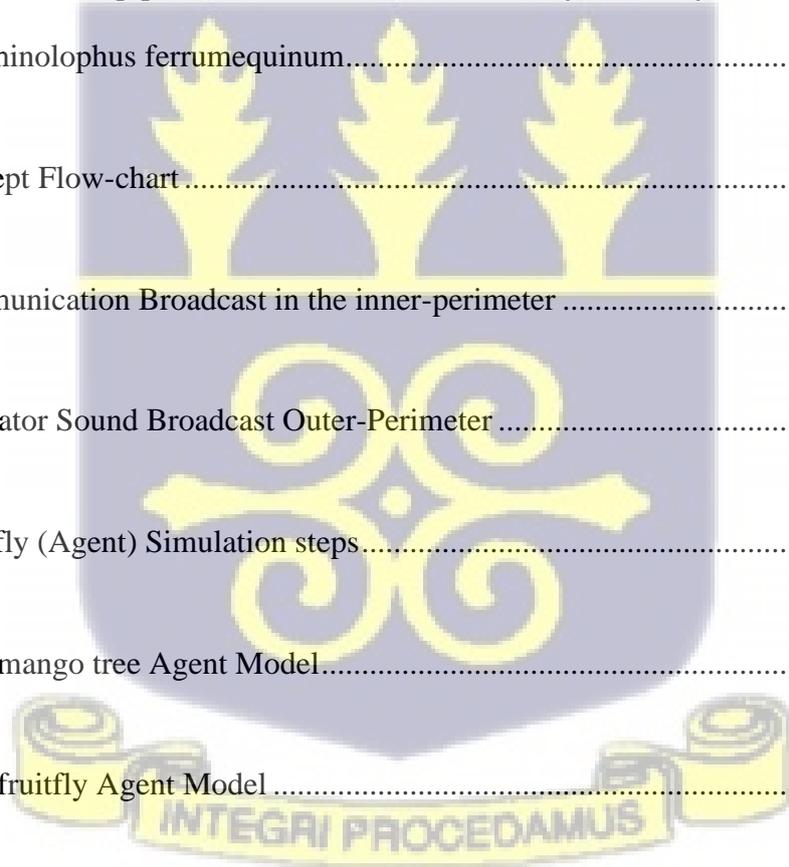


Figure 16: Cohesion in flocking implementation ..... 65

Figure 17: Alignment in flocking implementation ..... 67

Figure 18: Fruitfly Penetration Rate Result (Controlled Experiment)..... 72

Figure 19: Fruitfly Penetration Rate Result (Application of HPF):..... 73

Figure 20: WSN listen versus broadcast and sound intensity versus distance ratio ..... 75

Figure 21: WSN listen, broadcast and fruitflies cluster positions ratio ..... 77

Figure 22: WSN listen, broadcast and fruitflies cluster positions ratio ..... 78

Figure 23: WSN listen, broadcast and fruitflies cluster positions ratio ..... 79

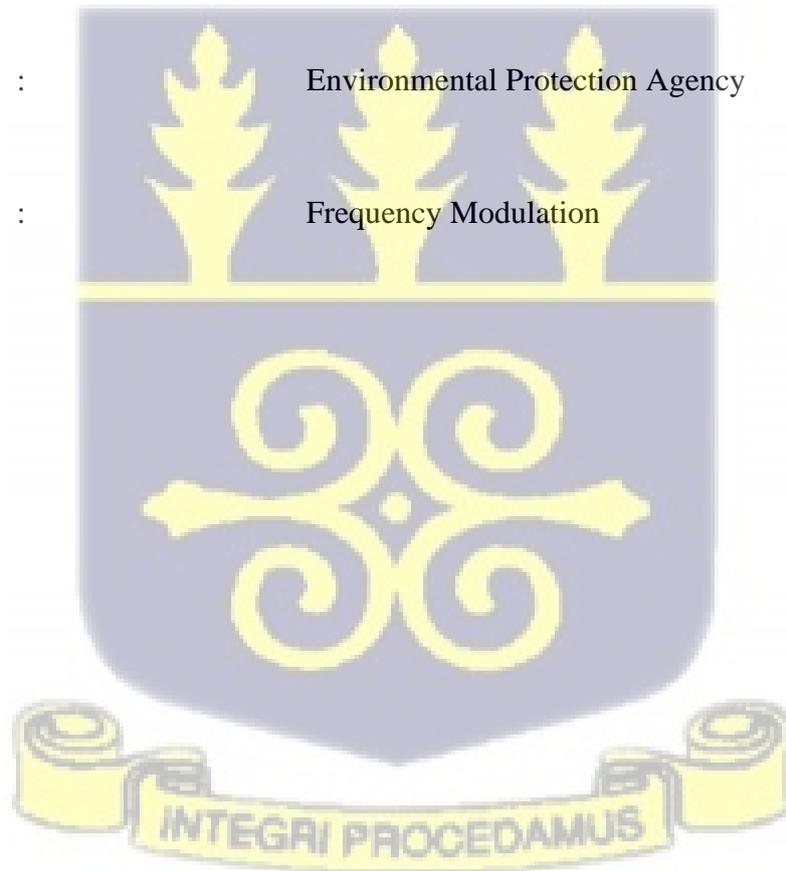


## ACRONYMS AND ABBREVIATIONS

<b>WSN</b>	:	Wireless Sensor Network
<b>HPF</b>	:	Habituation Prevention Framework
<b>IDE</b>	:	Integrated Development Environment
<b>RAST S</b>	:	Repast Simphony

**EPA** : Environmental Protection Agency

**FM** : Frequency Modulation



## CHAPTER ONE

### INTRODUCTION

#### 1.0 Introduction

According to (Forbes, 2023), (Harvard Business Review, 2022), and (The World Economic Forum, 2022), the surge in the application of technology in all human endeavour requires that more innovation be applied in the implementation of hardware and software (algorithms) to achieve efficiency. The above statement implies that technology should not just be applied to an area of human activity because the tools are available to be applied but emphasis must also be placed on how well the applied technology in the area of need is efficient in solving the identified problem without introducing a new problem to the society.

Agriculture has become sophisticated such that crop and animal production is no more a matter of chance or “the natural flow”. Conscious efforts must be made to improve yield. Using scientific and technological advances in determining what specific inputs and processes are needed to increase yield in food production is key in this era where due to the availability of information, many people have become conscious of what they want eat as food (Forbes, 2023).

In order to increase productivity and improve the quality of food we consume in general, automated technologies have become a major requirement in the agriculture space. Many devices that can sense the environment and if the need be take action have to be deployed on a fast pace in order to improve the output of agricultural activities. Wireless Sensor Networks and other sensing technologies have become important tools that have provided the medium for transforming the agricultural space. The introduction of sensing technologies in agriculture have help minimise human errors and fatigue in the application and management of agronomic practises (Keshtgari, & Deljoo, 2012).

However, the introduction of a technological system such the ultrasonic pest control system is humped by habituation. Habituation is a major problem with ultrasonic pest control devices. While the devices are designed to deter specific pests such as rodents and insects by emitting ultrasonic sound waves as a repellent, the pests may eventually become accustomed to the sound rather than avoid it, thereby reducing the effectiveness of the device (This Old House Reviews Team, 2023; Lutz, 2023).

Research has indicated that a majority of pests are able to habituate to ultrasonic devices (McGill University, 2017; University of Arizona, 2015; This Old House Reviews Team, 2023) therefore using these devices in controlling fruit flies in order to improve fruit quality for both export and domestic consumption becomes difficult hence the need for the development of a scare-path and shepherding algorithm to improve the effectiveness of these devices.

## **1.2 Problem Statement**

The exotic mango, known for its refined taste, is experiencing a decline in its appeal due to the infestation of the fruit fly (Niassy et al., 2023). The assurance of harvesting high-quality, exportable fruit is compromised as fruit flies lay their eggs during the mango's flowering stage. This results in the larvae hatching within the fruit once it has formed, significantly impacting its quality and marketability.

The application of ultrasonic technology for the control of fruit fly infestations in mango plantations has shown potential, but its effectiveness is compromised over time due to a phenomenon known as habituation. This research aims to address this challenge by developing a novel “scare-path and shepherding” algorithm to enhance the efficacy of ultrasonic pest control methods.

This issue is of significant importance given the global status of mango as the second most traded tropical fruit and fifth in terms of production, following citrus, apple, and banana (Mwaurah et al., 2020).

Despite the high demand for this nutritionally and economically valuable fruit, international trade is limited, with global transactions accounting for just over 2.5% of world production (Zakari, 2012). This limitation is largely due to the susceptibility of exotic mango varieties, which are preferred in the international market, to pest infestations, particularly from the fruit fly (*Drosophila Melanogaster*) (Abdullahi et al., 2011a). These flies lay their eggs in flowering mango fruits, leading to larvae hatching within the fruit and causing significant damage.

Therefore, the development of an effective and sustainable pest control method is crucial to enhance the quality and marketability of mangoes, thereby contributing to the growth of the global mango industry.

### **1.3 Current Remedies and their Shortcomings**

The two major remedies used to curtail the problem of fruit flies laying eggs in the mango fruit, some of the remedies implemented by farmers are the wearing of polyethene bags around individual mango tress during the flowering period of the fruit (Deku et al., 2021) and (Rubagumya et al., 2023). This method is applied immediately after pollination has happen because the pollinating insects of the mango fruit are of similar body size as the fruit flies and if not timely remove may result in a non-pollinated mango fruit.

Another important fruit flies control method is the use of pesticide at the early stages of the mango fruit development. The application method of pesticides in mango production within this

period of early fruit development is called spot treatment (Vayssières et al., 2007). This is where specific spots of the mango fruit identified to have signs of fruit fly infestation are applied with pesticide.

It must be noted that the above approaches adopted to control and reduce the effects of these flies on the mango fruits unfortunately do not provide a full proof remedy to the problem. Additionally, they reduce the mango yield at the end of the cropping season because the nets reduce the amount of pollination due to it covering the flowering fruits. Also the remedy presented additional cost to the environment due to use of chemicals, loss or misuse of man-hour on controlling fruit flies when that could be used to add acres of mango plantation. Where the farmers have enough resources to increase the farm size, he or she is discouraged due to the additional work that may be involved in implementing fruit fly control measures.

It is also observed that when the above control measures are implemented, the mean mortality ranged from 0 to 60% for eggs, nymphs, and adults (Deku et al., 2021) This indicates that approximately 40% plus of eggs and other hosts are available to cause harm during the cropping season for the mango fruits which usually results in additional losses apart from post-harvest losses. The percentage of the mango fruit lost during the harvesting season varies from season to season. For a rough estimate, about 20% to 60% percent of post-harvest losses occur in mango production and out of this, between 20% and 45% are as a result of fruit flies. Only 10% to 15% is as a result of other causes such as inadequate post-harvest storage facilities (Li et al., 2008) among others.

#### **1.4 Application of WSNs**

In the current technological era, wireless sensor networks (WSNs) have become one of the most widely utilized technologies, with applications spanning various fields. The recent

advancements in micro-sensor technology have enabled low-powered sensing in numerous applications, opening up opportunities for managing, monitoring, and controlling activities within the agricultural sector (Wireless Sensor Networks in Agriculture: Insights from Bibliometric, 2021; A Review on Precision Agriculture Using Wireless Sensor Networks, 2020).

WSNs can provide robust services in hostile or inaccessible environments where human intervention may be dangerous or nearly impossible. This technology holds promise for a multitude of applications in areas such as medical, military, transportation, entertainment, crisis management, disaster relief operations, homeland defense, and smart spaces (Sensor Based Smart Agriculture with IoT Technologies: A Review, 2023). It is projected that in the near future, WSNs will become an integral and essential aspect of our lives (Sensor Based Smart Agriculture with IoT Technologies: A Review, 2023). The continuous evolution and integration of WSNs in various sectors underscore the importance of this technology in shaping our future (Sensor Based Smart Agriculture with IoT Technologies: A Review, 2023).

#### **1.4.1 Precision Agriculture**

One major aspect of our lives that has become important for the application of technology is agriculture. This has become necessary with the increasing world population (Roser et al., 2020) and the need for abundant nutritious food (Kaini, 2020). In recent times, agriculture has become one of the major beneficiaries of innovations in technology to improve yield, and reduce pre-harvest and post-harvest losses.

This work focuses on improving the quality of mango fruits through use of ultrasonic fruit fly scare system designed with wireless sensor nodes for sensing the presence of fruit flies and arrays of ultrasonic emitting microphones.

Most of these sensing technologies cannot be profitable and do what is expected of them without the provision of custom problem-solving algorithms to receive and process the data appropriately. To be useful in the agriculture space, agricultural task-oriented software must be written and deployed to receive, analysed and make sense of the data from these sensing devices. One such important software created within the Habituation Prevention Framework of this research is called the *scare path and shepherding algorithm* developed by the author of this work.

This algorithm relies on the fruit flies hearing, to implement a coordinated listen and broadcast cycle of ultrasonics sound which is either friendly or hostile to the fruit flies depending on the motion path sensed by the sensing nodes and the type of sound being broadcasted by the broadcasting nodes. This enables the shepherding of the fruit flies away from the mango farm. The robustness and productive nature of this algorithm is what provided the foundation for this research on Using Scare Path and Shepherding Algorithm to Prevent Habituation of Fruit flies to Ultrasonic Sound in Ultrasonic Fruit fly Control Systems.

Other applications of WSN are outlined as follows

#### **1.4.2 Disaster Relief and crisis management**

In disaster management, WSNs are deployed in many scenarios which includes monitoring and providing feedback about the status of the situations within the disaster environment in such cases where human personnel may be not able to access the area of the disaster either due to distance or the hazardous nature of the disaster or crises environment. Feedbacks from the sensing nodes are used to make informed decision in order to avert the crisis.

### 1.4.3 Medical monitoring

With WSN, medical practitioners are able to implant devices and monitor into the bodies of their patients they wish to monitor to collect important data in order to make informed decision about their health. Specifically, they can be used to monitor patient vital signs, such as heart rate, blood pressure, and body temperature (Zhou, Liu, & Song, 2016). These devices can be worn by the patient, and the collected data is transmitted wirelessly to a central location where it can be monitored by healthcare professionals. This can help to identify potential problems early, and allow for timely interventions to prevent complications. In addition, wireless sensor nodes can be used to monitor the environment in hospitals and other healthcare facilities, such as air quality and temperature, to ensure that patients are being treated in optimal conditions.

### 1.4.4 Military and defence

Wireless sensor nodes are widely used in military and defence applications to improve situational awareness, surveillance, and security. Some examples of the use of wireless sensor nodes in military and defence are:

**Border control:** Wireless sensor nodes can be deployed along borders to monitor for unauthorized crossings and to detect potential threats (Gao, Wang, & Zhu, 2016). They can be equipped with sensors to detect movement, sound, and other anomalies, and can transmit this information wirelessly to a central location for analysis and response.

**Perimeter protection:** Wireless sensor network can be used to protect military bases, critical infrastructure, and other sensitive locations from unauthorized access or tampering (Cheng, Chen, & Li, 2015). They can be equipped with sensors to detect movement, sound, and other anomalies, and can alert security personnel in the event of a potential threat.

**Surveillance:** Wireless sensor nodes can be used to gather intelligence and to monitor enemy movements and activities (Wang et al., 2016). They can be deployed in a variety of environments, including land, sea, and air, and can be equipped with sensors to detect a wide range of signals and signals.

**Mine detection:** Wireless sensor network can be used to detect and locate mines and other explosive devices (Zhou, Hu, & Li, 2017). They can be deployed in a variety of environments, including land, sea, and air, and can be equipped with sensors to detect metal, chemical, and other types of mines.

### 1.4.5 Transportation

Wireless sensor nodes are widely used in transportation applications to improve efficiency, safety, and comfort. Wireless sensor network can be applied in area of transportation for traffic monitoring, public transport automation, logistics and supply chain management and aviation. The particular application in the specific areas have been elaborated below.

**Traffic monitoring:** Wireless sensor network can be deployed in roads, bridges, and tunnels to monitor traffic conditions, such as vehicle count, speed, and occupancy (Lin & Chen, 2015). This data can be used to optimize traffic flow, reduce congestion, and improve safety.

**Public transportation:** Wireless sensor network can be used to monitor the performance and condition of buses, trains, and other forms of public transportation (Hao, Tan, & Zhang, 2016). For example, sensor nodes can be used to monitor the doors, brakes, and engines of buses, and to detect and diagnose problems before they occur.

**Logistics and supply chain management:** Wireless sensor network can be used to track the movement of goods in logistics and supply chain systems (Wang, Zhu, & Wang, 2017). For

example, sensor nodes can be attached to shipping containers to monitor their location, temperature, and humidity, and to ensure that the goods are being transported under optimal conditions.

**Aviation:** Wireless sensor network are used in the maintenance of aircraft to monitor the condition of critical components, such as engines and landing gear (Zhang, Li, & Zhang, 2016). They can also be used to monitor the environment in aircraft cabins, such as temperature and humidity, to ensure the comfort of passengers.

#### **1.4.5 Industrial Automation**

Wireless sensor network can be used to monitor and control industrial processes, such as production lines, machinery, and equipment (Wang et al., 2015). In these applications, the sensor nodes are used to gather data about the operating conditions of the machinery, such as temperature, vibration, and pressure. This data can then be used to optimize the performance of the machinery, to predict when maintenance is needed, and to detect and diagnose problems before they become serious.

#### **1.4.5 Environmental monitoring**

Wireless sensor network can be deployed in a variety of environments to monitor temperature, humidity, air quality, soil moisture, and other parameters (Mao, Wu, & Zhang, 2015). For example, they have been used to monitor air quality in urban environments (Liu, Hu, & Cao, 2016), to monitor soil moisture in agricultural fields (Cheng, Zhang, & Wang, 2017), and to monitor water quality in lakes and rivers (Yao, Zhang, & Li, 2016). In these cases, the sensor nodes are deployed in a network, and the collected data is transmitted wirelessly to a central location where it can be analysed and used to optimize environmental conditions.

Therefore, the main goal of this work is to deliver at the end, a topological and scare path framework that shepherds approaching fruit flies out of mango plantations so that their attack on the mango fruit can be minimised thereby increasing the yield and revenue accrued from the mango production.

### **1.5 Solving Habituation with Algorithms**

The primary objective in this work is to implement an algorithm for the mitigation of habituation in ultrasonic fruit fly control systems. Clearly, the problem of habituation exists in many of the ultrasonic repellents that can be found on the market currently (Nguyen et al., 2020; Beier & Pruitt, 2002). Using systems modelling tools such as flow-chart, pseudocode and simulation, the research will design and test the scare-path and shepherding algorithm for habituation prevention with a particular feature process known as the “Listen and Broadcast” technique.

The artifact of this research is created by following the processes outlined in the software algorithm creation process as indicated in the previous paragraph.

### **1.6 Agent Based-Simulators**

An Agent-based modelling is the prevailing tool for the simulation and modelling real-life scenarios by representing the actors within the live context as programmable agents that can be manipulated by software techniques to interact within the virtual environment as though it was real-life (Zargayouna et al., 2013). The technique provides researchers the opportunity to run their ideas against any scenarios that might be present or anticipated to be present in the real world of the actors. There are a number of specific tools or simulation applications that can be used to implement any agent-based model.

Repast Symphony is one of the popular agent-based simulators, it can be used in many fields to

simulate natural events such as crime rate analysis, migration studies, weapon defend systems designs, transportation, marketing, precision agriculture, etc (Furfaro & Sacco, 2019; Wenger et al., 2021; Zargayouna et al., 2013).

The Repast Symphony simulator has been selected to undertake this research due to the researcher's familiarity with the Integrated Development Environment (IDE) that it is associated with. Also, the primary programming language used is Java/Groovy which is the go to programming language of the researcher.

## 1.6 Motivation

In Ghana's effort to make mango a non-traditional export produce (Agency, 2013a), a number of initiatives have been embarked upon to increase yield and improve quality of the mango fruit. However, one major limitation to achieving the goal of making mango a primary source of foreign exchange commodity to Ghana is the effect of pests; especially the fruit fly (*Bactrocera invadens*) ((HDU-DCS), 2013)(Agency, 2013b).

Commercial mango production both for the domestic and export market has been around in Ghana just in the late 1990s (FAO, 2009). The industry, being relatively young, is facing huge challenges with post-harvest losses. The processing industry is not well developed and unable to absorb much of the produce. Both small and large scale commercial mango producers in the Dangme –West District (now the Shai-Osudoku District) had up to 50% and 35% fruit rejection due to decay and mechanical damages respectively.

Furthermore, Melle and Buschmann (2013) registered fruit loss of up to 40% of total production in the same districts. Zakari (2012) reported an annual post-harvest loss of between 20-25% of total mango produced by Farm Management Services Limited, a mango farming organization in

the Yilo Krobo Municipality. According to the study, only about 15% of the total mango produced by the organization met export grade or standard.

Even though some preventive measures like cutting down and burning infested mango trees, using fly traps and insecticides have been implemented, the problem still haunts mango plantation farmers (Abdullahi et al., 2011b) (GhanaWeb, 2014).

Farmers have tried preventive techniques that included the use of ultrasonic to scare the flies away but no scholarly work that has specifically tried to address the problem of habituation in the agriculture, specifically in the area of fruit fly control in mango production.

The main goal of this work is to address the issue of habituation associated with use of ultrasonic fruit fly control system within the agricultural space by using mango plantation and fruit fly pest control the implementation of a scare path algorithm deployed on Wireless Sensor Nodes and Audio Broadcast Nodes that efficiently implements an ultrasonic for controlling fruit flies on mango plantation that stands the test of time.

### **1.7 Contribution**

This work addresses the issue of habituation which is associated with the use of ultrasonic pest controls systems. The particular interest is in minimising problems related to habituation as a result of using ultrasonic pest control by continuous broadcast within the agricultural space. A practical scare and shepherding scheme in this area has a broad impact on improving mango fruit quality and many other reasons such as reduction of the impact of agricultural chemicals on the environment.

It's important to note that there's no consensus on the effectiveness of ultrasonic pest control devices, and this can be attributed to a variety of factors. (Forbes Home, 2022; This Old House

Reviews Team, 2023; Backyard Gardener, 2020; Think IPM Blog, 2016). One prominent among them is habituation; a situation where pests become used to the ultrasonic sound within 3-7 days of application (Schumake & Shumake ', 1995a). Therefore, this research broadly proposes an algorithm to mitigate habituation. It is also essential to note that, habituation occurs as a result of long-term use of ultrasonic devices for pest control.

## 1.8 Objectives of the Research

This research seeks to achieve the following objectives:

- Propose a habituation prevention algorithm which adopts the “detect and broadcast technique” with ultrasonic devices.
- Propose intelligent shepherding algorithm to create a scare-away path for the fruit flies.
- Simulate habituation prevention algorithm using Repast Symphony Agent-Based Simulator.

## 1.9 Research Questions

This research is seeking to answer the following research questions:

- Can detecting before broadcast of Ultrasonic signal be more effective in the prevention of Habituation among fruitflies when used as a pest-control device in the control of fruitflies?
- Can intelligent shepherding algorithm help scare-away fruit flies during its attack on a mango plantation?

- Can Repast Symphony Agent-Based Simulator Simulate the habituation prevention algorithms presented in this work?

The goal of this research will be accomplished by using Repast Symphony Agent-Based to simulate both the shepherding and scare-path algorithms.

### **1.10 Limitations to the Study**

The researcher was confronted with the under listed problems in carrying out the research work:

1. An array of audio broadcast node required but are not readily available on the market as an off-the-shelf device therefore the research resorted to use simulation.
2. Inadequate previous works on fruit fly response to ultrasonic, in terms of habituation and its application in the context of pest control in mango production in Ghana.

### **1.11 Delimitations to the Study**

Even though numerous problems were encountered during the execution of this research, a number of factors made it possible to complete this work successfully. Among the positives is the computer programming skill requirement for this research which was readily available because of the experienced programming background of the researcher.

Repast Symphony was one important tool that provided the opportunity to run various scenarios against this work to determine the best conditions under which both the scare-path and habituation prevention algorithm work efficiently. Repast Symphony is an agent-based simulation environment. Simulation setups are programmed using java programming language.

## 1.12 Organisation of Chapter

The arrangement of the rest of the work is as follows. This work begins with a survey of work related to this research. This work includes a broad range of disciplines; so related work is presented on precision agriculture, wireless sensor networks, algorithms, animal hearing and audio signal processing and agent-based simulations architecture. The related works focus on contributions that are closely related to this dissertation. After the related work is a thorough description of the hardware, software, and the algorithm used in this dissertation. This detailed system description is necessary for the complexity of the systems that are defined within our habituation prevention framework. This introduces HPFs' capabilities and limitations. An evaluation of the framework concludes these chapters to verify that the overall system is functioning properly.

