COLLABORATIVE UNMANNED AERIAL AND GROUND SYSTEM FOR DETECTING INDOOR NURSERY PLANT DISEASES

GRADUATE PROJECT REPORT

Submitted to the Faculty of the Department of Computing Sciences Texas A&M University-Corpus Christi Corpus Christi, Texas

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Computer Science

By
Duc Hoai Trinh
Summer 2015

Committee Members

Dr. Ahmed Mahdy  
Committee Chairperson

Dr. Maryam Rahnemoonfar  
Committee Member

Dr. Dulal Kar  
Committee Member
ABSTRACT

For decades, agriculture has contributed to the production of essential food crops, raw materials for people and also to the climate change and global warming. Agriculture also has become a major contributor of economic development of a nation due to providing more employment opportunities and increasing national agricultural productivity. Because of agriculture’s important roles, growing healthy plants and avoiding plant diseases are the main missions of nursery where plants and trees are propagated in a rigorous process to supply for agricultural demand. This project implements a new approach using a cooperation between Unmanned Vehicle Systems to assist nursery growers in monitoring and detecting unhealthy plant effectively, accurately, promptly and autonomously. By cooperation between an unmanned aerial vehicle (UAV) and an unmanned ground vehicle (UGV) with digital image processing technology, nursery growers will be able to monitor health of plants including environmental parameters quickly with high precision without taking much effort. A Web-based user interface have been designed to display necessary information such as temperature, moisture levels or to help the user in selecting a plant that is suspected to be unhealthy.

Keywords: agriculture, nursery, remote sensing, unmanned aerial vehicle, unmanned ground vehicle
ACKNOWLEDGMENTS

This research has been performed at the graphic lab - the Innovation in Computing Research (iCORE) at the Texas A&M University-Corpus Christi.

I would like to thank Dr. Ahmed M. Mahdy for his assistance in this work.

I also would like to thank Dr. Maryam Rahnemoonfar for her support in image processing.

I also would like to thank Dr. Dulal Kar for his help on my report.
# TABLE OF CONTENTS

Abstract ................................................................................................................................. i

Acknowledgments ........................................................................................................ ii

Table of Contents ........................................................................................................ iii

1. Introduction ............................................................................................................. 1

2. Literature Review ................................................................................................... 8

3. System Design ......................................................................................................... 18

4. Results .................................................................................................................... 26

5. Conclusion and Future Work .............................................................................. 37

Bibliography and References .................................................................................... 38
1. INTRODUCTION

Agriculture has been an important natural food source for humans and animals for millions of years. Agriculture does not only play an important role in food supply at present, but also is a part of the economic development of a country by providing employment. However, plants have been seriously affected by climate change and diseases. There are lots of causes that might affect to the quality of plants including water level, temperature, soil moisture, movement, and light from the surrounding environment. Therefore, detection and treatment of diseases to produce high-quality plants for the community is one of the key component in agriculture, especially in nursery management where plants are propagated for human and social demand. An aerial remote sensing system is becoming an effectively method in monitoring and management plants data because of its capabilities. Comparing to a satellite remote sensing system, aerial remote sensing has a lower price, higher image resolution and more flexibility in covering particular regions. However, soil moisture, water level or pest infestations are unable to be measured remotely through a sensing system. Those data can be collected manually using measurement devices with necessary sensors checking on each individual plant of a nursery. This mission would take too much time and effort of growers which causes difficulty in monitoring and managing data. This paper presents a design and implementation of a system that collaborative unmanned aerial vehicle (UAV) and unmanned ground vehicle (UGV) for detecting plant diseases and collecting data in indoor nursery. The proposed design system is to use an unmanned aerial vehicle (UAV) taking images through a camera at selected locations by smart devices such as a tablet, a smart phone or a laptop of the nursery grower. The health of plants would be detected by analyzing green color using a color base method from images taken by a UAV. If unhealthy plants are detected, unmanned ground vehicle (UGV) carrying measuring soil
a moisture sensor or other necessary environmental sensors that a UAV cannot obtain, would go
to the unhealthy plant location to collect the data. Finally, the real-time data collected from the
unhealthy plant would be displayed on the devices of the nursery grower.

