PennState Extension

Unmanned Aerial Vehicle-Based Crop Scouting in Fruit Trees

As one of the United States' largest producers of tree-bearing fruits, Pennsylvania is the 4th largest producer of apples and the 3rd largest producer of peaches. However, growers are faced with new and different challenges every year.

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Figure 1. Unmanned aerial vehicle (UAV) in flight at the Fruit Research and Extension Center (FREC) orchards in Biglerville, PA. Photo: Long He, Penn State

Disease and pest attacks are major challenges that can devastate production yield and even kill entire trees. With proper inspection, these disease and pest infestations can be regulated and prevented, helping growers create the largest yield possible. Crop scouting is the action of identifying issues with individual trees and providing the grower with accurate information on how to control them.

Problems with Crop Scouting

Scouters usually walk or drive through orchards to see noticeable unhealthy or diseased trees to treat. However, this process is time-consuming, and infected trees can be easily overlooked by human eyes. The use of satellite imaging was attempted to look at an orchard from an ariel view. The picture that the satellite covers has a minimum area of 1 meter square per pixel, which is suboptimal for an orchard application because of the variation of canopies between trees. The picture would often become blurry and not suitable for individual tree spotting. To get a lower aerial view, cameras would be flown overhead to capture the higher resolution images. The cameras are usually attached to manned or unmanned aircraft to capture these images. The main issues with manned aircraft are that they need ideal weather to fly, which can be hard to plan for. Aircraft flights can become expensive, depending on the size and type of field that is under surveillance.

Scouters have now optimized the method of unmanned aerial vehicle (UAV) imaging with the usage of drones. They can fly over the desired field quickly and efficiently. Drones can be flown at lower altitudes and produce very high-quality images. These images are able to capture a few centimeters square per pixel, which is much higher quality when compared to the satellite's imagery. The high-quality image helps scouters identify the specific part of the tree that is unhealthy or diseased, leading them to be able to diagnose the problem and properly plan the course of action.

Basic UAV-based scouting advantages:

- Relatively low cost
- Time-efficient (scout a large orchard in a short time)
- High spatial resolution
- Disease map generation is possible
- Crop monitoring is possible even in rough terrain (not drivable using ground vehicles)
- Flexible availability

UAVs Used in Crop Scouting

The most popular type of drone used in agriculture is a multi-rotor drone. Multi-rotor drones are drones with more than two lift-generating motors. These drones generally have four to eight rotors. They are capable of flying lower to the ground to take more accurate and higher-resolution images. The operator can also change the type of camera on the drone to take different types of pictures for different applications. Companies like PrecisionHawk(https://www.precisionhawk.com/) and Sentera(https://sentera.com/) utilize the popular DJI Phantom 4 Pro(https://www.dji.com/) to capture the images. These companies attach a red-green-blue (RGB) and/or a normalized difference vegetation index (NDVI) camera to the drone and equip it with flight monitoring software that allows the drone to map a specific field through an app on a grower's smartphone or tablet. They also offer software that compiles the images into one picture of the field to get the full map in the specific index. Other software such as Pix4d, DroneDeploy, Simactive, Agisoft, Bentley, and Site Scan is programmed to process the images taken by the UAV to generate orthomosaic and disease maps.

(https://extension.psu.edu/media/wysiwyg//extensions/catalog_product/6cda9da2584b4478a64446d223e49f14/f/i/figure-2-jpg.jpg)

Figure 2. Different UAVs used in crop scouting at FREC orchards in Biglerville, PA (a) DJI Matrice 200 and (b) DJI Mavic 2 Pro. Photo: Tyler Shannon, Penn State

Cameras Used in Crop Scouting

Cameras that are attached to drones can take pictures of the ground, trees, and their varying features. Different cameras can pick up different light spectrums, from visible to non-visible light like near-infrared light waves. These cameras range in what they can detect, like diseases or defects in the plant, and can even detect the geography of the land. Color high-resolution RGB cameras are widely used in the past few years for crop health monitoring and scouting. Spectral cameras, including multispectral and hyperspectral, show promising potential for monitoring crop health due to their ability to capture multiple bands across the electromagnetic spectrum. Thermal cameras translate thermal energy into visible light in order to analyze tree canopy temperature and disease symptoms.

