UNIVERSITY OF NAIROBI

DEPARTMENT OF COMPUTING AND INFORMATICS

USING IMAGE PROCESSING FOR PLANT HEALTH MONITORING

BY

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A RESEARCH PROJECT SUBMITTED FOR THE PARTIAL FULFILLMENT FOR THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN DISTRIBUTED COMPUTING TECHNOLOGY, AT THE UNIVERSITY OF NAIROBI

DECLARATION

STUDENT

I hereby declare that this project is my own original work and has, to the best of my knowledge, not been submitted to any other institution of higher learning.

Signature.. Date....28/11/2023.......

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This project has been submitted as a partial fulfillment of requirements for the degree of Master of Science in Distributed Computing Technology with my approval as the University supervisor.

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DEDICATION

This Project is dedicated to God the Almighty for all the blessings and strength which has kept me going throughout the course of this project, my family, wife and children for their constant support and inspiration.

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I am indebted to my supervisor, Dr. Evans Miriti, for his unwavering support and constructive discussions during the entire period of this work. Many thanks are due also to the other members of the panel and review committee at the department of computing and informatics, University of Nairobi, Prof. William Okello Odongo, Dr. Christopher Chepken and Dr. Stephen Mburu who provided technical guidance, valid criticism, and direction that I so much needed through this research project.

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A special thanks to my family for their personal support and great patience always.

ABSTRACT

The problem farmers face in knowing the health status of the plants during the growth period has limited the yield produced, informed application of pesticide and sustainable agriculture. The challenge to better plant health monitoring is traceable to the methods used in the monitoring process.

The aim of this project was to investigate the application of image processing in solving plant health monitoring problems. The specific objectives that the project sought to address include; identification of spectral features for plant health state classification, developing of a model for plant health classification, developing image processing segmentations based on the models for plant health classification and developing a prototype for the plant health monitoring system. The intention was to have the data collected easily, understood, and interpreted for early mitigation plans on the onset of a change of plant health status.

In this project, two approaches were used where an unmanned aerial vehicle platform was used for carrying cameras to capture aerial images on specific coordinates. The images were then processed through an algorithm that was developed to identify Normalized Difference Vegetation Index (NDVI) data to generate the required data for development of the plant health monitoring prototype system. This was a continuous monitoring system as the plants were monitored through the planting to harvesting.

The plant health monitoring system prototype using image processing was developed. The acquired aerial images were processed from the planting to harvesting and a graph produced for tracking the health status of the plants.

The testing and evaluation findings revealed that a variation in graph pattern would indicate the onset of a change in health status. The evaluation of the system showed that the system can improve plant health monitoring for farmers as well as provide effective ways in determining plant health status.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

CMOS:	Complementary Metal Oxide Semiconductor
GIS:	Geographical Information System
GPS:	Global Positioning System
NDVI:	Normalized Difference Vegetation Index
QGIS:	Quantum Geographical Information System
SDI:	Special Disease Indices
SVI:	Spectral Vegetation Indices
UAV:	Unmanned Aerial Vehicle

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Agricultural products from crops form a large part of every person's diet. Producing food of sufficient quantity and quality is essential for the well-being of the people anywhere in the world. Agricultural plants, as living organisms, require water and nutrients to grow and are sensitive to extreme weather phenomena, diseases, and pests. Extreme weather conditions would affect the plant's health. The naked eye observation of plant health status by experts is the main approach adopted in practice as stated by (Weizheng et al., 2008). This would usually require specialists to be hired to identify symptoms of diseases on the plants. The specialist would give subjective results due to their difference in expertise and knowledge. Traditional farming methods are proving not to be productive and incur a lot of losses. This loss may be due to lack of information on the type of plant stress affecting the plants and late detection of the symptoms as stated by (Husin et al., 2012). In large scale farming, crop monitoring during the growing season consumes a lot of time and resources. Monitoring each crop on a farm may take months and may well be into the harvesting season. Monitoring crops will require data collection and analysis. The data collected will be useful in making decisions on what pesticides to use, what fertilizers to apply or what irrigation methods would best suit the crops being planted

1.2 Problem Statement

Amidst the growing global challenges confronting agriculture, including the ever-increasing demand for enhanced food production to support a burgeoning world population, the depletion of finite resources, and the persistent menace of plant diseases and environmental stressors, the need for innovative methodologies for comprehensive plant health monitoring has never been more pressing. Traditional methods of plant health assessment are intrinsically labor-intensive, subjective, and prone to delayed disease detection, resulting in suboptimal agricultural output. The integration of image processing techniques offers a promising avenue for automation and augmentation of plant health assessment, yet it grapples with multifaceted challenges. These challenges encompass the heterogeneity and unpredictability of image quality across diverse agricultural settings, the intricacies of accurate disease classification and timely anomaly detection, the imperative to acquire large-scale, meticulously annotated datasets, the necessity for fostering robust interdisciplinary collaboration between agriculture, biology, computer science, and engineering domains, the complexities of deploying image processing solutions in practical, resource-constrained agricultural environments, and the ethical considerations surrounding data privacy, intellectual property, and equitable access to technology. The resolution of these challenges is not only central to realizing the transformative potential of image processing in plant health monitoring but also holds the key to advancing global food security and establishing sustainable agricultural practices in an increasingly resource-scarce world.

1.3 Research Objectives

1.3.1 Main Objective

To develop and test unmanned aerial vehicle (UAV) based image processing system for calculation of normalized difference vegetation index (NDVI) to monitor plant health status in potato fields.

1.3.2 Specific Objectives

i. To identify spectral features for plant health state classification in plants.
ii. To develop a model for plant health classification.
iii. To develop an image processing system for image segmentation of plants based on features identified in (ii).
iv. To test the plant health monitoring system prototype

1.4 Significance of the Study

This system was critical for the development of an agricultural monitoring tool for farmers, agronomists, and county governments. The system will be able to estimate the growth pattern of a plant and the estimated yield. The system will be easy to use for prediction of the onset of a disease infection and help in the implementation of mitigation plans. Plant statisticians will be able to develop projections of the yields and be able to advise on better crop insurance covers based on the expected yield. County governments will benefit from the results of the monitoring for future planning and develop disease and pest prevention plans.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the current methodology and approaches for use in agricultural monitoring. These range from the remote capture of aerial images by remote sensors to image processing of multi spectral images for crop analysis and geo-referencing of the images. Application of image processing to aerial captured images and use of multi-spectral imaging to derive vegetation indices for application in plant health monitoring is also reviewed.

2.2 Vegetation Indices

Vegetation indices are derived from reflectance values at several wavelengths. This is derived with the use of remote sensing technology. Ashourloo et al., (2014), describes a spectral vegetation indices (SVIs) tool for detecting different plant diseases. The disease detection method is by use of a spectral database of a healthy plant and comparing the captured data with the data of the healthy crop as the diseases advances. In this research, effects of a disease on the leaf pigments and the structure of the plant are captured and indices are derived as a base for disease detection. The indices are derived from reflectance values at different wavelengths. For disease detection, the leaf reflectance spectrum may be changed in a specific way. There is need for special disease indices (SDIs) to detect the various plant diseases.

It is important to have the specific disease indices recorded in a database during the various stages of disease. The symptoms of diseases at various stages exhibit distinct color changes. This color changes from yellow, orange and then deep brown colors. Disease symptoms have a high impact on the spectral behavior of a leaf and vary the indices that are captured during processing. However, identification of the various stages of plant disease is difficult due to the changing environmental conditions. There is a need for multi-spectral sensors which capture different wavelengths and several bands to efficiently detect crop disease.