1.1. Problem Background

For decades, agriculture has contributed to climate change as global warming and to produce
essential food crops as well as the raw material for people. Agriculture also has become a major
contributor of economic development of a nation due to providing more employment
opportunities and increasing national agricultural productivity. According to United States
Department of Agriculture Economic Research Service, “The $144.38 billion of agricultural
exports in 2013 produced an additional $176.0 billion in economic activity for a total economic
output of $320.3 billion, also every $1 billion of U.S. agricultural exports in 2013 required 7,580
American jobs throughout the economy. In 2013, Agricultural export required 1,094,400 full-
time civilian job, including 793,900 jobs in the nonfarm sector” [1]. However, agriculture have
been seriously affected by climate change and diseases which can greatly reduce crop yields and
increase the rate of crop failure. Variables such as temperature, humidity, wind speed, radiation
also are main climatic factors affecting to crop growth and productivity. Figure 1 reflects the
effects of climate change on crop production in 2050. In fact, every country in the world is
experiencing a decline in agricultural productivity because of climate change [2]. For example,
in South Asia, because of climate change, 14% in rice, 44% to 49% in wheat and 9 to 19% in
maize production has reduced compare to result from no climate change condition. Those
numbers will keep increasing through years which bring a major threat to humanity. As a result
of climate change, the abundance of particular plants species may change rapidly, as species
may lose their ability to recover from other perturbations such as diseases, insect herbivores, and
climatic extremes within a background of climate changes [2]. Because of the impacts of climate change on the health of plants, which is unpredictable, it is very important and necessary to build plant health management strategies in order to deal with the climate change challenges and increase crop productivity in the future. Therefore, detection and treatment of diseases as well as monitoring and gathering data to produce high-quality plants for the community is one of the key strategies in agriculture, especially in nursery management where plants are propagated for human and social demand.

Figure 1: Effect of climate-change on crop production
1.2 Problem Description

Manual monitoring or applying remote sensing system such as satellite crop monitoring are common methods that used to gather and monitor data in agriculture. However, they have disadvantages that need to be addressed:

- Manual monitoring: The data can be used directly when the farmer needs for a decision. However, this traditional method is not efficient in a large area of the field. More employer are needed in order to collect the data information of the plants.

- Satellite crop monitoring: Even though, satellite crop monitoring brings many advantages features in monitoring agriculture, but the cost of the system and the obstruction of the cloud while processing data from satellite station to the land-station would be the huge disadvantage of the satellite remote sensing.

By taking the advantages of UAV and UGV, in this project, a prototype for monitoring agriculture is proposed for in indoor nursery plant management.

1.3 Proposed Technique

The proposed technique is explained in the following:

- Digital Image Processing:
  
  In order to detect the health of a plant, the domination of green color would be measured by converting the input image from RGB color to HSV color, because HSV color model have demonstrated better performance that RGB color model in image processing. Morphological image processing including erosion and dilation would be used to improve the performance result.

- Proportional Integral Derivative (PID) controllers:
In order to stabilize and control autonomously UAV’s flight, a type of control loop feedback controller is applied to stabilize UAV on top of the plant while streaming video to a data processing center.

- **Unmanned Aerial Vehicle (UAV) – Unmanned Ground Vehicle (UGV)**
  Recently, Unmanned Aerial Vehicle (UAV) or remotely piloted crafts are becoming a well-known devices and highly appreciated by scientists in agriculture monitoring such as for collection data or observation because of their flexibility in flight control, accuracy in data and signal processing, off-board sensors, and lower cost than other existing tools. However, there are several specific types of data that UAV could not collect such as water level or moisture information that would need an Unmanned Ground Vehicle (UGV) collecting.

- **E-Ko Outdoor Wireless System**
  According to Crossbow Technology Company, “eKo is a wireless, agricultural and environmental sensing system for crop monitoring, microclimate studies and environmental research”. By using eKo system, gathering data would be much easier with higher accuracy.

