Fact Sheet, FS-1056
February 2017

Providing Aerial Images through UAVs

Precision agriculture relies on accurate maps of soil properties and yield potential to uncover high- and low-yielding sections of a field. Some of these maps are obtained by remote sensing (gathering information from a distance), such as photography. Since its inception, precision agriculture has relied on remote sensing by planes and satellites to obtain various types of photos.

Satellites, such as LANDSAT, have provided images which can be analyzed for plant health by observing the wavelength of light reflected (Figure 1).[1, 2] Normalized Difference Vegetation Index (NDVI) is one way to analyze plant health, where the reflectance of near-infrared (NIR) wavelengths are compared to the visual spectrum (red, green, blue [RBG]) to measure a plants greenness, or photosynthetic activity.[3]

While this data has been valuable to agricultural and environmental research, obtaining satellite or aerial imagery can be expensive.[2] Satellite images may also be limited by cloud cover, which is often associated with the growing season.[2]

Drones, known to researchers as **unmanned aerial vehicles (UAV)**, are poised to solve some of these issues. A UAV can be flown on demand versus waiting for satellite coverage.[3] While similar to a model plane, UAVs are considered autonomous, which means there is no pilot on board. This characteristic of UAVs has led to a new regulatory environment with privacy concerns.

Figure 1. The reflectance of light from the red (a) and visual spectrum (b) can be useful to observe plant health

As an emerging technology, UAV costs may be high and actual application relatively unkown.[1,2] For field crop, nursery and orchard owners, understanding current options is necessary prior to fitting into the farm budget.

Although Gaining in Popularity, UAVs have been Part of University, Federal and Private Research Programs

Earlier work has focused on designing systems to fly. Some universities have worked on creating their own prototypes, while private industry has designed commercial products for sale.[2,3] Some earlier UAVs have included blimps, parachutes and kites, but their stability in the air for remote sensing is limited.[2,4]

Although terms are often used interchangeably, **UAS (unmanned aerial systems)** is another acronym used by researchers. UAS refers to the UAV as well as all of the equipment and software that can be associated. This may include sensors, global positioning systems (GPS) and communications equipment. Software is available to help guide and plan flights autonomously as well as analyze the data.

Two of the Most Popular UAVs are Known as Rotary and Fixed Wing

Rotary UAVs are similar to helicopters in appearance (Figure 2). A rotary UAV is often identified by the number of rotors (propellers) they have (e.g. a quadcopter = four rotors). For agricultural applications, rotary UAVs are excellent for scouting fields and hovering over chosen points, such as research plots. Due to their ability to vertically land and takeoff, rotary UAVs require minimal landing space.[4]

Figure 2. An example of a quadcopter, a rotary UAV with four propellers

Limited by flight speed (10-20 mph), rotary UAVs are not as stable when winds are greater than 15 mph[5]. Battery life is also shorter because more power must be diverted to the multiple rotors.[5,6] This shorter battery life makes rotary UAVs better for smaller fields, although gas-powered UAVs may solve this issue.[4,6]

Fixed-wing UAVs use lift and drag to stay afloat and use less battery life, so flight times can be between 1-2 hours (Figure 3). Fixed wings can also reach greater speeds (70 mph), although this is not recommended in order to reduce blur in photographs. While able to cover larger fields, fixed-wing UAVs also require more space to take off and land.[4] For a fixed wing, it is recommended to have a soft landing zone, such as soybean canopy.

Figure 3. An example of a fixed wing UAV, which is very similar to an airplane in appearance

Type of Sensor is Another Important Choice

Most camera sensors for UAVs are not new technology, but they do need to be adapted to fit and perform as needed (Figure 4). Sensors that can be used include visual and near-infrared (NIR) cameras. Having access to multiple bands of light is useful for calculating NDVI, which is the ratio of NIR *minus* red bands divided by NIR *plus* red bands. An off-the-shelf digital camera can be adapted for NIR images by removing the filter.[2,3]

Due to the need of both visual and NIR bands to calculate NDVI, two flights would need to be made with separate visual and NIR cameras. This can be overcome by using **multispectral** cameras (Figure 4), which may have four to twelve separate lenses with different filters. This allows the user to simultaneously capture many bands with one pass.