Table 1. Pros and cons of different cameras used in crop scouting

Camera Type	Pros	Cons
Color Cameras	Provides the color map of trees, leaves, and background. A cheaper option than the hyperspectral cameras	Sensitive to weather conditions (illumination variations, wind). Only 2-dimensional spectrum
Spectral cameras	Both color and spectral images. Capture a wide spectral range. In-depth analysis possible	Images captured are low in resolution than color cameras. Large data stored
Thermal cameras	Can work under low-light conditions. Can detect the individual plant's temperature difference	Limited time of day to be effective

Indices Used in Crop Scouting

The images that are captured by the drone are used to calculate the vegetation index (VI). The VIs are the combination of spectral bands to show soil, biomass, density, disease, and other plant qualities in a single map. Scouters generate these maps by using software, such as Pix4d and Agisoft, to combine their color and spectral images through particular equations (shown in Table 2). A few of the major indices are discussed below:

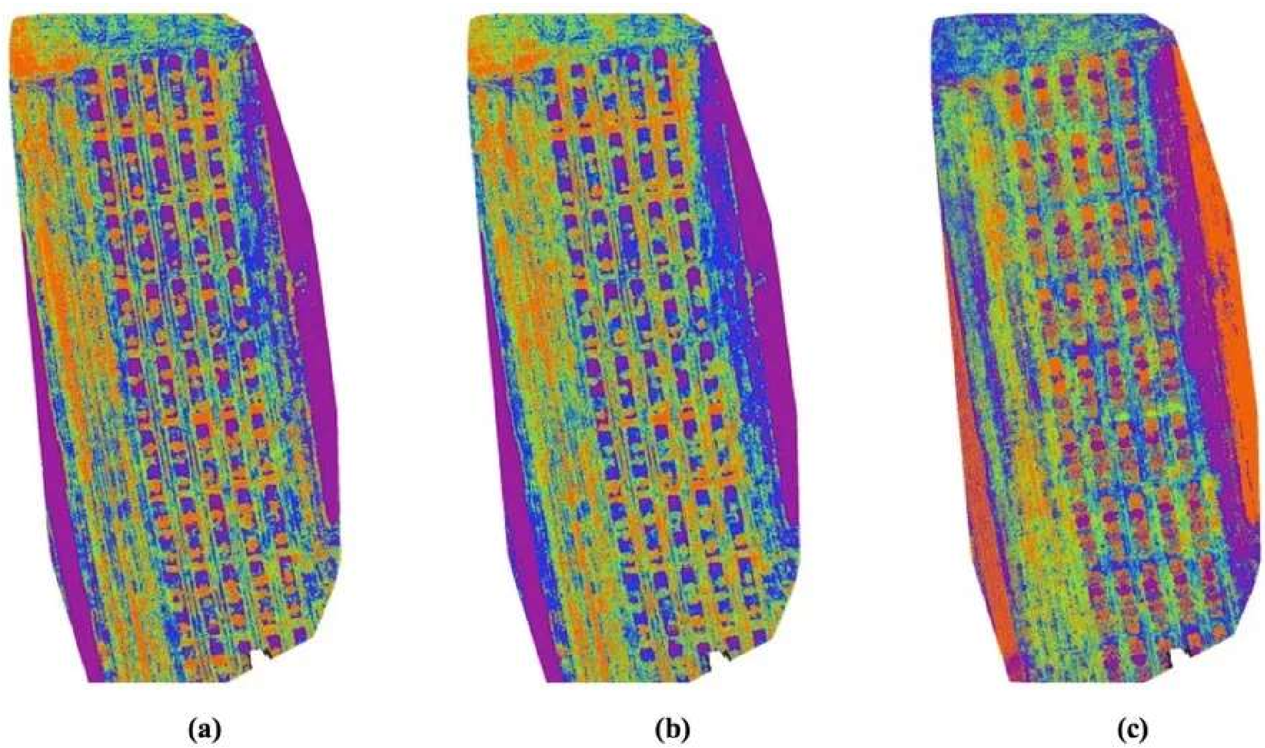

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Figure 3. Different vegetation indices (a) normalized difference vegetation index, (b) leaf chlorophyll index, and (c) structure intensive pigment index 2. Photo: Md Sultan Mahmud, Penn State

Normalized Difference Vegetation Index (NDVI)

A popular specialized camera uses the Normalized Difference Vegetation Index, otherwise known as an NDVI index. The NDVI calculates vegetation health, crop productivity and can be used to predict crop yield. This camera uses near-infrared (NIR) light and visible red light to evaluate the plant's health. The camera picks up how much reflected NIR, and the red light comes from the plant and gives an index number ranging from -1 to 1, where 0.1 to 0.2 is bare soil and 0.2 to 1 is vegetation (0.2 to 0.4: sparse vegetation; 0.4 to 0.6: moderate vegetation; 0.6 to 1: high density of green leaves).

Different varieties of plants will account for different types of mapping. Orchards tend to be more difficult to map because of the grass drive rows. To accommodate this problem, researchers have laid the NDVI map next to a color map of the particular region of interest to map the specific tree rows. Rows carry a higher index value due to their canopy coverage which helps differentiate trees and rows. By seeing the NDVI index beside the color tree, scouters are able to see which tree is under lower health and observe that particular tree. Scouters are also able to monitor the growth of the canopy from the time the tree was planted to when it can be harvested to ensure proper growth and health.

