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UAV How-To: Create a Forage Canopy Model with Photogrammetry

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Unmanned aerial vehicles (UAVs) are quickly becoming more integrated into producers' on-farm operations. With the advent of this new technology, users must understand how to convert raw UAV data into an applicable medium. Often the goal of UAV flights is to create a map of the output from a certain type of sensor. Thompson et al. (2018) have defined a general mapping process independent of drone type, sensor type, and mapping software. However, general mapping is significantly different than trying to record a three-dimensional model of the plant canopy structure. This article expands upon the workflow and details the process for developing a canopy model of a crop. This process was developed and tested for capturing the 3D canopy structure of alfalfa. After presenting the general procedure, the article shows the outcome of following this procedure for recording alfalfa canopies.

UAV Field Plant Canopy Models

UAV field plant canopy models are three-dimensional models of a crop canopy. These models are derived from many aerial images that are taken at various angles to the ground. Through photogrammetric analysis, the multi-perspective images are combined, corrected for distortion, and used to form a three-dimensional model of the canopy structure.

These three-dimensional canopy models are not to be confused with orthomosaic maps. Although the processing for both is similar, the outputs are quite different. An orthomosaic map is a two-dimensional image that has been projected onto a flat surface. By stitching multiple images together, the orthomosaic maps generally do not reveal the three-dimensional structure of the field. A canopy model takes this a step further by displaying the entire three-dimensional structure of the canopy surface.

Equipment and Software

- Unmanned aerial vehicle and applications/controllers for flying
- Photogrammetry software
- Clear, well-marked objects for collecting ground control points (GCP)
- High accuracy [e.g., Real Time Kinematics (RTK)] Global Navigation Satellite System (GNSS) device for recording GCP positions
- Spreadsheet or other record-keeping software
- Notepad

Data Collection

Ground Control Points

Ground control points are essential to the accuracy of creating forage canopies using photogrammetry. Depending upon the size of the area you wish to model, we recommend collecting five to 10 GCPs distributed in a grid-like pattern across each area you plan to scan. We recommend taking an aerial photograph of the field with the UAV, or for one member of your team to create a sketch of the area that you plan to capture. Use this image or sketch to locate and label the GCPs for later processing. Place the RTK GNSS receiver centered directly on top of each GCP and record the geographical coordinate and elevation. Take extra care to label each output with the respective GCP identified on the image or sketch.

UAV Flights

There are many government regulations pertaining to the operation of UAVs. You must ensure that the planned data collection mission will occur at a time and place permitted by applicable regulations. You must also follow piloting and equipment regulations. The Federal Aviation Administration (FAA) regulation Part 107 is likely to be the most applicable set of rules for these flights. Once you've verified you can operate over your field, develop a flight mission. Some basic guidelines to consider when developing a UAV mission include:

- Fly high enough to avoid any objects or obstructions such as trees or power lines (e.g., above ground level by at least 20 m (70 ft)).

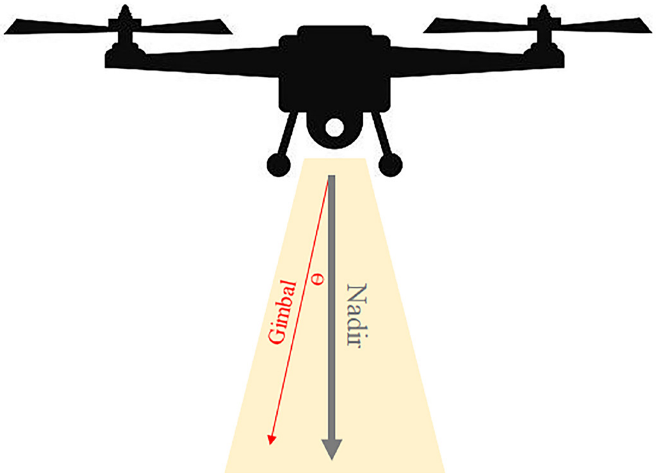

Figure 1. Nadir diagram. Fly with a gimbal pitch ≥15° from nadir.

- Fly at a normal to slow speed for the highest quality of photos.
- Have the drone hover and capture each image for the best image quality.
- Have the image overlap set to at least 85% for the front and 75% for the sides.
- Fly with a gimbal pitch not directly straight down (≤75° from horizontal or ≥15° from nadir/straight down, see Figure 1).