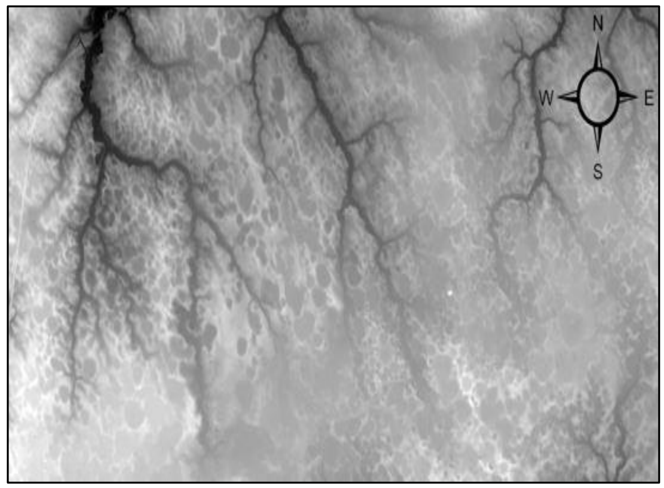
Figure 4. An off-the-shelf camera can be modified for NIR photos (a) or a multispectral camera that includes five lenses to obtain five different bands

Another type of camera used to observe more than one band is called **hyperspectral**. These sensors can sample a much wider wavelength at a finer resolution. The sensors will produce a lot of data, but may help discern minor differences in soil minerals, crop health or insect pressure.

A **thermal** camera picks up variations in heat and can be used to detect livestock or nighttime pests such as deer.

LiDAR (Light Reflection and Ranging) is a laser-based sensor that performs similar to radar. It can measure distance from the UAV to create very accurate maps of elevation (Figure 5).

Figure 5. LiDAR images are developed using a laser to accurately measure distance. This map of the Coastal Plain shows the detail that can be obtained with LiDAR (Photo courtesy of the USDA)



Elevation could also be determined using stereoscopy or photogrammetry. Often used to create 3D images, stereoscopy can also use two different images to determine elevation.

Another active sensor for UAVs is the **greenseeker** which emits red and NIR light to determine an immediate NDVI. Sensors already exist for mounting on tractors or as hand-held devices, but could also be adapted to UAVs.

To Capture One Field Requires More Photos Compared to a Satellite

Due to their distance from the Earth, satellites may be limited by cloud cover and resolution, but can

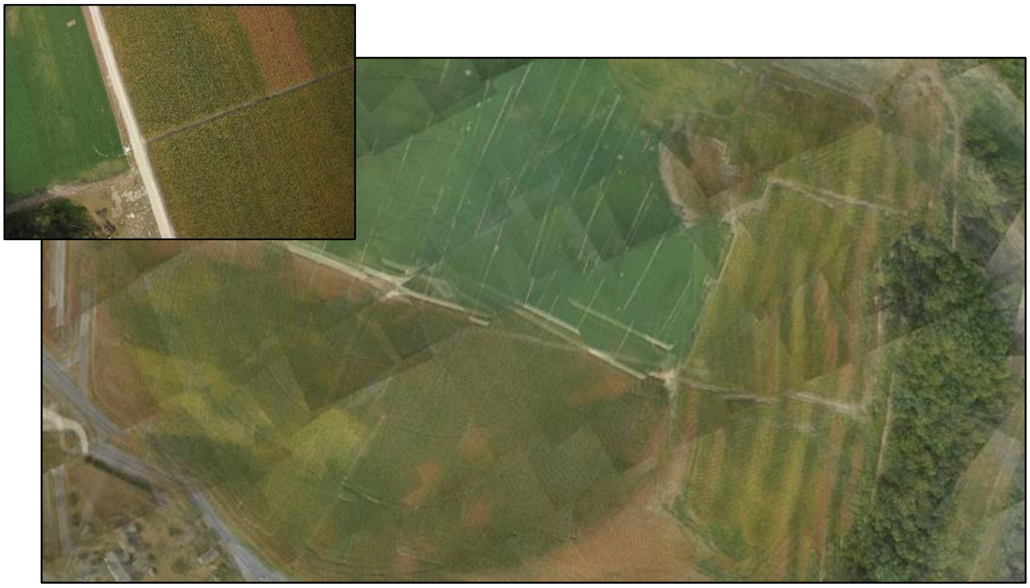


Figure 6. One image is easily obtained by a UAV (a). Combining those images into a mosaic of the entire field requires each photo to be marked by a GPS and sophisticated software to stitch them together. Without the software, roads and field boundaries may not line up (b)

easily take one photo of an entire field. For a 40-acre field (flying below 400 feet), a UAV may need to take up to 300 photos to map the entire field.

Like satellite photos, each picture must be georeferenced (marked with latitude and longitude coordinates). This is why UAVs must be equipped with GPS, which can be used to guide the UAV autonomously over a field as well as geoference each acquired image.

Images only need GPS coordinates if they are meant to be overlaid and combined into one whole picture of the landscape (Figure 6). These combined photographs are called orthomosaics, also called "ortho" for short. To create an accurate ortho, images should be overlapped by the UAV, with some recommendations being up to 70%. While this will increase the time required to take photos, it will increase the accuracy of the ortho.