Next, an introduction to the topological arrangement of listen and broadcast wireless nodes shepherding and scare-path algorithm is established. This cover determining how to place the L-B nodes based on the transmission power of the WSNs and the wavelength of the frequency in order not to result in dead zones. These contributions undergo extensive validation and mathematical modelling and testing. Included, are several experiments to validate the underlying ideas and test them in various frequency ranges within the ultrasonic spectrum. Using this procedure, this work is able to accurately measure the actual spacing that is required in the implementation of HPF within any pest prevention scenario within any mango plantation in Ghana. Furthermore, in order to verify the HPF's true robustness, Repast Symphony Agent-Based Simulator is used to simulate the topological framework components based on the mathematical models. This provided the means to test against all the possible scenarios within the real world. Finally, this dissertation concludes with a summary of the contributions and proposed future work.

## CHAPTER TWO

### RELATED LITERATURE

#### 2.0 Introduction

This chapter presents prior and existing work on wireless sensor networks solutions for precision agriculture, agent-based modelling and simulation with particular focus on sensory ecology and selective attention in insects' auditory neuron, audio signal processing, Repast Symphony Agent-Based Simulator and application of ultrasonic pest control systems in both domestic and agricultural settings.

This explores how these different areas contribute to developing systems of highly autonomous habituation prevention system to perform long-term environmental fruit fly control on mango plantations. The prior and existing works highlight common difficulties in this area, what is done to address the problem, and problems that are yet to be solved. Exploring these works motivate the contributions in the rest of this work and establishes the bases to which the rest of the content is developed.

#### 2.1 Technology and Automation in Agriculture

Agriculture has greatly benefited from increasing levels of technology and automation (Kondō et al., 2011). One of the largest impacts technologies has on agriculture is reducing the human labour needed for crop production. Increasingly large machines operate at greater speeds and perform more types of work on the field which reduces labour needs. Collectively, technological advances in sensing, automation, and farm management practices lead to precision agriculture. Precision agriculture uses advanced sensing, machinery, and farm management practices to precisely apply irrigation and fertiliser and create better planting techniques (Jason Clay, 2004).

The use of precision agriculture improves yields while reducing chemical and fertiliser needs.

In addition, these technological advances, combined with advancements in plant breeding and genetic engineering, are creating better plant hybrids (Eucarpia. Congress (18th : 2008 : Valencia et al., 2008). These advances sometimes present problems such as reduced resistance or the attraction of particular pests such as in the case of fruit flies on exotic mango farms in the tropical regions of the world (Nankinga et al., 2014).

Furthermore, there are other applications of technology and automation in agriculture. According to Ayoka Systems, these are referred to as seven (7) emerging technologies in agriculture (Ayoka, 2016). These technologies include soil and water sensors, weather tracking, satellite imaging, pervasive automation, minichromosomal technology, RFID and vertical farming. It has become very clear as indicated by Ayoka Systems that venture capitalists invested more than \$2 billion in agriculture technology start-ups in 2014 and again in 2015. This trend was expected to continue in 2016 because the demand for innovative farm technology was high, and when inventors showed results, modern farmers had demonstrated a willingness to embrace those inventions and new techniques.

Also, in the Global Food & Agriculture Investment Outlook 2015 report, the food & agriculture asset class includes over 240 investment funds that manage close to \$45 Billion in assets, on Valoral Advisors' proprietary database (Ayoka, 2016). This rise in investment means that a lot more technology will be incorporated to get value for money.

## **2.2 Wireless Sensor Network in Agriculture**

Sensors are appliances that can sense e.g. sound, light and weight with or without direct contact with the object. The agro & food sector uses sensor technology to collect data on the soil, crops

and animals through sensors that are integrated in all kinds of agricultural equipment and machines, aircraft and drones or even satellites. Sensors provide farmers with real-time information on their crops and livestock, enabling them to respond more effectively, e.g. by taking (corrective) measures. Sensor technology can be used to establish product quality and safety e.g. also the origin (de Wilde, 2016). One example of sensor technology in agriculture that this work focuses on is wireless sensor nodes.

Wireless Sensor Network as a tool for agriculture is becoming widespread over the world. The literature reviewed in this work is in relation to the general use of WSNs in pest and disease control. A categorisation was done on technological, non-technological and integrated solutions of pest monitoring and control. Performance and effectiveness were compared and analysed to determine if it was feasible to use WSNs for crop monitoring in developing countries (Azfar et al., 2015).

In addition, a further categorisation of pest control methods are generalised into non-technical, integrated and technical approaches. This work focused on the implementation of an integrated technical approach using ultrasonic. According to Azfar et al., analysis was conducted to determine how effective the three approaches to crop monitoring and disease control were with specific regards to cost, environmental friendliness, human health, product quality and labour saving. The study identified that by using WSNs in monitoring the effects of pest and diseases, the farmer's labour is reduced.

It is also important to note that there is great improvement in the detection of pests and diseases by the use of specialised sensing technologies as compared to non-technical, technical, and integrated approaches that do not incorporate these technologies. With evidence from the study, it becomes apparent that the habituation mitigation mechanisms must reduce the frequency of broadcast of the ultrasonic during use. The listen and broadcast technique with the help of the

scare-path and shepherding algorithm is intended to help reduce this to the barest minimum.

With the listen and broadcast technique, the sensing nodes are expected to sense the presence of the fruit fly by the sound they make with their wings during flight or when they are communicating. The respective data is collected from each listen node and sent over to the processor node for processing and the interpretation of the sign received signal in order return the appropriate action such the type of signal to broadcast namely avoidance, communication, including the amount intensity to apply to the broadcasted signal..

However, a few setbacks arise as a result of using sensing nodes in agriculture, in cases where a lot of sensing and broadcast nodes are required as per the research goal in this work. Among them is mainly the issue of power consumption of the nodes because they run on limited supply of power, it is difficult to deploy specialised algorithms that due to their processes require a lot of power to operate autonomously.

Secondly, Segal's law comes to play when WSNs are deployed in sensing the environment (Martin A Hebel et al., 2007, Beckwith et al., 2004). Segal's law asks the question as to how many WSNs are sufficiently enough to sense an environment in order to collect accurate data towards decision-making. In the case of this habituation mitigation system, many sensing nodes are required. This requirement becomes larger if the mango plantation is about many acres.

Furthermore, the requirements of the previous paragraph results in one of the major setbacks which is the unwillingness of farmer to buy high quality and specialised sensing technologies that can be well suited for the agricultural space.

The additional cost, both in terms of labour and finances, for installing these devices is a deterrent for farmers. It has been observed that farmers, particularly in Africa, are hesitant to

incorporate any cumbersome technology into their farming practices (Cost of crop protection measures - European Parliament, 2021; Agricultural Pest Control Services and Rentokil US, 2023; Development of Automated Devices for the Monitoring of Insect Pests, 2003; Digital technology and African smallholder agriculture: Implications for public policy, 2021).

### 2.2.1 Setbacks of Using Wireless Sensor Nodes in Agriculture

Some of the challenges associated with using Wireless Sensor Networks in Agriculture have been outlined below:

**Hardware Cost:** Due to the advance in semiconductor manufacturing technologies, the cost of manufacturing WSNs have become cheaper. Also, the economics of scale has helped reduced cost drastically but to the average farmer in Africa, for that matter Ghana who does not get easy access to capital, the cost is still high. Implementing a system such as the Habituation prevention model requires an array of audio sensor nodes that when put together in quantity could cost a fortune to such an average African farmer.

**System Architecture:** In their study, Tennina et al observe that the system architecture is presented to cope with the challenges imposed by the specific application scenario. This includes a network coding (NC) mechanism and a distributed localization solution that when applied to the agricultural environment could yield the needed results in terms of the performance of the sensor and broadcast nodes. “Preliminary results in a real environment show good system performance that meet our expectations.” (Tennina et al., 2014)

**Wireless Connectivity:** Wireless communication in indoor environments is still plagued with some challenges. Inter and intra communication is hampered if obstacles prevent nodes from having a line of sight to other nodes. In the case of agriculture, the inability of a node

to get the right signals at any point in time may reduce a complete cropping season to nothing. Since the implementation of the nodes is on the farm, tall trees and even the mango trees themselves could hinder its effectiveness.

**Programmability:** Some form of network re-programmability is desirable; doing so in energy and communication conservative form remains a challenge.

**Security:** The security challenges are at many levels.

- From the system point of view, it is critical that the information provided by the nodes be authenticated and the integrity verified since this information provides the feedback loop to expensive equipment controlling power consumption in the building.
- From the users' point of view, it is also critical that this information cannot be easily spoofed and it remains protected in the backend processor, since it may affect the privacy of users.
- People could remove the nodes from the farm.

Each of the challenges above set the direction for many of the information technology research needs.

### **2.3 Pest Control in Crop Production – The New Paradigm.**

According to Gabriel A. et al, every country must make a conscious effort to invest in new ways of mitigating the effect of pest and diseases on crops. Major Agricultural countries such as United States sometimes take this for granted. They argue that the nation must help advance the fortunes of their farmers by continuously engaging in activities that provides new ways of controlling pests.

Moreover, disease and pest management of the future must be improved while simultaneously reducing our dependence on pesticides as one of the many steps towards the goal of sustainable agriculture (Gabriel Arthur Kelman S Tolin Anne K Vidaver & James, 1995).

The desirable goal is to reduce the use of pesticides, but it relies on continued investments in research on alternative pest control techniques. The alternatives for many chemical-based pesticides are either not developed yet or are just not effective when applied. This research is broadly based across disciplines in computer science and biology in order to help find solution to the above situation. Moreover, many countries around the world depend not only on sustainable agriculture but also on constant and stable growth in agriculture to achieve a long-term increase in demand for quantity and quality of agricultural produce to sustain the changes in demand due to status changes in people.

Research in the area of ultrasonic fruit-fly control is one of the surest ways to reduce the over reliance on chemical pest control methods.

To combat pests successfully in sustainable agriculture, it seems less risky to apply the old practices of traditional farmers. Cultural practices have one of the highest potentials for reducing yield loss because of plant diseases. They can be manipulated to minimize inoculum production, survival and dissemination, as well as infection of many pathogens and disease development. Yet this area of disease control receives the least attention among the major control measures.

#### **2.4 Fruit-fly Pest Control in Mango Production – Current Trends**

*Bactrocera invadens* is one of the most studied flies that has accounted for eight noble prizes as of 2017 (Boehm, 2010). A sample of mango fruits were collected from randomly selected mango trees. The matured mango fruits were incubated individually. The fruit fly was the most

predominant, forming about 96% of the captured species that were incubated over the period.

One of the reasons why fruit fly is used in drug related research in recent times is its attraction to ethanol. This accounts for the reason why female fruit flies prefer to lay their eggs in things that contain about 5% ethanol (Kaun et al., 2012). Figure 1, displays a fruit-fly laying eggs on a mango fruit. Furthermore, it is observed that fruit flies are not attracted to mango fruits by chance but a group of sensory attributes leads them to it. This and many more reasons is what this research seeks to investigate in order to provide a solution to the problem of habituation in ultrasonic fruit fly control systems.



*Figure 1: Bactrocera invadens laying eggs in a mango fruit. (USDA, Bauer, S, 2014, October))*

The devastating effect of fruit flies is very visible on many Ghanaian mango plantations today. This is evident in the act of pre-ripen harvesting of the mango fruits on many farms around the country. Most farms are not aware that the flies lay eggs in the flowering mango therefore, the rest of this effect is transferred to the market and then to the final consumer. Management practices have helped reduce in a minimal way the effects of fruit flies on the fruit (Massebo & Tefera, 2015) but much more is needed to further reduce and if possible, completely wipe-out the effect of these flies on the mango fruit. Figure 2, shows devastating effects of the fruit-fly.



*Figure 2: Devastating Effects of Fruit fly. (Ekesi, S., et al, 2014)*

The fruit fly is a major mango pest. An investigation was conducted in India on finding a standardised all-in-one fruit fly management system that does not leave chemical residue on the fruit after harvest. A number of experiments were carried out at the Indian Institute of Horticulture. The techniques that resulted from the experiment achieved a reduction in the effects of fruit fly on the mango fruit (Verghese et al., 2006). The result showed how the control mechanism brought down fruit fly infestation to about 5% from an infestation range of between 16 and 67% in the planting season of 2004 and 2005. However, this reduction is not enough because one will need a complete wipe-out of the flies in order to get a yield that consumers can trust.

Whilst the results of the experiments conducted according to the paper is in the context of India, there is clear evidence that demonstrates that the same effects can be achieved in Ghana if the same technique is applied because Ghana lies in the tropics as in the case of India.

However, standardisation was required because the control measure was chemical based therefore the mango fruit could be hazardous to human consumption. The details about the chemical composition and how the harvested mango fruits are treated to avoid contamination

before consumption have been outlined in the experiment (Verghese et al., 2006) but are not relevant to this research.

Moreover, it is important to recognise from the experiment conducted by the authors of the paper how inadequate chemical-based remedies to the problem are. There is therefore the need to provide a lasting non-chemical-based remedy.

The report stated that there are a wide-range of ultrasonic, mechanical, electromagnetic and electrical devices that have been researched into, manufactured and have been sold. It is observed that no Environmental Protection Agency (EPA) regulation was available that guides the design and manufacturing processes of these repellents. A specification description is only required in instances where the repellent device is intended to be distributed commercially. It is evident in the report that, there is about 30-50% reduction in the activity levels of pests when the repellent is administered but habituation occurs (pests get used to the repellent) within 3-7 days (Verghese et al., 2006). It can be observed from the paper that the percentage reduction is inadequate against the problem of habituation. Therefore, the focus of this work is to tackle this problem of habituation by using scare path and shepherding algorithm implemented on Wireless Sensor Nodes and an array of audio broadcast nodes.

The work recognised through data set collected from their experiments that the efficacy of using ultrasonic repellent cannot be question. However, the weakness identified was with habituation when the device was used for a very short period (3-7 days). This also goes to show that the continuous broadcasting of the ultrasonic made habituation possible since animals easily adapt to their environment.

Easy adaptation to sound pressure waves is one evolution trait restricted to insects. Hearing by insect can be put into two major contexts; namely predator avoidance and communication.

As stated above, the hearing of insects may have evolved as an adaptation for detecting predators. In addition, insects' hearing and signalling may have evolved because of co-evolutionary processes for mate finding and mate recognition. The initial pressure for evolving such complex and useful auditory system is much different from what insects experience today (Verghese et al., 2006).

My focus in this work is on the strength of ideas that have been highlighted, namely: identification of the context in which insects perceive sound, this will be essential in the design process that is intended to help build an Integrated Ultrasonic Pest Control System to produce a repelling sound by combining ultrasonic in the context of predator and communication signalling.

## **2.5 Evolution of Insect Hearing**

While the sensing of substrate vibrations is common among invertebrate animals having an exoskeleton, a segmented body, and paired jointed appendages (also known as arthropods), the adaptation to receive sound pressure waves is restricted to insects, this is independently evident several times in different orders. In any studies undertaken, tympani organs are shown to derive from chordotonal precursors. This shows the effect of adapting to the changing needs for hearing. In furtherance of this, behavioural situations in which hearing has evolved has strongly resulted in the design and properties of the auditory system of most insects. (L. a. Miller & Surlykke, 2001).

Organs for hearing, which have evolved because of predator avoidance, are highly sensitive to a wide range of ultrasonic frequencies intended to release escape manoeuvres in life threatening situations. Communication based hearing in insects does not only require recognition and differentiation of highly specific sound patterns but also their localisation. (Stumpner & von

Helversen, 2001b).

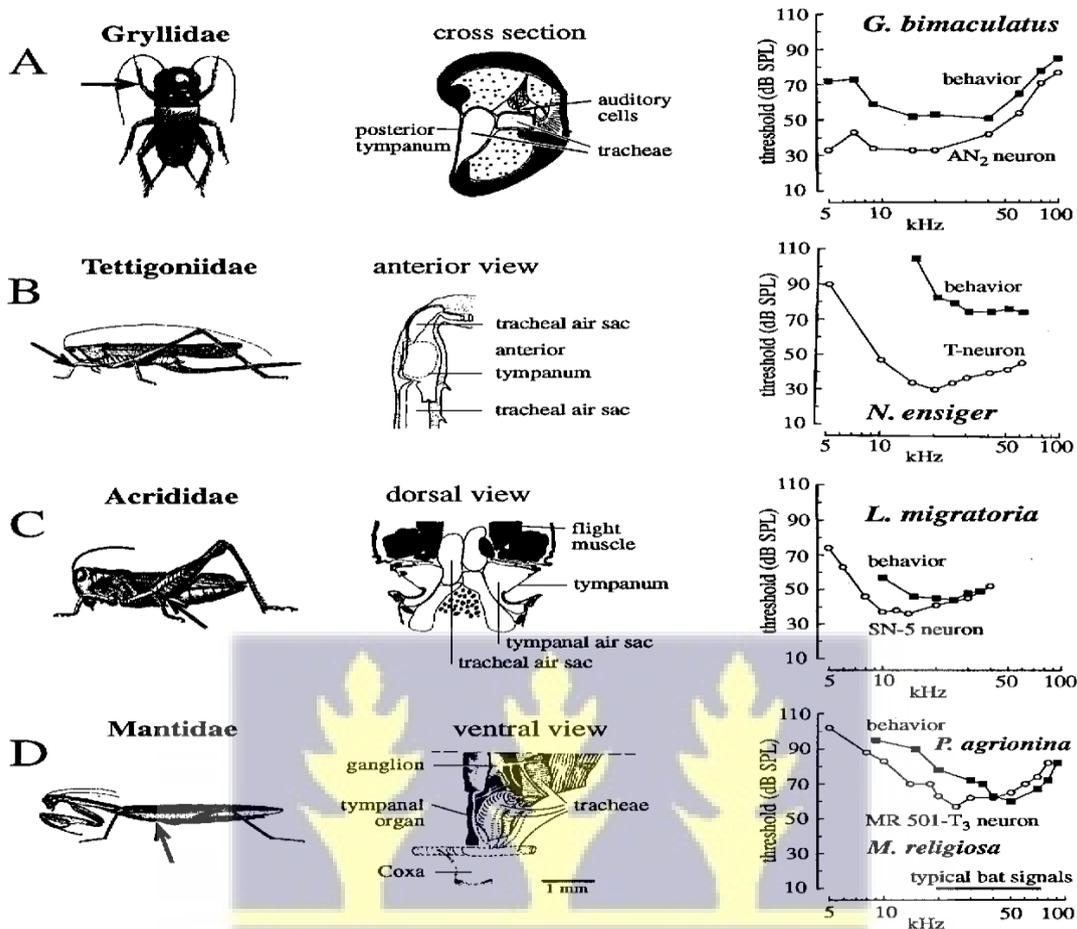


Figure 3: A variety of insects with auditory organ adapted for hearing bats (Miller, L. A., & Surlykke, A. (2001)).

Typically, the spectrum of signals from same species matches the best listening sensitivity of the receiver. To detect directional sound, insects use complex peripheral structures and further, enhanced by neuronal processing. This helps achieve side-specific gain control, which typically allows the insect to encode the loudest signal on each sides of the ear. Any resultant (filtered) information is then transmitted to the brain where the final steps of recognition and localisation occur.

The processes outlined above allow insects to undertake astonishing acoustic performances

which is similarly achieved by vertebrates.

### 2.5.1 Ultrasound Avoidance Behaviour

Ultrasound avoidance is the unconscious avoidance trait exhibited by many animal species that are regularly preyed upon by echolocating (using sound as a means of hunting down prey) predators (Yager et al., 1990). Ultrasound avoidance is known to have helped in the evolution of mechanisms for ultrasonic hearing in several groups of insects.

The ultrasonic sensitive ears, which have evolved in many insects, are based on a vibrating tympanic membrane, which is mainly used to sense insect predators such as bat's echolocating calls. The ultrasonic hearing go hand-in-hand with motor responses that cause evasion of the predating bat during flight (Wilson et al., 2007).

Ultrasonic hearing has evolved multiple times in insects and this continues to occur up to date because of the changes that are also occurring in the hunting techniques of predators. (L. a. Miller & Surlykke, 2001).

Many other species of insects use similar strategies which may seem like avoiding the ultrasonic but in reality, they are conditioned to avoid predators therefore they unconsciously respond to these ultrasonic.

### 2.5.2 Using Ultrasonic for Predator Avoidance

Most insects have evolved audition and escape behaviours in response changing predator behaviour, but other insects have the trait for detecting ultrasonic signals by creation. Some predators have evolved as well to improve their success rate during the process of hunting

prey. In other words, there is a kind of evolutionary traits simultaneously going on between insects and their predators.

Insect tympanal organs, or ears, consist basically of an external, thin membrane (the tympanum) and associated internal air sacs, or tracheae. The auditory (sensory) cells are attached to the tympanum or to an internal membrane (Yager, 1999). Tympanal organs of most modern tympanate insects respond to a wide band of frequencies extending well into the ultrasonic range (above 20 kHz), as was probably true for pre-Eocene tympanate insects as well. Tympanate insects are physically small animals that can produce high-frequency sounds more efficiently; hence, high frequencies are used by many insects for acoustical communication between conspecifics. Consequently, many sonorous insects were preadapted to the evolution of bats (R. Hoy et al., 1989).

The frequencies used by echolocating bats range generally from 20 kHz to 100 kHz, with some outliers using frequencies below 10 kHz or above 200 kHz. Higher frequencies improve resolution, but they attenuate at a greater rate (Surlykke, 1988) and the detection distance is reduced accordingly. The source level is the sound pressure level (SPL relative to 20  $\mu$ Pa), in decibels (dB), measured 10 cm in front of the bat's mouth. A bat using a source level of 110 dB at 20 kHz could detect the echo from an object the size of a moth at more than 5 m. Detection would occur at no more than 2.4 m if the bat used 100 kHz (Surlykke, 1988). From the insects' perspective, bats advertise their presence with the ultrasonic pulses used to stroboscopically probe the environment. Thus, insects are forewarned if they can hear ultrasound. This coincidentally exerts considerable selection pressure against those insects that either cannot hear or do not react (Surlykke, 1988).

The above review on (Surlykke, 1988), reveals how insects and bats rely on ultrasonic for either predator avoidance or prey capture. Using the predator avoidance sound, I will

broadcast an ultrasonic that sounds like the predator of the fruit fly that will therefore make them avoid areas of the mango fruit.

## **2.6 Detecting Ultrasonic broadcast from Flies (“The Bat Technique”)**

The technique for sensing an approaching fruit fly is adapted from the echolocation techniques used by insect-eating bats. The main goal for adapting the “Bat Technique” in the habituation prevention model is to eliminate the continuous broadcast of ultrasonic but rather do a “Listen before Broadcast technique” which is what the bat does to be able to catch prey. Below are the review of some of the important studies conducted in these techniques.

Echolocating animals emit signals of high frequency (mostly ultrasonic) and analyse the returning echoes to detect, characterize, and localize the reflected objects. Sophisticated echolocation systems have evolved only in the bat suborder Microchiroptera and in dolphins. Less efficient systems have been reported for a few species of the bat suborder Megachiroptera and for some birds (Henson & Schnitzler, 1980; Waters & Vollrath, 2003). Bats use echolocation for orientation in space, that is, for determining their position relative to the echo-producing environment. In addition, many bats, especially those that hunt for flying insects, use echolocation to detect, identify, and localize prey.

### **2.6.1 Perceptual problems for foraging bats**

One major perceptual challenge for foraging bats is interference from competing acoustic cues (Santos et al., 2018). Bats may rely on two distinct types of acoustic cues for prey detection: short-duration signals produced by their prey (e.g. insects), and continuous background sounds in the environment (e.g. wind rustling in leaves). These two sources of

acoustic cues can conflict if they are temporally and spectrally similar, such as when an insect's ultrasounds overlap with environmental noise (Santos et al., 2015).

This overlap can cause the bat to mistakenly perceive the noise as the prey, resulting in incorrect decisions and loss of potential food rewards. By creating 'acoustic clutter' of competing acoustic cues, interference from environmental noise potentially reduces the accuracy of prey detection, which in turn can significantly limit the foraging efficiency of bats (Stilz et al., 2010).

### 2.6.2 Signals Adapted for Specific Tasks

Foraging bats can use a variety of sound signals and strategies to identify food sources. Long-distance echolocation calls and accompanying biosonar systems enable bats to locate and distinguish prey from non-prey items within their environment (Polačik, Głowaciński, 2011).

Short-distance search calls and normal finesse approaching buzzes (Baerwald, Brigham, & Barclay, 2008) are also used in specific tasks and contexts. For example, aerial hawking bats use specialized searching, sounding, and pursuit calls for foraging and prey capture (Schnitzler & Kalko, 1998). These calls are typically species-specific, and involve the use of individualized frequency and intensity parameters to aid the bats in honing in on prey items (Arlettaz, Yao, Spada, Rutz, & Schnitzler, 2001).

On the other hand, nectar-feeding bats utilize the sensing of flower-emitted odor-plumes to aid in the location of food sources (Jones, Kalko, & Handley, 1992). These bats can modify their sonar signals to acquire more information on the features of the targets they are searching for, including size, shape, and distance of the flower reward (Parsons & Winemiller, 1995). By using signal adaptations, both aerial hawking and nectar-feeding bats

are able to effectively detect and capture prey items to keep themselves nourished in their natural environment. Figure 4 provide a pictorial representation of the signal patterns.

