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COLLEGE OF SCIENCE AND TECHNOLOGY

AFRICAN CENTER OF EXCELLENCE IN INTERNET OF THINGS

Design and Implementation of IoT Based Helopeltis Sp. Control System in Cashew nut Farm.

Submitted in partial fulfilment of the requirements for the award of

MASTER OF SCIENCE IN INTERNET OF THINGS

WIRELESS INTELLIGENT SENSOR NETWORKING

(MSC in IoT-WISENET)

Submitted by

Veronica E. Kannole - Reg. No. 220012874

Submission Date: January, 2022

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Under the supervision of

Supervisor: **Dr. RUSHINGABIGWI Gerard**

Co-Supervisor: **Dr. DIWANI Abubakar Bakar**

January 2022

DECLARATION.

I declare that the work in this dissertation titled "Design and implementation of an IoT-Based Helopeltis sp Control System in Cashew nut Farm" is an original work by the author at the University of Rwanda College of Science and Information technology in the African Center of Excellence Internet of Things.

Name and Signature of the Student. DATE

Veronica E. Kannole .... 05 January 2022

Name and Signature of the Supervisor. DATE

Dr. Gerard Rushingabigwi .... 05 January 2022

Name and Signature of the Co-Supervisor. DATE

Dr. Abubakar Bakar Diwani. .... 05 January 2022

BONAFIDE CERTIFICATE.

This is to certify that the dissertation report work is a record of the original work done by Miss Veronica E. Kannole a postgraduate student in MSc in Internet of Things (IoT) with specialization in Wireless Intelligent Sensors Networks (WISeNet), at University of Rwanda – College of Science and Technology in African Center of Excellence in Internet of Things (UR/CEST/ACEIoT). We certify that the work reported doesn't form a part of any other research project.

Supervisor:

Dr. RUSHINGABIGWI, Gerard

Signature:

Co-Supervisor:

Dr. DIWANI Abubakar Bakar

Signature:

The Head of Masters and Training ACEIoT

Dr. James RWIGEMA

Signature

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Research activity has never been a single person task due to its nature, that’s why I am motivated to express the warm appreciation to all those who contribute in one way or another.

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God bless you all.

ABSTRACT.

Agriculture is the main activity of the southern part of Tanzania residents, cashew nut being the most cash crop brought by Portuguese has never been yielding optimal yields due to the existence of pests especially Helopeltis sp. The Internet of Things (IoT) based Pest Control system aims to design the system which will be able to capture, identify and store the Helopeltis pest and also free the other non-targeted species. The system's blueprint has been laid out through the Proteus and Google Colab (Collaboration) simulation tools. The pest recognition process has been done in the Google Colab Pro using tensorflow and other dependencies packages; the accuracy of 98.15% was obtained while the mechanical part of wiping pests into and out of the container has been facilitated using the Proteus. The last part of the farmer notification SMS (Short Message Service) has also been implemented using Proteus. The control of the cashew nut pests will now be in a green way by discouraging the use of pesticides which also destroy the pollinators and degrade the quality of the soil, the crop and the environment. It has been found that the image training requires adequate resources including graphic card, memory and processing power. Also it has been noted that the more the pictures are used for the training the more accuracy the detection will be.

Keywords: Cashew nut, Helopeltis sp, IoT, SMS notification, pest recognition.

LIST OF ACRONYMS.

3S	Global positioning and remote Sensing technology
A	Ampere
ACEIoT	African Center of Excellence Internet of Things
BL	Black Lesion
BLE	Bluetooth Low Energy
Colab	Collaboration
DIT	Dar es Salaam Institute of Technology
GPRS	General Packet Radio Service
GPU	Graphics Processing Unit
GSM	Global System for Mobile Communication
IDE	Integrated Development Environment
KHz	Kilohertz
LCD	Liquid Crystal Display
LD	Leaf Damage
mA	MilliAmpere
mAh	MilliAmpere hour
ML	Machine Learning
ms	Milliseconds
PIR	Passive Infrared Sensor
RAM	Random Access Memory
SMS	Short Message Service
Sp	species
TF	Tensorflow
Wh	Watt hour
WISeNet	Wireless Intelligent Sensors Network.
WSN	Wireless Sensors Network

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CHAPTER 1.
INTRODUCTION.

1.1 Introduction

Growing crops has been the main activity for the most of the east Africans be it for business or for family consumption. The produce has never been enough to sustain the families due to the practice of small scale farming [1]. The agriculture sector is still struggling with various problems even to those practicing large scale farming, these include pests and diseases [2][3]. Researchers from various fields have been providing the solutions in a variety of ways; using wireless sensor networks, and biological control [4][5][6]. Researchers have gone further to develop disease resistant crops as the disease mitigation strategy [7][8]. Pests have not been left untouched; various mechanisms have been applied to solve the problem [9][10].

Agriculture plays a pivotal role in human beings and therefore it is worthy of conducting research on it, apart from this sector providing materials for the industries but also feeding people giving them various benefits including blood pressure and blood sugar regulation [11]. With the same motive this thesis intends to control Helopeltis sp pest using IoT and object detection methods to maintain the quality of the cashew nut crops, the soil and air for it discourage the use of pesticides.

1.2 Background and Motivation

Cashew nut crop is the cash crop with its origin from Brazil and spread to different countries including but not all India, Vietnam, Benin, Nigeria, Tanzania, Indonesia, Guinea-Bissau, Mozambique and Cote D'Ivoire. Its scientific name is (Anacardium occidentale L.) Cashew nuts are a good source of minerals, vitamins and Proteins [12]. Figure 1.1 shows the raw cashew nuts along with their apples that provide fresh juice or an alcohol once fermented, and the processed nuts ready to be consumed.

Figure 1.1. Raw cashew nuts and processed nuts.

Agriculture has been a good contributor in the economy in Tanzania especially through cash crops, unfortunately it has been producing poor yields and causing farmers to be poor. Speaking of Masasi, Nachingwea and Liwale districts in Mtwara the southern region of Tanzania, regardless of them being blessed with the vast and rich soil suitable for Cashew nut and other crops have never obtained the best cashew yields at its maximum potential due to the existence of Helopeltis sp as shown in Figure 1.2 other pests are Pseudotheraptus wayi and Aphis sp. The existence of pests and diseases are among the most agricultural threats facing the farmers in the southern part of Tanzania [13].

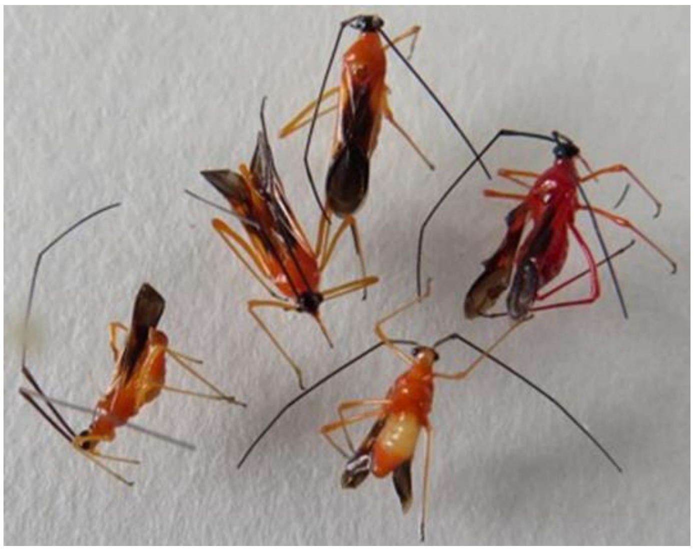

Figure 1.2. Helopeltis sp Pest.

In spite of Cashew nut being attacked by different pests as mentioned earlier there are natural enemies (parasitoids) that feed on the eggs and the pests as well for example; Telenomus cuspis, Erythmeles helopeltidis, Chaetostricha sp., Ufens sp. and Gonatocerus sp they feed on the Helopeltis eggs while the spiders, reduviid bugs, ants, praying mantids, mantispid flies, robber flies, and pentatomid bugs feed on the adults pests.

The Helopeltis sp are causing damage during the flushing, flowering and fruiting seasons, and they do it at mornings, evenings and after the rain times refer to Figure 1.3 for some damages images.

Figure 1.3. Damages caused by Helopeltis sp pest.

Parasitoids and predators are not sufficient enough to eliminate the problem and so the black lesions, leaf damage and crop dieback are inevitable [13].

The Helopeltis sp pest has been a threat not only in Tanzania but also in India where 90 pests were collected in one time observation being the highest number compared to other pests [14]. The situation is also marked as severe in the south and central zone of Tanzania, Figure 1.4 shows the damages and pest counts graph after the observation done at Liwale district the southern part of Tanzania.

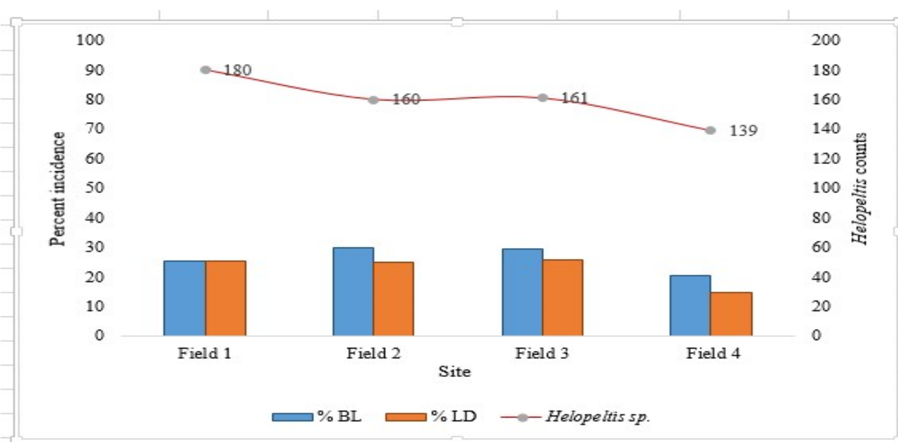

Figure 1.4. Damage and Pest counts in Liwale District.

Severe conditions were also observed in the central zone of Tanzania through Manyoni district as shown in Figure 1.5 where the maximum number of Helopeltis count was 124.

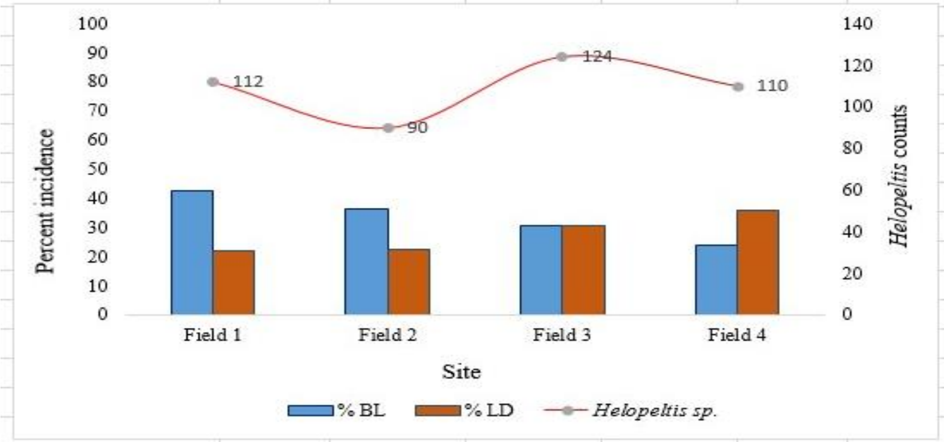

Figure 1.5. Damages and Pest counts in Manyoni District.

The good work has been done by researchers to control the pests by using Wireless Sensor Network to discover the existence of the pests at their early stages allowing the farmers to apply pesticides to the affected area only [15]. The online consultation services concerning the pests and disease are provided based on the data collected from the sensors present in the farm [16]. Others were also dealing with the ways and the reasons the diseases and pests grow by observing the atmospheric parameters for early discovery of the diseases [17]. The trial to use electromagnetic waves after heating the environment to 12-15 degrees so as to chase the pests has been done but no longer suitable due to suspicion on cancer issues [18]. Ultrasonic sensors have been used to make pests repel the area after being confused by the ultrasonic sound produced from the system, the negative impact of the system is that even the pollinators will disappear resulting in low yields[19].

Extensive works have been done by the researchers for paste management but there has been none that support green paste control by not using chemicals at all and that’s the gap to be filled by the proposed system.

1.3 Problem Statement.

The existence of Helopeltis sp pest in cashew nut farms that attacks the flowers, leaves, shoots, nuts and cashew nut apples ultimately resulting in low yields

1.4 Study Objectives.

There are targets set to be done for the accomplishment of the problem statement solution.