It is also recommended to have ground truthing points. These can be markers placed in a field that are previously georeferenced. They can be checked in each image to be sure the GPS unit referenced each photo correctly.

Camera Quality will Control how well you can Combine Overlapping Photos

UAVs that are within a farmer's budget may not have the best cameras for creating orthos. High-quality photogrammetry requires metric cameras that will adjust for distortion in the lens.[7] A cheaper, off-the-shelf consumer camera may have distortion, such as pincushion or barrel (Figure 7).

Figure 7 shows an example of barrel distortion. Compared to Figure 7a above, the center of the photo has been curved outward (Figure 7b). For measuring distance, crop health or creating an ortho, distortion like this would reduce accuracy. However, if the goal is to simply scout crops or watch for deer, a cheaper camera with distortion would work fine.

Another issue to examine when purchasing a camera is the dynamic range. If the landscape or time of day has a large range in brightness (dynamic range), a cheaper camera may not be able to discern the difference.[7]

Figure 7. A regular image of a wheat field (a) and one with barrel distortion altering the center of the photo (b)

Data Storage and Analysis is Another Hurdle for Individual Producers

Learning how to fly a UAV is relatively easy compared to storing and analyzing data. A 90-acre field may take 30 minutes of flight time to collect 302 photos, but this will also require about 2 GB of data. This will require a lot of storage space for large farms or agribusinesses.

Creating an ortho of the field also requires computing power and specialized software. Some of the most popular versions can be $3,500 to $8,000.

Another option is to upload photos to the internet to be processed in the cloud. Some companies and universities are creating algorithms to build orthos and analyze crop health for a pay-as-you-go fee. These costs should be weighed against acreage and accuracy.

Research Is Still Needed on Image Analysis for Plant Health

It needs to be emphasized that the actual economic benefits of data collection with UAV's is still unknown. The quality of the information and the accuracy of the analyses still needs research.

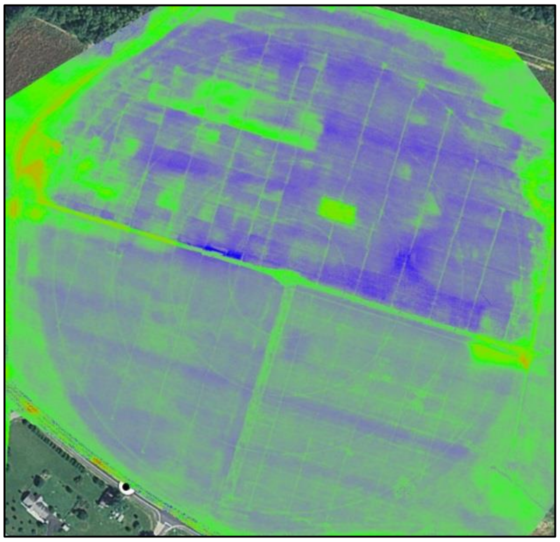
For some operations, outside of scouting for pests and damage, detailed analyses may provide little benefit. Paying for services at this time may not be advantageous.

NDVI is a good measure of plant health, and UAVs could map problem regions prior to side-dressing nitrogen. For Maryland, this may have to fit into the nutrient management regulatory framework.[5,6,8]

Stand counts have been a successful use of UAVs, since software can be programmed to recognize plant reflectance compared to bare soil.

Crop health is more difficult, as NDVI may recognize poor crop health, but not pinpoint whether it is caused by disease, nutrient deficiency or saturated

Figure 8. An aerial image converted to NDVI still has to be interpreted to be useful



soils.[8] Data collection can be relatively easy (Figure 8), but interpretation will take many years of research and analyses.

Regulations to Operate UAVs Still Being Developed

Anyone can fly a UAV as a hobby or for fun, but crop scouting is considered a commercial application and requires a remote pilot certificate.

To become a remote pilot, an individual must pass an aeronautical knowledge exam, be 16 years old and vetted by the transportation security administration. All hobby or model aircraft users must be at least 13 years old.

For commercial applications, UAVs must be flown during the day and kept under 400 feet within the pilot's line of sight. Class G airspace is okay to fly in, but all UAVs must be at least five miles from an airport. Direct permission is needed for airspace under air traffic control. The Federal Aviation Administration (FAA) has released an app called **B4UFly** that informs UAV pilots of any prohibited airspace in the area.

There are more restrictions than have been listed in this publication. To keep up with current regulations and out of trouble, please see the Federal Aviation Administration's website at https://www.faa.gov/uas/

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