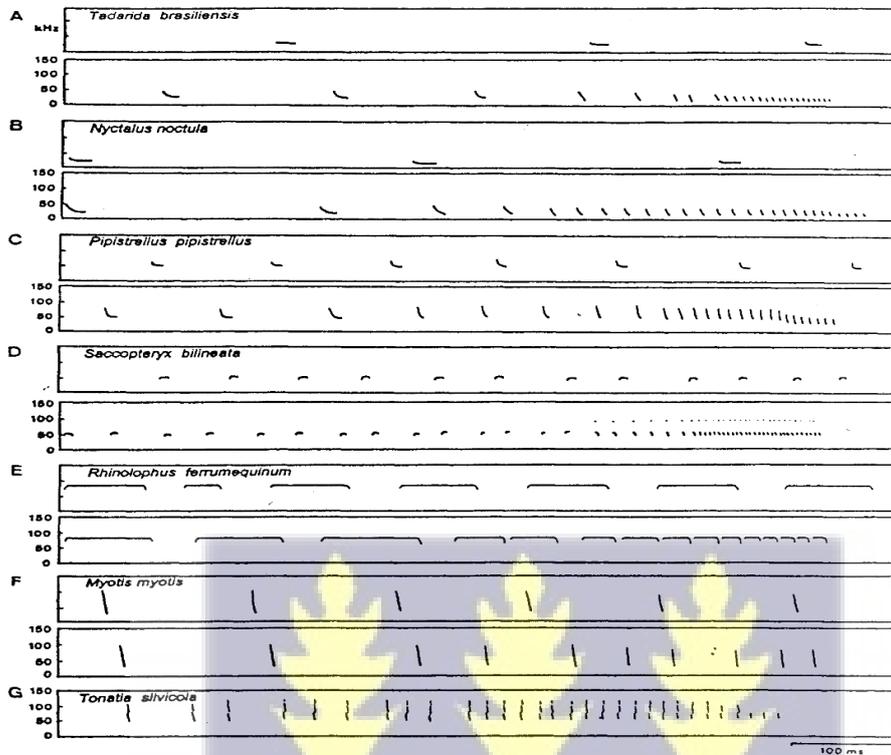


Figure 4: Search and approach signals of foraging bats. (a–e) Signals of bats that captured a flying insect at the end of the sequence. (f, g) Signals of bats that gleaned insects from a surface at the end of the sequence, (f) out of continuous search flight and (g) after the prey has been detected from a perch. In all sequences the increase in repetition rate and the reduction of sound duration indicate the switching from search to approach phase. Note the distinct terminal phase in bats that captured flying insects (a–e).

### 2.6.3 Narrowband Signals

When a signal hits a fluttering insect at the favourable instant when the insect's wings are perpendicular to the impinging sound wave, a short and very prominent amplitude peak in the echo, an acoustic glint, reveals the fluttering insect target. This glint, which can be up to

20–30 dB stronger than an echo from the body of the insect, also increases the probability of detection (Kober & Schnitzler, 1990), (Moss & Zagaeski, 1994). The probability of receiving such a glint depends on the duty cycle (the percentage of time in which signals are emitted) of the bat and the wing-beat rate of the insect. For example, a duty cycle of 10% and an insect wing-beat rate of 60 Hz produce an average perceived glint rate of 6 glints/s. (van de Pol et al. 2009)

#### 2.6.4 Broadband Signals

Broadband signals have been used in related biological study of tracking processes in bats. These have included recording the acoustic signals from their sonar emissions, as well as studies of the morphology and acoustic features of the signals (van de Pol et al. 2009). The use of broadband signals offers the benefit of relatively high energy transfer over long distances compared to the narrowband signals used by some other species (Hall and Burnett 1988). Furthermore, broadband signals are highly directional and are relatively resistant to scattering, making them well suited for accurate localization of acoustic sources (Riley et al. 1995). This is useful in the case of using the wireless sensing nodes for sensing the presence of fruit flies with the perimeter of the mango plantation.

#### 2.6.5 The Masking Problem

The Masking Problem, by foraging bats, is a detailed exploration of the challenges associated with echolocation in their environment. By examining the masking effect of background noise, the article examines how different types of noise can affect the bat's ability to use their echolocation. The authors investigate the acoustic properties of common background noises, such as from aircraft, and explain how sonar masking can lead to the bats being unable to identify and track prey accurately.

Furthermore, the article provides an overview of several possible solutions to this issue, such as using tactical maneuvers to reduce sonar masking and the implementation of additional acoustic communication methods. This paper serves as an important contribution to the field of animal foraging studies, offering an important insight into the obstacles that bats have to navigate in order to effectively manipulate their acoustic world (Mccue, M.D., Jones, G., Aldrich, P. et al., 2018)

Masking reduces the probability of detection in the zone in front of the bat where overlap occurs. The width of this signal-overlap zone depends on signal duration (Figure 5). For example, with a signal duration of 10 ms the overlap zone is 1.70 m wide at a speed of sound of 340 m/s. If undisturbed detection is only possible beyond this signal-overlap zone, signal duration sets a minimum detection distance. Each ms of signal duration adds 17 cm to this minimum detection distance.



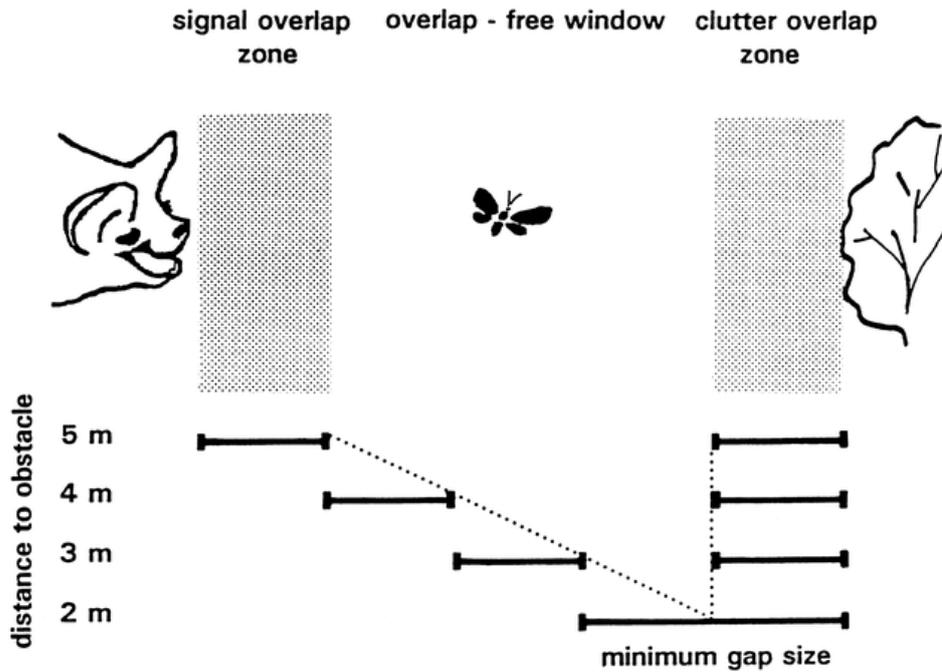


Figure 5: Schematic diagram of the masking situation for a bat foraging near vegetation and emitting signals with a duration of 6 ms. *The prey echo overlaps the emitted signal when the insect flies in the signal-overlap zone, and it overlaps the clutter echoes when it flies in the clutter-overlap zone. No overlap occurs when the insect flies in the overlap-free window. At a distance of 2 m the overlap-free window is closed, and for the given signal duration the bat has reached the minimum gap size where overlap-free echolocation is impossible (SCHNITZLER, H.-U., & KALKO, E. K. V., 2001).*

When an insect flies so close to clutter that its echoes overlap the clutter echoes, backward masking reduces the probability of detection in this clutter-overlap zone. The width of this clutter-overlap zone is determined also by signal duration. Only insects flying far away from the bat and from the clutter-producing background where no overlap occurs can be detected

without interference. By our definition, these insects fly in an overlap-free window (Figure 5). The forward- and backward-masking effects strongly depend on signal structure, on the SPL of prey echo and masking signals, and on their temporal relationship. Depending on the signal type used by a bat, the masking zone may be smaller than the overlap zone calculated from sound duration. For example, a study on *Myotis nattereri*, a bat that searches for prey using wideband FM signals very close to vegetation, indicates that these bats tolerate some overlap between prey and clutter echoes (Siemers & Schnitzler, 2000). Nevertheless, the calculation of the overlap zone is a useful tool to judge the danger of masking.



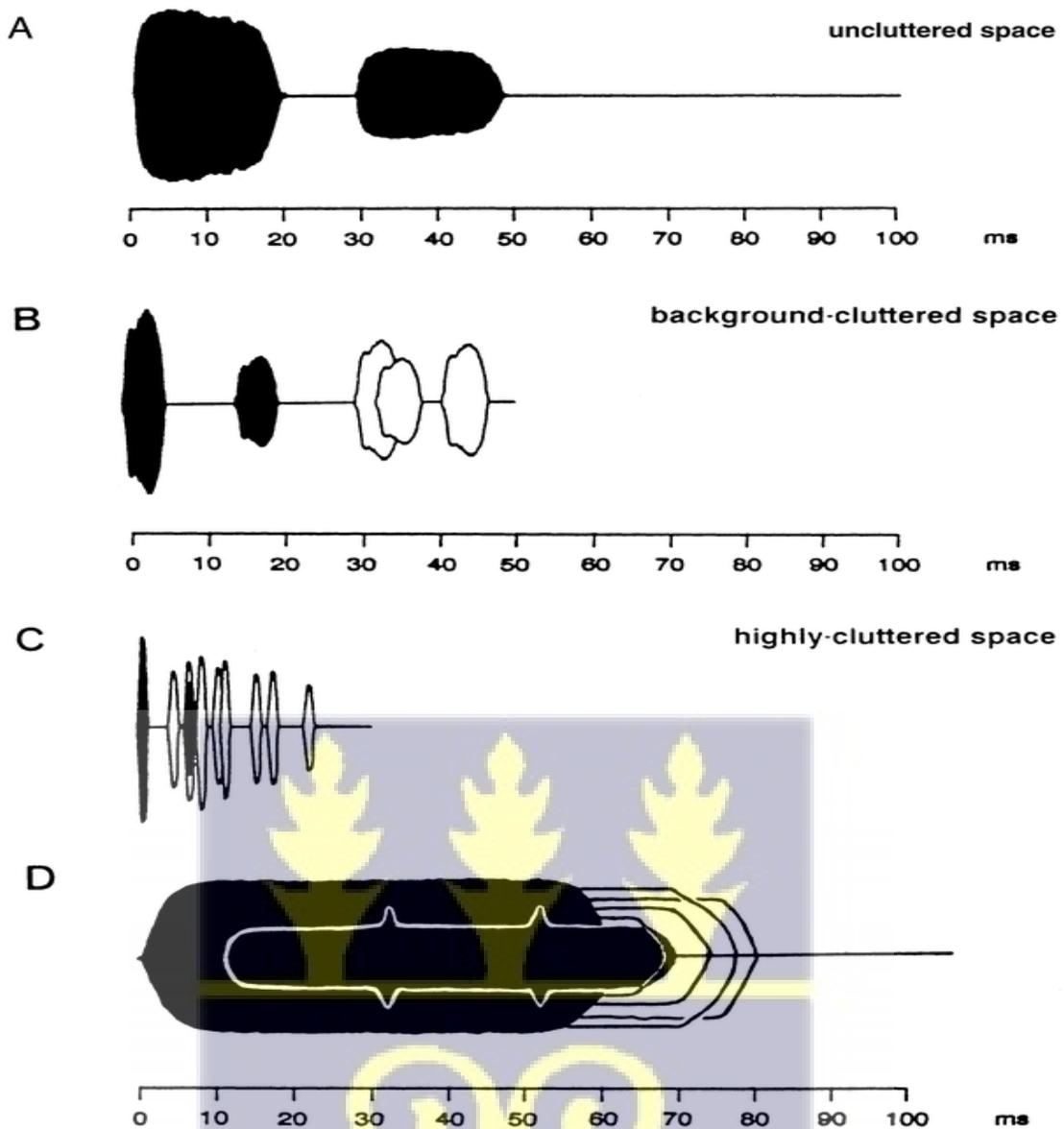


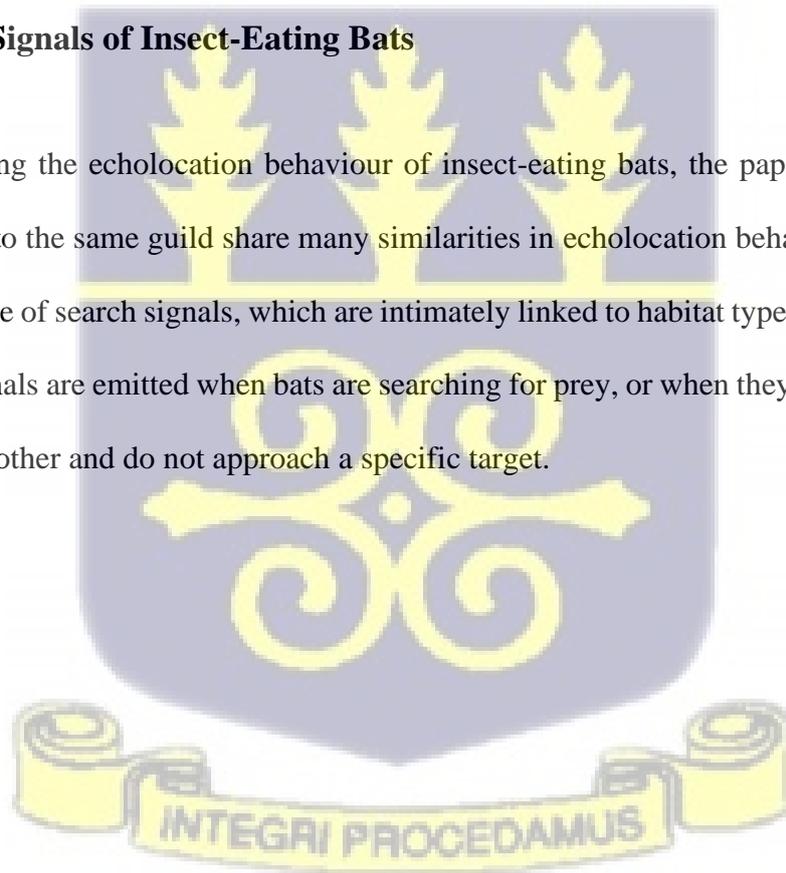
Figure 6: Schematic diagram of the input into the auditory system of bats that forage in different clutter situations. *The emitted pulse and the returning insect echo are depicted in black. (a) In uncluttered space, the pulse-echo-pair is far from clutter echoes. (b) In background-cluttered space, the pulse-echo pair is followed by clutter echoes (depicted in white). (c, d) In highly cluttered space, the target echo is buried in overlapping clutter echoes. Sound duration and envelope form correspond to search signals typical for the different spaces: (a) QCF signal of an open-space forager; (b) broadband FM-QCF signal of an edge and gap forager; (c) broadband FM signal of a narrow-space “FM”*

*forager; (d) long CF–FM signal of a narrow-space “CF” forager; the echo shows amplitude modulations, or glints, created by the beating wings of an insect (Hans-Ulrich Schnitzler, Elisabeth K. V. Kalko, 2001).*

In bats with long CF signals, the CF component of the emitted signal and that of the returning echo often overlap (Figure 6). This overlap produces no masking effect, because Doppler-shift compensation keeps the target echo in the range of the extremely sharply tuned neurons of the acoustic fovea, whereas the emitted signal is lower in frequency and falls in a range where the auditory threshold is high (Neuweiler, 1990). Therefore, long CF components of Doppler-compensating bats are not vulnerable to overlap.

#### **2.6.6 Search Signals of Insect-Eating Bats**

In describing the echolocation behaviour of insect-eating bats, the paper showed that bats belonging to the same guild share many similarities in echolocation behaviour, especially in the structure of search signals, which are intimately linked to habitat type and foraging mode. Search signals are emitted when bats are searching for prey, or when they commute from one place to another and do not approach a specific target.



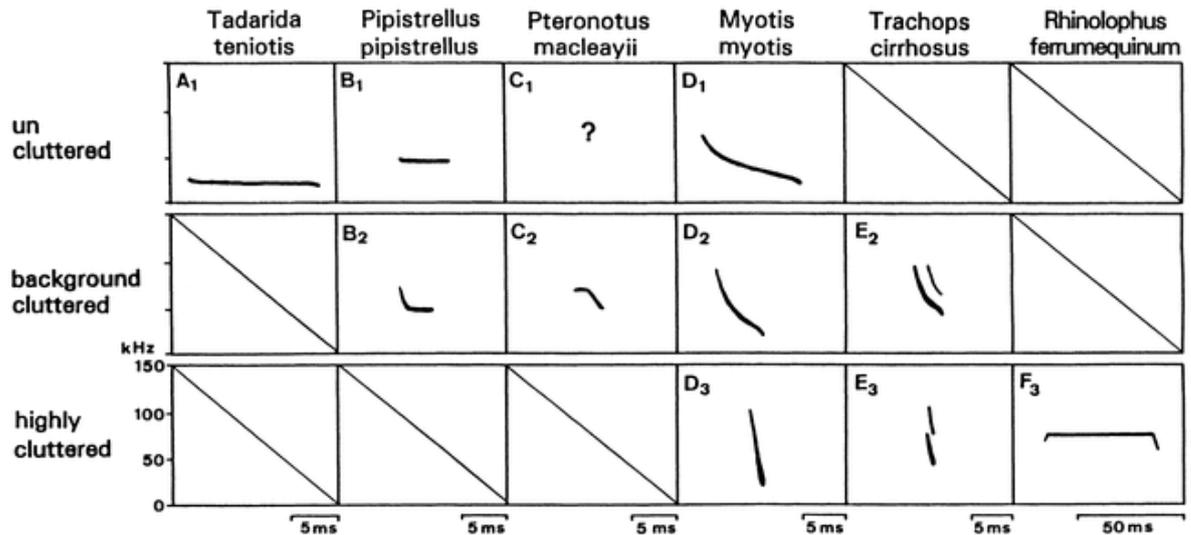


Figure 7: Examples of various search signals and their associated habitat types.

Note that bats may leave their preferred space for a less-cluttered space but not the reverse.

(a) *Tadarida teniotis*, (b) *Pipistrellus pipistrellus*, (c) *Pteronotus macleayii*, (d) *Myotis*

*myotis*, (e) *Trachops cirrhosus*, (f) *Rhinolophus ferrumequinum*

(“Sensory Ecology 8: Echolocation (bats vs moths).”, 2023)

### 2.6.7 Other Meaningful Categorizations of Bats

By Doppler-shift compensation and specialized hearing systems, they separate the long CF–FM emitted signal from the overlapping returning echoes in the frequency domain, and they evaluate flutter information.

Bats have the ability to change their foraging strategies throughout different seasons. Such seasonal changes have been observed in their diet, activity levels, and local habitat selection (Kerth, et al. 2018). Successional foraging: Bats can employ foraging strategies that take into account the successional nature of resources. For example, they may focus their foraging in

less disturbed areas, where food availability is greatest, then move on to adjacent disturbed sites once food resources have been seemingly depleted (Kerth, et al. 2018). Risk-sensitive foraging: Risk-sensitive foraging is employed by bats to mitigate the potential costs associated with acquiring food from a certain area. They may choose to forage in more protected areas, for instance in the forest canopy, rather than the forest floor, where predation is more likely. Studies have shown that bats may also switch between high- and low-risk foraging strategies depending on the resource availability in a particular area (Kerth, et al. 2018).

Additionally, Fenton differentiates between low- and high-signal intensity bats under the premise that this classification distinguishes aerial insectivores from gleaning bats. Fenton prefer to categorize bats into meaningful groups according to their main foraging habitat and behavioural strategy, not according to less distinctive signal parameters such as duty cycle and the highly variable signal intensity.

Leaning from the above, the scare-path and shepherding algorithm can take into account the time windows within the day or night that fruit flies may come out of their hideout to feed or lay eggs. This data can help save extra power in the nodes that are deployed and also be more precise when sensing is initiated, this will be done when the fruit flies are actually approaching the mango plantation.

#### **2.6.8 Effect of Bat Echolocation Behaviour on Sense-Before-Broadcast Technique.**

The echolocation techniques by bats based on the numerous reference papers and articles reviewed above establish the fundamental scientific basis for the use of similar schemes in the implementation of the listen module of the WSNs in the habituation prevention

framework. The “bat technique” as I refer to it, clearly sets the parameters such as the listen distance, resolution of masking problem.

Furthermore, the literature reviewed establish that narrowband signals are used for detection of the existence of flies and broadband signal is used to determine the size, the specific position and the type of insect. I believe this was essential in the avoidance of broadcasting the scare sound at the wrong time which increases the chances of habituation. The habituation model borrowed this scheme from the bats to help specifically detect a fruit fly within the prescribed proximity of the mango plantation.

## 2.7 Design and Implementation of Software Algorithms

Algorithm is a step-by-step set of instructions that you follow to achieve a task. Software algorithms are used across many aspects of computing, from web-browsers to gaming consoles and online streaming services. They are an essential part of the software development process (Shneyderman & Sosnovsky, 2010). They help ensure that a given set of instructions is followed precisely and efficiently (Garg, 2008). This makes algorithms an essential part of creating successful software.

To create an efficient software algorithm, there are a few important steps to take. Firstly, one must understand the problem domain. This means exploring the problem that the algorithm will be solving, breaking it down into simple steps and understanding the relationship between different components of the system (Garg, 2008).

Secondly, designing a solution that will satisfy the requirements of the problem is the next step. This includes creating a testable model by which the individual steps and overall structure of the algorithm can be analysed (Cereghetti et al., 2019). Thirdly, the

implementation of the algorithm is the final step. Here, the reasoning and logic used to solve the problem must be translated into code that the computer can understand and execute (Carrano & Prichard, 2016). Overall, creating software algorithms is an important part of making successful software. It requires significant knowledge and understanding of the problem and its components, as well as the logic used to solve it. With the right steps taken, it is possible to create algorithms that give",

For the habituation prevention mechanism, the problem identified was the continuous broadcast of the sound. Additionally, new ultrasonic groups are namely predator avoidance and communication are added in this research in order to increase the efficacy of the system.

Algorithms should be designed to minimize the number of resources needed to produce the output. This involves reducing the number of operations, minimizing access to files or data, and reducing the amount of memory required (Petre et al., 2017). It is very important because farmers in Ghana are normally unwilling to invest adequate financial resources in technology. Both sensing and the broadcast nodes need to operate using as little power as possible.

## **2.8 Agent-Based Model for Simulation**

Computer simulation in general, relates to the usage of a computational model in order to improve the understanding of a system's behaviour and/or to evaluate strategies for its operation, in explanatory or predictive schemes (Stefania Bandini, 2009). This is possible because the various variables (parameters) within the process and/or system can be modified in many different ways at a convenience.

To be more specific, this research of habituation prevention with special focus on mango production and fruit flies infestation in Ghana, agent-based modelling is the process of using

a computational model to represent and test a system. The key actors within such a system are represented as self-functioning agents that can perform tasks that satisfy the goal of the said system.

In particular, the main elements of any reference model are:

- **agents**, encompassing a possibly heterogeneous behavioural specification;
- **their environment**, supplying agents their perceptions and enabling their actions;
- **mechanisms of interaction among agents**: these mechanisms can either involve a direct exchange of information among the involved entities or an indirect one, realized through the possible perception by an agent of the effects of another agent's action.

Different situations and systems are characterised by the presence of autonomous entities whose local behaviours (actions and interactions) determine the evolution of the overall system; agent-based models are particularly suited to support the definition of models of such systems, but also to support the design and implementation of simulators. Agent-Based models and Multi-Agent Systems (MAS) have been adopted to simulate very different kinds of complex systems, from the simulation of socio-economic systems to the elaboration of scenarios for logistics optimization, from biological systems to urban planning (Stefania Bandini, 2009) (Fachada et al., 2015).

This work discusses the specific aspects of this approach to modelling and simulation from the perspective of Wireless Sensor Nodes, Audio Broadcast Nodes and their implementation in agriculture, describing the typical elements of an agent-based simulation model and the relevance to habituation prevention.

### 2.8.1 Characteristics of Agents in Agent-Based Modelling

Below is the outline of the characteristics expected of agents, with a simulation environment. These characteristics are defined based on the concept of what, how, where, when of the agent's existence within the simulation context. Agents may possess two or more of the characteristics stated below.