1.4.1 General Objective.

The major goal is to design the IoT based Helopeltis sp Control System that will identify and catch the targeted pest and inform the farmer on the status of the container once it is full. This goal will be accomplished through the following specific objectives.

1.4.1.1.1 Specific Objectives.

Sensing and identification module.

This module will aim at making sure that the Helopeltis insects visiting the trap are being caught by the camera and the images are sent to the control unit where the deep learning algorithms will compare the images to the ones stored in the database, will then decide the actions to be further taken with regard to the obtained results, a sensor will be installed on the wall of the container to sense whether the container is full or not and the proposed system will use wing, thorax and abdomen for pest identification.

Actuation module.

The module will receive commands from the first objective so as to perform the following actuation tasks;

- Freeing non targeted insects and other obstacles on top of the lid by wiping them out back to the environment.
- Storing the Helopeltis insects in the container by turning the lid 180 degrees.
- Wiping the targeted insects inside the container.

User communication module.

The proposed system design is expected to;

- Communicate the status of the container,
- Notify the user when the storage is full,

Notify the user when there is an obstacle that failed to be removed by the wiper.

1.5 Hypotheses.

This thesis intends to design the system that will control the Helopeltis sp pest using Internet of Things and machine learning while sending the notification message to the farmer upon the detection of the container status being full.

Study Scope

This thesis develops the design of the Helopeltis sp pest control system using the IoT and the machine learning through object detection mechanism. The design includes the notification module where text messages will be sent to the farmer once the pest collector is full. The simulation tools used are Proteus and Google Colab. The physical tools required to conduct the project have been stated in this document for future implementation.

The project uses the pests collected from Manyoni and Liwale districts located in the central and southern parts of Tanzania respectively.

1.6 Significance of the Study.

The output design of the IoT based Helopeltis sp control system will play a vital role on controlling the pests by discouraging the use of chemicals to control pests. The system design will ensure better crops, soil and air quality preservation and thus making it a green solution upon its implementation.

1.7 Organization of the Study.

This study has been organized into six chapters where each talks on a specific component or components as discussed below;

Chapter 1.

This chapter has nine items that collaboratively introduced the study while highlighting the reasons for conducting it and giving out the general background of the cashew nut Helopeltis pest and agriculture in general.

An area of the study concern is also included in the first chapter where the quest is clearly stated, the study objective section follows to start diving up the plans towards the solution. The study boundaries are clearly shown in the scope section of this chapter one.

Study significance and the conclusion are the last two parts of the chapter one where the viability and the importance of the study are well explained and the specific chapter conclusion is provided.

Chapter 2.

The study has considered the value of some other existing works and so there is no need to reinvent the wheel on the areas which are performing well.

This chapter contains the literature review where the works of various researchers related to the subject under consideration were discussed.

Chapter 3.

Research Methodology has been in detail explained in this chapter whereby all the mechanisms used to solve the research problem are presented.

Chapter 4.

This chapter explains the system analysis and design. System models and all the Proteus and Google Colab object detection simulations are well illustrated.

Chapter 5.

In this chapter all the results and discussions are done, it is the place where the realization of meeting the objectives is openly observable. The accuracy of 98.15% and precision of 92% is achieved and other model evaluation factors were also discussed.

Chapter 6.

This is the last chapter where the recommendations and the study general conclusion are explained.

The reference part shows the list of all cited documents in this study.

1.8 Summary.

Every business faces challenges of its kind, cashew nuts face the Helopeltis pests whereby they destroy leaves, flowers, apples and the cashew nut kernel. Researchers have worked and are still working on the best solution to solve the problem. This study in its defined scope has similar motivations to increase the cashew nut yields through its specific objectives which will result in a significant increase in profit upon its successful implementation

CHAPTER 2.

2.1 LITERATURE REVIEW

The pest control practices have been capturing the awareness of all levels from the individual farmer to the national level as many researches were done to fulfil the precondition for strategy development [13]. More efforts have been done to reduce the use of chemicals by employing the WSN (Wireless Sensors Network) system that will inform the farmer on the only pest affected region to be treated [15]. Comprehensive work has been done for involving different technologies like GPRS (General Packet Radio Service) , 3S (Global positioning and remote Sensing technology) , WSN and intelligence data processing and decision making to provide the farms and stakeholders on the early warning for crop diseases and pests existence, and the system provides online consultation on crop diseases and pests, this allows that the agricultural experts to advise the farmers on the proper usage of the pesticides usage [16].]. Other researchers have been writing on the ways and the reasons for the diseases and pests to grow, without discussing pest control methods [17]. More agricultural cashew nut best practices have also been discussed along with the ecological requirements [12]. The electromagnetic exposure methods have been implemented by some researchers as the means of controlling pests by exposing the pests to electromagnetic and warm them up to fifteen degrees before the wheat flourishing time so that they feel free reproduce themselves and also fly out to look for food where there is none, and this process will consume their energy and die before the flourishing or harvesting time. Unfortunately this method is no longer implementable due to cancer suspicions to human beings [18]. Cutworm pests control mechanism using the robot to apply barriers in the grape vines by applying wrapper rings to the trunks has been discussed. This method encourages the use of chemicals that are placed in the packing cloth of the wrapper [20]. Integrated pest management has been suggested by several researchers where all data about the pests and diseases are stored in the database, and the real time information from the sensors are being used by the agricultural experts to give out the necessary procedures to be taken to control the situation. The procedures can include the information on the type of pesticides to be used, the location of farm to be applied and the time to apply [21]. The IoT has also been used to control pests and diseases by using the PIR (Passive Infrared motion sensor) and ultrasonic generator, after the pests being observed sound will be generated 38-44 KHz for beetles and mosquitos while 60 KHz was used to repel the rodents [19]. The main drawback of this method is that even the non-targeted insects and pollinators like bees, ant, yellow banded special wasp and moths will also repel. Other researchers have based on the threat detection side by early detecting the pests attack, for any discovered disease the alert is sent to the farmer along with the advisory pesticides to be used [22]. Temperature and humidity sensors were used along with the camera so as to capture the present leaves conditions and being compared to the healthy leaves images, once deference is noted then message is sent to the farmer to alert on the changes and the possible caused and guidance on what to do to overcome the threat, the motor for the water or pesticides spray will be actuated depending on the value obtained from the moisture sensor and the computed results from the Arduino Pi 3B microcontroller respectively. Big data platforms have been used to handle real time data collected from the sensors placed in the farms where the analysis is done online and the agricultural experts answer questions from the farmers through their smart mobile phones or computers on a real time basis [23]. Some efforts also have been done to detect the pests as early as possible using video processing techniques and alerting the farmer on the location of the observed pests [24]. More technologies have been applied to solve the pest's threat, Machine learning has been used to identify the type of pest by considering the wing and the aculei parts. Once the pests are identified then will simplify on the way to control them [25]. It has been practiced for a long time now for solving different real life use cases like flower classification [26], pest prediction for the stored grains and other many cases [27].

The comparison study was conducted to determine the best Helopeltis sp control method between the three different formulas, the results obtained showed that all the three formulas improved the yields at different percentages but non targeted insects like natural enemies were also killed [28].

Online system was developed with the capabilities of reading the images posted by the farmer, analyzing them and giving out the insights and advising the farmer what should be done in a real time way [29]. In addition to that the system has been developed also to accept the image data along with the location coordinates [30]. Pests have been controlled not only in the farm but also at the storage areas. The integration of wireless sensor technology and a trap [31]. The STM32 microcontroller integrated with capacitance detection circuit has been used to detect the species of the pest and counting them out in the grain storage so that the store keeper can know what pests are there and to what extent [32].

It has been observed that the use of heating as the pest control mechanism affects the taste of the crops although it can kill all the pests at a hundred percent efficiency [33].

Cloud platform has been used to serve the storage and the intelligence part of the system by considering the data from the camera, environmental sensors for pest's management and agriculture best modern practices [34]. The image processing techniques have been applied by researchers for plant's disease discovery, this will allow the farmer to control it before it spreads out to more crops [35]. Some researchers have put their efforts on the best quality images generated from the camera for accurate pest classification through deep learning methods [36].

CHAPTER 3.

3.1 RESEARCH METHODOLOGY.

Various mechanisms were collectively used to accomplish the main objective of the research,

The activities done followed the Rapid Application Development (RAD) model.

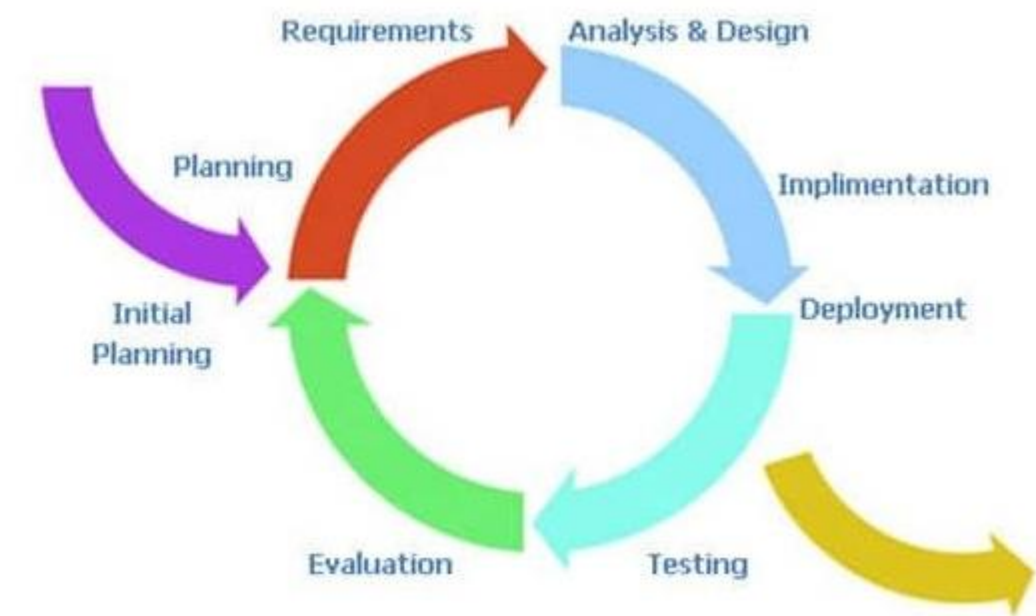

Figure 3.1 RAD Software Development Model [37]

This model allows the simultaneously execution of the project tasks hence saves time.

Advantages of RAD model [37].

- Customer feedbacks are accommodated
- Progress can be measured
- Saves time
- Customer's feedback is easily accommodated
- Change in requirements is easily handled

The model has the following phases;

a) Initial Planning.

This is the planning done at the beginning of the project whereby it is always subject to change depending on the new requirement observed. The initial planning was to use the physical components to implement the system but due to the lack of research fund the re-planning was done as explained in the last phase of this model

b) Requirements.

At this phase the system requirements were identified. On the simulation side the following were required;

Data from the cashew nut farms, internet connection, and software packages as shown in table 9 and table 10.

On the real implementation side the requirements will be;

Data, programmed Arduino Nano 33 BLE Sense microcontroller, Camera, wipers, container with the lid, stand, breadboards, jumper wires, Servo motors, solar power bank and ARDUINO SIM Cellular kit.

c) Analysis and Design.

The design of the Helopeltis control system provides the blue print for the easy implementation of the system. The block diagram shown in Figure 3.2 describes the work flow and processes to be taken by the system. The flow of data is clearly described by the flow diagram in Figure 4.1.

System analysis was done by considering each component as explained in chapter four of this document.

d) Implementation.

The system is implemented using the simulation tools although the details on the physical implementation is also given out by analyzing all the materials needed to build it.

The Google Colab was used to train data obtained from the cashew nut farms by applying the machine learning techniques to identify the Helopeltis pest under consideration, this was successfully done.

The Proteus simulation tool was used to perform the wiping process as well as the SMS notification process, this was also successfully implemented.

e) Deployment.

The simulation was deployed in the researcher’s HP Core i5 machine while the physical deployment will be done by the farmers in the days to come.

f) Testing.

Fifty three images were being tested and the system successfully identified the Helopeltis pest and the non- Helopeltis pest images.

g) Evaluation.

The system was well evaluated by meeting all the three specific objectives, whereby the pest was identified by 98.15% and the status of the container was correctly sensed, the actuation was correctly done by the wiping process and lastly the SMS were sent to the farmer to adhere to the user communication objective.

h) Planning.

This part of the model allows the re-planning of the system upon observation of any new requirement necessary to be included in the system.

After missing the research fund to buy the components the re-planning was done to shift to the simulation implementation, where it has new requirements as explained in the implementation phase of this model.

3.1.1 The System Architecture.

Figure 3.1 is the block diagram of the system where the intelligent part of the trap is practiced and all the methods are performed to obtain the expected actions and reactions.