- **User Interface : Web-platform application**
  A web-platform application using PHP language and MySQL server would be created to display the results. From a smart device or a computer, users would be able to select the plant to collect the data and checking the health status through a Web-platform application. Color signs would be placed right next to each plant as a positioning sign. The UAV automatically executes the mission from the landing station to reach the selected plant by following the colors signs.
1. Send a plant position to Data Processing Center (DPC)
2. DPC sends plant position to UAV via wireless network
3. UAV detects plant position
4. UAV sends collecting date request to DPC if unhealthy plant detected
5. DPC sends unhealthy plant position to UGV via wireless network
6. UGV reach the destination plant
7. UGV sends result to DPC
8. Results are displayed on user device

**Figure 2. General System Architecture**
After reaching the plant successfully, the process of measuring green color starts executing to check the health of the plant. If the green color is not dominating, it means that the plant is not healthy. A request would be sent to UGV through the data processing center that requires the UGV to reach to the selected plant and collect data. A tracking sensor system attached on the UGV would be used to assist the UGV tracking the road to the plant. The UGV also carries an eKo system device to get directly data such as temperature, wind, moisture; etc. The information of unhealthy plant would be sent back to the screen of the user device.

1.4 Objective and Contributions

The main goal of this project is to create a new prototype approach which assists plant growers in monitoring and managing health of plants by collaborative unmanned aerial and ground system to detect indoor plant diseases. In order to achieve this goal, the contributions can be defined as:

- Design and develop a wireless network solution for communicating between a UAV, a UGV and the data processing center (DPC) that would make the system autonomous. A PID controller is implemented to assist the UAV to stabilize on top of the plant. The UGV is made with Arduino hardware main board with a tracking sensor.

- Apply a color base method (e.g; threshold, morphology…) in detecting plant disease through measuring the green pixel on a plant leaf.

- Develop a web-platform application to assist the user to interact with the system conveniently which supports selecting the color position of the plant that needs to be detected to obtain.
2 LITERATURE REVIEW

1.2 Digital Image Processing

This section is a brief overview of the digital image processing principles of image, color, and morphological image that were used in the project. The first part gives a general overview about image form and its properties. The second part provides information about color images and the HSV color model. The third part introduces the morphological techniques in image processing.

1.2.1 The principal of images

Images can be defined as a two-dimensional function \( f(x, y) \), where \((x, y)\) denotes spatial coordinates. The amplitude \( f(x, y) \) is called the intensity or gray level of an image at that point [3]. A digital image is an image \( f(x, y) \) that has been discretized both in spatial coordinates and brightness. The elements of such a digital array are called image elements or pixels. An image \( f(x,y) \) must be digitalized both spatially and in amplitude to be suitable for computer processing. The 2D continuous image \( f(x,y) \) is divided into rows and columns.

![Figure 3. Coordinate convention of an image](image_url)
Elements in a coordinate system can be represented by the following equation:

$$
\begin{bmatrix}
    f(0,0) & f(0,1) & \cdots & f(0,N-1) \\
    f(1,0) & f(1,1) & \cdots & f(1,N-1) \\
    \vdots & \vdots & \ddots & \vdots \\
    f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \\
\end{bmatrix}
$$

**Figure 4.** Representation of an image $f(x,y)$ by rows and columns

The function $f(x, y)$ is formed by two main components: illumination and reflectance.

- **Illumination** - the quantity of illumination that comes from the source to the viewed scene.

- **Reflectance** - the quantity of illumination that comes from the object in the viewed scene.

When illumination and reflectance are combined, form $f(x, y)$ would be:

$$
f(x, y) = i(x, y) \cdot r(x, y) \quad (2.1)
$$

where

$$
0 < i(x, y) < \infty \quad (2.2)
$$

and

$$
0 < r(x, y) < 1 \quad (2.3)
$$

The nature of $i(x, y)$ is determined by the illumination source, and $r(x, y)$ is determined by the characteristics of the imaged objects. In order to create a digital image, continuously sensed data would be converted into digital form. Sampling and quantization processes are involved to do this transformation. Digitizing the coordinate values is called sampling. Digitizing the amplitude values is called quantization [3].
2.1.2 The HSV color model