- **Delegation:** The agent could perform a set of tasks on behalf of a user. Of course, the user should approve the task before it is executed.
- **Autonomy:** The agent could perform a set of tasks without the user's initiation, notification and confirmation, which could be activated by a fixed time, such as the nightly backup, or could be activated by a certain event, such as “after checking the mail box, go to the agenda.”
- **Communication:** The agent could interoperate with humans, other agents, legacy systems, and information sources. An agent could interact with the users to receive tasks or to specify the instruction through the agent-user interface, and could collaborate together in communities to achieve common goals.
- **Intelligence:** The agent could monitor its environment to respond or perform the task autonomously, and could have the ability of inference, reasoning to make appropriate decision of operation, and could sometimes learn from the reactions or interaction with the user to improve itself and, could dynamically adapt to and learn about their environment. They are adaptive to uncertainty and change.
- **Mobility:** The agent could transport itself from one machine to the other, across different architectures and platforms, taking advantages of the Internet.

Even though, intelligence is one of the characteristics, it could be seen as an embodiment of a group of other characteristics of an agent. In this work, an intelligent agent is implemented.

## 2.8.2 Repast Simphony Simulation

This section of this work presents a review of the Repast platform as an agent-based simulation application suite. It presents reviews on modelling agents with the Repast ecosystem with reference to modelling the Scare-Path and Shepherding algorithm for the mitigate of habituation through the use of ultrasonic prevention systems with specific emphasis on fruitflies infestation on mango plantation.

Recursive Porous Agent Simulation Toolkit (Repast) is a widely used, free, and open-source, agent-based modelling and simulation application set. There currently three Repast platforms, each of which has the same core features but a different environment for these features. Repast Simphony (Repast S) extends the Repast portfolio by offering a new approach to simulation development and execution (North et al., 2007).

One of the major ideas in this research is to broadcast a predator avoidance ultrasonic wave if the fruitflies are approaching the inner perimeter of the mango plantation. Studying the work of (Wilenski, 1998) modelling a wolf-sheep predation in Repast Simphony as a demonstration of how the Repast suite capable of simulating such scenarios. Their model represents a simple variation of predator prey behaviour using three agents: wolves, sheep, and grass. Both the wolves and sheep move randomly on a grid, and the movement has a cost in the form of lost energy.

The wolves and sheep usually need to eat food in order to replenish their energy, and they will die once their energy level reaches zero. Wolves prey on sheep and may eat them if the

two are located in the same spatial position, thereby increasing the wolf's energy level. Sheep may similarly eat grass if the sheep is located on a patch which contains living grass. Once a sheep eats the grass in its location, the grass needs to regrow before the sheep can eat it again.

Repast S models a re-grow rate for grass by counting down after the grass has been eaten in a specific location. Reproduction is modelled by a random process that creates a child from the parent, divides the energy of the parent agent in half, and assigns the energy equally to the parent and child (Tatara et al., 2006). Based on the above study by (Wilenski, 1998) and referenced by (Tatara et al., 2006), it is observed that all kinds of social and scientific ideas can be model and simulated in Repast S including the focus of this work which is the simulation of habituation prevention using scare-path and shepherding algorithm. It can be observed that the various agents namely: fruitflies, mango trees, plantation perimeter, wireless sensing nodes and wireless broadcast nodes can be configured for the simulation.

Furthermore, agent-based models have developed to maintain a tight coupling between individuals, their behaviours, and the space in which they interact. As a result, many models have been designed in a way that limits their ability to express behaviours and interactions. In a paper published by (Howe et al., 2006), they proposed a new approach toward designing simulations that builds upon the experiences of developing and working with several agent-based toolkits. This approach encourages flexibility and reusability of components and models.

The new implementations in the current core structure of the Repast Symphony agent-based modelling and simulation toolkit reflects the proposals by (Howe et al., 2006). By creating a 'proto-space' called a Context, they were able to provide suggestions that provide model designers with a container that can maintain a localized state for agents. A Context's state can maintain multiple interaction spaces called Projections, as well as more typical state

information. Projections are designed such that they can be used to represent a wide range of abstract spaces, from graphs to grids to realistic geographic spaces. Importantly, projections and agents or individuals are independent of one another.

Agents can be agnostic toward the type of projection in which they are interacting, and projections can be agnostic toward the type of agents whose relationships they maintain. Finally, the context provides a logical location to maintain agent behaviours that are dependent on localized agent interactions and environment. Also, in light of the modelling of the agents in this work, group agents are built and configured as a single agent and duplicated on need basis.



## CHAPTER THREE

### METHODOLOGY

#### 3.0 Introduction

The goal of this work is to provide habituation-mitigating framework for ultrasonic fruit fly control systems. This chapter is divided into six sections. This first Section outlines the various sections of this chapter. Section 3.1 explains the conceptual framework of the work. Section 3.2 describes the scope of the habituation simulation experiment. Section 3.3 shows the theoretical framework while 3.4 describes the method of analysis. Section 3.5 presents the type of data and sources and section 3.6 explains sample size and sampling technique.

#### 3.1 Conceptual Framework

Figure 3.1 is the concept flow-chart of the habituation prevention model. The flow-chart outlines the conceptual flow of the idea of habituation prevention. Listen-Broadcast Wireless Sensor Node (lb-nodes) are at the forefront of this concept. As in any system, the first step involves the initialisation of the components of the system. After initialisation of the lb-nodes, the nodes start the process of sensing the surrounding environment for the presence of fruit flies, using echolocation. This strategy involves the broadcast of high frequency ultrasonic between 30 and 100 megahertz, the lb-nodes analyse the returning echo to calculate the distance, and the type of insect, in this case, the system is designed to remove all cases which may not be fruit flies (Schnitzler & Kalko, 2001). The lb-nodes also adapt Doppler shift to determine whether the fruit fly is approaching or moving away from the nodes. Once the existence of fruit fly is detected within operational distance, the lb-nodes broadcast at randomly alternating, auditory disturbance and predator avoidance ultrasonic (Stumpner & von Helversen, 2001a) if the fruit fly is approaching. Alternatively, if the lb-

nodes detect that the fruit flies are leaving the farm, the randomly mounted external lb-nodes will begin to broadcast other communication ultrasonic with alternating random mating, offspring and parent call ultrasonic.

Furthermore, the lb-nodes in order to save some energy, sleep at random seconds once node fruit flies are not detected for a certain x-number of seconds. Even if on wake up the flies are in range, the implementation of varied broadcast techniques based on Doppler shift enable the habituation prevention system to create a scare-path that guides the fruit flies away from the mango plantation.

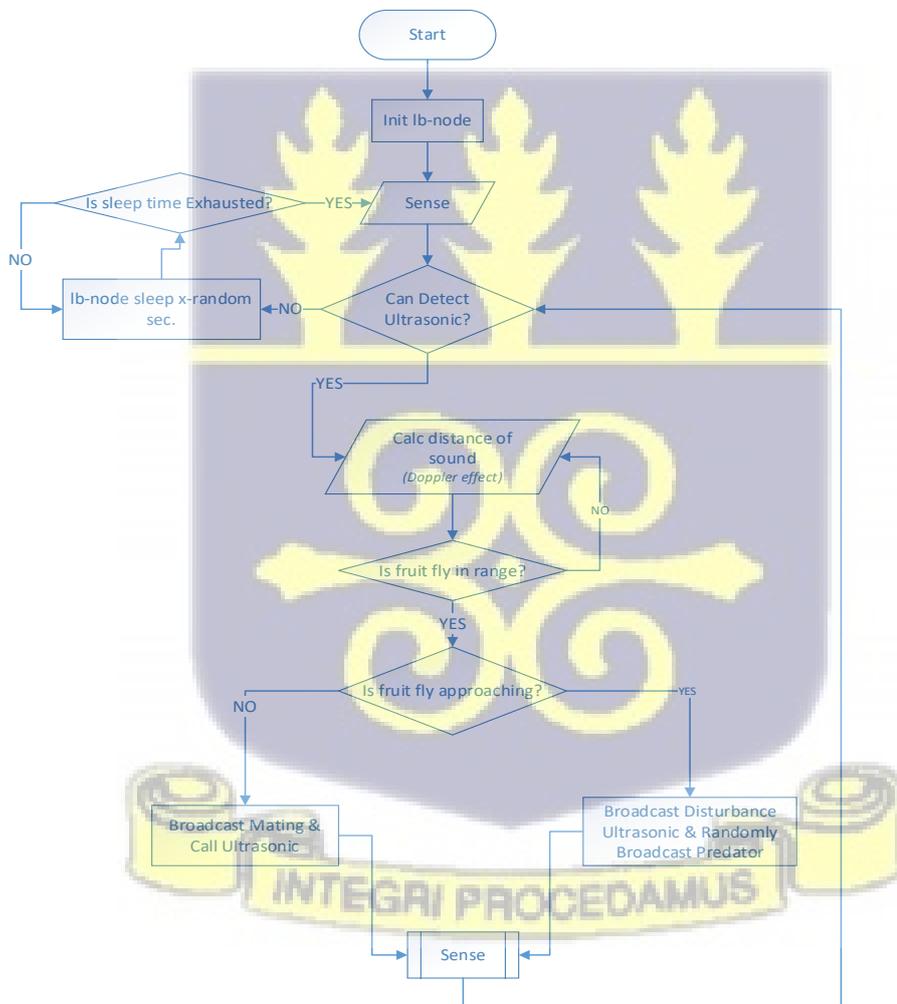


Figure 8: Scare-path and shepherding algorithm flowchat

### 3.2 Scope of Experiment

The simulation process starts with the creation of a digital replica of the ultrasonic384k. This unique ultrasonic microphone has an integrated analog-to-digital converter that is able to achieve a 384 kHz data-sampling rate, leak detection, predictive motor fault monitoring and has the function of smart autonomous recorder. The experiment continues with the habituation prevention set-up, with primary focus on lb-node spacing, initial start-up listen and broadcast frequency settings. Furthermore, categorisation and discrimination of ultrasonic from the fruit flies comes as communication, predator avoidance and auditory disturbance ultrasonic and setting up and testing of the flocking algorithm, namely; separation, cohesion and alignment. Finally implementing the simulation sequence as the completed Habituation-Mitigation system is done.

#### 3.2.1 Ultrasonic Devices

Majority of Habituation devices operate on the auditory disturbance principle. One main constraint to this technique of ultrasonic insect repellent is that, because animals easily can adapt to their environment, they easily get used to these disturbances from these devices. Another flaw to ultrasonic repellent implementation is the continuous broadcast of the sound (Schumake & Shumake ', 1995b).

Due to the above-identified shortfalls, the following is adapted in this work, namely

- **Detection:** Considering how the foraging bat does the detection of prey using ultrasonic, the process is formulated to demonstrates how the habituation-mitigation system does detection of the fruit and the step of calculating the distance between the

WSN and the fruit fly. Doppler shift is established as the basis for calculating the distance and speed of fruit flies because of the reflection of a moving object to a targeted sensing recipient which is expressed as  $f_d = \frac{2vf}{c-v}$ , where  $f_d$  is the observed frequency shift,  $v$  is the target velocity (with respect to sensor),  $f$  is the emitted frequency and  $c$ , the speed of sound. If there are multiple fruit flies approaching at different velocities, the reflected signal will have a content of multiple frequencies, one for each fruit fly. In this research, the operating or base listening frequency is 38KHz. That is, the sensor nodes are initialised at 38kHz each, which is the frequency at which most fruit flies flap their wings. For the purposes of echolocation, the broadcast frequency is set at 45KHz, this produces a masking off-set of about 11.8%. This reduces the interference between both the frequency received from the fruit fly and the echolocate frequency. The speed of sound  $c$ , is set at 344ms for this work, and this is used for all other calculations.

- **Classification:** Since bats categorise targets by means of specific echo information (Ostwald et al., 1988) or other features that reveal their nature, using Doppler-based calculations helped capture snapshot of the instantaneous velocities of one or more fruit flies by the lb-nodes (Raj et al., 2012).

The process of classification helped to get information about the fruit flies properties such as size, shape, material, and texture which are encoded in the complex temporal and spectral parameters of an echo thereby eliminating non fruit flies.

- **Localization:** Since Doppler sensor technique used in this work can operate over a range of 10 meters, the calculation that determines Echolocation reveals the position of a target by its range, and by its horizontal and vertical spatial angles. To determine the distance, we used the time delay between emitted signals and returning echo

encodes range. Using Binaural echo cues to describe the horizontal angle, and monaural spectral cues, the vertical angle is not necessary in this work because the lb-nodes are stationary (Lee et al., 1992), (Lee et al., 1992). In cases where sensors are moveable, the necessity of horizontal angle, and monaural spectral are indicated. The vertical angle may be required so that the sensor can accurately target the specific pinpoint location of the emitted signal.

### 3.2.2 Habituation

Many researchers have demonstrated how ultrasonic repellent devices become inefficient after a few days of usage. This is habituation. Habituation is a decrease in response to a stimulus, and is often cited in studies testing the efficacy of sonic pest devices (Hodge, 2013). Because of this reason, it is important to note, that, just broadcasting a bunch of ultrasonic without any contextual meaning to the listening organism rapidly results in the insect's getting used to the sound (Mott & Timbrook, 1988). Therefore, this habituation prevention system broadcasts three primary contextual sounds, namely communication (mating and offspring calls), predator presence and auditory disturbance. With these three concepts, the system is able to produce the efficiency that has always eluded researchers in this subject area. The contextual sounds are randomly picked and played; therefore, the fruit fly continues to feel the natural context for these sounds.

In the auditory disturbance model, I identify the power spectrum of an ultrasonic that matches the most sensitive area of a fruit fly's audiogram (MØHL & MILLER, 1976). Ultrasonic serves as acoustic equivalents of the attack-retarding eyespot display in the same species (Brown et al., 2007). Research conducted by University of Iowa, cited in

(GALLUZZO, 2013) indicates that fruit flies lost their hearing when exposed to 120 decibels. In our case, we broadcast between 90 and 110 decibels so as to take the flies to near deaf, so they can feel the great impact of it. This technique also provides bases for learning among fruit flies to avoid environment with such level of sound intensities in the future.

### 3.2.3 Ultrasonic Communication

As indicated in 3.2.1, communication in general with respect to this work is grouped under mating and offspring calls. In order to elude predators, insects and flies' communication is in ultrasonic most of the time because it provides a secure channel for information exchange within groups of fly species. Even though this work needed but did not focus on the specific threshold for this kind of communication among fruit flies, it is evident in (Hendrichs & Hendrichs, 1998; Zuk & Kolluru, 1998), M.A. Hendrichs et al., predating organisms of the fruit fly try to exploit especially the mating calls to attract them so as to prey on them. This is the reason why many organisms such as fruit flies have developed a communication method that does not fall within the auditory range of their predators. The structure of the communication signal implementation is such that, whilst the flies are between 30 and 50 meters way from the lb-nodes, the broadcasting of the communication ultrasonic begins. This enables the fruit flies to attract the flies away from the farm. In addition, because of the scare-path implementation, the lb-nodes arrangement is such that there is an outer perimeter and inner perimeter. This makes way for broadcast communication ultrasonic ahead once the fruit flies pass and an alternating predator and auditory disturbance ultrasonic behind. Figure 9 show a diagram of fruit flies that have theoretically crossed outer perimeter. This activates the outer lb-nodes to broadcast communication ultrasonic whilst the inner

perimeter lb-nodes initiates the broadcast of the predator and auditory disturbance ultrasonic.

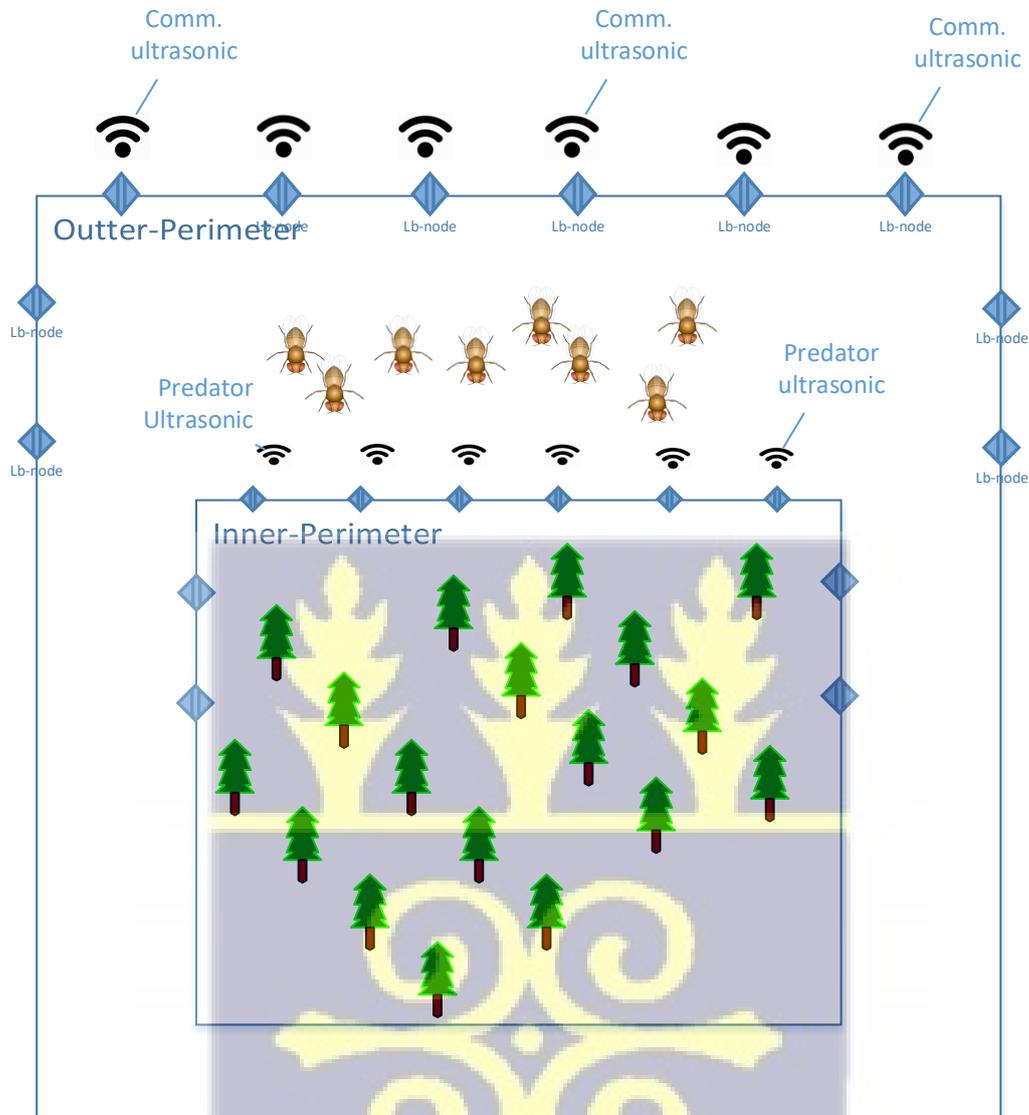


Figure 9: Communication Broadcast in the inner-perimeter

### 3.2.4 Predator Avoidance and Auditory Disturbance Ultrasonic

Listening to predators in the habitat of organisms is one of the survival instincts of any species of the animal kingdom. This skill is highly useful in escape maneuverers, which is essential for survival. The fruit fly has many natural enemies they always avoid because

they prey on them or prey on their eggs or offspring. A list of predators of the fruit fly is outlined in a United States Department of Agriculture (USDA) document titled “Natural Enemies of True Fruit Flies (Tephritidae)” (Stibick, n.d.). However, for this work, we store and broadcast primary predator acoustics and ultrasonic of predators like ant, beetle, frog and spider. One major advantage of this method is that it reduces the fruit fly population because during the season of laying eggs, ants especially feed on their eggs. When measured, many species of ants produce stridulating. The typical frequency, made by ants is around 50,000 cycles/sec, which is 50 KHz. Echoes generated from this frequency where the distance between the ant and the reflected object is 100mm is returned at 0.0006 seconds. According to J. R. Esperson in (ESPERSON, 1994), same results were recorded.



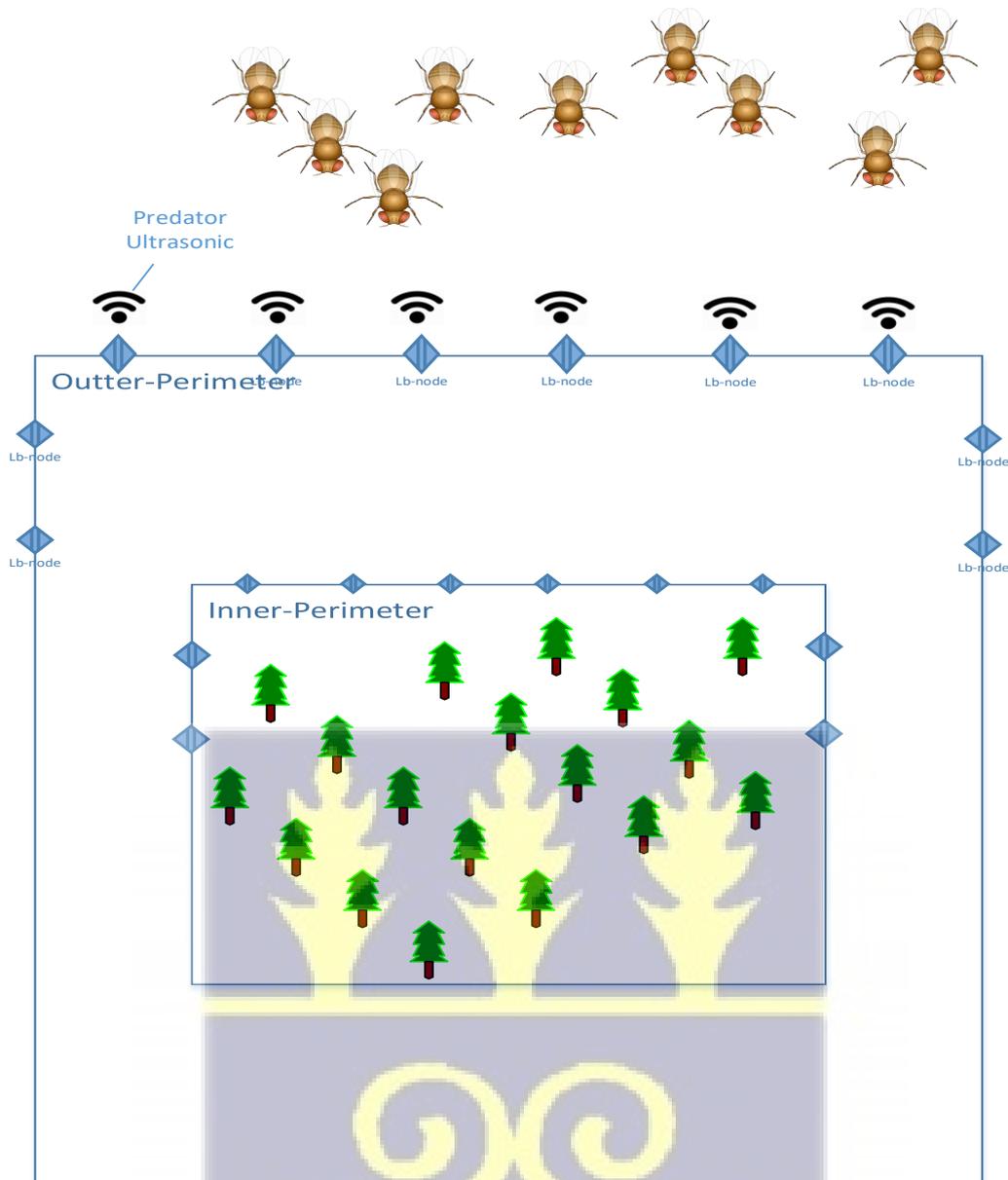


Figure 10: Predator Sound Broadcast Outer-Perimeter

### 3.3 Theoretical Framework

The study of insect auditory signalling dates back to about three decades (Yager, 1999). It is evident in research that many insect predators like bats take advantage of auditory signalling to locate and capture their prey (Neuweiler, 1989). In addition, insects use auditory signalling to communicate among themselves in order to carry out escape manoeuvres (Robert et al., n.d.) in instances of predator attacks. Many works on insect signalling also recognise that, at

a certain sound intensity, sound could be injurious to insects especially fruit flies (curioussciencewriters.org, 2014). The theoretical basis for this work is established on the premises above. Majority of the experiments are designed in a way to exploit the features within the auditory evolution of insects. For that matter fruit flies are used in developing a habituation mitigation system form control of fruit flies on mango plantations in Ghana.

### 3.4 Methods of Analysis

To get the result of this research, the simulation was conducted using Repast Symphony Agent-Based Simulator. In addition, complimenting application packages such as MS Excel and Graph Digitizer were used.