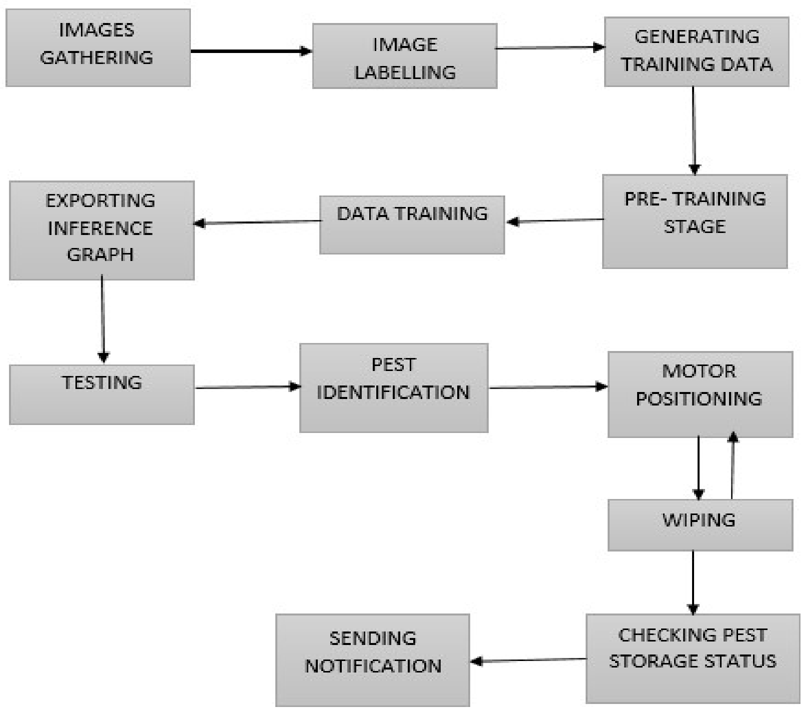

Figure 3.2. System block diagram.

The block diagram is divided into two sections as explained below;

The Pest Identification Section.

This part has been accomplished using the Google Colab Pro platform, and is comprised of the following blocks;

- Image gathering

Camera was used to take Helopeltis pictures from the eight farms visited.

- Image labeling

In a laptop the software called Labelimg used to label all the 123 images.

- Generating training data

The obtained data are not suitable for training until they are converted into to Tensorflow (TF) records for the training model to handle them. The python scripts were used to complete this conversion task.

- Pre Training stage

These are the procedures after generating the TF records but before data training taking place. They include creating a label map and editing the faster rcnn inception model to serve the research requirement.

- Data training

The python command is run to initiate the training process. The training was done for three hours.

- Exporting Inference graph

The frozen graph is generated by running the python script, this graph contains the classifier that will be classifying every detected object.

- Testing

The exact image name is written in the script to be tested for the identification.

- Pest Identification

The matched object will be covered with the rectangle along with the percentage of accuracy.

The System Actuation Section.

This section contains the following blocks;

- Motor Positioning

The servo motor will return to its initial position after moving the wiper to the specified direction.

- Wiping

The wiper will move in clockwise direction to mimic the wiping into the container action and anticlockwise for wiping out to the environment.

- Checking Pest storage status and

The container will have the sensor to sense once it is full, the PIR sensor in the Proteus will be controlled by potentiometer that acts as the obstacle to represent the fullness or emptiness of the storage.

- Sending Notification

This process will be triggered by the storage container status especially when it is full so that the farmer does the emptying.

3.1.2 Data Management.

Data images and the pests count was done in Manyoni and Liwale districts where in each district four various fields were visited and ten cashew nut trees from each field were considered this makes up the total of 80 cashew nut trees.

Table 1. Field 1 Data from Manyoni District.

	INSECT PESTS SCORING SHEET								
Zone: Central									
District: : Manyoni									
Field: 2									
				Pan/shoot with		**Dieback**		**Nut counts**	
Treatment	**Tree No**	**Tree side**	**Total shoots**	**BL**	**LD**	**Shoots (0-4)**	**Helopeltis**	**Total**	**Damaged**
Manyoni	1	N	34	11	7	1	12	0	0
		S	33	8	5			0	0
	2	N	16	8	4	0	14	0	0
		S	22	10	3			0	0
	3	N	32	13	2	0	13	0	0
		S	29	8	8			0	0
	4	N	26	9	5	0	11	0	0
		S	29	7	12			0	0
	5	N	28	8	8	0	10	0	0
		S	30	11	3			0	0
	6	N	32	16	4	0	8	0	0
		S	34	18	8			0	0
	7	N	29	13	5	0	9	0	0
		S	30	9	7			0	0
	8	N	12	7	2	0	11	0	0
		S	14	6	11			0	0
	9	N	27	15	4	1	15	0	0
		S	24	13	5			0	0
	10	N	28	20	2	1	9	0	0
		S	30	13	6			0	0

BL stands for Black Lesion and LD stands for Leaf Damage.

Table 2. Field 2 Data from Manyoni District.

	INSECT PESTS SCORING SHEET								
Zone: Central									
District: : Manyoni									
Field: 2									
				Pan/shoot with		**Dieback**		**Nut counts**	
Treatment	**Tree No**	**Tree side**	**Total shoots**	**BL**	**LD**	**Shoots (0-4)**	**Helopeltis**	**Total**	**Damaged**
Manyoni	1	N	31	11	5	1	10	0	0
		S	33	9	2			0	0
	2	N	30	18	3	0	12	0	0
		S	30	9	2			0	0
	3	N	30	11	6	0	8	0	0
		S	27	8	4			0	0
	4	N	28	14	8	0	14	0	0
		S	27	8	3			0	0
	5	N	30	13	4	0	5	0	0
		S	34	10	6			0	0
	6	N	27	11	7	1	8	0	0
		S	29	6	9			0	0
	7	N	35	8	11	0	6	0	0
		S	34	10	4			0	0
	8	N	30	11	12	0	9	0	0
		S	34	9	8			0	0
	9	N	24	11	7	2	11	0	0
		S	30	9	12			0	0
	10	N	23	13	8	0	7	0	0
		S	27	12	9			0	0

Shoots dieback is leveled in a 0-4 scale where;

- 0 represents 0%
- 1 represents 1-25%
- 2 represents 26-50%
- 3 represents 51-75%
- 4 represents 76- 100%

Trees were categorized into North and South directions while being examined.

Table 3. Field 3 Data from Manyoni District.

	INSECT PESTS SCORING SHEET								
Zone: Central									
District: : Manyoni									
Field: 3									
				Pan/shoot with		**Dieback**		**Nut counts**	
Treatment	**Tree No**	**Tree side**	**Total shoots**	**BL**	**LD**	**Shoots (0-4)**	**Helopeltis**	**Total**	**Damaged**
Manyoni	1	N	28	12	15	0	18	0	0
		S	31	11	8			0	0
	2	N	30	10	12	0	15	0	0
		S	30	8	13			0	0
	3	N	33	10	2	0	13	0	0
		S	27	4	6			0	0
	4	N	28	8	7	0	9	0	0
		S	27	7	4			0	0
	5	N	32	10	11	0	11	0	0
		S	29	13	4			0	0
	6	N	31	6	16	0	9	0	0
		S	29	9	8			0	0
	7	N	30	11	11	0	10	0	0
		S	31	8	5			0	0
	8	N	29	3	10	0	12	0	0
		S	28	8	9			0	0
	9	N	25	8	11	0	11	0	0
		S	30	9	7			0	0
	10	N	30	14	8	0	16	0	0
		S	30	12	11			0	0

The data collection method was done with the following tools;

- Tally counter – whenever a pest is seen this device was pressed to do the counting while concentrating on searching for the pests.
- Camera –used to capture pictures of the damaged leaves and shoots and taking pictures of the pests.
- Containers –the collected pests were firstly reserved in these containers.
- Clear glass containers –used in the lab to store the pests permanently.

- Alcohol – used to preserve the insects for a long time.

Table 4. Field 4 Data from Manyoni District.

	INSECT PESTS SCORING SHEET								
Zone: Central									
District: : Manyoni									
Field: 4									
				Pan/shoot with		**Dieback**		**Nut counts**	
Treatment	**Tree No**	**Tree side**	**Total shoots**	**BL**	**LD**	**Shoots (0-4)**	**Helopeltis**	**Total**	**Damaged**
Manyoni	1	N	27	15	11	0	7	0	0
		S	24	9	5			0	0
	2	N	30	11	8	0	11	0	0
		S	28	5	7			0	0
	3	N	32	5	13	0	13	0	0
		S	30	3	9			0	0
	4	N	31	1	8	0	8	0	0
		S	26	4	7			0	0
	5	N	30	8	10	0	15	0	0
		S	25	2	14			0	0
	6	N	28	4	9	0	9	0	0
		S	29	3	6			0	0
	7	N	32	5	14	0	19	0	0
		S	25	7	12			0	0
	8	N	29	3	8	0	10	0	0
		S	26	6	13			0	0
	9	N	25	8	9	0	12	0	0
		S	24	9	14			0	0
	10	N	30	11	8	0	6	0	0
		S	30	12	16			0	0

A total of 40 cashew nut trees from Manyoni district were used to collect the pests and also observing other damages done by the pest as shown from table 1-4.

Table 5. Field 1 Data from Liwale District.

	INSECT PESTS SCORING SHEET								
Zone: Southern									
District: : Liwale									
Field: 1									
				Pan/shoot with		**Dieback**		**Nut counts**	
Treatment	**Tree No**	**Tree side**	**Total shoots**	**BL**	**LD**	**Shoots (0-4)**	**Helopeltis**	**Total**	**Damaged**
Liwale	1	**N**	30	11	9	1	20	0	0
		S	26	6	5			0	0
	2	N	29	8	7	0	16	0	0
		S	32	14	10			0	0
	3	N	33	9	8	0	14	0	0
		S	30	6	10			0	0
	4	N	26	5	7	2	22	0	0
		S	29	6	9			0	0
	5	N	29	7	10	0	20	0	0
		S	30	4	4			0	0
	6	N	32	6	8	0	11	0	0
		S	26	8	4			0	0
	7	N	27	8	10	1	17	0	0
		S	32	10	6			0	0
	8	N	27	7	5	0	18	0	0
		S	29	5	7			0	0
	9	N	27	8	6	0	12	0	0
		S	30	10	7			0	0
	10	N	29	5	8	1	10	0	0
		S	31	6	8			0	0

Nut counts is zero because by the time data was collected it was not at nut bearing season.

Table 6. Field 2 Data from Liwale District.

	INSECT PESTS SCORING SHEET								
Zone: Southern									
District: : Liwale									
Field: 2									
				Pan/shoot with		**Dieback**		**Nut counts**	
Treatment	**Tree No.**	**Tree side**	**Total shoots**	**BL**	**LD**	**Shoots (0-4)**	**Helopeltis**	**Total**	**Damaged**
Liwale	1	**N**	29	7	4	0	23	0	0
		S	26	10	8			0	0
	2	N	30	8	4	0	12	0	0
		S	29	7	10			0	0
	3	N	28	5	6	1	18	0	0
		S	29	4	5			0	0
	4	N	31	10	7	0	16	0	0
		S	27	8	6			0	0
	5	N	28	7	7	0	13	0	0
		S	32	10	8			0	0
	6	N	29	11	8	0	10	0	0
		S	30	13	6			0	0
	7	N	30	10	8	1	19	0	0
		S	29	6	10			0	0
	8	N	27	8	8	0	23	0	0
		S	32	9	7			0	0
	9	N	30	8	7	0	20	0	0
		S	27	8	13			0	0
	10	N	27	10	7	0	26	0	0
		S	30	14	5			0	0

The excel software was used to get insights out of the data and the graphs were created refer to Figure 4-5.

Table 7. Field 3 Data from Liwale District.

	INSECT PESTS SCORING SHEET								
Zone: Southern									
District: : Liwale									
Field: 3									
				Pan/shoot with		**Dieback**		**Nut counts**	
Treatment	**Tree No**	**Tree side**	**Total shoots**	**BL**	**LD**	**Shoots (0-4)**	**Helopeltis**	**Total**	**Damaged**
Liwale	1	**N**	30	14	6	0	22	0	0
		S	27	7	2			0	0
	2	N	28	10	5	0	14	0	0
		S	29	9	3			0	0
	3	N	30	4	6	0	19	0	0
		S	26	5	7			0	0
	4	N	30	10	8	1	13	0	0
		S	28	9	11			0	0
	5	N	32	10	6	0	21	0	0
		S	29	8	14			0	0
	6	N	30	10	10	0	17	0	0
		S	26	6	13			0	0
	7	N	29	10	7	0	14	0	0
		S	24	5	13			0	0
	8	N	18	6	8	0	16	0	0
		S	25	4	3			0	0
	9	N	29	8	4	1	15	0	0
		S	28	13	2			0	0
	10	N	30	7	7	0	10	0	0
		S	26	9	4			0	0

Table 8. Field 4 Data from Liwale District.