2.3 UAV for Aerial Image Capture

There are different platforms for use in acquiring aerial images. The different platforms for imaging include the use of satellites, aircraft and unmanned aerial vehicles (UAV). (Maltese et al.,

2015) describe the comparison of different platforms for use in remote image capture. The research aims at demonstrating the cost effectiveness of using unmanned aerial vehicles (UAV) versus traditional acquisition platforms, such as satellite and aircraft. The use of a specific platform will be considered on the effectiveness of low operational costs, high operational flexibility, and high spatial resolution of imagery. In Kenya, the use of UAV is cost effective. This enables the use of high-resolution images, at minimum cost in comparison to the use of aircraft or satellite platforms.

The UAV technology has grown in recent years outlines the capabilities of UAVs for high performance, stability and reliability which have improved (Li and Yang, 2012). UAVs are capable of aerial photography and capture high resolution aerial images. The UAVs can realize autonomous navigation for use in remote image capture.

2.4 Precision Farming

Global positioning systems (GPS) are used in support of various agricultural processes. GPS coordinates are used as reference points on digital maps of a farm to develop geo- referenced points. By accurately determining points of interest, it is possible to use GPS as a vital component for automatic steering and steering-assist systems for agricultural vehicles. (Thomson and Smith, 2008) describes the use of global positioning system (GPS) in support for a myriad of agricultural applications including aerial application of nutrients, pesticides, and growth regulators. The research was able to identify and relay GPS coordinates to an aircraft which is used for application of pesticides to a common ground reference point. However, the study highlights the interference and delay in transmission of GPS coordinates to the aircraft which lead to magnitudes of error which can be over- come by use of UAVs which fly and hover over the ground reference points and points of interests as they capture images.

2.5 Summary

There are several technologies used in remote sensing. Satellite imagery is one of the common technologies in use. Satellite image resolution is exceptionally low in comparison to UAV based imagery. Satellite technology has several challenges that UAV based image capturing has been able to overcome. Remote sensing techniques on satellite images must undergo several processes. This process is to eliminate the different challenges and obstacles that face satellite images. These techniques are not applicable in UAV captured images because of the high resolution of the sensors carried on the UAV. Following (Matese et al., 2015) and the recent literature, the proposed solution is developed by use of un-manned aerial vehicle to acquire aerial images for plant heath monitoring. The intended system will help to monitor surface reflectance from plants to monitor photosynthesis using multi spectral cameras and aid in the determination of the plant health status.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

In this chapter, the design process of the system was presented. The objective was to build a prototype that will aid in the continuous monitoring of plants done by use of multi-spectral camera images acquired by use of unmanned aerial vehicle (UAV), from the planting to harvesting period of potato plants. Image processing aided in the extraction of vegetation indices such as Normalized Difference Vegetation Indices (NDVI) for examining the amount of chlorophyll in a plant. NDVI values of images captured were used for analysis and comparison to generate monitoring graphs. This chapter highlighted the various methods and procedures that were adopted in conducting the study.

3.2 Requirements Analysis

3.2.1 The Process of Obtaining Requirements

Stakeholder Identification and Selection

The first crucial step in obtaining requirements for the system's development involved the identification and selection of relevant stakeholders. A multidisciplinary approach was adopted to ensure comprehensive coverage of perspectives. Stakeholders were selected based on their expertise in relevant fields such as agriculture, remote sensing, image processing, and UAV technology. These individuals included agronomists, agricultural engineers, remote sensing experts, and UAV operators. Additionally, domain experts from the potato farming sector were consulted to gain insights into the specific requirements and challenges faced in potato cultivation.

Surveys and Interviews

A series of structured surveys and in-depth interviews were conducted with the selected stakeholders to elicit their domain-specific knowledge and requirements. The surveys were designed to collect quantitative data on the expectations and preferences of stakeholders, while the interviews provided a platform for in-depth discussions to uncover nuanced requirements. Open-ended questions were incorporated into the interviews to encourage stakeholders to express their perspectives freely. The surveys and interviews were instrumental in capturing both the explicit and implicit needs of the system.

Literature Review

In parallel with the primary data collection efforts, an extensive review of existing literature, scientific publications, and industry reports was undertaken. This secondary source of information served to provide a broader context for understanding emerging trends, technological advancements, and best practices in plant health monitoring using multi-spectral imagery and UAVs. The literature review also played a pivotal role in cross-referencing the requirements obtained from stakeholders with established industry benchmarks.

3.2.2 The Actual Requirements Identified

System Features and Functions

The requirements analysis process yielded a comprehensive set of requirements that shaped the design and functionality of the plant health monitoring system. The key requirements identified can be summarized as follows:

Multi-Spectral Imaging Capability: The system must be equipped with a multi-spectral camera capable of capturing images at specific wavelengths to facilitate NDVI calculation.

UAV Integration: Integration with UAV technology is imperative for autonomous aerial data acquisition over the potato cultivation area.

Continuous Monitoring: Continuous monitoring, from the planting stage to the harvesting period, is essential to provide a holistic view of plant health throughout the growth cycle.

Monitoring Graphs: A user-friendly interface should be designed to present monitoring graphs that visualize the variations in NDVI values, facilitating informed decision-making by stakeholders.

These requirements, shaped through stakeholder engagement, data collection, and comprehensive analysis, served as the foundation for the subsequent stages of system design, development, and implementation.

3.3 System Design

The proposed system for monitoring plant health status during growth comprises of unmanned aerial vehicle (UAV), which is fitted with sensors for navigation purposes, cameras for image acquisition, and graphic user interface (GUI) capabilities for graphical presentation of data.

3.3.1 The Architecture Design

The architectural design phase aimed at defining the high-level structure of the plant health monitoring system. It encompassed the identification and specification of components that form part of the system, their interactions, and overall system flow. To ensure seamless integration of multi-spectral imagery acquisition and processing, a modular design approach was adopted.

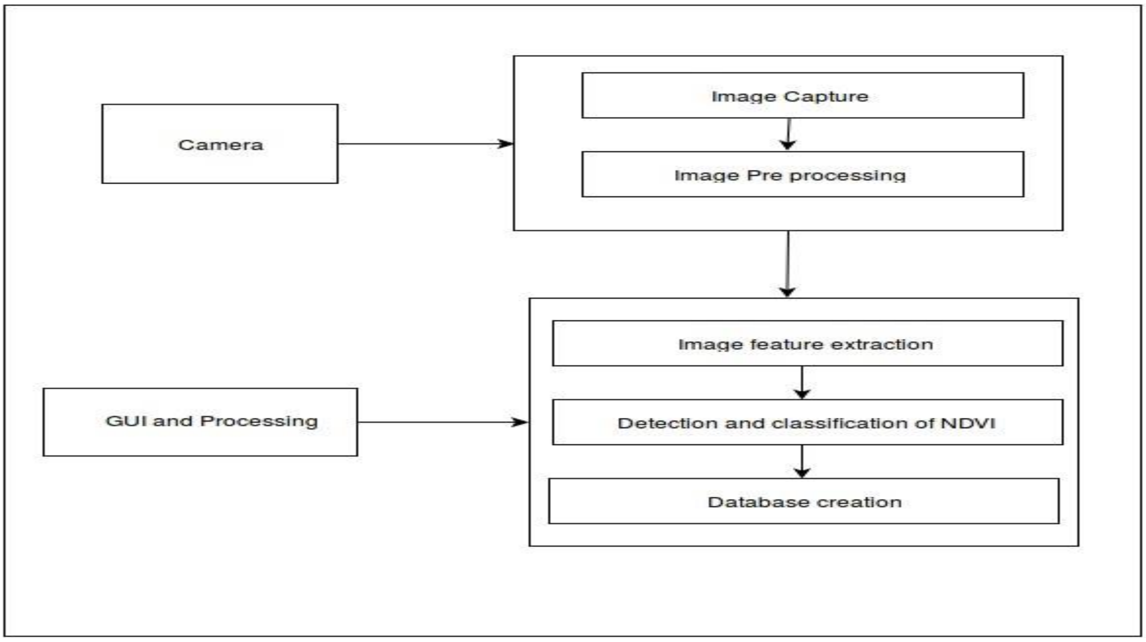


Figure 3.1 ***System Architecture Diagram***

Key architectural components that form part of the system include UAV interface which is fitted with sensors and cameras for navigation and data acquisition purposes. The architectural design of the system also includes an image data processing module which is based on MATLAB 2010 libraries, a database system for storing and managing image and NDVI data, and user interface for data visualization and analysis.