#### 3.4.1 Simulation Steps

The agents represented in this simulation are grouped under active and passive agents. Active agents in this work have the ability to sense and response to their environment whilst passive agents are stationary within the simulation environment. The active agents in this research are fruit flies and Listen-broadcast Node (lb-node). Mango trees and perimeter fencing are examples of passive agents in this simulation. Additionally, in figure 11, below, the flow chart shows the simulation steps for the fruit fly agent. After the initialisation of the agents and the environment, the fruit fly agents take to flocking (moving synchronously around in a group without collusion), then figure 9 represents the lb-nodes also begins its activity. The process of sensing and initiating the various responses based on the outcome of the sensed ultrasonic is evident in whether the mobile agent, in this case the fruit fly is able to make a decision of flocking away from the lb-node or flocking toward the lb-node in cases of communication and predator/auditory avoidance ultrasonic respectively.

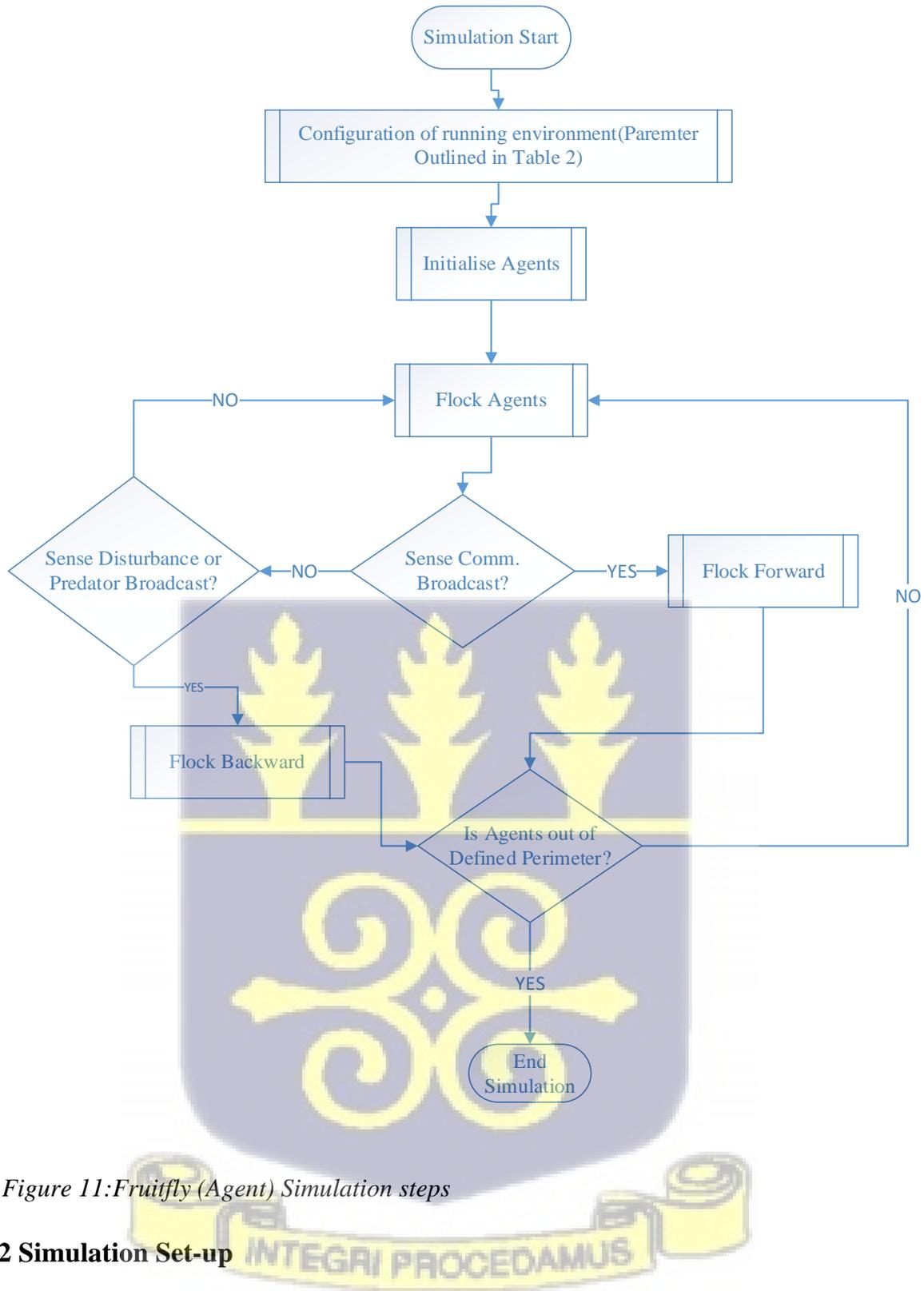
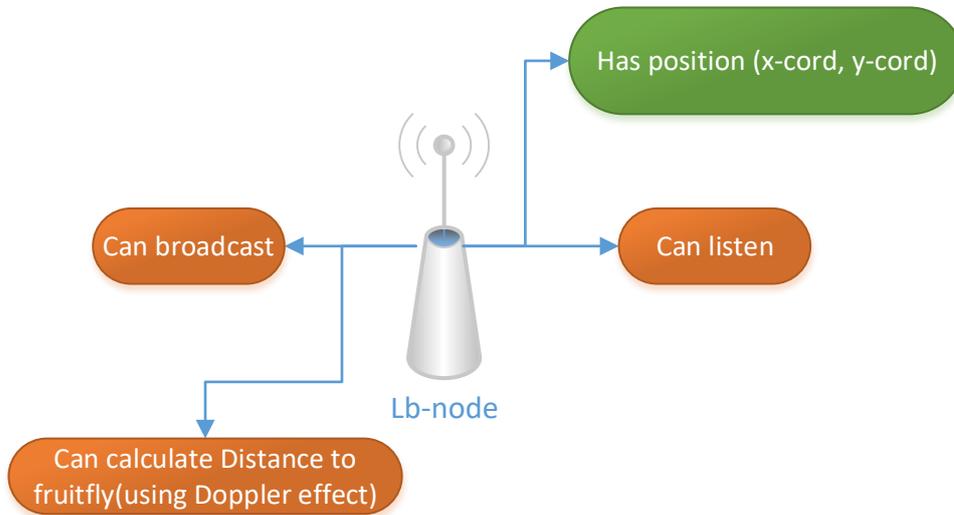


Figure 11: Fruitfly (Agent) Simulation steps

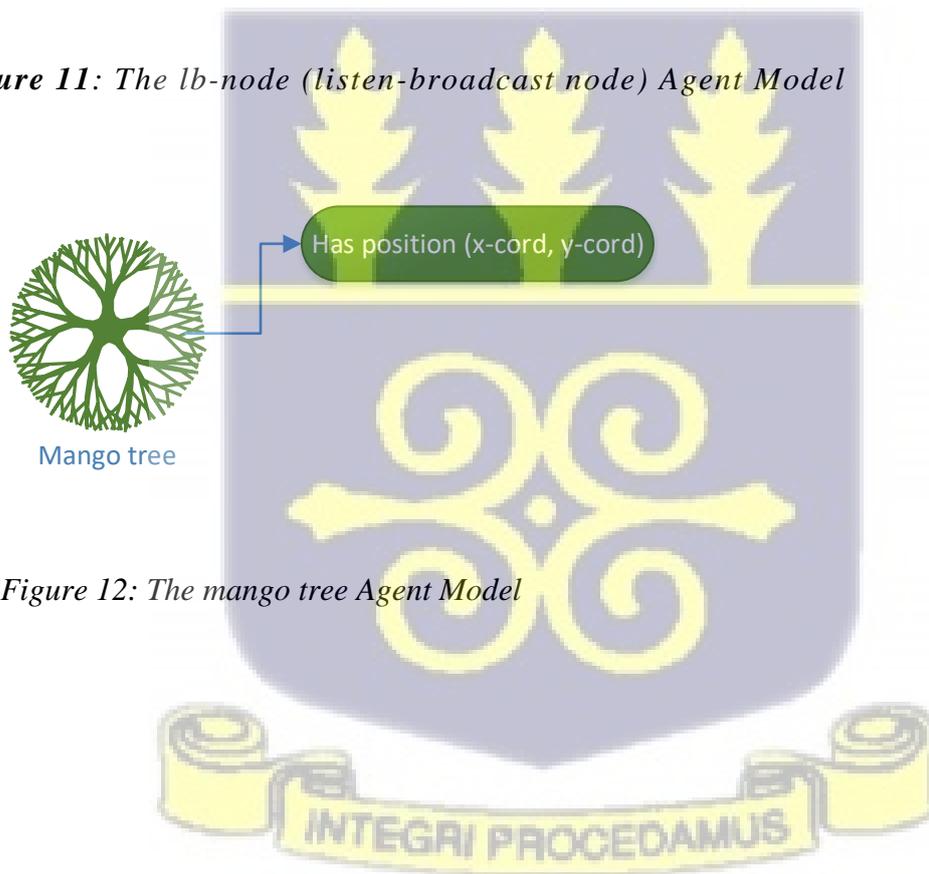
### 3.4.2 Simulation Set-up

The simulation set up involves three main agents, namely fruitfly, lb-node and mango trees; the first two agents are active agents whilst the last are passive agents. Below is the entity

and function diagram of the agents associated with this research on habituation prevention on ultrasonic fruit fly control system.



**Figure 11:** The lb-node (listen-broadcast node) Agent Model



**Figure 12:** The mango tree Agent Model

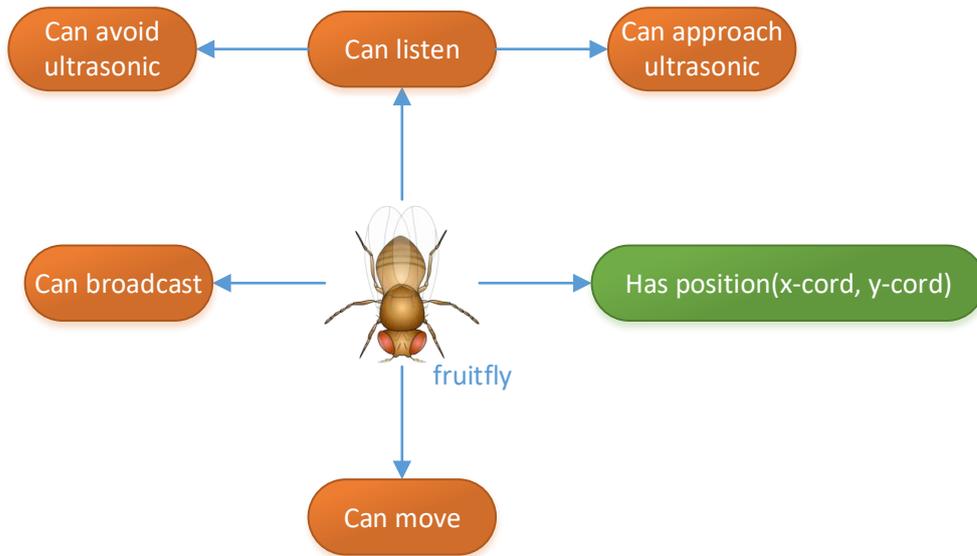


Figure 13: The fruitfly Agent Model

The diagrams in figure [11, 12, 13] represent the agents' attributes and functions implementation with groovy in Repast Symphony Agent-Based Simulator. In the diagrams, the function that each agent is programmed to perform is clearly outlined. It is important to note that all functions are represented with red-orange whilst the attributes are presented in green.

### 3.4.3 Listen-Broadcast Technique

One important problem this work seeks to resolved is the problem of the fruit fly's getting used to auditory disturbance ultrasonic from ultrasonic repellent devices. The source of this problem is the continuous broadcast of the ultrasonic sound. This work resolves the problem by performing a listen before broadcast. What this means is that, lb-nodes are always on the standby, listening to the fruit flies that may be within 50 meters. Using Doppler effect, the lb-nodes are able to accurately calculate the distance between them and the fruit fly. This method also helps provide information on whether the fly is approaching or moving away from the lb-node. If it is approaching, an appropriate auditory disturbance or predator

presence ultrasonic is broadcasted. Alternatively, if the lb-nodes detects that the fruit flies are leaving the farm, the randomly mounted external lb-nodes will begin to broadcast other communication ultrasonic with alternating random mating, offspring and parent call ultrasonic.



$$D = 0.5 * C * (T1 - T0) \dots (EQ1)$$

Figure 14: Listen-Broadcast Diagram

To perform the listen-broadcast sequence, Doppler shift technique is used. Figure 14 shows the implementation. According to the diagram, a fruit fly is traveling at speed V as shown in figure 14, the wavelength of the received (reflected) sonic burst ( $rx$ ) will be different from that of the transmitted burst ( $tx$ ) (Doppler Effect). The following relationship can be deduced:

$$k_{rx} = C * \frac{k_{tx}}{(C+V)} \rightarrow \text{fruit fly approaching.}$$

$$k_{rx} = C * \frac{k_{tx}}{(C-V)} \rightarrow \text{fruit fly retreating.}$$

Where:

$k$  = Wavelength ( $k_{tx}$  transmitted wavelength,  $k_{rx}$  received wavelength)

$C$  = Velocity of Sound

$V$  = Velocity of the fruit fly

Since  $Frequency = \frac{1}{(Time\ period)}$  and  $Frequency = \frac{(velocity\ of\ sound)}{wavelength}$ , this relationship can be re-written using EQ2 and 3 for  $V$  in terms of frequency. It goes like this:

$$V = C * \left( \frac{F_{rx}}{F_{tx} - 1} \right) \rightarrow \text{fruit fly approaching}$$

$$V = C * \left( \frac{1 - F_{rx}}{F_{tx} - 1} \right) \rightarrow \text{fruit fly retreating}$$

Here F stands for frequency

### 3.4.4 Scare-Path Algorithm Implementation

Apart from providing a list of broadcast ultrasonic to play on wireless sensor nodes, the activities of performing this function have been co-ordinated in such a way to intelligently direct or lead the fruit flies out of the mango plantation. Manipulating the three (3) primary broadcast ultrasonic, using Doppler shift to calculate the position and distance of the fruit fly enables our habituation prevention system to navigate the fruit fly out of the farm.

The implementation is the scare-path algorithm as follows:

Table 1: Scare-Path Process Table

Steps	Action
1	Sense Fruit fly
2	Broadcast echolocation signal
3	Get a reflected signal from echolocation broadcast

4	Measure amplitude of the reflected signal to determine the type of approaching organism
5	If fruit fly based on listen frequency and amplitude then...
6	Use $D = 0.5 * C * (T1 - T0) \dots (EQ1)$ to calculate the distance and position of the fruit fly
7	(a) If approaching, broadcast predator avoidance and auditory distress ultrasonic (b) If moving away, broadcast communication ultrasonic.
8	Alternate appropriately until cannot sense fruit fly

### 3.4.5 Principle of Separation

There are three principles guiding any agent flocking implementation. One among them is separation; a behaviour that causes an agent to steer away from all of its neighbours. In the situation here, the separation aspect of the fruit fly flocking algorithm enables the fruit flies avoid colliding with one another.



Figure 15: Separation in flocking implementation:

Similarities exist between this and the rest two (cohesion and alignment) but one essential difference in implementation is that, when a neighbouring agent (fruit fly) is found, the distance from the agent (fruit fly) to the neighbour is added to the computation vector. This is expressed with an algorithm below

$$\begin{aligned} \text{newXCord} += \text{agent.x} - \text{this.agent.x}; \quad \text{newYCord} + \\ = \text{agent.y} - \text{this.agent.y} \end{aligned}$$

**Data:** A fruitfly.

**Result:** The course of the fruitfly is updated.

```
goal ← (0,0);
neighbours ← getNeighbours(fruitfly);
foreach nFruitfly in neighbours do
goal ← goal + positionOf(fruitfly) - positionOf(nFruitfly);
end
goal ← goal / neighbours.size();
steerToward(goal, fruitfly);
```

To get the new location  $(x,y)$  of the agent, compute its vector and divide by the corresponding neighbour count, and then the resultant vector is negated in order for the agent (fruit fly) to steer (navigate) away from its neighbours correctly. Below is the Repast Symphony (Groovy Source code) implementation of separation (Bachelor & Stockholm, 2011).

### 3.4.6 Principle of Cohesion

Cohesion in flocking is to steer to move toward the average position of local flock mates. In this habituation prevention system, each fruit fly is programmed to obey the cohesion principle. Fruit flies within a flock are attracted to one another as long as they are within the detection range, but outside the separation range. This goal is to have the flies flock together, but not to be too close that they are on top of each other. If there are too many flies in the flock, the separation range will need to be incremented. This is represented graphically as:

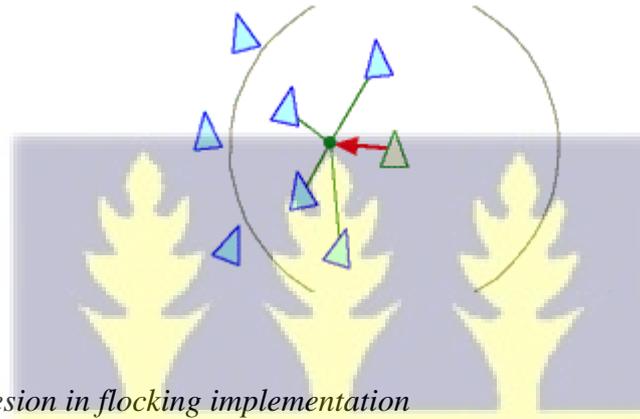


Figure 16: Cohesion in flocking implementation

The implementation is identical to that of the alignment behaviour, which is explained in the next section, but there are some key differences. Firstly, instead of adding the velocity to the computation vector, the position is added instead.

Like the previous, the vector for the computation is divided by the neighbour count, resulting in the position that matches the center of mass. Since, we do not want the center of mass itself, we want the direction to the center of mass, so we recalculate the vector as the distance from the fruit fly to the center of mass. Finally, the result is normalised and returned. This is represented as  $v.x += agent.x$ ;  $v.y += agent.y$ . The algorithm is presented as follows:

**Data:** A fruitfly.

**Result:** The course of the fruitfly is updated.

```
goal ← (0,0);
neighbours ← getNeighbours(fruitfly);
foreach nFruitfly in neighbours do
goal ← goal + positionOf(nFruitfly);
end
goal ← goal / neighbours.size();
steerToward(goal, fruitfly);
```

### 3.4.7 Principle of Alignment

The core principle guiding alignment is steering towards the average heading of local flock partner. In simple terms, this means that every fruit fly looks at where the other fruit flies immediate to them are heading and then adjust their speed and head position accordingly. In other words, this rule tries to make the fruit flies mimic each other's course and speed. If this rule was not used the fruit flies would bounce around a lot and not form the beautiful flocking patterns that can be seen in real flocks. The alignment algorithm is presented as follows:

```
v.x += agent.velocity.x;    v.y +
    = agent.velocity.y;    neighborCount ++;
```

**Data:** A fruitfly.

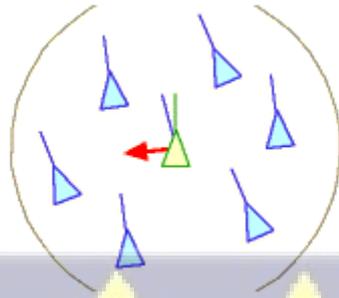
**Result:** The course and velocity of the fruitfly is updated.

```
dCourse ← 0;
dVelocity ← 0;
neighbours ← getNeighbours(fruitfly);
foreach nFruitfly in neighbours do
dCourse ← dCourse + getCourse(nFruitfly) - getCourse(fruitfly);
dVelocity ← dVelocity + getVelocity(nFruitfly) - getVelocity(fruitfly);
```

**end**

```
dCourse ← dCourse / neighbours.size();  
dVelocity ← dVelocity / neighbours.size();  
fruitfly.addCourse(dCourse);  
fruitfly.addVelocity(dVelocity);
```

Figure 17 is a pictorial representation of alignment where the agent in focus is trying to get the heading and velocity of its neighbours.



*Figure 17: Alignment in flocking implementation*

### **3.5 Types of Data and Sources**

The main goal of this work is to provide a habituation mitigation framework for ultrasonic fruit fly control system; the types of data are initial listen and broadcast frequencies for both fruit flies and the lb-nodes which are numeric in nature. Additionally, the base measurement is in thousands (1000). What this means is that every value used in this work is first converted to a thousand based unit because the velocity of sound used throughout this work is 340 m/s and for a KHz to conform to meters, a base of 1000 becomes the multiplier.

The sources of data for this work apart from the initial frequency inputs, includes the various runs of the simulation set. Repast Symphony Agent-Based simulator provides all the data output used for the analysis and conclusion for this work. The habituation mitigation

simulation was ran three times and the result was collected from Retest Observer Context of Repast Symphony.

### 3.6 Sample Size

The sample size for this research of habituation prevention is calved around the agents used. The minimum number is required for the successful simulations, result observation, collection and analysis. Based on the regular size of an experimental mango farm, the assumption of land size is 5% approximately 202  $m^2$  of one acre, the number of fruitflies per each run of three is 100, lb-nodes used in the same scenario is 25 per perimeter; which means there was 100 nodes in all for the four sides of the 5% land size. The number of mango trees based on final row spacing distance of 10 meter in a triangular form is 20. The sample sizes determination is arrived at by the computational (available hardware and software resource) capabilities of the simulation computer and the time needed to observe, collect and analyse the simulation results.

### 3.7 Chapter Highlights

In this chapter, the concept design and its implementation is developed. The emphasis here is on the components such as the simulation environment used, how the agents (fruit flies, listen-broadcast nodes and mango trees) were set up for the experiment to proceed.

Furthermore, the theoretical foundation is established for the choice of approach for habituation prevention and the methods, which were used to achieve the goals of this research. Apart from putting forth the methods, sub-concepts under flocking namely separation, cohesion and alignment which are the ingredient for any agent-based simulation were also used.

Finally, the type of data, source and sample size is highlighted with specific reference to initial agents set up, simulation runs and the display of results for further analysis.



## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.0 Introduction

This chapter presents the results and discussion for habituation-mitigating framework for ultrasonic fruit fly control systems simulation using Repast Symphony Agent-Based Simulator. Section 4.1 describes the simulation runs, which comprises of four sub-sections with categorisations under controlled and HPM experiment results. Section 4.2 presents listen and broadcast ratio in the simulation runs, Section 4.3 shows results of primary broadcast sounds with specific emphasis on communication, predator avoidance and auditory disturbance ultrasonic. Additionally, Section 4.4 presents results and discussions on fruit flies penetration ratio. This demonstrates the differences of results, comparing the controlled run with the HPM run. Finally, Section 4.5 summarises and highlights the various sections discussed in this chapter with reference to the entire habituation prevention framework.

#### 4.1 The Simulation Run Results

The simulation experiment run is divided into two parts namely, controlled run and habituation prevention model run. The controlled run contains simulation setup that establishes the bases for the experiment for which to plot the rest of the simulation results against. It does not implement any algorithm for habituation prevention. Fruit flies flock freely with the simulation experiment. The result is captured and used for the rest of comparative analysis.

In the habituation prevention simulation run, the habituation prevention algorithm is fully implemented and the result collected for analysis.

#### 4.1.1 Configuration Condition of Controlled and Habituation Prevention

##### Experiments

This section presents the initial setup for both the controlled and Habituation Prevention Framework (HPF) simulation experiments. Table 2 present the configuration conditions for the simulation in Repast Symphony Agent-Based Simulator

*Table 2: Controlled and HPM Simulation Configuration Table*

Name	Number	Type of Agent	Initial Position 2D- Space (x-cord, y-cord)
<b>Fruitfly</b>	100	Active	[-70,-70][-70,70] [70,-70][70,70]
<b>Listen-Broadcast Node</b>	100	Active	[-60,-60][-60,60] [60,-60][60,60]
<b>Mango Tree</b>	20	Passive	[-55,-55][-55,55] [55,-55][55,55]

The configuration table in Table 2 shows agents by name, number (quantity), type and by initial position in a 2-dimensional space within the simulation environment. The various nodes in use in this experiment includes, fruitflies, listen-broadcast node and mango trees. The intention of the experiment is to prevent fruitflies from attacking the mango fruits using ultrasonic with the scare-path and shepherding algorithm implemented on the host node. The primary challenges associate with this solution was the fact that fruitflies easily get use to (habituate) to the ultrasonic if the signal is continually broadcasted with adopting techniques that prevents this adoption. To address the specific remedies provides, highlighting the underlying factor that make provides the efficient machinery to the fruitflies easily adopt is nature, visa-vi the hostilities that exists with in the habitat of these fruitflies forces to quickly adopt to situations that increases their chances of survival. Observing from

the data table provided above, a difference of 10 units have been allocated in terms of the positioning and the arrangement of the various node relevant to this experiment. This helped in the initialisation of the experiment (simulation).