		INSECT PESTS SCORING SHEET							
Zone: Southern									
District: : Liwale									
Field: 4									
				Pan/shoot with		**Dieback**		**Nut counts**	
Treatment	**Tree No**	**Tree side**	**Total shoots**	**BL**	**LD**	**Shoots (0-4)**	**Helopeltis**	**Total**	**Damaged**
Liwale	1	**N**	24	5	4	0	14	0	0
		S	30	7	3			0	0
	2	N	27	0	6	0	19	0	0
		S	30	7	5			0	0
	3	N	27	8	4	0	12	0	0
		S	30	7	1			0	0
	4	N	29	6	4	0	10	0	0
		S	23	5	2			0	0
	5	N	30	6	3	0	13	0	0
		S	28	4	0			0	0
	6	N	29	5	2	1	16	0	0
		S	31	5	7			0	0
	7	N	24	6	9	0	12	0	0
		S	30	9	3			0	0
	8	N	32	11	5	0	18	0	0
		S	26	6	5			0	0
	9	N	27	4	3	0	10	0	0
		S	30	5	4			0	0
	10	N	28	4	4	1	15	0	0
		S	32	6	8			0	0

Data from Liwale district are shown in table 5-8. All the data from both districts were collected during the morning or evening as that's the conducive time because during the day pests hide under the leaves.

The live collected pests were used to do the training process for the object recognition module.

This system design will be implemented using Google Colab through tensor-Flow machine learning library as shown in table 9 and Proteus simulation software as shown in table 10.

Table 9. Object Recognition Tools Table.

TOOL USED.	**RESOURCES**
1. Operating System.	Windows 10.
2. Programming language.	Python.
3. Labelling Software.	Labelimg.
4. GPU Card.	Google Colab Pro.
5. Processor.	Google Colab Pro.
6. Memory.	Google Colab High Memory.
7. Machine learning.	Tensorflow library.
8. Plotting tool.	Tensor board.

The corei5 laptop with windows 10 was used to run all the simulations. The computer had other software pre-installed necessary for the job facilitation and simplification for example Microsoft office, Visual studio and Python.

The collected images were labeled using the free source image labelling tool called Labelimg, where each picture was identified with its coordinates. The labeling process automatically produces the .xml file meaning that if a single image has two pests then two xml files will be produced. This is a benefit because the more the images the more accuracy of the object recognition process will be.

The training was done in the Google Colab Pro, a platform that offers the virtual processor, memory and GPU card. Almost three hours was used to train data to get a minimal loss of 0.004, the tensor board is used to show the loss graphs trends while the training process is going on.

Table 10. System Actuation Tools Table.

TOOL USED.	RESOURCES
1. Simulation	Proteus software
2. Sensing	IR Obstacle Sensor library
3. Texting	SIM900D library
4. Wiping	Servo motor library
5. Obstacle	Potentiometer
6. Display	LCD, Virtual terminals
7. Microcontroller	Arduino UNO

The actuation events of the system required the tools and resources shown in table 10, whereby the Arduino Uno in the Proteus software handled all other resources. IR Obstacle Sensor library was used to show the emptiness or fullness of the pest storage collector with the help of potentiometer to act as the full presence and empty presence of the pests by varying its values.

The alerting mechanism was facilitated using SIM900D library and the sent text messages were shown through the virtual terminal. Servo motor does the wiping process by rotating through 180 degrees.

More explanations and results are available in chapter four of this document.

3.1.3 Tools.

The implementation of the system is based on the software only although in the future works the combination of hardware and software can be used.

Google Colab Pro.

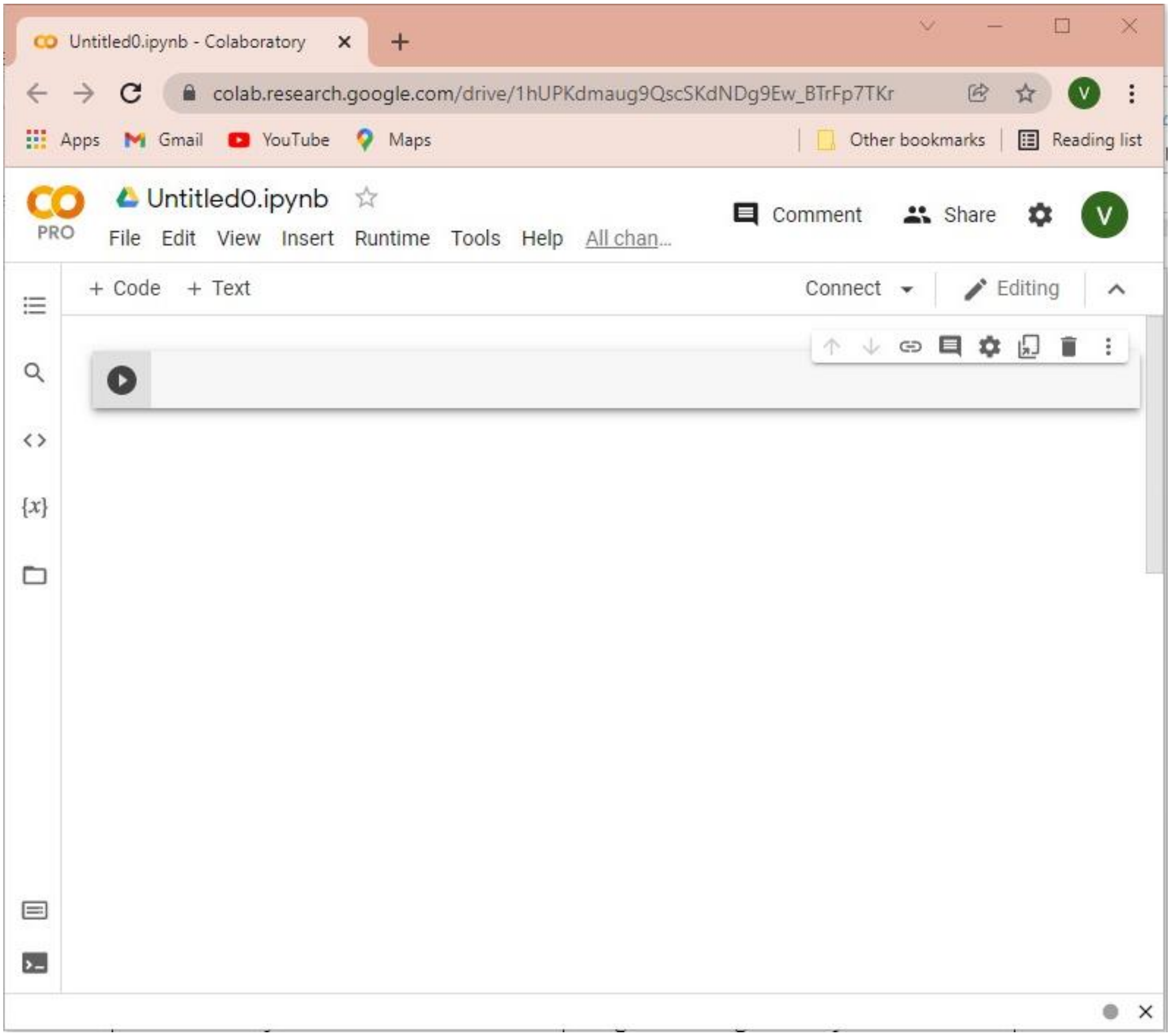

Figure 3.3 Google Colab layout.

Google Colab Pro is commercial version of the Google Colab which is free but with some resources limitations. The monthly subscription fee is paid to overcome the system halting problem that occurs few minutes after the training starts. Referring to Figure 3.3 the layout is almost the same for both version except the commercial one has the word Pro in its logo.

This platform has built in Python and other packages necessary to run the machine learning codes for object detection online without having the adequate physical RAM and GPUs [38].

Proteus Design Suite 8.1.

This is a powerful software for designing circuits and doing prototype virtually.

Advantages of Proteus over the physical construction of the system [39].

- Saves time
- Less prone to errors
- Prevents loss by not burning the devices as for physical construction
- Easy debugging
- Provides access to expensive components like oscilloscope.

The Helopeltis control system used this software for simulating the sensing and wiping processes.

Figure 3.4 Proteus Design Suite Layout.

Apart from doing simulation Proteus offers other functionalities as shown in Figure 3.4. More services and support are unlocked after the software purchase.

Arduino IDE.

Is the platform for writing and debugging codes for various projects, it works with the Proteus software to execute commands written in Arduino.

Advantages of Arduino IDE [40].

- Open source
- Works in any kind of operating system
- Cheap
- Simple to use even to the beginners.

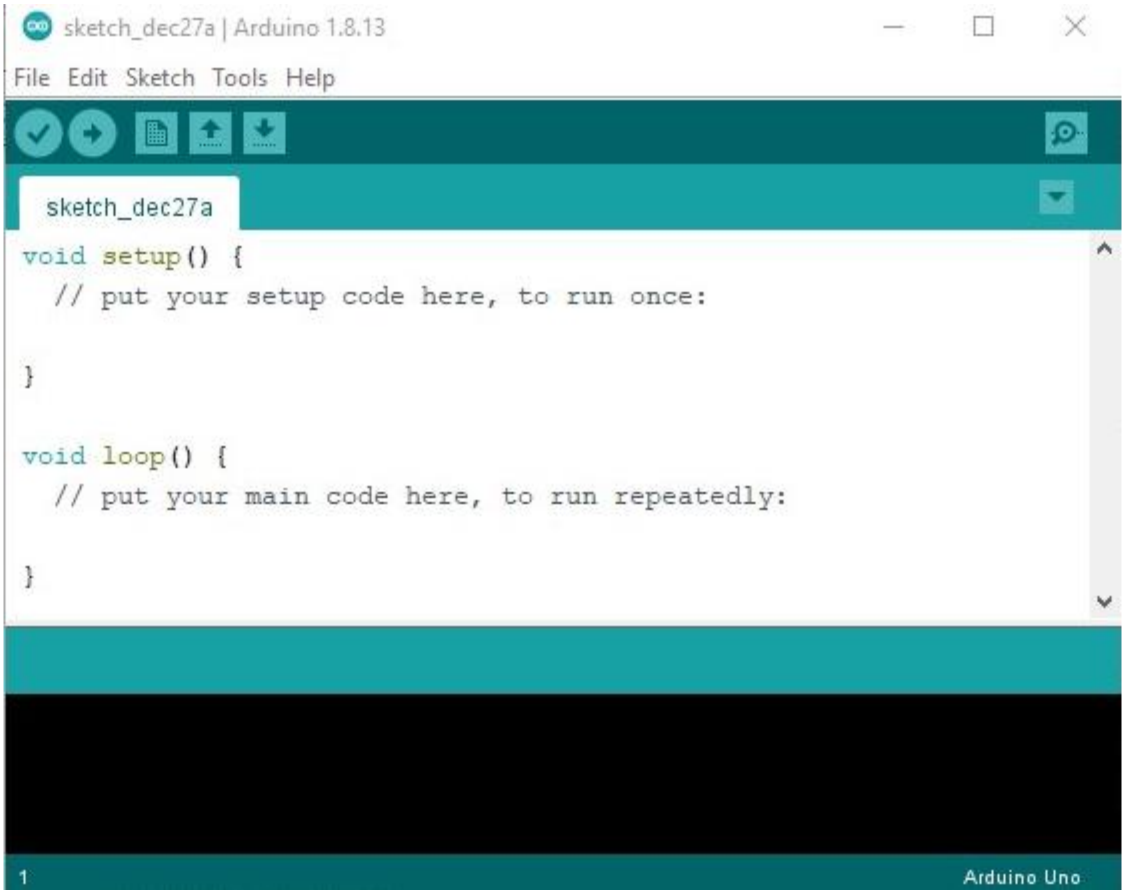

Figure 3.5 Arduino IDE Layout,

The arduino files are called sketches and comes with the initial codes by default showing where to write repeating codes and none repeating codes as shown in Figure 3.5.

CHAPTER 4.

4.1 SYSTEM ANALYSIS AND DESIGN.

A. The physical layout.

The trap will be composed of a camera, container with lid, wipers on top of the lid and control unit. The insects are expected to land on the top of the storage container where captured by the camera refer to Figure 4.1, the images will be sent to the control unit for processing and analysis, from there the system will then decide whether the captured images are of the Helopeltis species or not. The wipers will be activated to wipe out or in the storage container the insects found are non Helopeltis and Helopeltis respectively allowing pollinators to live as they are not the targeted ones.

The container lid with its inbuilt automatic wiper will be rotated 180 degrees so as to wipe and pour the Helopeltis inside the container while leaving the other side of the lid doing the catching process.