A color image can be represented in different types of color space for different applications, including RGB, CMYK, CMY, HIS, or HSV. However, the HSV color model is mainly discussed in this project. The RGB model is mostly used in hardware oriented application, such as a color monitor. In the RGB color model, images are represented by three components red, green, and blue [4]. Although the human eye is strongly perceptive to red, green, and blue, the RGB representation is not well suited for describing a color image from the human perception point of view. Moreover, a color is not simply formed by these three primary colors [4]. In order to overcome this weakness of RGB color, HSV (Hue – Saturation – Luminance) had been proposed by Alvy Ray Smith et al [5] in 1978. HSV color model defines color to three basic features of the color: hue, saturation and luminance.

![Figure 5. HSV color model](image)

- **Hue (H):** is the basic feature of color or represents a dominant color. It is expressed as a number from 0 to 360 degree.
- **Saturation (S):** is the amount of the gray level or white amount that added to the image. It is ranged from 0% to 100%. Zero percent means that the image is totally white.

- **Luminance (V):** is the brightness of the color. It is also ranged from 0% to 100%. Zero percent means that the image is totally dark.

The HSV model is a nonlinear transformation of the RGB color model [4]; therefore, the HSV color model can be defined as the following equation:

\[
H = \begin{cases} 
60 \left( \frac{G - B}{\delta} \right), & \text{If MAX = R} \\
60 \left( \frac{B - R}{\delta} + 2 \right), & \text{If MAX = G} \\
60 \left( \frac{R - G}{\delta} + 4 \right), & \text{If MAX = B} \\
\text{not defined,} & \text{If MAX = 0}
\end{cases}
\]

\[
S = \begin{cases} 
\frac{\delta}{\text{MAX}}, & \text{If MAX} \neq 0 \\
0, & \text{If MAX} = 0
\end{cases}
\]

\[
V = \text{MAX}
\]

Where R, G, B are corresponding values of pixels in RGB image. \(\delta = (\text{MAX} - \text{MIN})\), \(\text{MAX} = \text{max}(R, G, B)\), and \(\text{MIN} = \text{min}(R, G, B)\) [4].

Experimental results from previous research have shown that the features extracted from the HSV color space have performed better than the RGB color model and quite similar to the way in which humans perceive color [4, 5]. Therefore, in order to improve the performance of detecting the positioning signs of the plant and measuring the dominating of green color in this project, RGB images, which are acquired from the UAV camera, would be converted to the HSV color model.
2.1.3 Morphological Image Processing Technique

The morphological image process contains different types of image processing techniques that interact with the shape of features in an image [6]. Binary images may contain numerous imperfections in a region. In particular, the binary regions produced by simple thresholding are distorted by noise and texture. Morphological filtering simplified segmented images by smoothing out object outlines using filling small region and eliminating noise. The goal of morphological image processing is to remove these imperfections by taking into for the form and structure of the image [7]. A small shape is generated, called a structuring element, in order to examine the object in the filling process. Dilation and erosion are basic morphological processing operations that are applied to the structuring element of the image.

- Dilation: expanding the Foreground [7]

Suppose that A is an original image and B is the structuring element. The dilation process is computed by sliding B on the image A. The result of dilation can be written as following equation

$$A \oplus B$$  \hspace{1cm} (2.5)

![Figure 6. Original – Applied Mask - Dilated Image](image)

- Erosion: Shrinking the Foreground [7]
Suppose that A is an original image and B is the structuring element. The erosion process is also computed by sliding B on image A. However, instead of growing and thickening the object, the erosion process is used for thinning an object, as the following

\[ A \ominus B \]

![Image of erosion process](image.png)

**Figure 7.** Original - Applied Mask - Eroded image

- Combination of Erosion and Dilation

The combination of erosion and dilation would eliminate unwanted small regions, which are not necessary in object detections. Morphological image processing techniques have been applied in this project to improve the performance of detecting the positioning signs of the plant and measuring the dominating of green color in this project by removing unnecessary small areas.