#### 4.1.2 Controlled Experiment Simulation Results

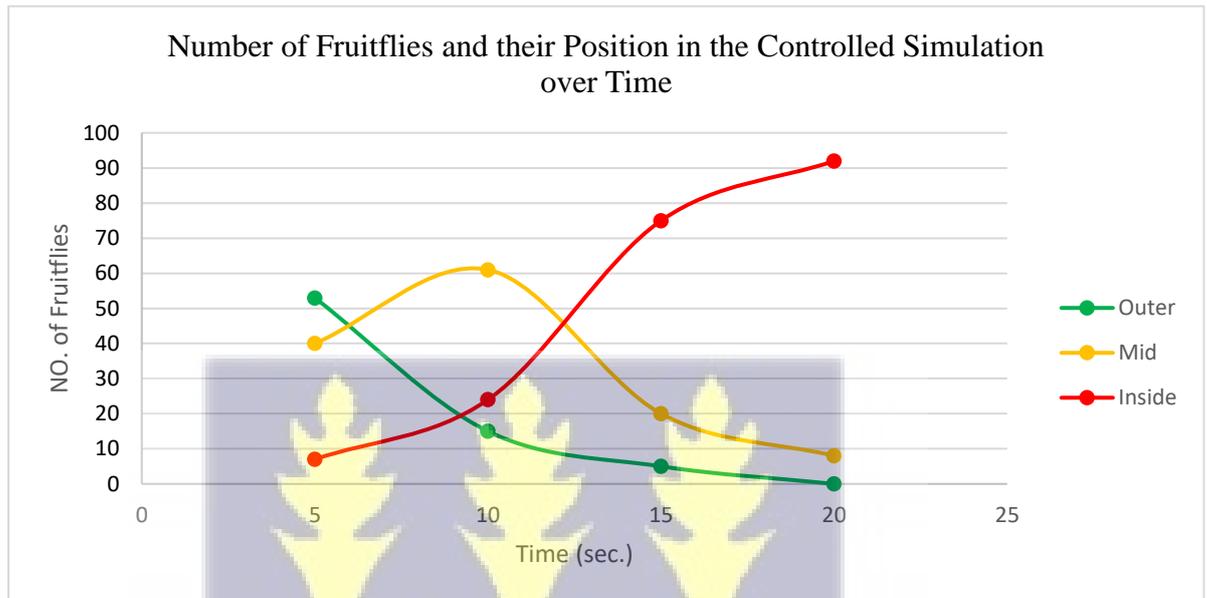


Figure 18: Fruitfly Penetration Rate Result (Controlled Experiment)

The graph in figure 18 presents results from the controlled simulation where the simulation experiment is devoid of habituation prevention model. The result from the simulation above is an outcome based on the controlled experiment that run for approximately 20 sec. As noted above, the habituation prevention was not introduced or implemented in this run. The red trail shows the position or movement count per frame simulation frame of fruitflies that were at the outer perimeter, whilst the yellow trail indicates the movement count of the flies mid-way through and finally the green tails shows flies in the inner perimeter of the simulated mango plantation, the specific counts are highlighted at an interval of 5 seconds. In the results, more than half, representing 60% of the fruit flies were in the mid perimeter of the

mango farm just half way through the simulation experiment. The result also shows that just after a third of the simulation time, over 70% representing about 75 fruit flies were in the inside of the mango farm. This shows the extent of fruitfly attack without an efficacious defence.

#### 4.1.3 Habituation Mitigation Model Simulation Results

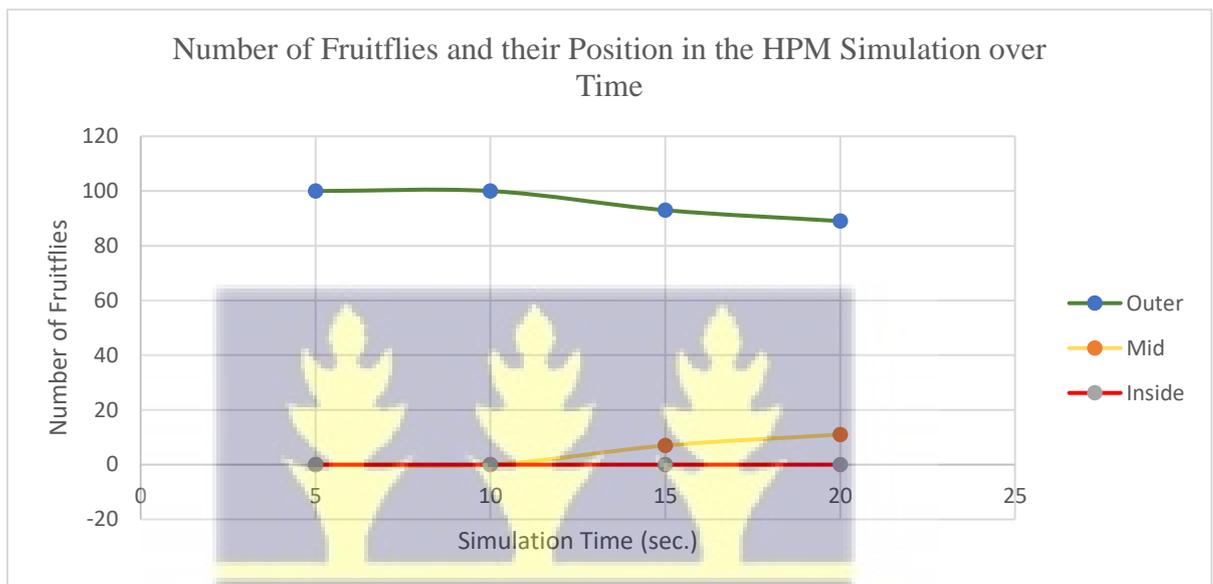


Figure 19: Fruitfly Penetration Rate Result (Application of HPF):

The above figure, represents the actual application simulation of habituation prevention framework. Observing from the simulation plot, the number of fruitflies entry into the mango plantation. From a general perspective, it can be observed from the red trail once again representing fruitflies movement count over the period of the simulation experiment. From a summarised view, the red trail stayed zero (0) all the time over the period of experimentation of the Habitual Prevention Framework. Secondly, the yellow trail representing the fruitfly movement count at the mid perimeter of the mango plantation show a very small rate of penetration. With time, the number of fruitflies penetration begin to decline due to the

multiplicity of signal been broadcasted. Details of the differentiating ultrasonic signal ratios have been presented in the subsequent graphs. Observing from the graph, the penetration levels peaked around 12 seconds of simulation, this rise, based on the auditory composition of inserts, for that matter fruitflies demonstrates that they were gradually becoming used-to(habituated) to the ultrasonic sound been broadcasted within the particular range of time as show in figure 19. Percentage-wise, there was about 8% rise in the penetration levels whilst at around 15 seconds of simulation, an overall rise in penetration was 10%. This shows an equal decline in the number of fruitflies flying around the outer perimeter on the mango plantation by the same margin.

Furthermore, within the time range of between 15 and 18 seconds, the penetration rate, that is the number of fruitflies inside the outer perimeter of the simulated mango plantation begins to rise whilst the number inside the mid perimeter of the mango plantation shows a reverse trend. Much of the habituation prevention strategies employed are well explain figure 18 and 19.

From the above graph, it is evident that, something is happening which has reduced the penetration rate of the fruitflies. It is also clear that those fruitflies which have managed to get access to the farm, after some point in time begin to withdraw from the farm. This is attributed to the engagement of Habitual Prevention Framework. It also important to noted that varied ultrasonic signal were broadcasted to achieve the feet. The first part of the strategies adapted as to the kind of signal modulation versus how to appropriately detect and broadcast at any point in time in the simulation experiment is presented under the next section.

## 4.2 Listen and Broadcast Ratio

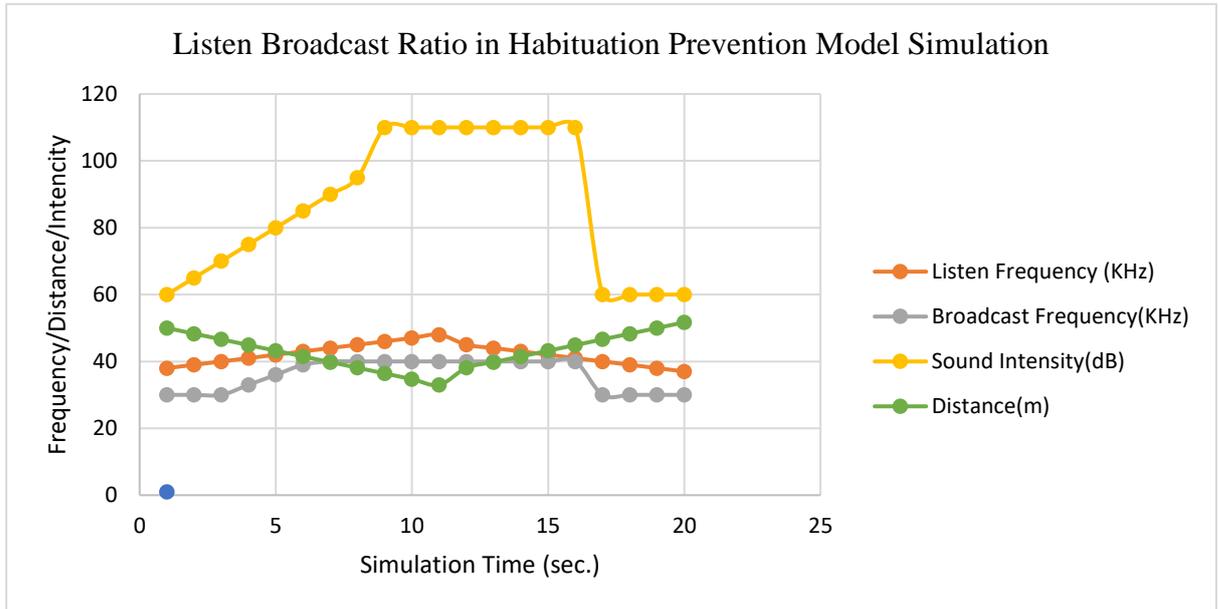
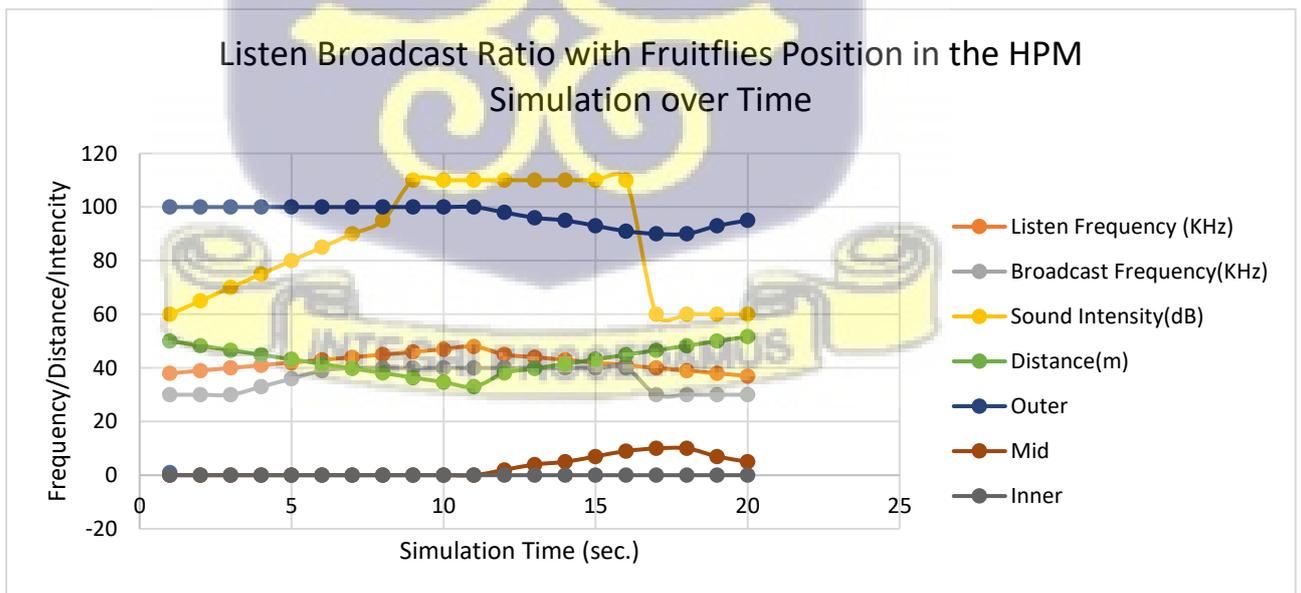


Figure 20: WSN listen versus broadcast and sound intensity versus distance ratio

In figure 20, the essence of the researcher is to determine the optimal or a range of optimal distances within the listen and broadcast period with a moderation of the sound intensity and how these variables affect the movement of the fruitflies from or to the plantation as the algorithm runs autonomously. The observation as per the figure above, shows that, at that start of the simulation, the listen frequency (set with the listen frequency band of the fruitflies) is at around 39kHz, the broadcast frequency is set at 35kHz whilst the sound intensity of both lb frequencies is at 60db. This configuration was necessary because at this time, the intention was to scare the fruitflies away from the plantation. Whilst at these configurations for about 5 secs, it is seen that the distance of direction of the fruitflies is toward the plantation. The distance registered in the simulation is about 41 meters. In about 10 secs of the simulation, since the starting distance (location of the fruitflies) is about 55meters, this demonstrates that the fruitflies were rather moving toward the plantation instead of moving away from it. Furthermore, the listening frequency in most of the

simulation run is mostly higher than the broadcast frequency due to the high frequency sensitivity of small insects/animals. In most case, small animal have sound sensitivity above 20khz. What this implies is that, the fruitflies in a real-life world will mostly be producing sound that are of higher frequencies than they perceive within their habitat. Looking at figure 20 again, it is observed that at 5secs of simulation, the broadcast frequency is 36Khz, but the listen frequency is about 43.2khz, furthermore in the simulation, at 10secs, the broadcast frequency is 40Khz and the listen frequency is 47Khz. It is seen that the sound intensity also peaks. This is due to the fact that the periods between 10secs and 15secs, the number of fruitflies getting close to the plantation arena and detected by the WSNs begin to rise therefore the scare-path algorithm is trying to increase the sound intensity in order to produce a more disturbance ultrasonic signal.

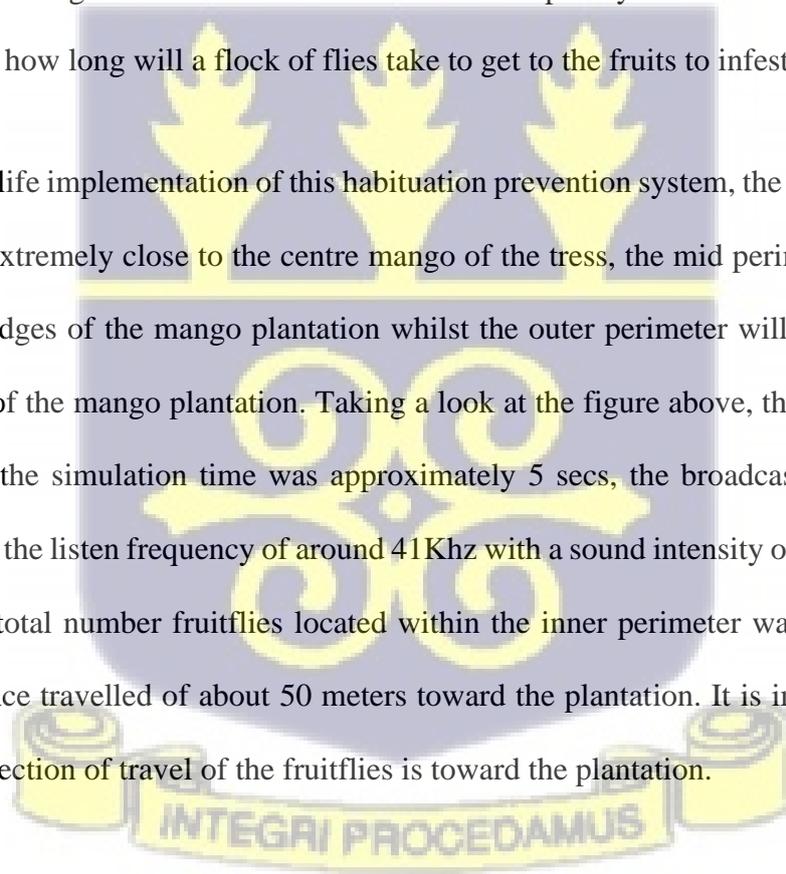
#### 4.3 Results Based on Communication, Avoidance and Disturbance Broadcasts



*Figure 21: WSN listen, broadcast and fruitflies cluster positions ratio*

The figure labelled 21 represents the ratio of fruitflies versus the various kinds of ultrasonic sound, be it listen, broadcast and their respective sound intensities. Comparing this to the previous figure 21, it observed that whilst the previous figure finds the ratio of the interaction among the listen, broadcast sound intensities and the distance travelled by the entire flock of fruitflies, the later, presents similar ratios with a slight modification identifying the headcount of fruitflies per a defined zone of the simulation area; namely inner, mid and outer perimeters. This aspect of the simulation tries to look the situation where a flock of fruitflies intend to attack a mango plantation within a time space of 25 secs and a simulation distance of 100 meters, how long will take the fruitflies take to completely arrived at the mango trees, for that matter how long will a flock of flies take to get to the fruits to infests them.

In the real-life implementation of this habituation prevention system, the inner perimeter will represent extremely close to the centre mango of the tress, the mid perimeter will represent the outer edges of the mango plantation whilst the outer perimeter will represent the outer perimeter of the mango plantation. Taking a look at the figure above, the research observed that when the simulation time was approximately 5 secs, the broadcast frequency was at 39Khz and the listen frequency of around 41Khz with a sound intensity of about 80bd in both cases, the total number fruitflies located within the inner perimeter was basically zero (0) with distance travelled of about 50 meters toward the plantation. It is important to indicate that the direction of travel of the fruitflies is toward the plantation.



#### 4.4 Results Based on the Comparison of Listen/Broadcast Ratio with Fruitflies

##### Penetration over time

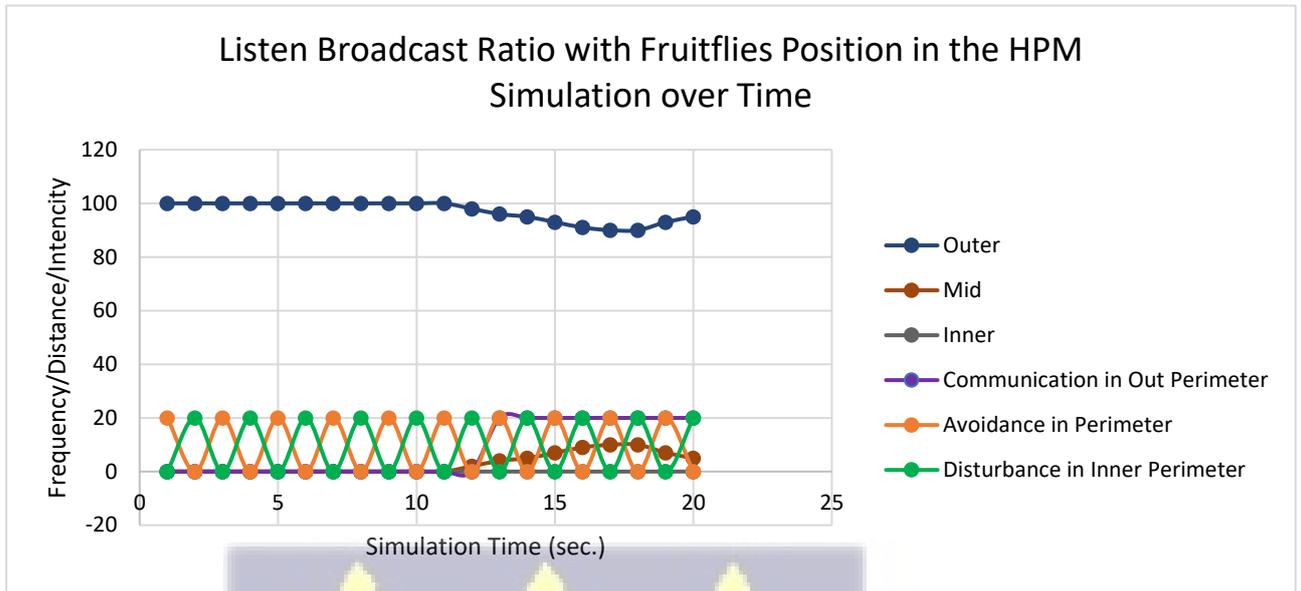


Figure 22: WSN listen, broadcast and fruitflies cluster positions ratio

Figure 22 presents the simulation results of the configuration of communication, avoidance and disturbance ultrasonic sounds broadcasted at various stages of the simulation period. Observing from the data, whilst all the fruitfly nodes were outside the plantation arena, there is a continuous but alternating broadcasting of disturbance and avoidance ultrasonic inside the perimeter of the plantation whilst communication signals were broadcasted from the outer perimeter. As indicated in my simulation design and implementation, the intention to broadcast the avoidance and disturbance signals in the inner perimeter is to scare away the fruitflies from the trees whilst the communication signal is to attract the them toward the outside of the plantation arena. Taking a cue from this, it is observed that when the communication signal was introduced at about between 55% and 60% into the simulation, the number of fruitflies that were moving toward the mid to inner perimeter of the plantation arena began to rise. By the time the simulation was in the period of 15secs, the total number

of fruitflies in the outer perimeter reduced from 100 to 93 whilst the remaining 7 fruitfly nodes have advance in the mid area of the plantation. It is within the same period that the communication signal was introduced. The increase in the presence of fruitflies in the mid perimeter may be due to the signal interference between the three (3) signals being broadcasted at same time. Since these signals are being broadcasted in the ultrasonic range, the chances of interference is high due to the high frequency range of the signals.

The above figure, represents the actual application simulation of habituation prevention

#### 4.5 Fruit flies Penetration Ratio (Control versus Habituation Mitigation Model)

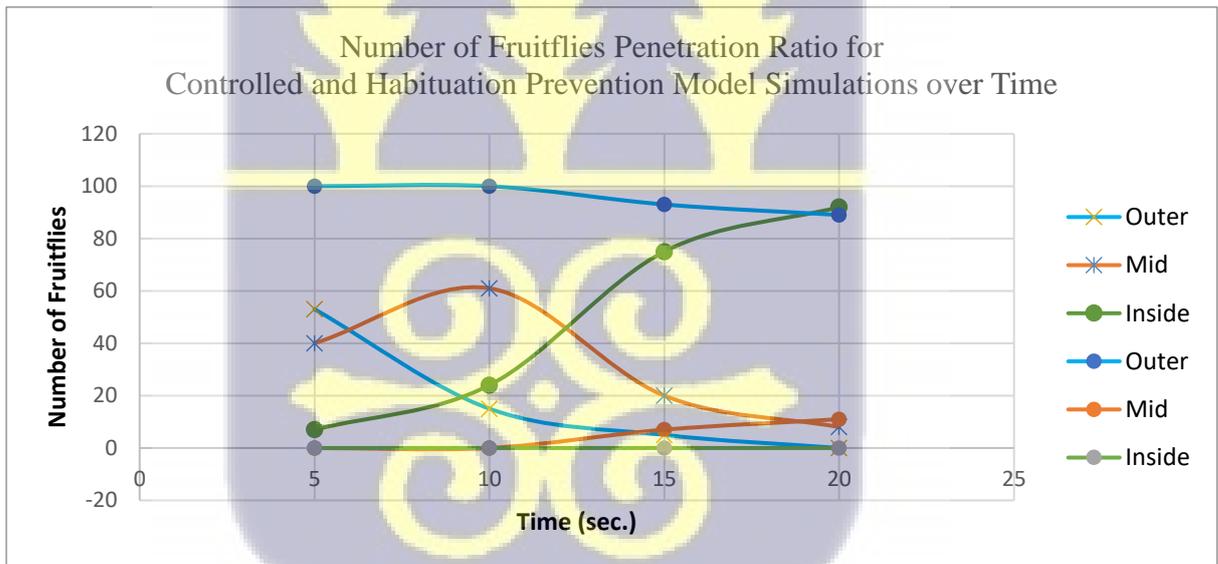


Figure 23: WSN listen, broadcast and fruitflies cluster positions ratio

The figure above compares the penetration ratios of the controlled and the habituation prevention simulation. The total number fruitflies node used in both scenarios is 100. Since the results of both have been discussed separately in earlier figures, this section focuses on

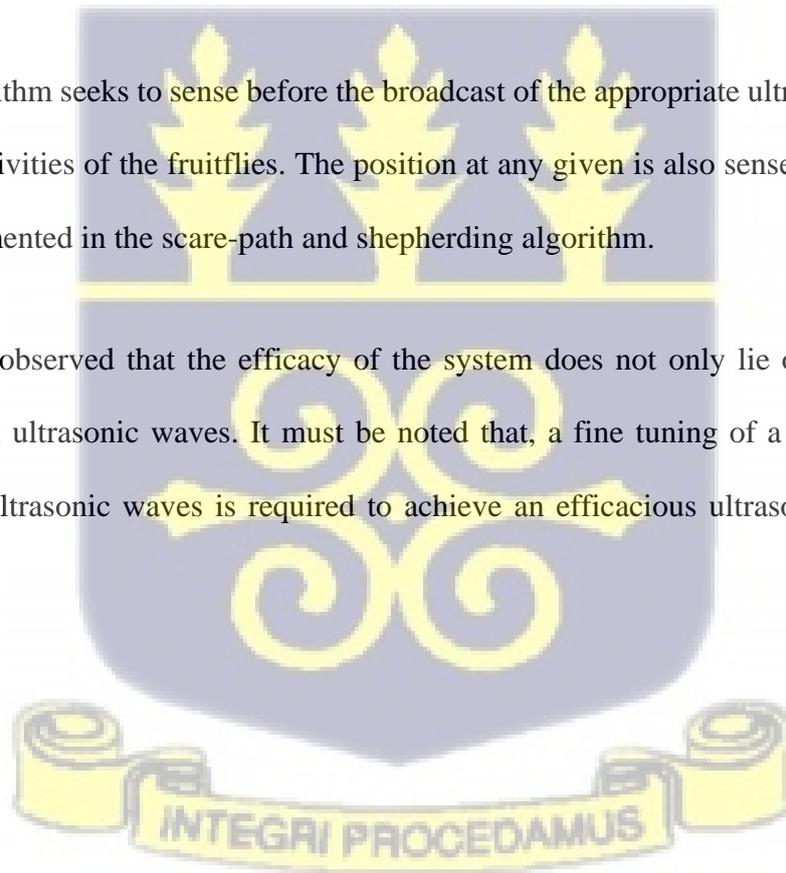
the differences that is observed in the results. By a simulation period of 5 secs, the results indicate 47 more fruitflies nodes within the outer perimeter of the plantation enclosure when the **HPM** was implemented, this represents a 47% improvement in the penetration of the fruitflies. In 10 secs of simulation, the result from the penetration ratio of the fruitfly nodes into the plantation enclosure is still 0.