The design prioritized modularity, scalability, and fault tolerance to accommodate future system enhancements and accommodate a diverse range of users, from agricultural experts to farmers. The basic steps for plant health monitoring and classification using image processing are shown in (Figure 3.1).

3.3.2 Image Acquisition

The cameras used for acquiring the images are a commercial RGB camera and multi-spectral cameras. These cameras were mounted on an Oktokopter XL, an-eight propeller UAV designed to help capture aerial images on specified coordinates.

Commercial Camera

The imaging system used was a canon EOS digital rebel XTI camera. Figure 3.2 below. The camera consists of a 10.1 Megapixel APS-C Size CMOS Sensor With an effective pixel resolution of (3,904 x/598). The camera supports 3 bands of images namely Red, Green, and Blue. The camera was also installed with an external trigger port which is connected and controlled by the UAV.

Figure 3.2 Canon Commercial Camera

Multi-Spectral Camera

Multi-spectral image acquisition was acquired using point gray research CMLN-13S2M-CS camera. Figure 3.3 below. The camera features a Sony mono chroma ICX445 CCD sensor with a resolution of (1296 x 964). The pixel size of 3.75 µm with Gain Range of 0 dB to 24 dB. The triggering modes are standard, bulb, skip frames and overlapped which are controlled from the UAV.

Figure 3.3 Point Gray Camera.

3.3.3 Unmanned Aerial Vehicle

The unmanned aerial vehicle used was a Mikrokopter octocopter XL as shown in Figure 3.4. This is a multi-rotor UAV with a payload of 3Kg. The Mikrokopter had capability of holding its altitude and position with the assistance of GPS while airborne. The Mikrokopter was programmed via a wireless communication interface. The wire-less interface enabled the Mikrokopter to relay its current GPS coordinate to a laptop and receive the GPS coordinate and altitude instructions. The triggering of the cameras was via a radio control interface on 2.4 GHz wireless frequency.

Figure 3.4 Mikrokopter Multirotor OctoCopter

3.3.2 User Interface Design

User interface (UI) design focused on creating an intuitive and user-friendly platform for stakeholders to interact with the system. The design incorporated data visualization tools, real-time monitoring features, and an accessible dashboard for users to access NDVI-based insights. The NDVI values are calculated from captured plant images and provide tools for in-depth analysis, including anomaly detection, trend analysis, and comparison with established thresholds.

Usability testing and feedback from potential end-users were leveraged to refine the UI design, ensuring that it aligned with the specific needs and preferences of the intended user base.

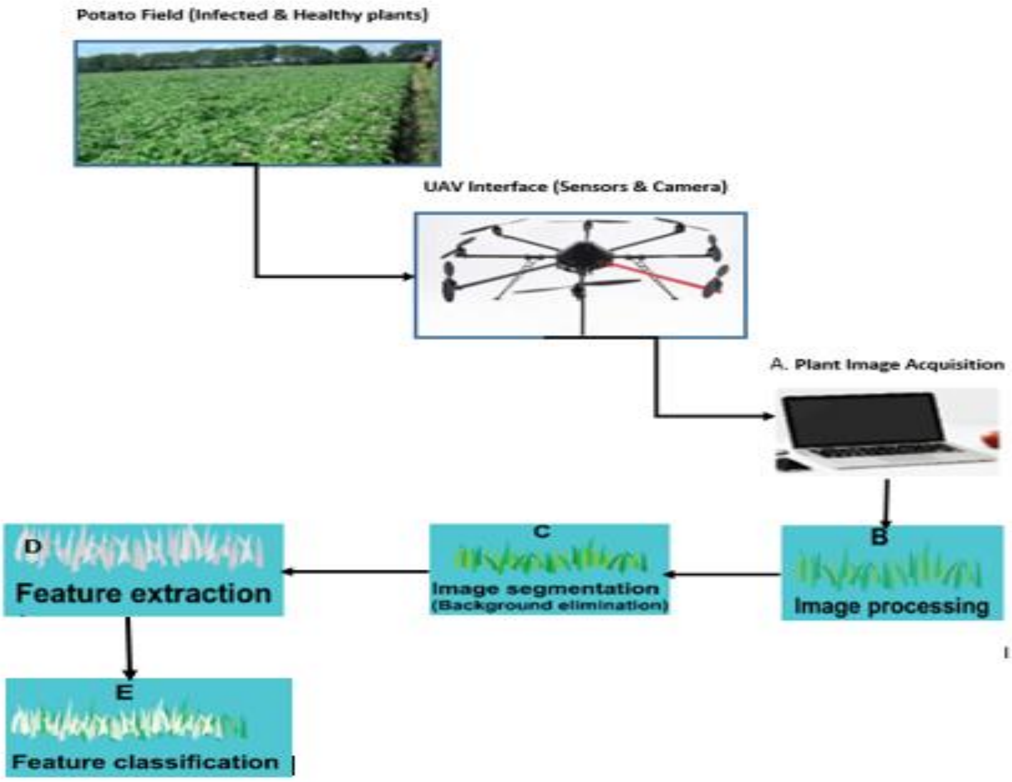


Figure 3.5 Expected User Interface

3.4 Implementation

3.4.1 Software Development

The implementation phase translated the system design into functional software components. The software development process is centered on coding the UAV interface, image processing algorithms, database integration, and the user interface. MATLAB 2010 libraries were employed to harness the power of image processing for NDVI calculation, data processing and generation of relevant vegetation indices. Extensive testing and debugging were conducted during this phase to ensure that the software components operated cohesively and efficiently.

3.4.2 Image Acquisition

Aerial image acquisition is by use of an Unmanned aerial vehicle (UAV) mounted with cameras. Flight altitude is suggested at 20 meters. The images were captured in three bands by use of tetracam ADC multi-spectral camera. These bands were green (G), red(R) and near infra-red (NIR) working from 520 to 920 nanometer wavelength. Prior to image capturing, a reflectance measurement was captured by use of a white reference image. Pix- elWrench2 software (Tetracam Inc., Chatsworth, CA, USA) was used to manage transform and export tetracam ADC images of each band.

3.4.3 Image Pre-Processing

Each multi spectral image acquired was geo-referenced. Geo-referencing was done by use of open-source software known as quantum geographical information system (QGIS) to enable repeated monitoring and image acquisition of the same reference point. By use of GPS coordinates, it became possible to collect repeated data from a referenced GPS coordinate. The UAV was programmed to maintain altitude and position for the camera to acquire the image.