### 2.2 Unmanned Aerial Vehicles

According to U.S Unmanned aerial systems, since 1917, unmanned aerial vehicles (UAVs) have been researched and developed by the United States military [8]. There are several different names for an UAV, like drones and remotely piloted vehicles (RPVs), but the names have the same meaning, to describe the ability to fly without a pilot, which reduces the exposure risk of the aircraft operator.
The UAVs can be remotely controlled by a pilot at a ground control station, autonomously based on a preprogrammed route, or even able to be integrated into any complex autonomous system. In addition, the UAV can be expendable or recoverable and can carry a payload of extra sensor devices. Because of its ability to perform multiple missions as well as its success in recent military operations [9], UAVs are not only considered as advanced weapons in the military, but are also applied in science and are commercialized products today. The use of UAVs to conduct surveillance and collect other information will have a significant impact to people. UAVs have a wide range of application for different research area; therefore, scientists can use a UAV in wildlife research, atmospheric research, and disaster relief. Moreover, UAVs’ advantages over satellites and piloted aircrafts would assist growers in monitoring and management crops effectively in agriculture. In the next section, unmanned ground vehicles will be introduced and described in details.

2.3 Unmanned Ground Vehicle

An unmanned ground vehicle (UGV) is a vehicle that operates on the ground surface without an onboard human driver [10]. UGVs can be employed for a variety of scenarios,
including inspection and gathering information areas from where humans are not able to, such as the search for victims in rubble after an earthquake or even transporting weapons and food to a fighting zone in a war. Like UAVs, UGVs can be remotely controlled by an operator or can autonomously make decisions about its behavior based on a preprogramed route [10].

**Figure 9. Unmanned Ground Vehicle in Agriculture**

In addition, a set of external sensors will be equipped to UGVs including visible-infrared cameras, radar, high-sensitivity microphone in order to improve the performance of UGVs [10] [11]. UGVs are able to obtain environmental information in agriculture applications, make the decision when facing to dead-ends, or easily passing different types of terrain with equipped sensors [10] [11]. In this project, an UGV was used to carry environmental sensors which are for collecting the plant’s environmental information, and the line tracking sensors which drive the UGV on the right track during reaching the plant. In the next section, existing methods and their advantage as well as disadvantage will be discussed in detail.
2.4 Existing methods

This section would discuss about difference methods in monitoring and gathering information of the plant in agriculture. The advantage and disadvantage also are compared to each other.

Without the assistance of high technology, manual monitoring and recording methods is still being used to generate useful information based on data from a sensors network or measurement tools [12]. The data after acquirement can be stored directly as reports and be used whenever the user needs. Those data reports can be considered as a farming diary. In order to obtain the plant’s environmental information, a user simply checks each plant and collect the data by using a simple measurement device. In this methods, measurement tools are inexpensive but simple and effective in use [12, 13]. The obtained data can be managed by a support software and then shared with other farmers via the internet. However, it is difficult to train farmers to use support software, especially the elderly, also the implementation of these methods requires farmers to interrupt their field operations to input data which is not efficient [13]. In addition, manual monitoring is becoming obsolete because of the expansion of agricultural fields resulting in a need for human labor in excess of which is available [12]. Therefore, in order to increase agricultural productivity, it is important to monitor the field environment, crop conditions, and farming operations effectively instead of simply relying on farmers’ experiences as well as simple measurement tools [13].

Remote sensing can be defined as the collection and interpretation of information about an object or an area, without being in contact with the object [14]. Aircrafts including unmanned aerial vehicles or unmanned ground vehicles and satellites are the different
type of platforms for remote sensing of the earth [14]. With the introduction of unmanned systems and satellites system, the collection of remotely sensed data has greatly improved as a result presenting an economical way to get information over large areas [14]. Therefore, there are many applications identified based on the information about the natural environment obtained by remotely sensing platforms, especially in agriculture. Satellites remote sensing techniques is a powerful tool for the monitoring of the Earth’s surface and atmosphere by providing important coverage, mapping and classification of land cover features such as vegetation, soil, water and forests [14, 15].