Achieving the above image recording parameters usually requires some type of mission planning software, as manually controlled flights will not provide the precision and consistency that enable successful photogrammetry processing to create 3D canopy models. The mission planning software will lay out the flight path and image capture points and create a set of UAV navigation and control commands. These commands become the flight mission, which an automated navigation program will use to control the UAV during its operation.

The specifics of running an automated data collection mission will vary between UAVs, manufacturers, automated navigation software, and even software versions. Follow the appropriate instructions for your equipment.

While there are differences in procedures, one consideration that is consistently important is the launch location. Often, the navigation software used to run the mission will provide automatic take-off and/or landing. Many UAV platforms also attempt to land at the launch location in the event of an equipment failure, such as loss of communication with the operator's control station. Because a landing operation back at the launch site could be automated and even unexpected, it is important to select a suitable launching site away from non-participating bystanders.

Appropriate ground conditions for a launch site vary based on the platform, but the UAV needs to rest stably on the ground, and nothing (such as plant leaves) should be near the propellers. There should be no obstructions overhead. Since the GNSS location devices in UAVs are generally only accurate to 3 m to 5 m (10 ft to 15 ft), the launch area should be of this size.

Table 1. Converting from decimal minutes to decimal degrees.

Triangle Field							
Latitude				**Longitude**			
Label	**Degrees**	**Decimal Minutes**	**Decimal Degrees**	**Degrees**	**Decimal Minutes**	**Decimal Degrees**	**Altitude (m)**
11	38	7.08563335	38.11809389	-84	30.54000404	-84.50900007	267.509
15	38	7.07453901	38.11790898	-84	30.50825244	-84.50847087	266.879

While the UAV is in flight, maintain a visual line of sight throughout the duration of the mission. Longer missions may require you to land, replace batteries, and then resume the flight. This should not interfere with the image collection as long the proper procedures for the navigation software are followed.

Data Processing

Ground Control Points

Depending upon the GNSS receiver and application you use, you may need to convert the location coordinates of the GCPs into decimal degrees. A spreadsheet is a great tool for this (Table 1)

Once you've verified the coordinates from the GCPs are in decimal degrees, save them in a suitable format with a GCP label, latitude, longitude, and altitude. Check your photogrammetry processing program for formatting details. Many of them can directly import GCPs from a properly formatted text (.txt) or comma-separated value (.csv) file. For example, this is a format that works with Pix4D:

GCP#, Latitude, Longitude, Altitude (m)
Ex. 15, 38.11790898,-84.50847087,
266.879

Photogrammetry Processing

The precise steps for photogrammetry processing depend on the equipment and software used. Some processing programs and autonomous navigation programs are integrated to simplify some steps, but the overall procedures will be similar. First, the images taken by the UAV must be separated and associated with individual missions. If the mission control software does not do this automatically, it will be useful to consider the timestamps on the images and to have a complete set of notes on when, and in what order, missions were flown. For each mission and its set of images, create a new photogrammetry project and import the images into the project.

The GNSS coordinates, coordinate system, and camera model should automatically be detected from metadata associated with each image file. Verify that you are working in the correct unit system. Most photogrammetry processing programs can be tuned for different types of output. Select options for "3D Model" or similar, rather than 2D mapping. Some programs may suggest starting processing as soon as the images are loaded, but first, check the image layout and input the GCPs.

With the images loaded, you can see your flight path and the location of every image taken. Verify that there are no clumps of missing images, but a couple missing here or there is not of substantial concern. If there are missing images, restart the process: sort the images, create a new project and reimport the images.

The last step before processing is importing and identifying the GCPs. It may be necessary to provide a horizontal and vertical accuracy if the GNSS receiver did not store accuracy levels with the GCP location data. If the GNSS receiver was operating in RTK-mode, a reasonable default value is 0.02 m (0.06 ft).

Next, it is necessary to tag the GCPs in the images. Locate and mark each GCP on 3 to 10 separate images. It may be helpful to sort images by distance from GCP. When finished, verify that the GCPs are roughly where they are supposed to be spatially in relationship with the field, flight plan, and images.

You may now begin processing. Some software breaks up the processing steps. After the initial processing step, check the ground sampling distance (GSD), Root Mean Square Error (RMSE), and camera calibration. If these are not within an acceptable range, check earlier steps in the process. If everything appears acceptable, continue processing to create the full point cloud, orthomosaic mesh, and output products. The length of time to process will vary based on your computer specifications, but approximately one hour per 100 images is typical.