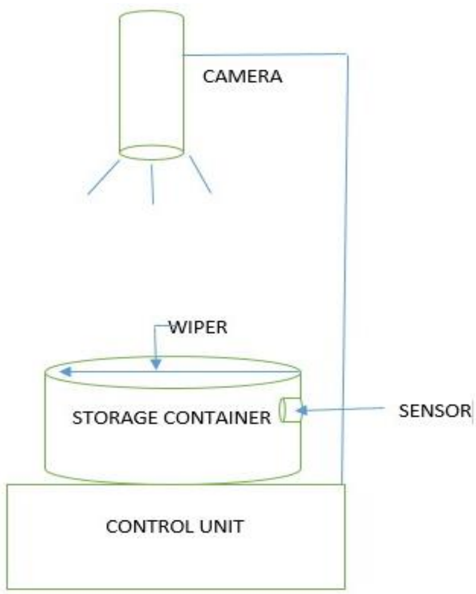

Figure 4.1. The Physical Layout.

4.1.1 Components to be used for the system implementation.

Upon the physical implementation of the system the following items or similar to them will be used.

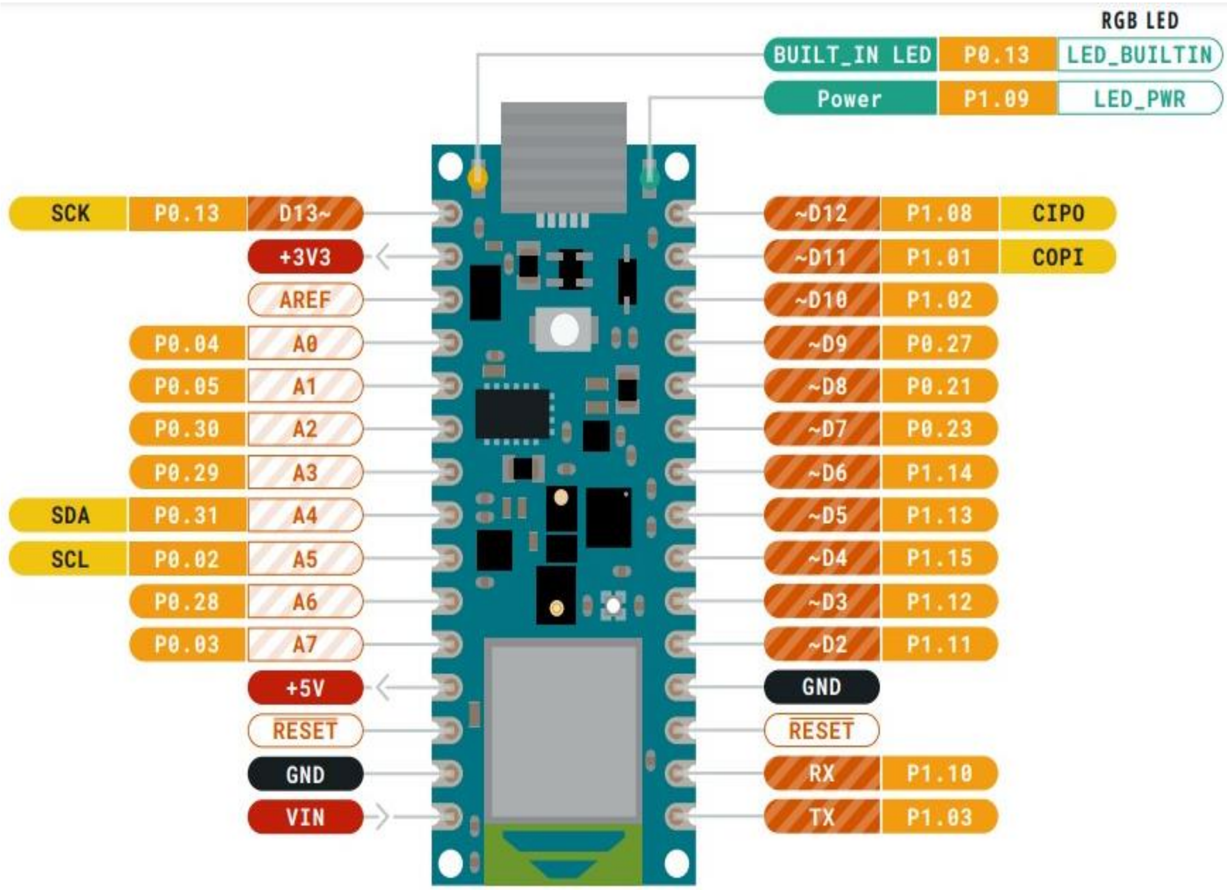

Figure 4.2 Arduino Nano 33 BLE Sense with Headers [41].

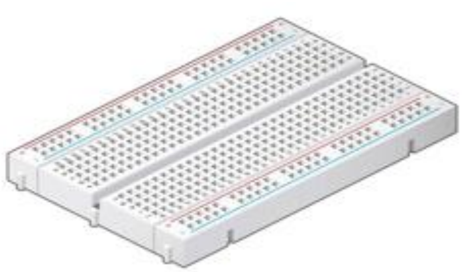

Figure 4.3 Breadboards [42].

The system can use the microcontroller specified in Figure 4.2. This type of the hardware is chosen due to its compatibility with the TinyML tensorflow library and also the Arduino microcontrollers are very popular by being used by many which results in the availability community support once needed.

The hardware shown in Figure 4.3 is used to connect all the devices to the microcontroller, this device helps the prototype to be neat and easy debugging in case of sketch errors.

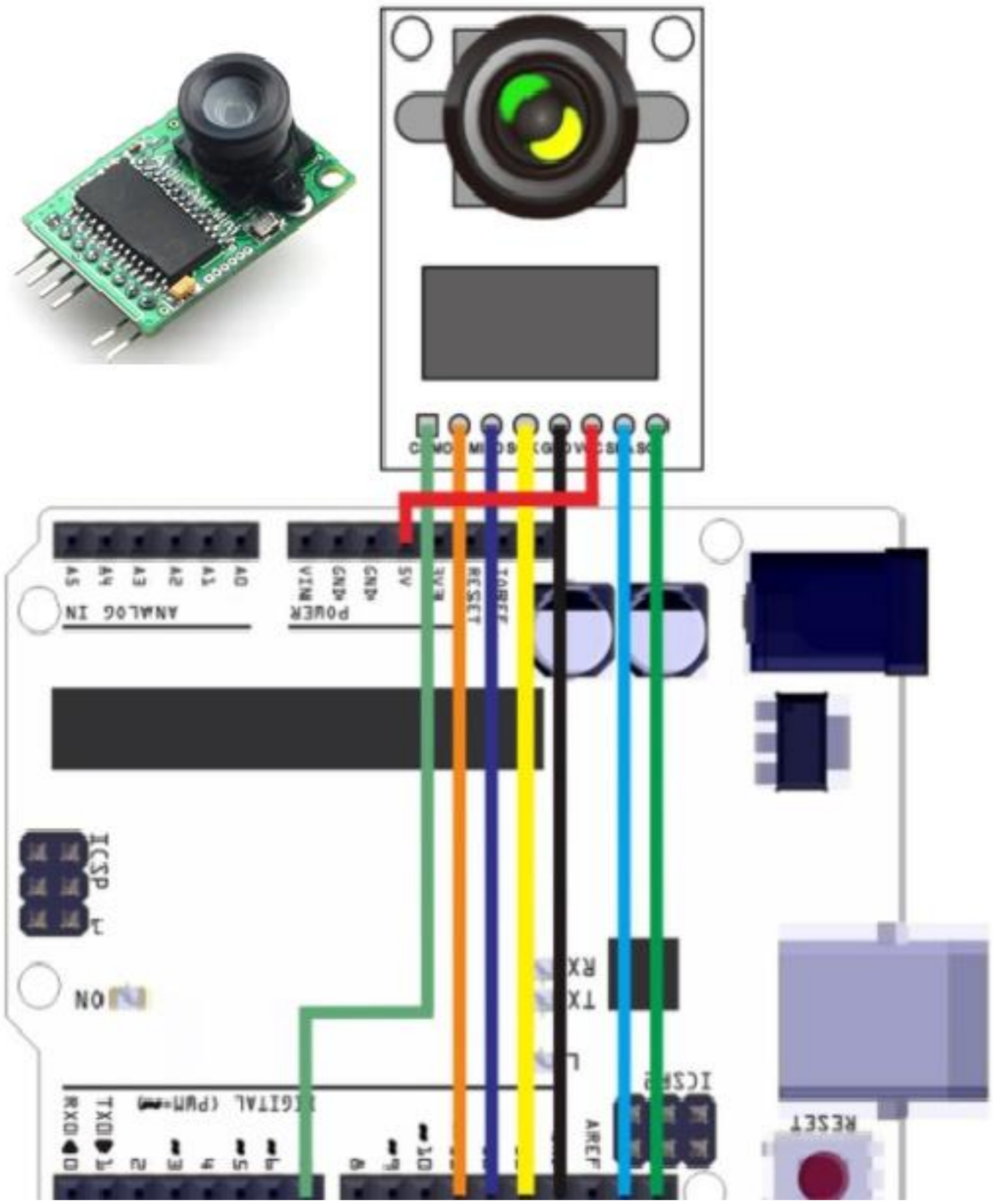

Figure 4.4. Arducam 2MP Mini Module Camera [43].

Figure 4.5 Jumper wires [44].

As the system has the image processing variable that makes the component in Figure 4.4 very important because it has 2MP CMOS image sensor of type OV2640. The Helopeltis pests images will be captured by this component and the processing will be done for further insights.

Components on the board will be connected using the jumper wires shown in Figure 4.5. These wires are divided into three categories;

- Both end females wires
- Both ends male wires
- Female and male ends wires

Those three types will serve all types of connections that will be made on the board.

Figure 4.6. Servo Motors [45].

Figure 4.7 wiper [46].

Figure 4.8 Solar Power Bank [47].

The wiping into the container process as well as wiping out to the environment processes needs the components represented in Figure 4.6 and Figure 4.7. The motor will be rotating the wiper 180 degrees as in line with the commands from the microcontroller.

The proposed system also requires the component in Figure 4.8 to supply power to other components including motors and camera. The capacity of the battery is 30,000mAh.

Figure 4.9. ARDUINO SIM Cellular kit [48].

Figure 4.10. Tripod Stand [49].

The proposed system will be sending messages to the farmer once the container is full or there is a concern that needs to be known that makes the container to be full. Figure 4.9 shows the communication kit that is capable of sending text messages to the cellular phone as well as sending data to the cloud for further manipulations and insights.

The camera module discussed earlier will be held by the item shown in Figure 4.10, this component can be elongated up to 67 inches.

4.2 Power Calculations.

The power calculations have been done based on the assumption that the system running time will be a total of 6 hours. This will be from 5:00 AM TO 10:00 AM and from 6:00 PM TO 7:00 PM. This is because the Helopeltis pest feeds only during the early morning and the late evening [50].

Table 11. Processing Power.

	PROCESSING POWER						
S/N	Component	Active current (mA)	Sleep current (mA)	Power supply (V)	Active Power(W) I(active)*V	Sleep Power(W) I(sleep)*V	Duty cycle (A) I sleep * t sleep) / (t active + t sleep)
1	The Nano 33 BLE Sense (with headers)	15	0.002	3.3	49.5	0.0066	0.012500333
2	Arducam Mini Module Camera	70	20	3.3	231	66	0.061666667
3	Feetech FT90B Digital Servo 9g Micro RC Servo Motor 180 Degree.	75	4	3	225	12	0.063166667
4	ARDUINO SIM - MKR GSM 1400 Cellular kit	46		3.3	151.8	0	0.038333333
	TOTAL	206	24.002		657.3	78.0066	0.175667

The variables shown in table 11 have been used in the power consumption calculations to determine the time to be taken by the battery before it needs to be recharged.

POWER CONSUMPTION (Wh) = DUTY CYCLE * MICROCONTROLLER VOLTAGE*TIME THE SYSTEM WILL BE ON.

= 0175667 *3.3*6

= 3.4782066Wh.

TOTAL CURRENT (mA) = ACTIVE CURRENT +SLEEP CURRENT.

= 206+ 24.002

TOTAL CURRENT (mA) = 230.002 mA.

CALCULATING THE TIME TAKEN BEFORE BATTERY RECHARGE (hours) = battery capacity / total current

=30,000mAh/230.002mA

=130.4336h.

=5.4347 Days

This means the battery will be able to work for approximately 5 days.

B. The Flow of Data.

Targeted pest is expected to land on top of the container lid whereby the camera will take a shot and the machine learning part will identify whether it is a pest or not for the appropriate events to be initiated. The flow of data in the whole system is shown in Figure 4.11.