3.4.4 Image Feature Extraction

Multi-spectral images acquired by the UAV were processed to calculate NDVI of the plants. A set of statistical tools were applied to analyze the acquired images for vegetation indexing. Basic statistics histogram was implemented by use of Matlab software. Data sets were generated by analysis of each individual pixel of the image to generate indices as outlined by (Yagci et al., 2014b). The expected NDVI was in the range of -1 to 1. Where positive values indicated increasing green leaves and negative values indicated non- vegetated features such as water, barren areas, or roads. The mean NDVI data for each processed image was captured and a graphical presentation of the data was derived.

3.4.5 Monitoring System

The monitoring system was obtained by logging the measured NDVI and the age of plant. Mean values of pixels covered by leaves were processed and presented by plotting a graph for easy interpretation and understanding. The graph plotted was the NDVI value verses the age of plant. This was the presentation of chlorophyll level at the different age of the plant as stated by (Geng et al., 2014). The system had a library of healthy plant NDVI data which was compared to measured values for determination of health status the plants.

3.4.6 Graphical User Interface

The system had a graphical user interface, where a graph of the collected data is represented. The user interface enables one to view date of planting, display the number of days since the plant was planted, display the current health status graphically and have alarm indicators if the data is below the expected range. The system was automated and thus guides the user with instructions of how to capture and store a measurement.

3.4.7 Hardware Integration

Simultaneously, the hardware integration phase focused on setting up the UAV hardware and configuring it to capture multi-spectral imagery as per system requirements. This involved the installation of the multi-spectral camera, ensuring proper calibration, and testing the communication interfaces with the software system. UAV operators received training to ensure safe and effective data acquisition flights.

3.5 Testing

3.5.1 Component Testing

The testing phase primarily centered on component-level testing to assess the functionality and reliability of individual system elements. This involved rigorous examination of the UAV interface, image processing algorithms, database operations, and user interface modules. Component testing was instrumental in identifying and rectifying software bugs, hardware malfunctions, and compatibility issues. Test cases were designed to validate the accuracy of NDVI calculations and data storage capabilities.

3.5.2 Integration Testing

Integration testing focused on evaluating the interaction between various system components. It assessed how well the UAV interface, image processing module, database system, and user interface worked together to collect, process, and present NDVI data. Integration testing aimed to ensure data integrity, real-time data updates, and system responsiveness.

3.6 Evaluation

The evaluation phase was dedicated to preparing and executing a series of controlled experiments to assess the system's performance and its utility in real-world agricultural contexts. Experimental design encompassed the formulation of research hypotheses, selection of experimental variables, and determination of data collection methods. Controlled experiments were designed to compare the system's performance against established benchmarks and to measure its impact on plant health monitoring efficiency.

3.7 System Testing

The testing of the system was a continuous process through the planting season of the potato plants. It was required that data captured by satellite be compared with the data captured from multi-spectral camera. Other tests will include testing the accuracy of the captured images of the system.

3.7.1 Comparison of ground-based and satellite based NDVI

The NDVI data captured by the system was compared with data captured from the satellite NDVI. This required satellite image to be acquired on the same date as the ground-based measurement as outlined by (Bagis and Berk Ustundag, 2013). This required continuous image processing and generation of synthetic NDVI values to be computed and a model was generated. With every newly acquired satellite image, the model was updated. The model was used for generation of calibration data. The data was used for generation of optimal conditions for the system.

3.7.2 Accuracy of the System

Due to changing atmospheric conditions such as spectrum conditions, ground reflectance and elevation parameters of the plants, measurement of surface reflectance of the leaves on a pixel was affected as stated by (Xie et al., 2010). This required that an image reference of a known reflectance was captured by the camera before any image acquisition. This aided in the determination of the data accuracy for the system. The system was able evaluate spectral response and characteristics of reflectance of the potato plant leaves.

3.8 Measurement Procedure

A sample field of planted potatoes was located at the University of Nairobi, Kabete Campus. The fields were of different varieties of potatoes. The sampling areas were located by identifying plants in experimental fields. Control points were laid in the fields. Control points are areas where GPS coordinates were recorded and used for aligning and identifying the location of the acquired images. Control point coordinates were also programmed to the UAV for directing the flight path. For each control point, ten images were acquired at an altitude of twenty meters. A single measurement consisted of taking two images. Sample image and a reference image. The two images are then used in the data extraction process.

3.9 UAV Configuration

Pre-flight planning was necessary. Pre-flight plans helped identify all the requirements for the flight such as clear weather conditions, battery connections, attachment of cameras/sensors, UAV calibration and flight tests.

3.9.1 UAV Battery Charging

Mikrokopter XL UAV were designed to use Lithium Polymer (LiPo) batteries. These batteries came in four cells and provide a voltage of 14.8V at currents of 6600 MAh. The flight time for a single battery was 5 to 7 minutes. To increase the flight time, the UAV flew with two batteries connected in parallel. This ensured the same voltage and more current for flights to enable up to 15 minutes of flight time for the UAV.

3.9.2 Propeller Configuration

The Mikrokopter XL UAV body was not designed with aerodynamics in place. It was critical that the propellers were well configured, and its aerodynamics professionally installed as outlined in Figure 3.5. The Mikrokopter used 8 propellers for flying. Figure 3.6. The direction of the flight was changed by altering the speed of each individual propeller. This was done through a radio control and a flight control connected to the UAV platform.

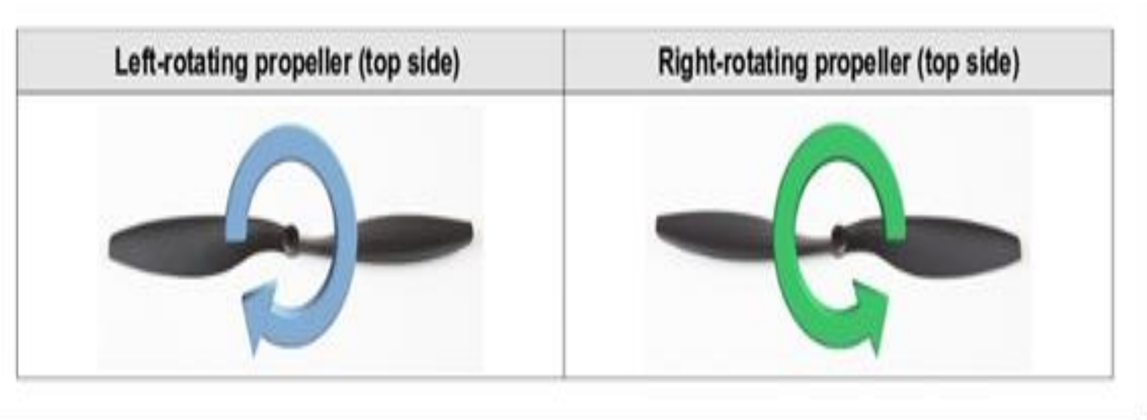


Figure 3.6 Propeller Orientation

Figure 3.7 Propeller Installation and Direction of Rotation.