#### 4.5 Chapter Highlights

This chapter provide insights into the results derived from the simulation runs. The results presented demonstrates the efficacy of the Ultrasonic fruitfly control system if implemented using the scare-path and shepherding algorithm.

The algorithm seeks to sense before the broadcast of the appropriate ultrasonic waves based on the activities of the fruitflies. The position at any given is also sensed before any action as implemented in the scare-path and shepherding algorithm.

It is also observed that the efficacy of the system does not only lie on broadcasting the individual ultrasonic waves. It must be noted that, a fine tuning of a combination of the primary ultrasonic waves is required to achieve an efficacious ultrasonic fruitfly control system.



## CHAPTER 5

### CONCLUSION

#### 5.0 Introduction

The research was conducted to establish a habituation prevention framework for ultrasonic pest control devices in general with the particular interest in minimising the problem related to habituation as a result of using ultrasonic pest control by continuous broadcast within the agricultural space. A practical scare and shepherding scheme in this area has a broad impact on improving mango fruit quality and many other reasons such as reduction of the impact of agricultural chemicals on the environment.

The design and implementation of the habituation prevention and the scare path scheme were based on the signalling activities of foraging bats as predators and their prey insects and also an alternating broadcast of the three primary signals. Whilst some of the ideas from foraging bats helped to calculate the distance between the fruitfly nodes and the WSNs at any given period within the simulation, the way other flying insects perceive sound within their habitat and species helped to select and play the appropriate communication signal in order to attract the fruitflies away from the plantation arena.

Furthermore, the simulation configuration came from the various flocking algorithms available within computational science space. Other important tools found in Repast Symphony such as model library came in handy. Repast Symphony was chosen for the simulation due to its' out of the box support for agent-based simulation.

## 5.1 Conclusion

In order to implement an efficacious habituation prevention system, three types of ultrasonic signals, namely communication, disturbance and avoidance signals must be configured to broadcast at specific frequency ranges with a combination of well-defined sound intensity.

This is evident in a set of results derived from a simulation runs where, even though the three set of signals were being broadcasted concurrently, however a number of fruitfly nodes were still able to penetrate into the mid perimeter of the plantation arena. This may be due to the interference arising from ultrasonic signals cancelling each other which in some cases resulted in a different kind of ultrasonic signal which might mean something different to the fruitflies.

### 5.1.1 Ultrasonic Signal

Ultrasonic waves have a frequency greater than 20 kHz that human ear cannot detect. However, certain creatures such as mosquitoes, dogs, and bats show responses to it. The velocity of sound in air is 332 m/sec so the wavelength is  $\lambda < 1.66$  cm. These waves can be applied in fields such as precision agriculture, military defence and security, medical monitoring, transportation, environmental monitoring, etc.

In the case of this work, these waves were applied to help mitigate the effects of fruitflies on the quality of mango fruits harvested for both local consumption and international export. Using Ultrasonic waves with the help of the scare-path and shepherding algorithm can help reduce the infestation of fruit flies on the mango fruit by many folds.

### **5.1.2 Ultrasonic Signal Sensing using WSNs.**

In this work, the scare-path and shepherding schemes required a medium to enable the detection of ultrasonic waves. WSN as a technology was configured in the Repast Symphony Simulation environment with ultrasonic waves sensing abilities. Since ultrasonic waves are detected in frequency range of greater than 20kHz, the sensor nodes were virtual configured as such.

The Ultramic 384K BLE by dodotronic is the hardware equivalent of Audio Wireless Sensing Nodes used in the simulation setup of this research. The setup parameters are 48kHz to 384kHz sampling rate at 24kHz to 192kHz bandwidth.

In the real world, this microphone hardware has a recording ability therefore provides the opportunity to capture the ultrasonic waves that are being produced by the fruit flies. These recorded waves could be stored and analysed in combination with the results from this work in order to improve the efficacy of the Ultrasonic Fruitfly control mechanism.

### **5.1.3 Ultrasonic Signal Broadcasting using Array of Audio Nodes**

The audio broadcast nodes used in this work are modelled around a regular audio speaker. The three types of ultrasonic namely; communication, auditory disturbance and predator avoidance are pre-recorded, selected by the analysis of the sensing from the audio sensing nodes based on the scare-path and shepherding algorithm and played.

The research believes that having a specialised speaker to broadcast the three primary ultrasonic waves prescribed in this work could help improve the efficiency of the habituation prevention fruitfly control system.

#### **5.1.4 Habituation.**

The primary focus of this work is to provide a scare-path and shepherding algorithm that can be implemented to mitigate the effects of fruitflies in mango plantation. The continuous broadcast of the ultrasonic results in the fruitflies getting used to it. This resultant behaviour is called habituation.

Many living things possess this attribute. Once they are introduced to some kind of stimulus continuously, they get adapted to that stimulus. If that stimulus is pleasant, by way of a rewarding or having a history of a reward to that organism, then the organism gets attracted to the stimulus. The stimulus could invoke a history of punishment too. In that case, the organism tends to avoid it. If the stimulus provided has a history of punishment but the current stimulus does not provide an after punishment when the organism expects it, then the fear or avoidance history is updated to otherwise.

The above scenario presents a challenge to any kind of pest control system that relies on the biology of the organism to prevent it hence the need for this habituation prevention scheme using scare-path and shepherding algorithm.

#### **5.1.5 Scare-path and shepherding algorithm**

Based on the explanations provided in the sub-section 5.1.4, it is important a system is implemented in such a way that the scare or attraction stimulus is not activated in a continuous manner. The scare-path and shepherding algorithm provides a systematic way to activate the stimulus by first of all analysing the presence or absence of the fruitflies before activating the stimulus. In this algorithm, the researcher allowed the system to make a calculated guess and picks the appropriate stimulus to apply from the three primary ultrasonic waves namely:

communication, auditory disturbance and predator avoidance ultrasonic waves.

## 5.2 Recommendation

The motivation for this body is the fact that a lot of exotic mangos is produced for export from Ghana but at the end of the harvest period the total yields of the fruit is affected by fruitflies. Many western countries that import mango out of the country have a lot of strictive rules in terms of the condition they want the mango fruit in before approval for export. The reason why some of the fruits do not meet the specification of the foreign buyers is fruitflies. My intention is to provide a lasting solution to this problem with minimal environmental impact.

It is important that simulation might a good way to identify the problems and solutions associated with something but they still do not provide the actual real-life situation. It is my recommendation that funds are provide so this experiment can be carried out in a live field.

Furthermore, in the various results that have been presented, it is observed that not all fruitflies are eliminated from the plantation arena. In future works, the researcher or anyone interested can look into interferences of Ultrasonic (communication, avoidance and disturbance) sound produced and how to eliminated them in order to have an efficient system

Many ultrasonic devices are on the market that are advertised a efficient for pest control. Majority of the time, these devices do not work as advertised. Furthermore, expectation is that, with a few modifications, the mechanism if employed in accident prevention on our roads can help mitigate accidents that occur around sharp curves on the roads.

## REFERENCES

- A fly's hearing* | *Iowa Now*. ( Retrieved July 26, 2018, from <https://now.uiowa.edu/2013/09/flys-hearing>
- Abdullahi, G., Obeng-Ofori, D., Afreh-Nuamah, K., & Billah, M. K. (2011a). Perception of Ghanaian mango farmers on the pest status and current management practices for the control of the African invader fly. *New York Science Journal*, 4(2), 74–80.
- Abdullahi, G., Obeng-Ofori, D., Afreh-Nuamah, K., & Billah, M. K. (2011b). *Perception of Ghanaian mango farmers on the pest status and current management practices for the control of the African invader fly Bactrocera invadens (Diptera:Tephritidae)*. <http://ugspace.ug.edu.gh/handle/123456789/2395>
- Agency, G. N. (2013a). *Fruit flies make Ghana mangoes unattractive worldwide* | *Business News* 2013-03-08. <https://www.ghanaweb.com/GhanaHomePage/NewsArchive/Fruit-flies-make-Ghana-mangoes-unattractive-worldwide-267069>
- Agency, G. N. (2013b). *Mango farmers call on African leaders to collaborate to fight fruit fly menace* / *Ghana News Agency (GNA)*. <http://www.ghananewsagency.org/economics/mango-farmers-call-on-african-leaders-to-collaborate-to-fight-fruit-fly-menace--57072>
- Ayoka. (2016). *Emerging Agriculture Technologies*. <https://www.ayokasystems.com/news/emerging-agriculture-technologies/>

Azfar, S., Nadeem, A., & Basit, A. (2015). Pest detection and control techniques using wireless sensor network: A review. *Journal of Entomology and Zoology Studies JEZS*, 3(32), 92–99. <http://www.entomoljournal.com/vol3Issue2/pdf/3-2-49.1.pdf>

Bachelor, C. E., & Stockholm, S. T. (2011). *Simulation of the Flocking Behavior of Birds with the Boids Algorithm Bachelor of Science Thesis Simulation of the Flocking Behavior of Birds with the Boids Algorithm.*

Beckwith, R., Teibel, D., & Bowen, P. (2004). Report from the field: results from an agricultural wireless sensor network. *29th Annual IEEE International Conference on Local Computer Networks*, 471–478. <https://doi.org/10.1109/LCN.2004.105>

Boehm, H.-P. (2010). Graphen - wie eine Laborkuriosität plötzlich äußerst interessant wurde. *Angewandte Chemie*, 122(49), 9520–9523. <https://doi.org/10.1002/ange.201004096>

Boonman, A. M., Boonman, M., Bretschneider, F., & van de Grind, W. A. (1998). Prey detection in trawling insectivorous bats: duckweed affects hunting behaviour in Daubenton's bat, *Myotis daubentonii*. *Behavioral Ecology and Sociobiology*, 44(2), 99–107. <https://doi.org/10.1007/s002650050521>

Brown, S. G., Boettner, G. H., & Yack, J. E. (2007). Clicking caterpillars: acoustic aposematism in *Antheraea polyphemus* and other Bombycoidea. *Journal of Experimental Biology*, 210(6), 993–1005. <https://doi.org/10.1242/jeb.001990>

Calatrava-Requena, J., González-Roa, M. C., & Sayadi, S. (2013). INTRA-EUROPEAN MANGO TRADE BUSINESS: FACTS FROM FIGURES. *Acta Horticulturae*, 992, 49–54. <https://doi.org/10.17660/ActaHortic.2013.992.3>

curioussciencewriters.org. (2014). *Listen up! Fruit Flies Key to Hearing Loss Research* / *curiousSCIENCEwriters*. <https://curioussciencewriters.org/2014/10/14/listen-up-fruit-flies-hearing-loss/>

de Wilde, S. (2016). *The Future of Technology in Agriculture*. <http://stt.nl/stt/wp-content/uploads/2016/05/ENG-Toekomstverkenning-agri-food-Web.pdf>

Deku, G., Combey, R., Doggett, S. L., & Mensah, B. A. (2021). Assessment of Tropical Bed Bug (Hemiptera: Cimicidae), Infestations in Cape Coast, Ghana: Household Control Practices and Efficacy of Commercial Insecticides and Long-Lasting Insecticidal Nets against Field Bed Bugs. *Journal of Medical Entomology*, 58(4). <https://doi.org/10.1093/jme/tjab042>

ESPERSON, J. R. (1994). Do Ants Use Ultrasound for Personal Communication (Hymenoptera: Formicidae)? *Australian Journal of Entomology*, 33(3), 213–215. <https://doi.org/10.1111/j.1440-6055.1994.tb01220.x>

Eucarpia. Congress (18th : 2008 : Valencia, S., Prohens, Jaime., & Badenes, M. L. (2008). *Modern variety breeding for present and future needs : proceedings of the 18th EUCARPIA General Congress, 9-12 September 2008, Valencia, Spain*. Editorial Universidad Politécnicade Valencia. [https://books.google.com.gh/books/about/Modern\\_Variety\\_Breeding\\_for\\_Present\\_and.htm?hl=&id=WUycNUwN83UC&redir\\_esc=y](https://books.google.com.gh/books/about/Modern_Variety_Breeding_for_Present_and.htm?hl=&id=WUycNUwN83UC&redir_esc=y)

Fachada, N., Lopes, V. v., Martins, R. C., & Rosa, A. C. (2015). Towards a standard model for research in agent-based modeling and simulation. *PeerJ Computer Science*, 1, e36. <https://doi.org/10.7717/peerj-cs.36>

Fenton, B. (1999). *Describing the echolocation calls and behaviour of bats*. Acta Chiropterologica.

[https://www.researchgate.net/publication/297872537\\_Describing\\_the\\_echolocation\\_calls\\_and\\_behaviour\\_of\\_bats](https://www.researchgate.net/publication/297872537_Describing_the_echolocation_calls_and_behaviour_of_bats)

Fenton, M. B. (1990). The foraging behaviour and ecology of animal-eating bats. *Canadian Journal of Zoology*, 68(3), 411–422. <https://doi.org/10.1139/z90-061>

Furfaro, A., & Sacco, L. (2019). Exploiting Adaptive Ladder Queue into Repast Simulation platform. *Proceedings of the 2018 IEEE/ACM 22nd International Symposium on Distributed Simulation and Real Time Applications, DS-RT 2018*. <https://doi.org/10.1109/DISTRA.2018.8601019>

Gabriel Arthur Kelman S Tolin Anne K Vidaver, C. J., & James, R. (1995). *Research on plant disease and pest management is essential to sustainable agriculture*. <http://digitalcommons.unl.edu/plantpathpapers>

Galán Saúco, V. (2013). WORLDWIDE MANGO PRODUCTION AND MARKET: CURRENT SITUATION AND FUTURE PROSPECTS. *Acta Horticulturae*, 992, 37–48. <https://doi.org/10.17660/ActaHortic.2013.992.2>

GALLUZZO, G. (2013). *A fly's hearing* | Iowa Now. <https://now.uiowa.edu/2013/09/flys-hearing>

GhanaWeb. (2014). *Fruit-fly worry for B/A mango farmers* | Business News 2014-02-04. <https://www.ghanaweb.com/GhanaHomePage/business/Fruit-fly-worry-for-B-A-mango-farmers-299686>

(HDU-DCS), M. (2013). *Fruit Fly Management – Ministry of Food & Agriculture*.  
[http://mofa.gov.gh/site/?page\\_id=14116](http://mofa.gov.gh/site/?page_id=14116)

Hendrichs, M. A., & Hendrichs, J. (1998). Perfumed to be killed: Interception of Mediterranean fruit fly (Diptera: Tephritidae) sexual signaling by predatory foraging wasps (Hymenoptera: Vespidae). *Annals of the Entomological Society of America*, 91(2), 228–234.  
<https://doi.org/10.1093/aesa/91.2.228>

Henson, O. W., & Schnitzler, H.-U. (1980). Performance of Airborne Biosonar Systems: II. Vertebrates Other than Microchiroptera. In *Animal Sonar Systems* (pp. 183–195). Springer US. [https://doi.org/10.1007/978-1-4684-7254-7\\_7](https://doi.org/10.1007/978-1-4684-7254-7_7)

Hodge, J. (2013). *Science and Technology Forecast Research Needs and Priorities*. 2009(November), 12–15.

Howe, T. R., Collier, N. T., North, M. J., Parker, M. T., Vos, J. R., Corp.), (PantaRei, Chicago), (Univ. of, & Urbana), (Univ. of Illinois at. (2006). *Containing agents : contexts, projections, and agents*. <https://www.osti.gov/biblio/1015536>

Hoy, R., Nolen, T., & Brodfuehrer, P. (1989). The neuroethology of acoustic startle and escape in flying insects. *Journal of Experimental Biology*, 146(1).

Hoy, R. R. (1992). The Evolution of Hearing in Insects as an Adaptation to Predation from Bats. In *The Evolutionary Biology of Hearing* (pp. 115–129). Springer New York. [https://doi.org/10.1007/978-1-4612-2784-7\\_8](https://doi.org/10.1007/978-1-4612-2784-7_8)

Jason Clay. (2004). World Agriculture and Environment: A Commodity-by-Commodity Guide to Impacts and Practices. In *Island Press*. Island Press.

[https://books.google.com.gh/books/about/World\\_Agriculture\\_and\\_the\\_Environment.html?hl=&id=zFpfGMeTax4C&redir\\_esc=y](https://books.google.com.gh/books/about/World_Agriculture_and_the_Environment.html?hl=&id=zFpfGMeTax4C&redir_esc=y)

Jensen, M. E., & Miller, L. A. (1999). Echolocation signals of the bat *Eptesicus serotinus* recorded using a vertical microphone array: effect of flight altitude on searching signals. *Behavioral Ecology and Sociobiology*, 47(1–2), 60–69. <https://doi.org/10.1007/s002650050650>

Jondhale, S. R., Maheswar, R., & Lloret, J. (2022). Fundamentals of Wireless Sensor Networks. In *EAI/Springer Innovations in Communication and Computing*. [https://doi.org/10.1007/978-3-030-74061-0\\_1](https://doi.org/10.1007/978-3-030-74061-0_1)

Kaini, M. (2020). Role of Agriculture in ensuring Food Security. *International Journal of Humanities and Applied Social Science*. <https://doi.org/10.33642/ijhass.v5n1p1>

Kalko, ElisabethK. V., & Schnitzler, H.-U. (1993). Plasticity in echolocation signals of European pipistrelle bats in search flight: implications for habitat use and prey detection. *Behavioral Ecology and Sociobiology*, 33(6), 415–428. <https://doi.org/10.1007/BF00170257>

Kalko, E. K. v., & Schnitzler, H.-U. (1989). The echolocation and hunting behavior of Daubenton's bat, *Myotis daubentoni*. *Behavioral Ecology and Sociobiology*, 24(4), 225–238. <https://doi.org/10.1007/BF00295202>

Kaun, K. R., Devineni, A. v., & Heberlein, U. (2012). *Drosophila melanogaster* as a model to study drug addiction. *Human Genetics*, 131(6), 959–975. <https://doi.org/10.1007/s00439-012-1146-6>

Keshtgari, M., & Deljoo, A. (2012). A Wireless Sensor Network Solution for Precision Agriculture Based on Zigbee Technology. *Wireless Sensor Network*, 4(1), 25–30. <https://doi.org/10.4236/wsn.2012.41004>

Kober, R., & Schnitzler, H. (1990). Information in sonar echoes of fluttering insects available for echolocating bats. *The Journal of the Acoustical Society of America*, 87(2), 882–896. <https://doi.org/10.1121/1.398898>

Kondō, N., Monta, M., & Noguchi, Noboru. (2011). *Agricultural robots : mechanisms and practice*. Kyoto University Press. [https://books.google.com.gh/books/about/Agricultural\\_Robots.html?hl=&id=83eTwQ1TppcC&redir\\_esc=y](https://books.google.com.gh/books/about/Agricultural_Robots.html?hl=&id=83eTwQ1TppcC&redir_esc=y)

Lee, D. N., van der Weel, F. R., Hitchcock, T., Matejowsky, E., & Pettigrew, J. D. (1992). Common principle of guidance by echolocation and vision. *Journal of Comparative Physiology A*, 171(5), 563–571. <https://doi.org/10.1007/BF00194105>

Li, X., Deng, Y., & Ding, L. (2008). Study on precision agriculture monitoring framework based on WSN. *2nd International Conference on Anti-Counterfeiting, Security and Identification, ASID 2008*, 182–185. <https://doi.org/10.1109/IWASID.2008.4688381>

Martin A Hebel, M. A., Ralph F Tate, R. F., & Dennis G Watson, D. G. (2007). Results of Wireless Sensor Network Transceiver Testing for Agricultural Applications. *2007 Minneapolis, Minnesota, June 17-20, 2007*, 8. <https://doi.org/10.13031/2013.23186>

Massebo, F., & Tefera, Z. (2015). Status of *Bactrocera invadens* (Diptera: Tephritidae) in mango-producing areas of Arba Minch, southwestern Ethiopia. *Journal of Insect Science (Online)*, 15(1), 166. <https://doi.org/10.1093/jisesa/ieu166>

Miller, L. A. (1975). The behaviour of flying green lacewings, *Chrysopa carnea*, in the presence of ultrasound. *Journal of Insect Physiology*, 21(1), 205–219. [https://doi.org/10.1016/0022-1910\(75\)90080-3](https://doi.org/10.1016/0022-1910(75)90080-3)

Miller, L. A., & Olesen, J. (1979). Avoidance behavior in green lacewings - I. Behavior of free flying green lacewings to hunting bats and ultrasound. *Journal of Comparative Physiology* □ A, 131(2), 113–120. <https://doi.org/10.1007/BF00619071>

Miller, L. a., & Surlykke, A. (2001). *How Some Insects Detect and Avoid Being Eaten by Bats: Tactics and Countertactics of Prey and Predator*. BioScience. [https://doi.org/10.1641/0006-3568\(2001\)051\[0570:HSIDAA\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2001)051[0570:HSIDAA]2.0.CO;2)

MØHL, B., & MILLER, L. A. (1976). Ultrasonic Clicks Produced by the Peacock Butterfly: A Possible Bat-Repellent Mechanism. *Journal of Experimental Biology*, 64(3).

Moss, C. F., & Schnitzler, H.-U. (1995). *Behavioral Studies of Auditory Information Processing* (pp. 87–145). Springer, New York, NY. [https://doi.org/10.1007/978-1-4612-2556-0\\_3](https://doi.org/10.1007/978-1-4612-2556-0_3)

Moss, C. F., & Zagaeski, M. (1994). Acoustic information available to bats using frequency-modulated sounds for the perception of insect prey. *The Journal of the Acoustical Society of America*, 95(5), 2745–2756. <https://doi.org/10.1121/1.409843>

Mott, D., & Timbrook, S. (1988). ALLEVIATING NUISANCE CANADA GOOSE PROBLEMS WITH ACOUSTICAL STIMULI. *Proceedings of the Thirteenth Vertebrate Pest Conference (1988)*. <https://digitalcommons.unl.edu/vpcthirteen/61>

Mwaurah, P. W., Kumar, S., Kumar, N., Panghal, A., Attkan, A. K., Singh, V. K., & Garg, M. K. (2020). Physicochemical characteristics, bioactive compounds and industrial applications of

mango kernel and its products: A review. *Comprehensive Reviews in Food Science and Food Safety*, 19(5). <https://doi.org/10.1111/1541-4337.12598>

Nankinga, C. M., Isabirye, B. E., Muyinza, H., Rwomushana, I., Stevenson, P. C., Mayamba, A., Aool, W., & Akol, A. M. (2014). Fruit fly infestation in mango: A threat to the Horticultural sector in Uganda. *Uganda Journal of Agricultural Sciences*, 15(1), 1–14. <https://www.ajol.info/index.php/ujas/article/viewFile/126176/115702>

Neuweiler, G. (1989). Foraging ecology and audition in echolocating bats. *Trends in Ecology & Evolution*, 4(6), 160–166. [https://doi.org/10.1016/0169-5347\(89\)90120-1](https://doi.org/10.1016/0169-5347(89)90120-1)

Neuweiler, G. (1990). Auditory adaptations for prey capture in echolocating bats. *Physiological Reviews*, 70(3), 615–641. <https://doi.org/10.1152/physrev.1990.70.3.615>

North, M. J., Tataru, E., & Ozik, J. (2007). *Visual agent-based model development with repast symphony. Intelligent Process Supervision for Batch Fermentation Processes View project Agent-based Modeling and Simulation Initiative at Argonne National Laboratory View project*. <https://www.researchgate.net/publication/236555809>

Ostwald, J., Schnitzler, H.-U., & Schuller, G. (1988). Target Discrimination and Target Classification in Echolocating Bats. In *Animal Sonar* (pp. 413–434). Springer US. [https://doi.org/10.1007/978-1-4684-7493-0\\_42](https://doi.org/10.1007/978-1-4684-7493-0_42)

Pye, D. (1980). Adaptiveness of echolocation signals in bats Flexibility in behaviour and in evolution. *Trends in Neurosciences*, 3(10), 232–235. [https://doi.org/10.1016/S0166-2236\(80\)80071-3](https://doi.org/10.1016/S0166-2236(80)80071-3)

Raj, B., Kalgaonkar, K., Harrison, C., & Dietz, P. (2012). Ultrasonic doppler sensing in HCI. *IEEE Pervasive Computing*, 11(2), 24–29. <https://doi.org/10.1109/MPRV.2012.17>

Robert, D., Amoroso, J., Science, R. H.-, & 1992, undefined. (n.d.). The evolutionary convergence of hearing in a parasitoid fly and its cricket host. *Science.Sciencemag.Org*. Retrieved March 24, 2018, from <http://science.sciencemag.org/content/258/5085/1135.short>

Root, R. B. (1967). The Niche Exploitation Pattern of the Blue-Gray Gnatcatcher. *Ecological Monographs*, 37(4), 317–350. <https://doi.org/10.2307/1942327>

Roser, M., Ritchie, H., & Ortiz-Ospina, E. (2020). World Population Growth- Our World in Data. In *Population Reference Bureau*.