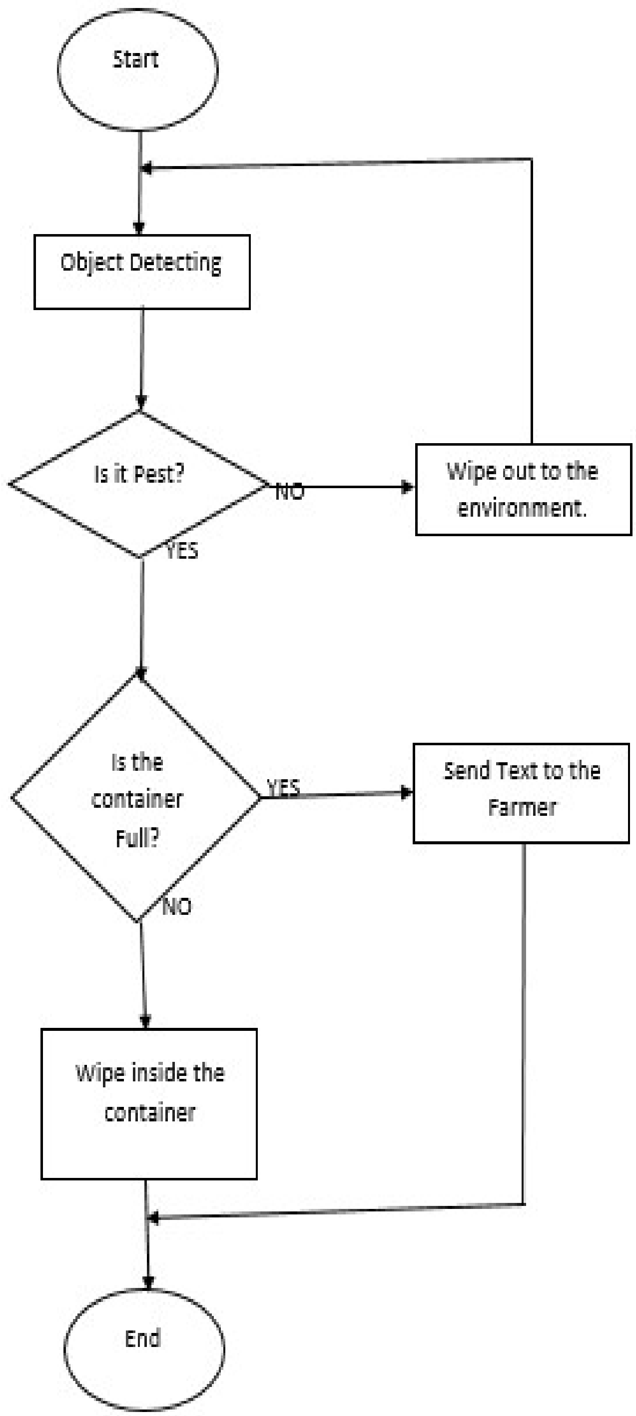

Figure 4.11. The System Data Flow Diagram.

CHAPTER 5.

5.1 RESULTS AND ANALYSIS.

Sensing unit.

This section will provide the inputs to the system. It consists two items;

Camera.

The pictures of the pests on top of the container lid will be taken using the camera, alternatively Apple IPhone 6 phone camera, Techno Cammon 12 and Infinix hot 10 were used to take pictures for the training and testing.

Sensor.

This module will be sensing the level of the container so that the emptying process could be done once full. This part is simulated using IR OBSTACLE SENSOR in Proteus whereby potentiometer is used to control it by acting as the obstacle by varying voltages. For visibility purposes the yellow LED will be on when the container is full and will be off for the empty status of the container. The results will be shown on the virtual terminal as shown in Figure 5.1.

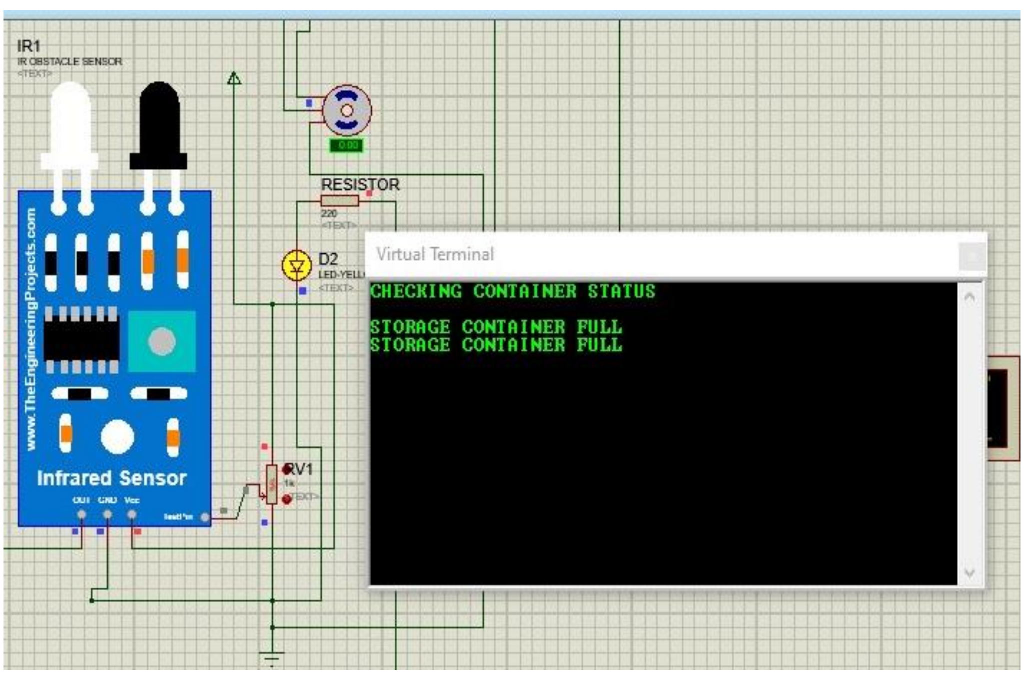

Figure 5.1. Sensing the container status.

5.1.1 Identification unit.

This unit has four main stages;

- Image preprocessing.

This process involves taking the total of 123 pictures of the Helopeltis sp in different backgrounds refer to Figure 5.2. The wings, thorax and abdomen will be highly considered while taking the pictures.

Figure 5.2. Helopeltis sp pest in various backgrounds.

- Model Creation.

This stage involves the labelling process of all pictures obtained from the previous process.

This has been done using Labelimg which is a free source software.

This process is crucial as while labeling the xml of each image is automatically produced, these xml files are used in the later stages for converting them into csv files. Figure 5.3 shows the content of one labeled image xml file.

The images in xml file formats show the coordinates of the bounding rectangles of each image.

IMG_0722 - Notepad

File Edit Format View Help


```xml
<annotation>
	<folder>train1</folder>
	<filename>IMG_0722.JPG</filename>
	<path>C:\Users\user\Desktop\FROM IPHONE\train1\IMG_0722.JPG</path>
	<source>
		<database>Unknown</database>
	</source>
	<size>
		<width>3264</width>
		<height>2448</height>
		<depth>3</depth>
	</size>
	<segmented>0</segmented>
	<object>
		<name>Helopeltis</name>
		<pose>Unspecified</pose>
		<truncated>0</truncated>
		<difficult>0</difficult>
		<bndbox>
			<xmin>996</xmin>
			<ymin>817</ymin>
			<xmax>1339</xmax>
			<ymax>1317</ymax>
		</bndbox>
	</object>
```


Figure 5.3. Image xml file.

- Model Training

This stage was accomplished in Google Colab using tensorflow object detection API.

Anaconda with built-in Python programming language has been used to install some package dependencies necessary for the training to take place.

Faster RCNN detection model was used to train the Helopeltis images because of its high accuracy behavior though with slower speed compared to other models available in the tensorflow model zoo.

The training was successfully done for more than two hours through the commercial Colab Pro as the free version of the Colab ran out of memory, this caused several crushes in the middle of the training process. Training was stopped after reaching at most the loss of 0.004 as shown in Figure 5.4. The training process can be started from where it left off while stopped as long as the internet connection is available. The longer the time to train data the less loss will be and the more accuracy the detection will be refer to Figure 5.5 that shows the inference graph produced by tensor board.

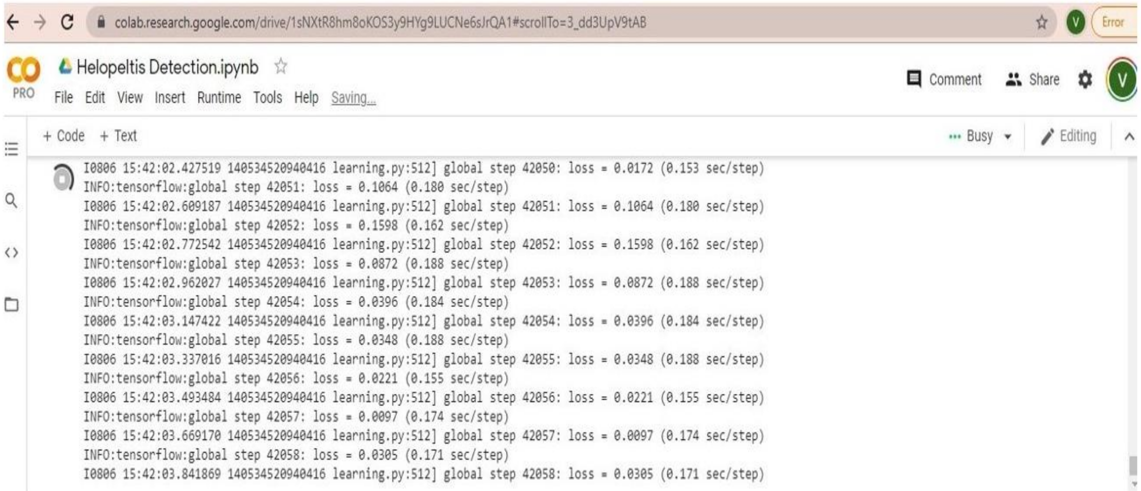

Figure 5.4. Training process.

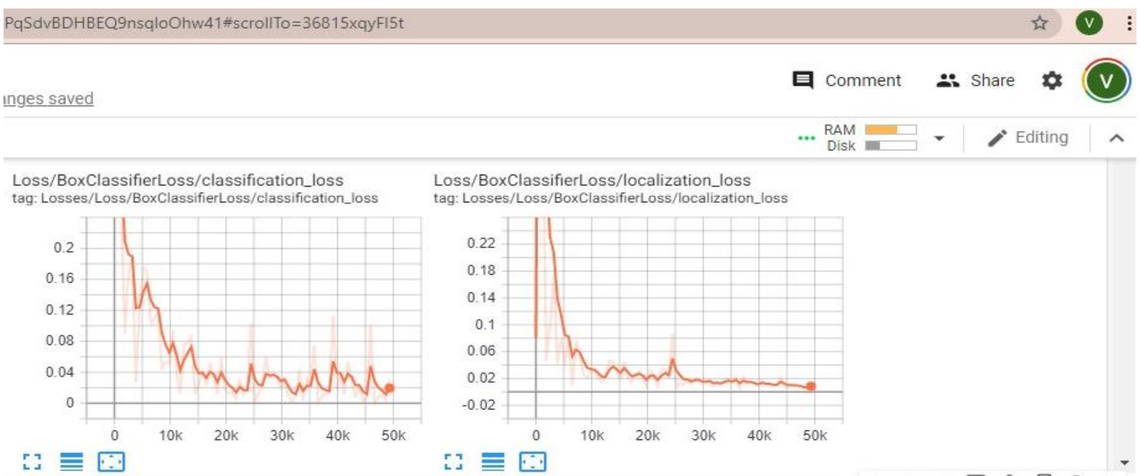

Figure 5.5. The loss graph.

Testing the pest detection functionality.

This was done in the Colab by running the series of python scripts that enabled it to detect one Helopeltis image named as “test”. The model was able to classify the object at 100% accuracy refer to Figure 5.6.

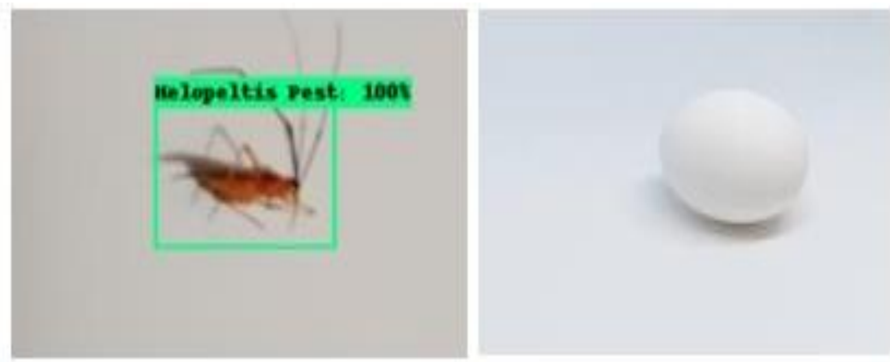

Figure 5.6. Helopeltis detection results.