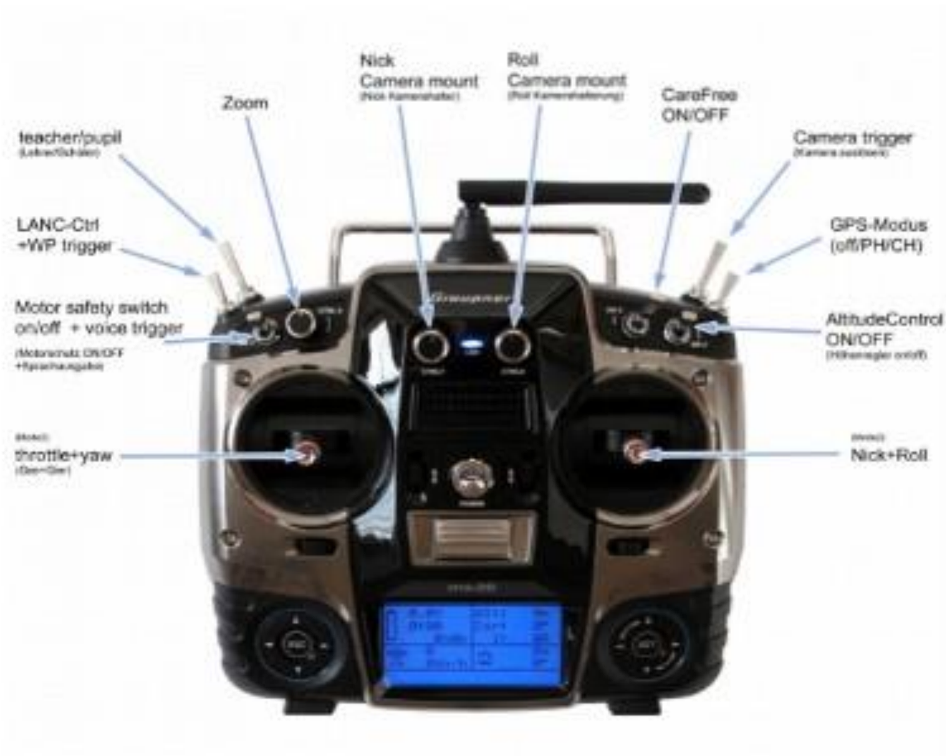
3.9.3 Radio Configuration

The Mikrokopter XL was controlled by use of a graupner mx-20 radio transmitter. It was used for flying the UAV, controlling the camera, initiating the flight autonomy, receiving telemetry data and controlling other attached sensors on the UAV. The radio controller was 16 channels for control as outlined in Figure 3.7 below and Figure 3.8 outlining the assigned channels on the radio.

Figure 3.8 Transmitter/Receiver MX-20 Configurations List

Ch.	Assignment in the KopterTool	Functions	Switch MX-20 (Mode2)	Switch MC-20 (Mode2)	Switch MC-32 (Mode2)
1	Gas	Control throttle	Control sticks left	Control sticks left	Control sticks left
2	Roll	Control roll	Control stick right	Control stick right	Control stick right
3	Nick	Control nick	Control stick right	Control stick right	Control stick right
4	Yaw	Control yaw	Control stick left	Control stick left	Control stick left
5	Ch5	Function HoldHeight	SW 3	SW 7	(right) SW 3
6	Ch6	Function GPS (PositionHold / ComingHome)	CTRL 10	SW 5/6	(right) SW 6
7	Poti3	Camera Zoom	CTRL6	Slider right	Slider right
8	Ch8	Function CareFree	SW 2	SW 9	(left) SW 4
9	Poti5	Camera tilt (Nick)	CTRL 7	Slider left	Slider left
10	Poti6	Camera tilt (Roll)	CTRL 8	Potentiometer	Potentiometer
11	Poti7	Trigger camera - ModSp.1 (LANC - ModSp.2)	SW 9 (CTRL9)	SW 8	(right) SW 8
12	Ch12	Function Motor-Safety switch & Voice output	SW 1	SW 14	(left) SW 7
13	Ch13	Auto Start / Land	n/a	n/a	(right) SW1
14	Ch14	-	n/a	n/a	-
15	Ch15	-	n/a	n/a	-
16	Ch16	-	n/a	n/a	-

Figure 3.9 Graupner MX-20 Radio Controller



3.9.4 Camera Installation

The Mikrokopter battery housing was installed at the center and bottom of the UAV. Battery holder provided mounting points for the camera. The camera was mounted at the bottom of the battery also so that it centrally installed on the platform. Once mounted, to capture images on landscape or portrait format, the orientation of the UAV flight was set to fly at the format which images will be captured.

3.9.5 UAV Configuration

The Mikrokopter configurations available for alteration were;

- GPS properties
- Altitude control
- Camera configurations
- Propeller configuration
- Navigation configuration

These configurations were very critical in ensuring that the UAV fly in autonomy or con- trolled by the radio control from the ground. Figure 3.9 highlights some of the configuration used on the flight controller for the Mikrokopter XL.

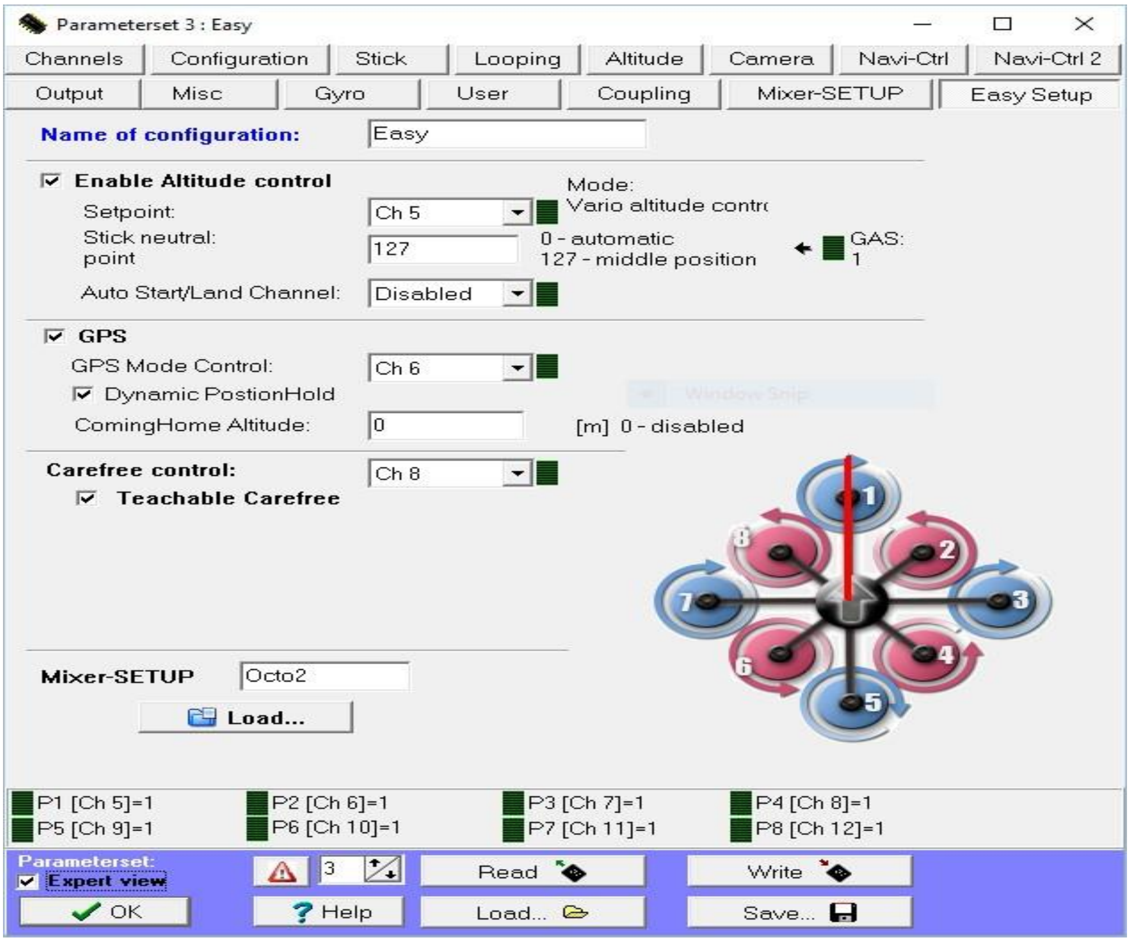


Figure 3.10 Mikrokopter Settings Adjustments.