However, satellite remote sensing techniques still have several disadvantages. But many of the sensors do not have the ability to obtain data due to cloud cover. The low spatial resolution is also considered as one of the disadvantages of satellite remote sensing [16]. These disadvantages will seriously affect to the qualities of data obtained from satellites. Large quantities of data which are obtained from satellite remote sensing need to be stored and analyzed for the processing [16]. Finally, data from satellite remote sensing are often expensive when acquired from private organizations.
3 SYSTEM DESIGN

This chapter gives a detailed description of the system design including devices choice, optimization method, and some implementation details.

3.1 Hardware Choice

3.1.1 Unmanned Aerial Vehicles

The AR-Drone quadcopter is used for implementation in this project. The AR-Drone quadcopter has a carbon-fiber frame, plastic body, four motors, sensor and control board, and two cameras. The drone operator can set directly its yaw, pitch, roll, and vertical speed, and the control board adjusts the motor speed to stabilize the drone at the required pose. The drone can achieve a speed over 5 m.s\(^{-1}\) and its battery provides enough energy up to 13 minutes of continuous flight. The drone control computer is based on the ARM9 processor running at 468MHz with 128 MB of DDR RAM running at 200MHz. A software interface was provided by the manufacturer; therefore, the drone can communicate via an ad-hoc WiFi network. [17, 18].

Figure 10. Component details of an ARDrone
3.1.2 Unmanned Ground Vehicle

In this project, a robot, which is made by students from Texas A&M University – Corpus Christi, was selected as the unmanned ground vehicle, called Rizzy. Rizzy have a steel body frame and four wheels. Rizzy is controlled by Arduino board which is connected to a computer. Because of its steel body frame and powerful motors, Rizzy can carry heavy objects to complete a task. In this project, environmental sensors would be placed on top of Rizzy. A line tracking sensor system, which consists of 4 infrared light sensors, is designed to allow Rizzy to detect the dark line on a surface. There are 3 infrared line tracking sensors are used to autonomously navigate a line-marked path. Rizzy will stop when reaching the unhealthy plant by using an infrared light sensor on the right side.

![Image of Rizzy Robot]

**Figure 11.** Rizzy Robot – Line tracking sensor system
3.2 Software Platform Choice

3.2.1 OPENCV

OpenCV is an open source computer vision library which is written in C and C++. OpenCV runs under Linux, Windows or Mac OS X operating system platform. OpenCV provides over 500 functions including almost all image processing techniques and algorithms in many areas. In this project, detecting positioning sign of a plant and measuring the dominating of green color are implemented using OpenCV and C++ programming language [19].

3.2.2 MySQL

MySQL is the world’s most popular open source database [20]. MySQL is covered under the GNU General Public License (GPL) and the GNU Lesser General Public License (LGPL). MySQL also has many application programming interfaces (APIs) which give the developer to access and shape the database via programs in various languages. APIs are available for C, C++, Tcl, Python, PHP, and Perl. Some of the most popular for programming Web interfaces are PHP and Perl [21]. In order to make the communication between UAV and UGV, a MySQL database server is installed in a data processing center.

3.3 The algorithm and implementations

3.3.1 Communication between user and data processing center

A web-based application was built to assist user interacting with the system more effectively. The plant position is selected by a user from the application which is sent to the data processing center. The field idplant in table tbl_UAV is used to store the plant’s position.
3.3.2 Communication between UAV and data processing center

This section explains the implementation of image processing techniques, controlling the behavior of UAV motor and communication between UAV and data processing center. The general operation of this function is presented by the following flow-chart in figure 13. As mentioned in the previous section, the ARDrone was provided to the customer including a library programming; therefore, the connection between ARDrone and data processing center can be implemented by several simple commands. In this section, Microsoft C++ programming language was used to implement the algorithm. In order to start the ARDrone, the class named ARDrone is provided as an initial variable.

```cpp
ARDrone ardrone;
```

The UAV requests the value for `idplant` in the table `tbl_UAV` from MySQL server to check if the user needs to detect the plant. The input images must be transferred directly from the UAV to the data processing center for processing. ARDrone and OpenCV library provide a function to do this task by following command:

```cpp
cv::Mat image = ardrone.getImage();
```
Figure 13: Flowchart of interaction between UAV and DPC

UAV AR.Drone 2.0

Start

Getting request from user

Detecting the color

Measuring the green pixels

If unhealthy plants is detected?