5.1.2 Evaluation of the Model.

Four items were used to know how well the model performs. Fifty four images used to test and validate the model by calculating precision, accuracy, recall and F1 score with the following formulas.

Precision% = TP / (TP +FP)*100

= 23 / (23+1)*100

= 95.83%

Accuracy% = (TP+TN) / (TP+TN+FP+FN) *100

= (23+30) / (23+30+1+0) *100

= 98.15%

Recall% = TP / (TP +FN)*100

= 23/ (23+0) *100

= 100%

F1 Score = 2*(Precision*Recall) / (Precision + Recall)

= 2*(95.83*100) / (95.83+100)

= 97.87%

Where TP stands for true positives and they are actual pests.

TN stands for true negatives and they are not pests.

FP stands for False Positives These were detected as positives but they are not pests.

FN stands for False Negative. These are pests but the system didn't recognize them.

5.1.3 Actuation Unit.

The physical observation of the Helopeltis motions proves that 1 second response time is adequate to capture the pest, to increase efficiency the Servo motor with the ability to actuate 180 degrees with 480milli milliseconds will be used.

This unit is comprised of three processes;

- Wiping into the container.

The lid which is controlled by the servo motor will be actuated to turn 180 degrees then the wiper will wipe them in the container. Servo motor in Proteus will rotate 180 degrees clockwise to mimic turning the lid and wiping into the container upon the detection of the Helopeltis pest refer to Figure 24.

- Wiping out to the environment.

This system design is intending to leave free other non-targeted insects for they could be of most important like cashew nut pollinators, the wiper will be activated to wipe them out back to the environment without turning the lid, the anticlockwise movement of the motor is for the empty container status and the wiping out process refer to Figure 5.7.

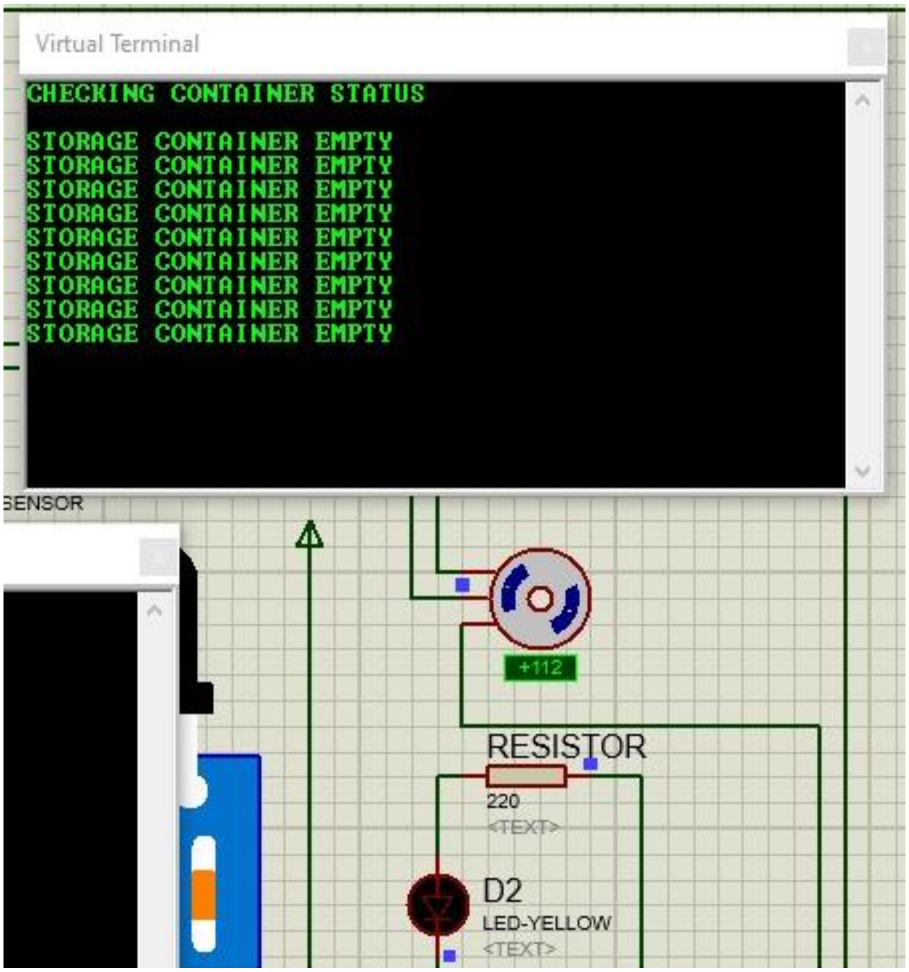

Figure 5.7. The anticlockwise movement of the Servo motor.

- Sending notification to the farmer.

Farmer will be notified in case the container is full or the existence of an obstacle on the lid which cannot be wiped by any reason.

Referring to Figure 5.8. The "Container is Full" text messages will be sent to farmer once the potentiometer value is very low voltage for the higher values the "Container is Empty" text will be shown on the virtual terminal but no message will be sent to the farmer. These messages will be visible through the two virtual terminals connected to the microcontroller, sensor and the GSM module.

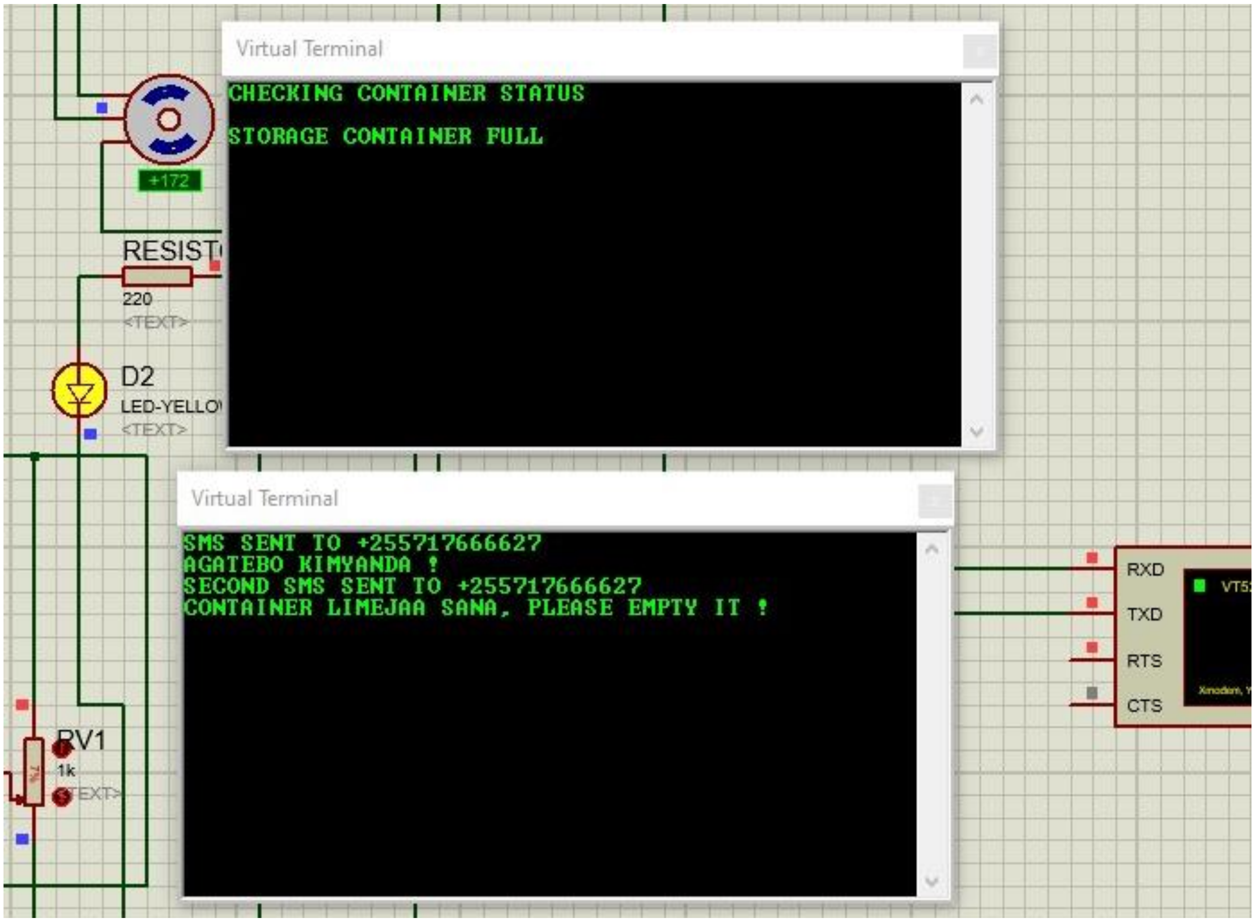

Figure 5.8. Notification Message.

The first virtual terminal is used to display the status of the container while the second shows the SMS sent to the cashew nut farmer about the container status specifically when the container is full.

Three languages have been used in the text messages which are Kinyarwanda, Kiswahili and English;

- Agatebo Kimyanda means the dustbin or collector is full
- Container limejaa Sana means the container is too full.

CHAPTER 6.

CONCLUSION, RECOMMENDATION AND FUTURE WORKS.

6.1 Conclusion.

Agriculture plays a pivotal role in human beings and therefore it is worthy of conducting research on it, apart from this sector providing materials for the industries but also feeding people giving them various benefits including blood pressure and blood sugar regulation. This sector faces pest and disease problems causing the production of poor yields that directly affects the availability of the nutrients. This thesis designed the Helopeltis sp pest control mechanism using Internet of Things and machine learning, also the system will be sending the notification message to the cashew nut farmer upon the detection of the container status being full, this was successfully implemented with the accuracy of 98.15% using the Google Colab Pro platform and other events were successfully done in Proteus.

6.2 Recommendation.

This system design is open for future implementations, and can also be used to solve the pest problem with the similar characteristics as Helopeltis. It should also be noted that there is no limit for the number of images to be used for training because the more images the more accuracy will be achieved but this is at the expense of time and internet connection charges.

It has been found that the training process requires high processing power and memory.

6.3 Future Works.

The system is open for future works by;

- Using the solar system instead of the battery
- Using the same arduino microcontroller to collect environmental data including light intensity, humidity, temperature, and pressure for further insights.
- Sending data to the cloud for further analysis and
- Adding another system for emptying the collector automatically

REFERENCES.

[1] M. Pack and K. Mehta, "Design of affordable greenhouses for East Africa," *Proc. - 2012 IEEE Glob. Humanit. Technol. Conf. GHTC 2012*, pp. 104–110, 2012, doi: 10.1109/GHTC.2012.66.

[2] B. W. Waweru, P. Rukundo, D. C. Kilalo, D. W. Miano, and J. W. Kimenju, "Effect of border crops and intercropping on aphid infestation and the associated viral diseases in hot pepper (Capsicum sp.)," *Crop Prot.*, vol. 145, no. March, p. 105623, 2021, doi: 10.1016/j.cropro.2021.105623.

[3] F. C. O. Freire, J. E. Cardoso, A. A. dos Santos, and F. M. P. Viana, "Diseases of cashew nut plants (Anacardium occidentale L.) in Brazil," *Crop Prot.*, vol. 21, no. 6, pp. 489–494, 2002, doi: 10.1016/S0261-2194(01)00138-7.

[4] M. R. M. Kassim, "IoT Applications in Smart Agriculture: Issues and Challenges," *2020 IEEE Conf. Open Syst. ICOS 2020*, pp. 19–24, 2020, doi: 10.1109/ICOS50156.2020.9293672.

[5] T. Bhosale, M. Patil, and V. Wadhai, "A smart farming alternative for small Pomegranate farms of India," *2015 Int. Conf. Commun. Signal Process. ICCSP 2015*, pp. 540–544, 2015, doi: 10.1109/ICCSP.2015.7322543.

[6] Y. Elad, N. E. Malathrakis, and A. J. Dik, "Biological control of Botrytis-incited diseases and powdery mildews in greenhouse crops," *Crop Prot.*, vol. 15, no. 3, pp. 229–240, 1996, doi: 10.1016/0261-2194(95)00129-8.

[7] A. Schultink and A. D. Steinbrenner, "A playbook for developing disease-resistant crops through immune receptor identification and transfer," *Curr. Opin. Plant Biol.*, vol. 62, p. 102089, 2021, doi: 10.1016/j.pbi.2021.102089.