3.9.6 Flight Path Configuration

The GPS plays a critical role in flying the UAV. The GPS was used to fly the drone autonomously through defined coordinates. The coordinates were programmed onto the UAV by using a reference goggle map of the actual flight area and coordinates are programmed onto the system so that each coordinate is used as a way-point Figure 3.10.

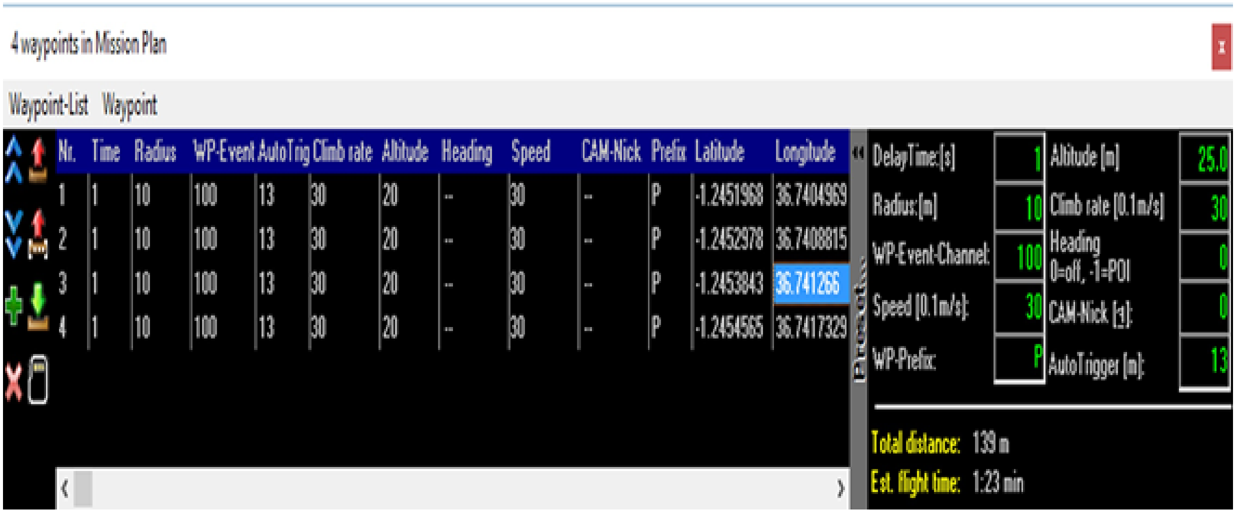


Figure 3.11 Mikrokopter Way-Points Generation.

Once coordinates, altitude and speed of drone were identified, the Mikrokopter software generates waypoints labeled as P1, P2, P3 and P4 as outlined in Figure 3.11. At each point, the images were captured by triggering a switch on the radio control to acquire an Image.

Figure 3.12 Mikrokopter Google Map Reference Image with Waypoints.

3.10 Camera Alignment

Images acquired using the point gray camera required alignment. This was because the cameras were mounted on a 3D printed mounting. The camera's focus area was not in the same area. This required the image processing algorithm used to shift the images to alignment on either the horizontal plane or the vertical plane.

3.11 Detection of Green Leaves

The algorithm used a procedure that can detect green leaves from an image. It acquired a color image from the camera with a resolution of (2592 X 3888) and separated into the three bands of Red, Green, and Blue. Then used NDVI to differentiate between the green color and other colors.

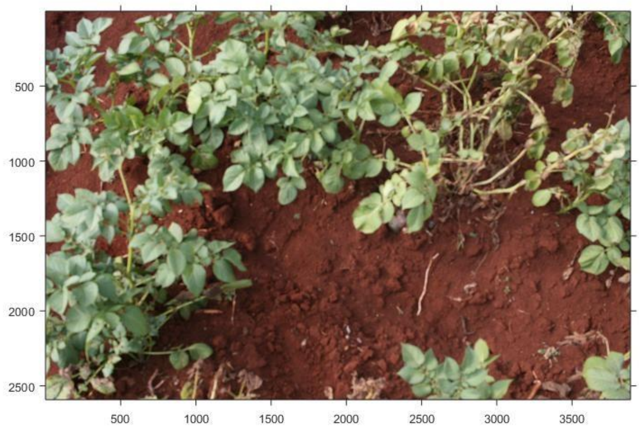


Figure 3.13 Image Acquired from a Canon Camera.

3.11.1 Detection of green leaf pixels

Under controlled illumination, the color of green leaves was distinguished from the colors of other objects in the field, such as ground, dry branches and foliage as alighted in Figure 3.12 Above. The algorithm used Normalized Difference Vegetation Index (NDVI) for green leaf detection. The NDVI values are in the range of -1 to 1. Green vegetation was in NDVI values of 0 to 1. The algorithm used the following formula;

Normalized Difference Vegetation Index,

NDVI = (ρNIR − ρRED) / (ρNIR + ρRED)

3.11.2 NDVI Image

The algorithm generated NDVI imaging from the raw image acquired in Figure 3.12. The processed NDVI image in Figure 3.13 below highlights the NDVI values in gray scale.

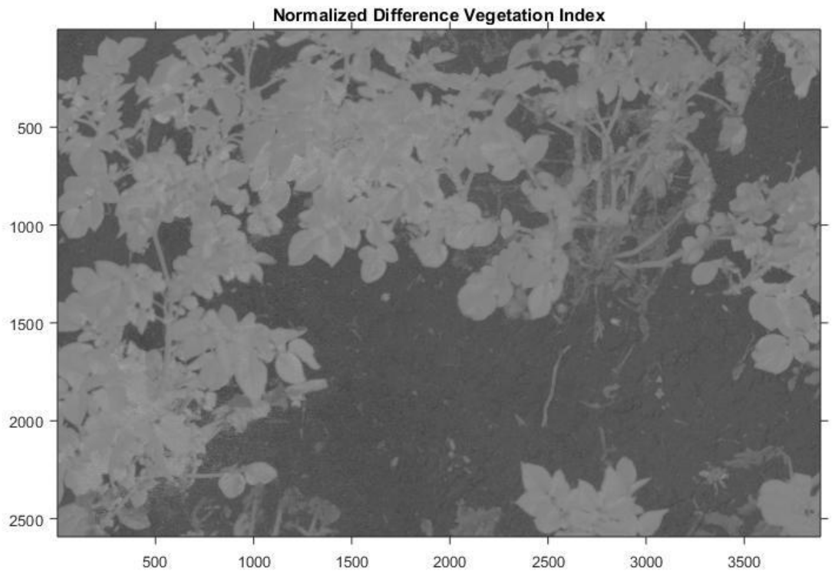


Figure 3.14 Processed NDVI Image.

3.11.3 Binary image

The binary image held the pixel values representing the areas covered with green leaf as shown in Figure 3.14 below. Each white pixel represented values of 1 and black pixels the values of 0. A threshold value of 0.1 was set. The threshold value represented the values of vegetation cover in green and blacks any other color. The algorithm calculated the total sum of white pixels and logged them on a matrix for representation on a graph thus representing the areas covered by green leaves.