No

End

Yes

Send the plant position to the data processing center

* Data Processing Center
* XAMPP Server
* MySQL Database

Loop
The RGB video which are obtained from the UAV must be converted to HSV color model as mentioned in chapter 2.

```cpp
cv::Mat hsv;
cv::cvtColor(image, hsv, cv::COLOR_BGR2HSV);
```

Moreover, applying morphological techniques and the corresponding range of color value in HSV model improves the accuracy rate of detecting the positioning sign of each plant and measurement of the dominating green color:

```cpp
// Set range of value for color
int minH = 0, maxH = 179;
int minS = 141, maxS = 255;
int minV = 116, maxV = 158;

int erosion_size = 1;
Mat element = getStructuringElement(cv::MORPH_CROSS,
                                    cv::Size(2 * erosion_size + 1, 2 * erosion_size + 1),
                                    cv::Point(erosion_size, erosion_size) );

// Apply morphological - erosion and dilation
erode(image, image, element);
dilate(image, image, element);
```

However, in order to make the UAV stable on top of the plant while detecting the positioning sign, the PID control was applied to control the behavior of the UAV motor.

```cpp
// PID Controller
vx = kp * error_x + ki * integral_x + kd * derivative_x;
vy = kp * error_y + ki * integral_y + kd * derivative_y;
vz = 0.0;
vz = 0.0;
ardrone.move3D(vx, vy, vz, vr); // Control the UAV motors
```

After measuring the green pixels’ color on the plant leaves, the plant position will be stored in the database if unhealthy status is detected.
### 3.3.3 Communication between UGV and data processing center

The UGV is always sending a request to the data processing center to check the unhealthy plant position which was stored by UAV. The general flow of this function is presented by the following flow-chart in figure 14. After getting the position of the plant from data processing center, UGV will reach the destination by using a line tracking system.

![Flowchart of interaction between UGV and DPC](image)

**Figure 14**: Flowchart of interaction between UGV and DPC
For this function, Microsoft C# programming language was used to implement the algorithm:

```csharp
SerialPort port = new SerialPort("COM4", 9600);
port.Open();
```

A new serial port is created to communicate between the UGV computer and Arduino board. Through this port, each line tracking sensor is read and converted to integer variable as following code:

```csharp
string data = port.ReadLine();
leftSensor = data.Substring(1, 1);
centerSensor = data.Substring(3, 1);
rightSensor = data.Substring(5, 1);
detectSensor = data.Substring(7, 1);
iLeftSensor = Int32.Parse(leftSensor);
iRightSensor = Int32.Parse(rightSensor);
iCenterSensor = Int32.Parse(centerSensor);
iDetectSensor = Int32.Parse(detectSensor);
```
4 RESULTS

The results of this project are demonstrated in three main sections. In section 4.1, the web-based application is presented. The results of applying image processing technique on detecting the health of a plant and positioning is demonstrated in the section 4.2. Finally, the UGV and its functionality in this project are shown in the section 4.3.

4.1 Web-based application user interface

A simple web-platform application was built using HTML, CSS language for client-side and PHP 5.4.31 used for the server-side. This web-platform application would assist a user to interact with the whole system.

![Figure 15](image_url)

**Figure 15.** The web-platform application user interface. Blue panel: plant 1. Red panel: plant 2. Purple panel: base station.

Figure 15 shows the web-platform application user interface which is opened by a web browser from a computer or a smart device. The blue panel is for the first plant. The red panel is for the second plant. The purple panel is the base station on the ground. The
health status and information about temperature or moisture information would be displayed on the report page as shown in the following figure 16.

![Report Page Image]

**Figure 16:** The report page

By creating a web-platform user interface, the user would be able to connect and control the system through the internet from different devices.