Schnitzler, H.-U., & Kalko, E. K. v. (2001). Echolocation by Insect-Eating Bats We define four distinct functional groups of bats and find differences in signal structure that correlate with the typical echolocation tasks faced by each group Perceptual problems for foraging bats. *Source: BioScience*, 51(7), 557–569. [https://doi.org/10.1641/0006-3568\(2001\)051\[0557:ebieb\]2.0.co;2](https://doi.org/10.1641/0006-3568(2001)051[0557:ebieb]2.0.co;2)

SCHNITZLER, H.-U., & KALKO, E. K. v. (2009). Echolocation by Insect-Eating Bats. [Http://Dx.Doi.Org/10.1641/0006-3568\(2001\)051\[0557:EBIEB\]2.0.CO;2](Http://Dx.Doi.Org/10.1641/0006-3568(2001)051[0557:EBIEB]2.0.CO;2). [https://doi.org/10.1641/0006-3568\(2001\)051\[0557:EBIEB\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2001)051[0557:EBIEB]2.0.CO;2)

Schnitzler, H.-U., Kalko, E. K. v., Kaipf, I., & Grinnell, A. D. (1994). Fishing and echolocation behavior of the greater bulldog bat, *Noctilio leporinus*, in the field. *Behavioral Ecology and Sociobiology*, 35(5), 327–345. <https://doi.org/10.1007/BF00184422>

Schnitzler, H.-U., Moss, C. F., & Denzinger, A. (2003). From spatial orientation to food acquisition in echolocating bats. *Trends in Ecology & Evolution*, 18(8), 386–394. [https://doi.org/10.1016/S0169-5347\(03\)00185-X](https://doi.org/10.1016/S0169-5347(03)00185-X)

Schumake, S. A., & Shumake ', S. A. (1995a). Electronic Rodent Repellent Devices: A Review of Efficacy Test Protocols and Regulatory Actions. *National Wildlife Research Center Repellents Conference*, 34. <http://digitalcommons.unl.edu/nwrcrepellants>

Schumake, S. A., & Shumake ', S. A. (1995b). Electronic Rodent Repellent Devices: A Review of Efficacy Test Protocols and Regulatory Actions. *National Wildlife Research Center Repellents Conference*, 34. <http://digitalcommons.unl.edu/nwrcrepellants>

Siemers, B. M., & Schnitzler, H.-U. (2000). Natterer's bat ( *Myotis nattereri* Kuhl, 1818) hawks for prey close to vegetation using echolocation signals of very broad bandwidth. *Behavioral Ecology and Sociobiology*, 47(6), 400–412. <https://doi.org/10.1007/s002650050683>

Simmons, J. A., & Stein, R. A. (1980). Acoustic imaging in bat sonar: Echolocation signals and the evolution of echolocation. *Journal of Comparative Physiology? A*, 135(1), 61–84. <https://doi.org/10.1007/BF00660182>

Stefania Bandini, S. M. and G. V. (2009). *Agent Based Modeling and Simulation: An Informatics Perspective*. <http://jasss.soc.surrey.ac.uk/12/4/4.html>

Stibick, J. N. L. (n.d.). *Natural Enemies of True Fruit Flies ( Tephritidae )*.

Stumpner, A., & von Helversen, D. (2001a). Evolution and function of auditory systems in insects. *Naturwissenschaften*, 88(4), 159–170. <https://doi.org/10.1007/s001140100223>

- Stumpner, A., & von Helversen, D. (2001b). Evolution and function of auditory systems in insects. In *Naturwissenschaften* (Vol. 88, Issue 4, pp. 159–170). <https://doi.org/10.1007/s001140100223>
- Surlykke, A. (1988). Interaction Between Echolocating Bats and Their Prey. In *Animal Sonar* (pp. 551–566). Springer US. [https://doi.org/10.1007/978-1-4684-7493-0\\_56](https://doi.org/10.1007/978-1-4684-7493-0_56)
- Tatara, E., North, M., Howe, T., Collier, N., Vos, J., Sciences, D., Corp, P., Chicago, U., & Illinois, U. (2006, January). *An introduction to repast simphony modeling using a simple predator-prey example.*
- Vayssières, J. F., Sanogo, F., & Noussourou, M. (2007). Inventory of the fruit fly species (Diptera: Tephritidae) linked to the mango tree in Mali, and tests of integrated control. *Fruits*, 62(5). <https://doi.org/10.1051/fruits:2007029>
- Vergheze, A., Sreedevi, K., & Nagaraju, D. K. (2006). Pre and Post harvest IPM for the Mango Fruit Fly , *Bactrocera dorsalis* ( hendel ). *Symposium A Quarterly Journal In Modern Foreign Literatures*, September, 179–182. [https://www.researchgate.net/profile/Kolla\\_Sreedevi/publication/237453125\\_Pre\\_and\\_Post\\_harvest\\_IPM\\_for\\_the\\_Mango\\_Fruit\\_Fly\\_Bactrocera\\_dorsalis\\_hendel/links/553bcb6b0cf245bdd76671d9.pdf](https://www.researchgate.net/profile/Kolla_Sreedevi/publication/237453125_Pre_and_Post_harvest_IPM_for_the_Mango_Fruit_Fly_Bactrocera_dorsalis_hendel/links/553bcb6b0cf245bdd76671d9.pdf)
- von der Emde, G., & Schnitzler, H.-U. (1990). Classification of insects by echolocating greater horseshoe bats. *Journal of Comparative Physiology A*, 167(3), 423–430. <https://doi.org/10.1007/BF00192577>

- Waters, D. A., & Vollrath, C. (2003). Echolocation Performance and Call Structure in the Megachiropteran Fruit-Bat *Rousettus aegyptiacus*. *Acta Chiropterologica*, 5(2), 209–219. <https://doi.org/10.3161/001.005.0205>
- Wenger, M., Acoltzi, J., & Fukuda, M. (2021). Comparing Thread Migration, Mobile Agents, and ABM Simulators in Distributed Data Analysis. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 12946 LNAI. [https://doi.org/10.1007/978-3-030-85739-4\\_27](https://doi.org/10.1007/978-3-030-85739-4_27)
- Wilson, M., Hanlon, R. T., Tyack, P. L., & Madsen, P. T. (2007). Intense ultrasonic clicks from echolocating toothed whales do not elicit anti-predator responses or debilitate the squid *Loligo pealeii*. *Biology Letters*, 3(3), 225–227. <https://doi.org/10.1098/rsbl.2007.0005>
- Yager, D. D. (1999). Structure, development, and evolution of insect auditory systems. *Microscopy Research and Technique*, 47(6), 380–400. [https://doi.org/10.1002/\(SICI\)1097-0029\(19991215\)47:6<380::AID-JEMT3>3.0.CO;2-P](https://doi.org/10.1002/(SICI)1097-0029(19991215)47:6<380::AID-JEMT3>3.0.CO;2-P)
- Yager, D. D., May, M. L., & Fenton, M. B. (1990). Ultrasound-triggered, flight-gated evasive maneuvers in the praying mantis *Parasphendale agrionina*. I. Free flight. *The Journal of Experimental Biology*, 152(1), 17–39. <http://www.ncbi.nlm.nih.gov/pubmed/2230635>
- Zakari, A. K. (2012). *GHANA National Mango Study*. 58.
- Zargayouna, M., Zeddini, B., Scemama, G., & Othman, A. (2013). Agent-based simulator for travelers multimodal mobility. *Frontiers in Artificial Intelligence and Applications*, 252. <https://doi.org/10.3233/978-1-61499-254-7-81>

Zuk, M., & Kolluru, G. R. (1998). Exploitation of Sexual Signals by Predators and Parasitoids.

*The Quarterly Review of Biology*, 73(4), 415–438. <https://doi.org/10.1086/420412>



## APPENDIX

### Implementation Examples

```
package habituation_prevention_relogo.relogo

import static repast.simphony.relogo.Utility.*;

import static repast.simphony.relogo.UtilityG.*;

import repast.simphony.relogo.BasePatch;

import repast.simphony.relogo.BaseTurtle;

import repast.simphony.relogo.Plural;

import repast.simphony.relogo.Stop;

import repast.simphony.relogo.Utility;

import repast.simphony.relogo.UtilityG;

import repast.simphony.relogo.*;
```

```
class Fruitfly extends BaseTurtle {
```

```
    def neighborhoodRadius = 4
```

```
    def desiredDistance = 2
```



```
def cohesionWeight = Utility.randomFloat(0.2) + 0.4
```

```
def separationWeight = 1.0 - cohesionWeight
```

```
def turnSpeed = Utility.random(5) + 5
```

```
/**
```

```
* The method that every Boid runs every tick.
```

```
*/
```

```
def step(){
```

```
  forward(0.3)
```

```
  def heading = getHeading()
```

```
  setHeading(averageTwoDirections(
```

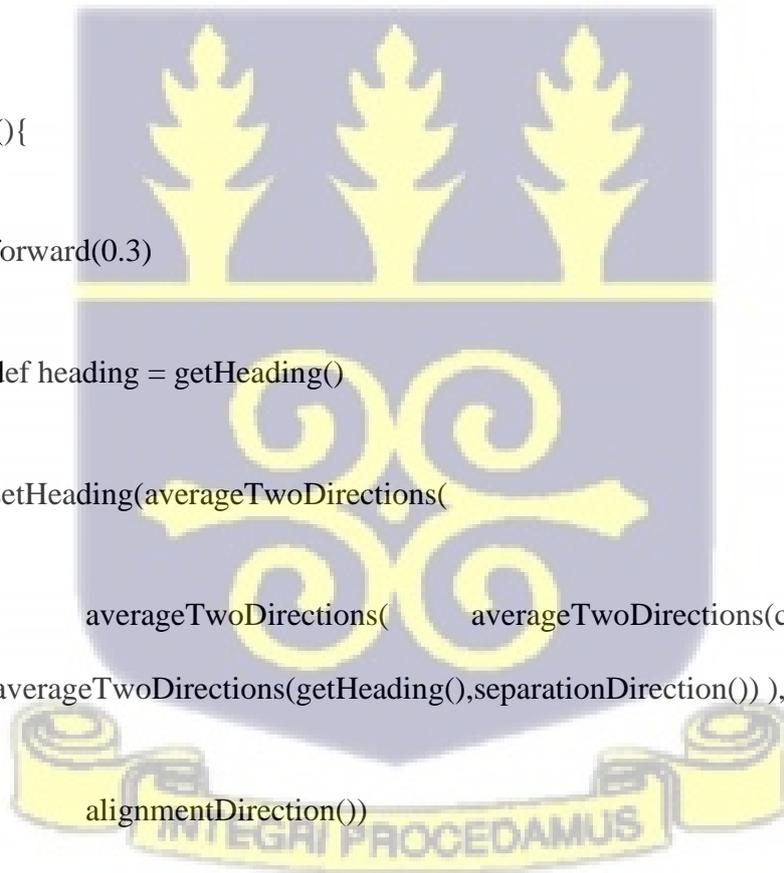
```
    averageTwoDirections(      averageTwoDirections(cohesionDirection(),
```

```
    getHeading(), averageTwoDirections(getHeading(),separationDirection() ),
```

```
    alignmentDirection())
```

```
  )
```

```
}
```



```
/**
```

```
 * This method returns a direction in which this Boid should travel in order to follow the  
Separation steering method
```

```
 * @return heading--the direction in degrees
```

```
 */
```

```
def separationDirection(){
```

```
    def boidsTooClose = inRadius(turtles(), desiredDistance)
```

```
    boidsTooClose = other(boidsTooClose)
```

```
    if(boidsTooClose.size() > 0){
```

```
        def boidsTooCloseSize = boidsTooClose.size()
```

```
        def closestBoid = minOneOf( boidsTooClose, { distance(it)} )
```

```
        def avgDirectionOfTooCloseBoids = towards(closestBoid)
```

```
        boidsTooClose.remove(closestBoid)
```

```
        if(boidsTooClose.size() > 0){
```



```
        for(Boid boid: boidsTooClose){

            avgDirectionOfTooCloseBoids = averageTwoDirections(
avgDirectionOfTooCloseBoids, towards(boid) )

        }

    }

//        if(distance(closestBoid) < desiredDistance*0.5){

moveAwayFrom(avgDirectionOfTooCloseBoids,(0.2*separationWeight))

//        }

        if(toMyLeft(avgDirectionOfTooCloseBoids)){

            return (getHeading() + turnSpeed*separationWeight)

        }else{

            return (getHeading() - turnSpeed*separationWeight)

        }

    }else{

        return getHeading()

    }

}
```



```
}
```

```
}
```

```
/**
```

\* This method returns a direction in which this Boid should travel in order to follow the Cohesion steering method

\* @return heading--the new direction in degrees

```
*/
```

```
def cohesionDirection(){
```

```
    def boidSet = inRadius(turtles(),neighborhoodRadius)
```

```
    boidSet = other(boidSet)
```

```
    if(boidSet.size() > 0){
```

```
        def avgBoidDirection = getHeading()
```

```
        for(Boid boid : boidSet){
```

```
            avgBoidDirection
```

```
=
```

```
            averageTwoDirections(towards(boid),avgBoidDirection)
```



```
}
```

```
def avgBoidDistance = desiredDistance
```

```
for(Boid boid : boidSet){
```

```
    avgBoidDistance = (avgBoidDistance + distance(boid)) / 2
```

```
}
```

```
if(avgBoidDistance > desiredDistance){
```

```
    return avgBoidDirection
```

```
}else{
```

```
    return getHeading()
```

```
}
```

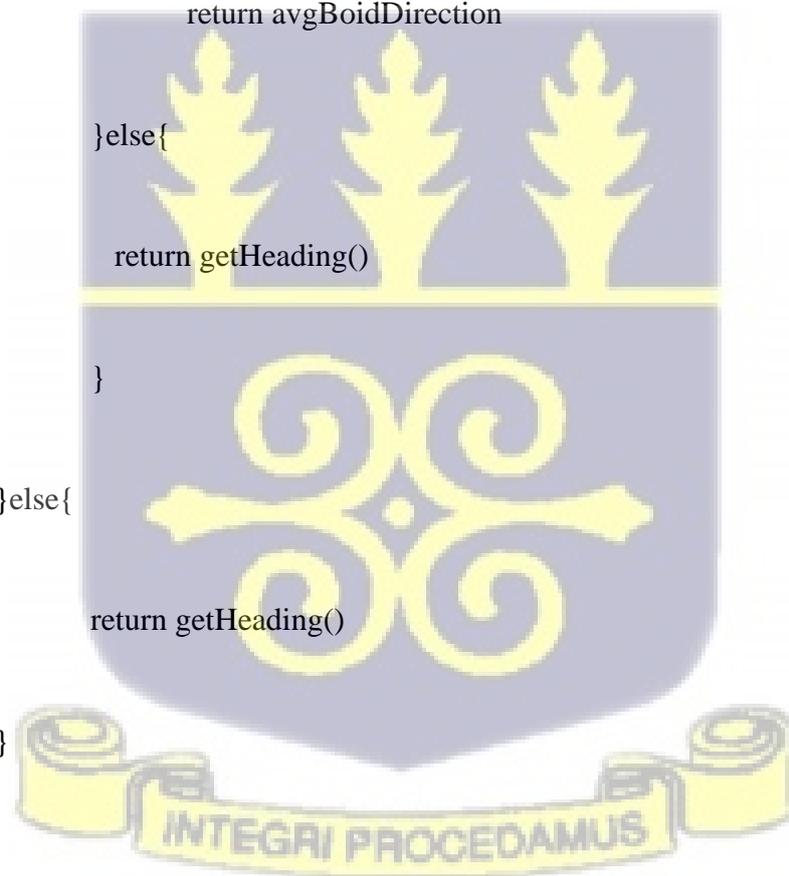
```
}else{
```

```
    return getHeading()
```

```
}
```

```
}
```

```
/**
```



\* This method returns a direction in which this Boid should travel in order to follow the Separation steering method

```
* @return averageHeading--the direction in radians

*/

def alignmentDirection(){

    def boidSet = inRadius(turtles(),neighborhoodRadius)

    boidSet = other(boidSet)

    def heading = getHeading()

    for(Boid boid : boidSet){

        heading = averageTwoDirections( heading, boid.getHeading() )

    }

    return heading

}

/**
```

\* Returns the direction halfway between one direction and another.

\* @param dir1--first angle in degrees

\* @param dir2--second angle in degrees

\* @return a double value between 0 and 360 representing a direction

\*/

```
def averageTwoDirections(double dir1, double dir2){
```

```
    if(Math.abs(dir1-dir2) < 180){
```

```
        return (dir1+dir2)/2
```

```
    }
```

```
    else return oppositeDirection((oppositeDirection(dir1) + oppositeDirection(dir2))
```

```
    / 2)
```

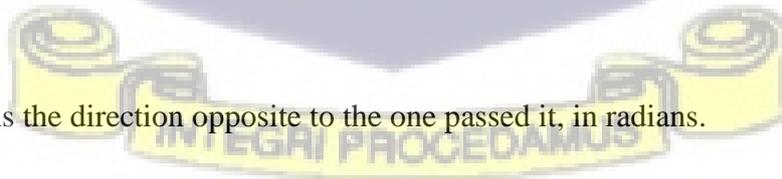
```
}
```

```
/**
```

```
* Returns the direction opposite to the one passed it, in radians.
```

```
* @param angle--a direction in radians
```

```
* @return the opposite direction as angle in radians
```



```
*/
```

```
def oppositeDirection(double dir){
```

```
    return (dir + 180) % 360
```

```
}
```

```
/**
```

```
 * @param angle--a direction in radians
```

```
 * @return boolean value denoting whether the angle passed as argument is on the left-  
hand side of the calling Boid.
```

```
*/
```

```
def toMyLeft(double dir){
```

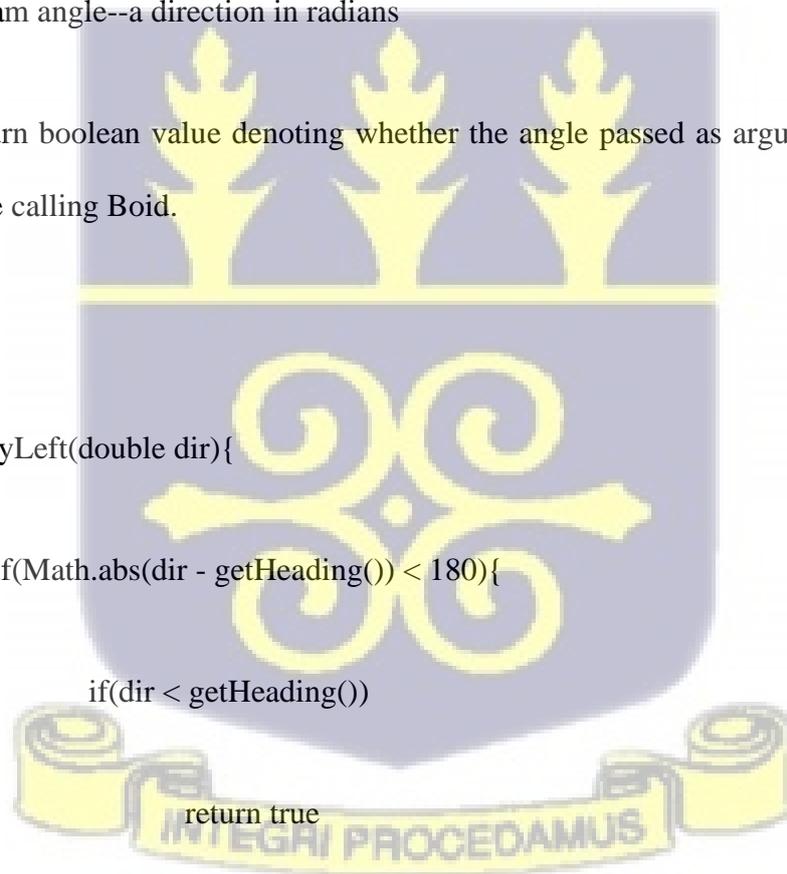
```
    if(Math.abs(dir - getHeading()) < 180){
```

```
        if(dir < getHeading())
```

```
            return true
```

```
        else return false
```

```
    }else{
```



```
        if(dir < getHeading())

                return false

        else return true

    }

}
```

```
/**
```

```
* Moves the calling Boid some amount in a direction.
```

```
* @param direction--the direction to move the Boid
```

```
* @param dist--the amount to move the Boid
```

```
*/
```

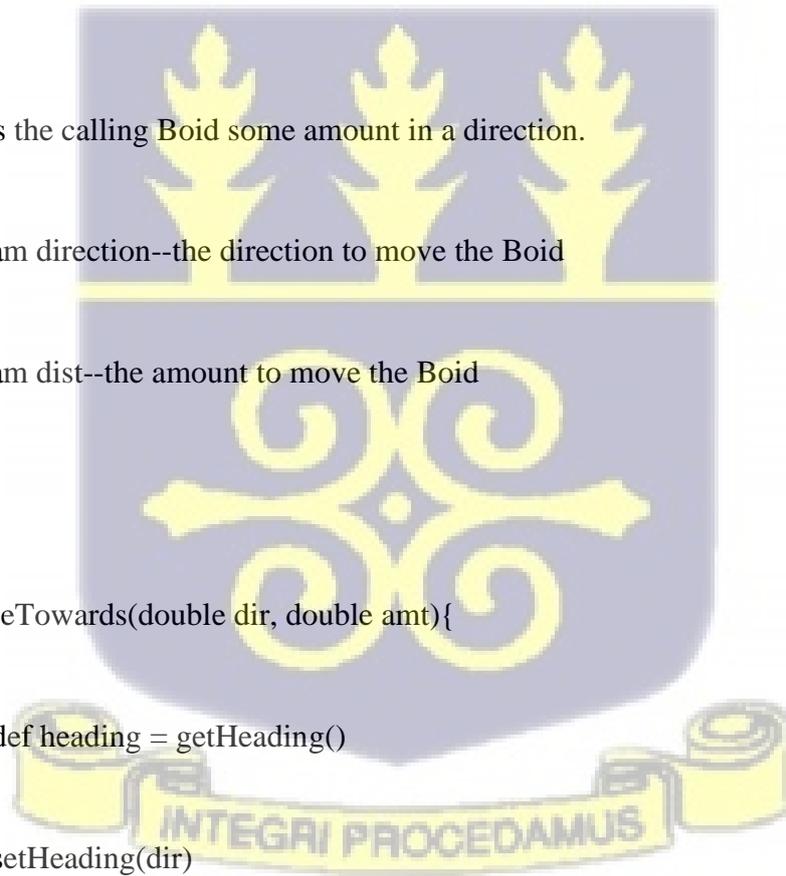
```
def moveTowards(double dir, double amt){
```

```
    def heading = getHeading()
```

```
    setHeading(dir)
```

```
    forward(amt)
```

```
    setHeading(heading)
```



```
}
```

```
/**
```

```
* Moves the calling Boid some amount in the opposite of a direction.
```

```
* @param direction--the opposite of the direction to move the Boid
```

```
* @param dist--the amount to move the Boid
```

```
*/
```

```
def moveAwayFrom(double dir, double amt){
```

```
    def heading = getHeading()
```

```
    setHeading( oppositeDirection(dir) )
```

```
    forward(amt)
```

```
    setHeading(heading)
```

```
}
```

```
}
```