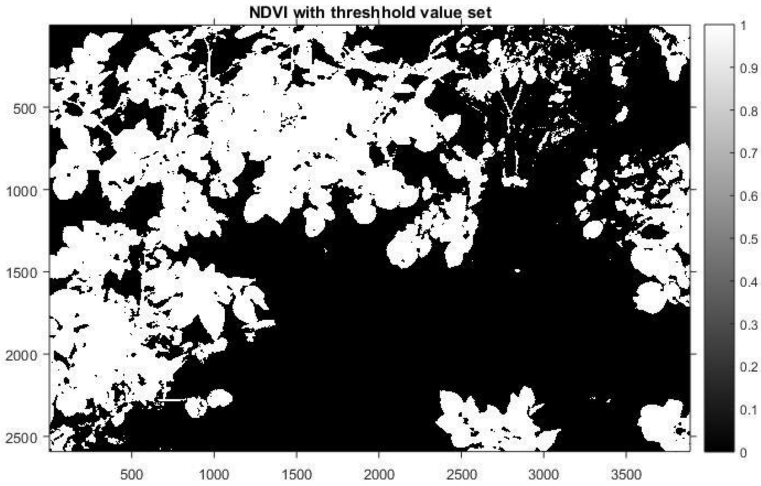


Figure 3.15 Binary Image after image processing

3.11.4 Green Leaf Registration

Green leaf registration was required to calculate the total values of area covered by the green leaves. Images acquired for processing were collected and labeled according to the day and age of the plants. The algorithm detected leaves coverage in all the images that were acquired. The data was then computed and logged onto a matrix with the defined days and age of the plant. This logged data was then used to plot a graph to represent the leaf coverage areas against the age of plant.

3.12 Field Tests

The monitoring system was deployed at the University of Nairobi Kabete Campus in August 2016. The goal of deployment was:

i. To acquire images from the field

ii. To evaluate the green leaf estimation accuracy of the system.

iii. To discover issues that need to be improved for future practical applications.

3.13 Experimental Design

The prototype design included four critical issues: potato plants, farm for data collection and ground truth. We selected Tigoni potato breed. This is a popular potato plant that is typically grown by farmers in the whole country. The Kabete Campus was an excellent choice because of the proximity to Nairobi. There are other potato experiments at Kabete Campus which was a reliable source for data collection for the system. The prototype system gave complementary data collection that was to be compared with the results from other experiments.

The area of each block is about one eighth of an acre. There were twenty rows of about ten potato plants. The ground truth of plant health was by human count conducted by farm workers. The blocks were marked by stickers and indicate the date they were planted. Thus, each image acquired was referenced to the date of planting.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The chapter presents results and discussion of results of potato plant health experimental evaluation conducted at Upper Kabete Campus. Upon completing the evaluation experiments, the results were systematically collected, analyzed, and reported. This phase involved quantitative assessment of the system's accuracy in NDVI calculation, its effectiveness in continuous monitoring, and its impact on decision-making in potato cultivation. These findings were reported in a structured manner, including data analysis techniques, statistical results, and visual representations to convey the system's efficacy in aiding plant health monitoring.

4.2 Experimental Results

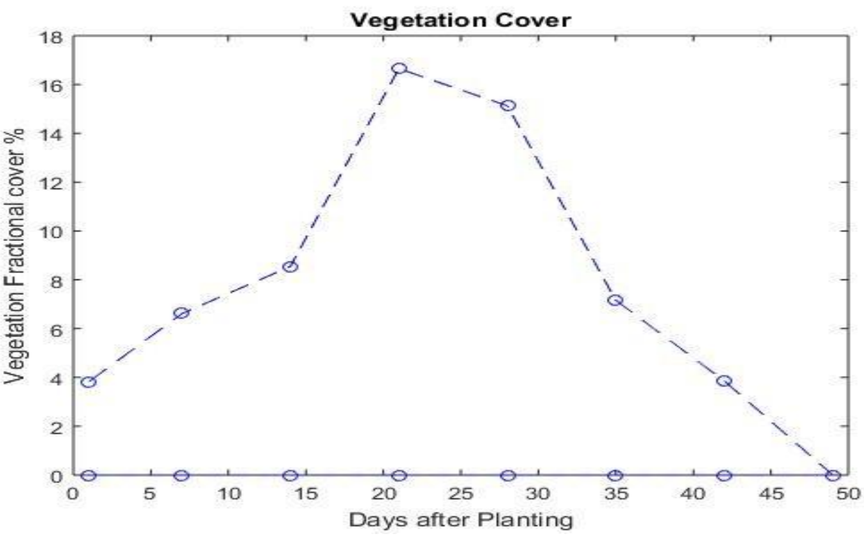


Figure 4.1 Vegetation Cover in Comparison to Age of Plant

Figure 4.1 shows plant health estimation. The area of coverage was in percentage. The lower the percentage, the lower the area of cover by leaves. As biomass increases, the cover will increase. As plants were infected by disease, the green leaf cover percentage reduced. As the plants were nearing maturity, senescence (natural aging of the plant) occurred, thus we expected the graph to start having a falling edge.

4.3 Comparison of Healthy and Unhealthy Plant Biomass

The system was capable of distinguishing healthy plants from unhealthy. The green leaf coverage area for a healthy plant was more compared to one which was not. Figure 3.16 below outlines the difference between healthy and unhealthy plants when the algorithm was applied to the images when calculating the health of the plant.

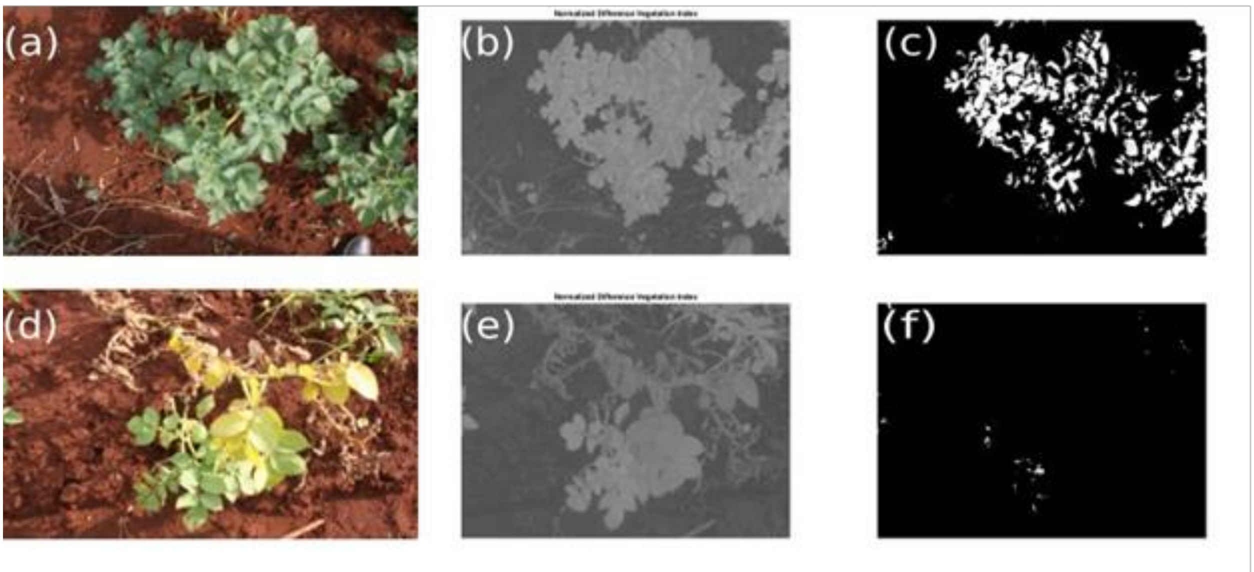


Figure 4.2 Images of Healthy & Unhealthy Potato Plants

Figure 4.2 (a) Raw image of a healthy potato plant, (b) NDVI image of healthy plant, (c) Binary image of healthy potato plant (d) Raw image of unhealthy potato plant, (e) NDVI image of unhealthy potato plant, (f) Binary image of un- healthy potato plant.