### 4.2 Detecting color positioning and green color by the UAV

After receiving the request from the user, the UAV would fly up and detect the color position based on an on-board vertical camera and image processing technique. In this example, the suspected plant under red colored position was selected by a user from the smart phone. The camera directly transfers the video to the data processing center. By applying thresholding technique, the red color was detected easily. The input video is converted from RGB model color to HSV color model as shown in figure 17 and figure 18.
Figure 17: RGB color image from UAV

Figure 18: HSV color model
In order to obtain the color in HSV color model, the H – S – V color channel needs to be set in a specific range of values. As shown in figure 19, the red color panel is to be set in following range of values:

\[
H = [\min H, \max H] = [0, 179] \\
S = [\min S, \max S] = [141, 255] \\
V = [\min V, \max V] = [116, 158]
\]

**Figure 19**: Binalizing image with corresponding H-S-V range of values

However, one of the limitations of image segmentation by thresholding is that it causes a lot of noise that needs to be removed. In this case, a morphological technique has been applied to remove unwanted region; therefore, the UAV would see the target clearly without any confusion. Figure 15 shows the result of the image after applying the erosion and dilation morphological technique. The red target in figure 20 is clearer than the red target in figure 21 which contains noise.
Figure 20: Applying erosion – dilation to remove noise

Figure 21: Detection of red position color
In order to measure green color pixels on the plant’s leaves, the UAV needs to stay stable on top of the plant for at least 3 seconds. The PID controller have been programmed to control the behavior of the UAV’s motor as shown in figure 22.

**Figure 22:** The UAV is staying stable on top of the plant

**Figure 23:** Detecting the green color of healthy plant
**Figure 24:** Applying erosion – dilation to remove unwanted regions

**Figure 25:** The result of measuring the green pixels in case of healthy plant
Figure 26: Detecting the green color of unhealthy plant

Figure 27: The result of measuring the green pixels in case of unhealthy plant
4.3 Reaching the unhealthy plant using tracking sensor

The UGV uses the line tracking sensor to reach the target plant directly without going out of track. Environmental information would be collected by Eko System device.

Figure 28: UGV with line tracking sensors
Figure 29: The line tracking sensor.

Figure 30: UGV carrying EKo system with moisture and temperature sensor
4.4 Limitations

In this project, the health of a plant is determined by examining the color of the leaves. It is really difficult to check the health status of a plant if there are a lot of green color noise around the ground. The green color noise could be counted as the green color of the leaves. Therefore, thresholding images from the UAV and measuring the green are not enough to determine the health of a plant; especially, if this project would be brought from the lab to reality. This image processing technique would be one of the limitations of the project that needs improvement. Furthermore, testing this system outdoor is impossible at this time due to weather which might affect the direction of the UAV. The different type of terrain would also cause difficulty for the UGV while moving. In addition, FAA Certificate of Authorization (COA) For Unmanned Aircraft Systems (UAS) is required for flying an UAV outside.

**Figure 31**: UGV stopped at target plant
5. CONCLUSION AND FUTURE WORK

In this project, the design, implementation and the results of a collaboration between Unmanned Arial Vehicle (UAV) and Unmanned Ground Vehicle (UGV) in detecting the health status of the plants and collecting the information from a plant are presented. To facilitate interaction with the system, a web-based application has been deployed. Different image processing techniques including converting RGB color model to HSV color model, thresholding, and morphological techniques have been applied to detect the plant’s position and measuring the green color on the plant. The control loop feedback mechanism, PID controller was implemented to control the behavior of the UAV motors.

In this project, environmental sensors including temperature and soil moisture sensors were carried by an UGV. After successfully detecting unhealthy plant, the UGV reaches the unhealthy plant using a line tracking sensor system. Finally, environmental information as well as position and status of the plant would be sent and displayed on the user device’s screen. In future work, sophisticated image processing techniques such as texture segmentation could be applied in detecting the health status of a plant in order to increase accuracy of the results. Upgrading to high-quality camera is necessary to obtain better results. Instead of positioning color, GPS position could be used for implementation outside. Because of the important role of agriculture, growing healthy plants and avoiding plant diseases is the main mission of nursery. This project implements a prototype to assist nursery growers in monitoring and detecting unhealthy plants effectively, accurately, promptly and autonomously by a cooperation between Unmanned Vehicle Systems. As a proof of concept, the results of the collaborative
unmanned aerial and ground system for detecting indoor nursery plant diseases are found to be successful.

6. REFERENCES