[8] Y. Deng, Y. Ning, D. L. Yang, K. Zhai, G. L. Wang, and Z. He, "Molecular Basis of Disease Resistance and Perspectives on Breeding Strategies for Resistance Improvement in Crops," *Mol. Plant*, vol. 13, no. 10, pp. 1402–1419, 2020, doi: 10.1016/j.molp.2020.09.018.

[9] S. Diabate *et al.*, "Push-pull strategy combined with net houses for controlling cowpea insect pests and enhancing crop yields," *Crop Prot.*, vol. 141, p. 105480, 2021, doi: 10.1016/j.cropro.2020.105480.

[10] L. Johnston-Fennell, J. Tooker, B. A. Nault, and K. Wickings, "Preventative pest management in field crops influences the biological control potential of epigeal arthropods and soil-borne entomopathogenic fungi," *F. Crop. Res.*, vol. 272, p. 108265, Oct. 2021, doi: 10.1016/J.FCR.2021.108265.

[11] R. O. Arise, O. O. Taofeek, K. Babaita, R. I. Adeoye, and O. Osemwegie, "Blood pressure and sugar regulating potentials of Anarcadium occidentale nut globulin and albumin hydrolysates," *Heliyon*, vol. 7, no. 3, p. e06384, 2021, doi: 10.1016/j.heliyon.2021.e06384.

[12] F. A. Kapinga, L. J. F. Kasuga, and E. M. Kafiriti, “Growth And Production Of Cashew Nut,” *Soils, Plant Growth Crop Prod. Prod. Cashew Nut*, vol. 1, no. 1, pp. 1–10, 2010.

[13] B. Boniface, “Status of sucking insect pests in cashew growing locations of South and Central Zones , Tanzania,” 2020, doi: 10.12692/ijb/16.4.34-45.

[14] I.- Directorate, “Insect pests of cashew & their management,” no. 27, 2015.

[15] A. A. Adeline sneha, R. Chakravarthi, and J. A. Glenn, “A review on energy efficient image feature transmission in WSN for micro region pest control,” *Int. Conf. Electr. Electron. Optim. Tech. ICEEOT 2016*, pp. 4859–4862, 2016, doi: 10.1109/ICEEOT.2016.7755643.

[16] Y. Shi, Z. Wang, X. Wang, and S. Zhang, “Internet of Things Application to Monitoring Plant Disease and Insect Pests,” *Proc. 2015 Int. Conf. Appl. Sci. Eng. Innov.*, vol. 12, no. Asei, pp. 31–34, 2015, doi: 10.2991/asei-15.2015.7.

[17] D. Gupta and M. Belwal, “Pest Identification and Control of Diseases in Crop Fields through Image Processing and Tracking of Atmospheric Parameters,” *2018 2nd Int. Conf. I-SMAC (IoT Soc. Mobile, Anal. Cloud) (I-SMAC)I-SMAC (IoT Soc. Mobile, Anal. Cloud) (I-SMAC), 2018 2nd Int. Conf.*, pp. 289–294, 2018, doi: 10.1109/I-SMAC.2018.8653695.

[18] M. Anis *et al.*, “Agricultural Applications,” *Nanovate*, pp. 235–242, 2017, doi: 10.1007/978-3-319-44863-3_13.

[19] K. Saranya, P. Uva Dharini, P. Uva Darshni, and S. Monisha, “IoT Based Pest Controlling System for Smart Agriculture,” *Proc. 4th Int. Conf. Commun. Electron. Syst. ICCES 2019*, no. Icces, pp. 1548–1552, 2019, doi: 10.1109/ICCES45898.2019.9002046.

[20] T. Lee, S. Hudson Prof., and J. Y. Chang, “Design and development of an automated band wrapper robot for grapevine pest control,” *ICARA 2009 - Proc. 4th Int. Conf. Auton. Robot. Agents*, pp. 10–14, 2009, doi: 10.1109/ICARA.2000.4803971.

[21] A. Chougule, V. K. Jha, and D. Mukhopadhyay, “Using IoT for integrated pest management,” *2016 Int. Conf. Internet Things Appl. IOTA 2016*, pp. 17–22, 2016, doi: 10.1109/IOTA.2016.7562688.

[22] B. Vijayalakshmi, “Smart Pest Control System in Agriculture,” *2019 IEEE Int. Conf. Intell. Tech. Control. Optim. Signal Process.*, pp. 1–4, 2019, doi: 10.1109/INCOS45849.2019.8951351.

[23] S. Zhang, X. Chen, and S. Wang, “Research on the monitoring system of wheat diseases, pests and weeds based on IOT,” *Proc. 9th Int. Conf. Comput. Sci. Educ. ICCCSE 2014*, no. Iccse, pp. 981–985, 2014, doi: 10.1109/ICCSE.2014.6926609.

[24] M. Wadhai, “Technique,” pp. 544–547, 2015.

[25] F. A. Faria *et al.*, “Automatic identification of fruit flies (Diptera : Tephritidae),” *J. Vis. Commun. Image Represent.*, 2014, doi: 10.1016/j.jvcir.2014.06.014.

[26] N. R. Gavai, Y. A. Jakhade, S. A. Tribhuvan, and R. Bhattad, “MobileNets for flower classification using TensorFlow,” *2017 Int. Conf. Big Data, IoT Data Sci. BID 2017*, vol.

2018-Janua, pp. 154–158, 2018, doi: 10.1109/BID.2017.8336590.

[27] X. Liu, C. Wang, Y. Su, and T. Hu, "Integrating multimedia and artifical intelligence for pest prediction and aeration control of stored grain bins," *ICEMI 2009 - Proc. 9th Int. Conf. Electron. Meas. Instruments*, pp. 880–883, 2009, doi: 10.1109/ICEMI.2009.5274158.

[28] Siswanto, I. M. Trisawa, E. Karmawati, and S. Suhesti, "Control of Conopomorpha cramerella, Helopeltis sp., and Phytophthora palmivora using botanical and biological pesticides," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 418, no. 1, pp. 0–8, 2020, doi: 10.1088/1755-1315/418/1/012086.

[29] C. Liu and K. Cai, "Design and implement of web-based intelligent decision support system for prevention and control of fruit tree diseases and pests," *Proc. 2009 4th Int. Conf. Comput. Sci. Educ. ICCSE 2009*, pp. 1269–1271, 2009, doi: 10.1109/ICCSE.2009.5228408.

[30] K. A. . Upendra, W. L. A. T. . Lakmali, W. Harshan, N. Gihan, and J. Goonatillake, "Social Life Network for Disease and Pest Control," p. 266, 2014.

[31] S. F. Qi and Y. H. Li, "A new wireless sensor used in grain pests detection," *Proc. - 2012 Int. Conf. Control Eng. Commun. Technol. ICCECT 2012*, pp. 755–758, 2012, doi: 10.1109/ICCECT.2012.97.

[32] F. Qiao, C. Ji, X. Zeng, and J. Zhang, "A capacitive pest detection approach based on STM32 microcontroller," *2019 6th Int. Conf. Syst. Informatics, ICSAI 2019*, no. Icsai, pp. 1035–1039, 2019, doi: 10.1109/ICSAI48974.2019.9010239.

[33] P. Saeung, S. Santalunai, T. Thosdeekoraphat, and C. Thongsopa, "Improved efficiency of insect pest control system by SSPA," *2018 5th Int. Conf. Ind. Eng. Appl. ICIEA 2018*, pp. 179–183, 2018, doi: 10.1109/IEA.2018.8387092.

[34] T. C. Hsu, H. Yang, Y. C. Chung, and C. H. Hsu, "A Creative IoT agriculture platform for cloud fog computing," *Sustain. Comput. Informatics Syst.*, vol. 28, 2020, doi: 10.1016/j.suscom.2018.10.006.

[35] E. Suganya, S. Sountharrajan, S. K. Shandilya, and M. Karthiga, *IoT in Agriculture Investigation on Plant Diseases and Nutrient Level Using Image Analysis Techniques*. Elsevier Inc., 2019.

[36] Q. Dai, X. Cheng, Y. Qiao, and Y. Zhang, "Agricultural pest super-resolution and identification with attention enhanced residual and dense fusion generative and adversarial network," *IEEE Access*, vol. 8, pp. 81943–81959, 2020, doi: 10.1109/ACCESS.2020.2991552.

[37] "SDLC - RAD Model." https://www.tutorialspoint.com/sdlc/sdlc_rad_model.htm (accessed Dec. 23, 2021).

[38] "Welcome To Colaboratory - Colaboratory." https://colab.research.google.com/ (accessed Dec. 27, 2021).

[39] "Introduction to Proteus - The Engineering Knowledge."

https://www.theengineeringknowledge.com/introduction-to-proteus/ (accessed Dec. 27, 2021).

[40] "Arduino Technology Architecture and its Applications." https://www.watelectronics.com/arduino-technology-architecture-and-applications/ (accessed Dec. 27, 2021).

[41] "Arduino Nano 33 BLE Sense with headers — Arduino Official Store." https://store.arduino.cc/products/arduino-nano-33-ble-sense-with-headers?queryID=undefined (accessed Dec. 27, 2021).

[42] "Amazon.com: SunFounder Breadboards Kit 3PCS 830 Point 2PCS 400 Point Solderless Breadboards for Arduino Proto Shield Distribution Connecting Blocks(5 Pack) : Electronics." https://www.amazon.com/SunFounder-Breadboards-Solderless-Distribution-Connecting/dp/B082KBF7MM/ref=pd_vtp_7?pd_rd_w=kUctR&pf_rd_p=96226b5f-2d9a-439b-be45-97603787c682&pf_rd_r=6WW8SE298BC5DD6WW4PG&pd_rd_r=cda3ed76-08e5-4821-92e6-6118f9259397&pd_rd_wg=oQZpL&pd_rd_i=B082KBF7MM&psc=1 (accessed Aug. 10, 2021).

[43] "Amazon.com: Arducam Mini Module Camera Shield with OV2640 2 Megapixels Lens for Arduino UNO Mega2560 Board and Raspberry Pi Pico : Electronics." https://www.amazon.com/Arducam-Module-Megapixels-Arduino-Mega2560/dp/B012UXNDOY/ref=sr_1_1_sspa?dchild=1&keywords=Arducam+Mini+Module+Camera&qid=1621011157&sr=8-1- (accessed Aug. 10, 2021).

[44] "Amazon.com: ELEGOO 120pcs Multicolored Dupont Wire 40pin Male to Female, 40pin Male to Male, 40pin Female to Female Breadboard Jumper Wires Ribbon Cables Kit Compatible with Arduino Projects : Electronics." https://www.amazon.com/Elegoo-EL-CP-004-Multicolored-Breadboard-arduino/dp/B01EV70C78/ref=sr_1_6?dchild=1&keywords=Breadboard+Jumper+Wires&qid=1621011323&sr=8-6 (accessed Aug. 10, 2021).

[45] "4pcs Feetech FT90B Digital Servo 9g Micro RC Servo Motor 180 Degree for Arduino Robot 3v Servo|Home Automation Modules| - AliExpress." https://www.aliexpress.com/item/1005002329200679.html (accessed Aug. 10, 2021).

[46] "Amazon.com: TRICO Exact Fit 10-B Rear Integral Wiper Blade - 10" : Automotive." https://www.amazon.com/Trico-10-B-Exact-Wiper-Blade/dp/B014K09SPS/ref=sr_1_11?dchild=1&keywords=small+wiper+blades&qid=1620906662&sr=8-11 (accessed Aug. 10, 2021).

[47] "Solar Power Bank, Charger 30000mAh External Battery Pack with Type 2 USB | eBay." https://www.ebay.com/itm/132878989407?var=432177085795 (accessed Aug. 10, 2021).

[48] "ARDUINO SIM - MKR GSM 1400 Cellular Kit." https://store.arduino.cc/arduino-sim-mkr-gsm-1400-cellular-kit-1417 (accessed Aug. 10, 2021).

[49] "Amazon.com: UBeesize 67'' Phone Tripod Stand & Selfie Stick Tripod, All in One Professional Tripod, Cellphone Tripod with Wireless Remote and Phone Holder, Compatible with All Phones/Cameras,Load capacity: 1.5 Kg : Cell Phones &

Accessories." https://www.amazon.com/UBeesize-Professional-Cellphone-Bluetooth-Compatible/dp/B08D6KM95D/ref=sr_1_3?dchild=1&keywords=iStabilizer+Travel+Light+Mobile+Phone+Video+Camera+Selfie+Tripod+Stand&qid=1620920879&sr=8-3 (accessed Aug. 10, 2021).

[50] P. L. Saroj, P. S. Bhat, and K. K. Srikumar, "Tea mosquito bug (Helopeltis spp.) - A devastating pest of cashew plantations in India: A review," *Indian J. Agric. Sci.*, vol. 86, no. 2, pp. 151–162, 2016.