4.4 Achievements

The first objective was to identify spectral features for plant health state classification in potato plants. The spectral features identified were based on NDVI data that was pro- posed. The NDVI data classifies the amount of green of the plants leaves which is used as a basis for calculating the health status. The NDVI data is used to discriminate between green leaves, soil, dry leaves, and branches. The NDVI is used to calculate thresholds of the amount of green leaf present on a plant. The prototype can produce data of green leaves from the captured images after processing through the developed algorithm. The second objective was to develop a model for plant health classification. The model that was proposed includes the processing of raw images to extract features that aid in the extraction of data from the images. The raw data is then processed through several stages to get a well formatted image having relevant data. The data will then be used by the algorithm to plant health status.

The third objective was to develop an image processing system for plant health monitoring. The developed algorithm was accomplished using Matlab. This was used for analysis of captured images and to generate graphical results for identification of the plant health. The data presentation was achieved by having a system that outputs graph data as a presentation of the health status for monitoring and tracking of the health status.

The fourth objective was to develop and build a prototype for potato plant health monitoring system. The prototype was developed, built, and tested. The potato health monitoring system was found to be working well; consisting of unmanned aerial vehicles as a platform for carrying sensors. Evaluation of its applicability and usability revealed that it can help inform a potato farmer of the onset of a disease and aid in development early mitigation plans. The plants' yield at each planting season is improved as there are records of the previous data which is used as a reference for improvement and determination of better yields.

4.5 Recommendations

The introduction of an unmanned aerial vehicle plant health monitoring system is a solution that would improve data consistent collection, processing, and analysis of plant health. The following areas arising from the research project are proposed for further research:

1. Application of different vegetation indexes to complement data from Normalized Difference Vegetation Index (NDVI) because of changes in reflectance by the plants as outlined by (Dworak et al., 2013) due to environmental conditions.
2. The use of morphology to separate different plants. It will be important to differentiate between crops and weeds for better data accuracy. Morphologists will be able to identify specific characteristics of diseases that affect plants.
3. Plants have a growing cycle from planting to harvesting. For this, it is important that discrimination of senescence (natural aging of the plant) and death due pest and diseases are differentiated in the system.

4.6 Limitations

1. The study had challenges in getting flight permits for the unmanned aerial vehicles as the government of Kenya does not have regulations in place.
2. Changing environmental conditions would hinder consistent data collection. Data cannot be collected on a rainy day as the reflectance would highly affect the images collected.
3. Limited flight time of 15 minutes for the UAV. Covering large tracks of land is impossible on a single charge of battery pack.

4.7 Conclusion

The findings from the project showed that plant monitoring by use of eye and professionals is not sufficient and data are interpreted based on the human judgment and knowledge base. The study also revealed that the introduction of a monitoring system would improve potato plant health and availability of data. The system provides means of monitoring through a graph to aid in quick interpretation of the data from the planting period to the harvesting period. The prototype testing revealed that capability of monitoring a large area or section of a farm from a single image. The development of the prototype demonstrated the capability of the system to be quickly deployed and use of minimal resources for data collection and monitoring of potato plants.

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APPENDIX: MATLAB CODE

Code for acquisition of image from camera using MATLAB

```
vid1=videoinput('pointgrey',2,'F7Mono161296x964Mode0');
vid2=videoinput('pointgrey',1,'F7Mono161296x964Mode0');
src=getselectedsource(vid1);
src=getselectedsource(vid2);
i=20;
vid1.FramesPerTrigger=1;
vid2.FramesPerTrigger=1;
%preview(vid1);
start(vid1);
mkdir('C:\mastersproject')
imagename = ['C:\mastersproject\cam NIR' num2str(i) '.tif'];
imwrite(getdata(vid1), imagename);
stoppreview(vid1);
%preview(vid2);
start(vid2);
mkdir('C:\mastersproject')
imagename2 = ['C:\mastersproject\camred' num2str(i) '.tif'];
imwrite(getdata(vid2), imagename2);
stoppreview(vid2);
```

Code for NDVI Generation

```
data=imread('grass2.jpg');%load TTC image:
figure
imshow(data);
title('raw image');

red=data(:,:,1);%read red channel data(layer 2)
nir=data(:,:,2);%read nir channel data(layer 3)
%G=data(:,:,2);%read nir channel data(layer 3)

red=double(red);%change data format to double
nir=double(nir);%change data format to double
 ndvi=(nir−red)./(nir+red);%computr NDVI

%imshow(ndvi)%display NDVI
figure
imshow(ndvi,'DisplayRange',[−1,1])
title('Normalized Difference Vegetation Index')
%%ndvi threshold
threshold=0.4;
q=(ndvi>threshold);
%Threshold Applied')
figure
```

```
imshow ( q , [ ] ) , c o l o r b a r ;

t i t l e ( ’ NDVI w i t h t h r e s h h o l d v a l u e s e t ’ ) ;
```

Generation of graph from processed data

```
% d a t a = i m r e a d ( ’ g r a s s . j p g ’ ) ; % l o a d TTC i m a g e :

i m a g e r e s o l u t i o n = 1 0 0 7 7 6 9 6 ;

g p i x e l s = z e r o s ( 8 ) ;

n o d a y s = [ 1 , 7 , 1 4 , 2 1 , 2 8 , 3 5 , 4 2 , 4 9 ] ;

f o r i = 1 : 8

%C a p t u r e i m a g e s f r o m f i l e s

d a t a=i m r e a d ( [ ’C : \ U s e r s \ D e s k t o p \ p r o j e c t \ t e t r a c a m \ g r a s s ’ num2str
( i ) ’ . j p g ’ ] ) ;

r e d = d a t a ( : , : , 1 ) ; % r e a d r e d c h a n n e l d a t a ( l a y e r 2 )

n i r = d a t a ( : , : , 2 ) ; % r e a d n i r c h a n n e l d a t a ( l a y e r 2 )

% G = d a t a ( : , : , 3 ) ; % r e a d n i r c h a n n e l d a t a ( l a y e r 3 )


r e d = d o u b l e ( r e d ) ; % c h a n g e d a t a f o r m a t t o d o u b l e

n i r = d o u b l e ( n i r ) ; % c h a n g e d a t a f o r m a t t o d o u b l e

n d v i = ( n i r − r e d ) . / (n i r + r e d ) ; % c o m p u t r NDVI


% %n d v i t h r e s h o l d

t h r e s h o l d = 0 . 1 ;

n d v i t h r e s h o l d = ( n d v i > t h r e s h o l d ) ;
```

```
%sum all pixels with binary value 1
pixelsgreen=sum(ndvithreshold(:)==1);
e=(pixelsgreen*100)/imageresolution;
gpixels(i)=e;
plot(nodays,gpixels,'b--o');
title('Vegetation Cover')
xlabel('Days after Planting')
ylabel('Vegetation Fractional cover %')
```