Leaf Chlorophyll Index (LCI)

This index calculates the amount of chlorophyll in the leaves of the trees. Typically, this index provides the most useful information when taken in the late summer months as chlorophyll index patterns are highly correlated with the crop's final yield.

Structure Intensive Pigment Index 2 (SIPI2)

This index is useful in areas of the high variation of canopy structure and leaf area index. This is due to its high sensitivity to the carotenoid to chlorophyll ratio. The values range from 0 to 2, where healthy plants range from 0.8 to 1.8 in the index.

Visible Atmospherically Resistant Index (VARI)

The visible atmospherically resistant index highlights the vegetation of the plant while degrading atmospheric interferences to calculate vegetation fraction. Essentially, this index allows the scouter to fly on cloudy or very bright days without worrying about finding the perfect weather condition.

Table 2. Purpose and advantages of discussed vegetation indices

Index	Purpose	Advantages	Formula*
NDVI	Used for leaf coverage and plant health	Most common, Detects canopy coverage and density, Growth trends and dynamics over time	(nir – red) / (nir + red)
LCI	Shows chlorophyll content of leaf coverage	Image does not saturate as canopy grows	(nir- rededge) / (nir + red)
SIPI2	Shows variability of the canopy in trees	Early detection of disease or other plant stress, Low values indicate plant disease	(nir – green) / (nir – red)
VARI	Emphasizes vegetation fraction with less atmospheric effects	Able to use in variable weather conditions	(green – red) / (green + red – blue)

* nir (near-infrared), red, green, blue, and rededge are the five channels/bands of a multi-spectral camera.

Conclusions

UAV-based crop scouting is becoming more and more popular as drones and cameras become more widely known and readily available. Companies have been able to make these devices more affordable and more accurate than anything before. Scouts inspect larger areas in a shorter time, proving that this technology has the potential to make greater strides in the future. Being able to detect problems earlier on leads to proactive disease and pest control in the orchard leading to an increase in the grower's yield.

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