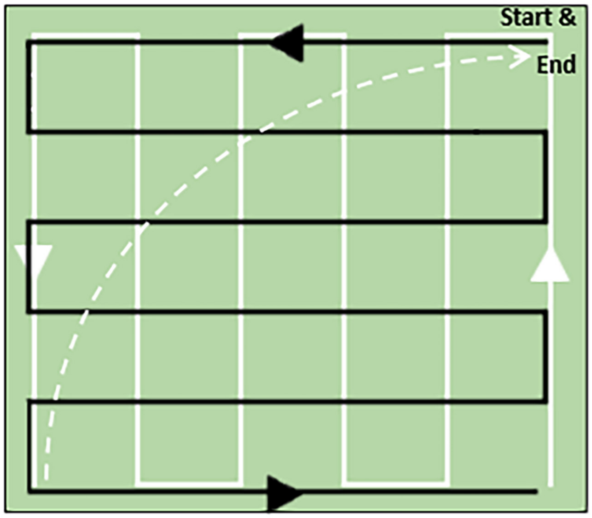

Figure 2. An example layout for flying in a double grid pattern as defined by the black and white paths. Return to the launch location at the end of each mission as indicated by the dashed white line.

Figure 3. GCP best practices. Collect five to 10 points per field distributed in a grid-like pattern as indicated by the Xs.

Suggestions for Troubleshooting

Sometimes the 3D model creation method fails. In these cases, the field may appear with strange gaps, or multiple copies of the field can appear at odd angles. If this happens, it may be necessary to adjust some of the data collection and processing steps.

- Fly in a double grid pattern (Figure 2).
- It is very important in agriculture applications that you have a front overlap of at least 85% and a side overlap of at least 75%.
- Use a combination of straight down (Nadir) and angled gimbal shots to get a better-processed model.
- Use an automated process for flight control and image capture to ensure accuracy and consistency.
- Double-check data files and data structure. Photogrammetry uses large sets of images as inputs, and the outputs also require a lot of memory. Ensure that the files are available locally for the photogrammetry program and that the operating system has not compressed or moved any of the necessary files.

Example Implementation

Applied Equipment and Software

- DJI Phantom 4 Pro UAV, controller, and iPad tablet
- DJI Go & DJI GS Pro Mobile Applications
- Pix4Dmapper
- Trimble 5800 RTK GNSS
- NTRIP Mobile Application
- Microsoft Excel and Notepad

Applied Data Collection

Ground Control Points

We collected our GCPs by taking a screenshot of NTRIP Client and labeling it with the GCP being located. See Figure 3 for a GCP best practices example. However, it is still possible to create acceptable models with non-ideal placement. Our sample collection flights were combined with other experiments so our GCPs were clustered in a single region of the field. NTRIP provides the locations in degrees and decimal minutes, but the processing software we used, Pix4Dmapper, required the points to be in decimal degrees. Therefore, we converted the latitudes and longitudes in Microsoft Excel and recorded them in a .txt file, as seen in Table 2.

Table 2. The final format of GCPs before being imported into Pix4Dmapper.

GCPs_06-04-2019_triangle.txt
11,38.11809389,-84.50900007,267.509
15,38.11790898,-84.50847087,266.879

UAV Flight Parameters

Flights 1 and 2

- Elevation: 50 m (165 ft)
- Overlap: Front = 85%, Side = 75%
- Speed: ~ 5.7 m/s (18.7 ft/s)
- Gimbal Pitch Angle from horizontal:
  -90° (Flight 1)
  -75° (Flight 2)
- Image Capture: at equal intervals perpendicular to MainPath (without stopping)
- Resolution: ~1.4 cm/pixel (0.55 in/pixel)

Flight 3

- Elevation: 30 m (100 ft)
- Overlap: Front = 85%, Side = 75%
- Speed: 3.4 m/s (11.2 ft/s)
- Gimbal Pitch Angle: -90°
- Image Capture: at equal intervals perpendicular to MainPath (without stopping)
- Resolution: ~0.8 cm/pixel (0.31 in/pixel)

Results

We flew each flight mission eight times (two fields on four different dates) for a total of 24 unique flights. When processing each flight with GCPs, we recorded the Model RMSE, Model GSD, and Camera Optimization relative difference. After processing each flight to create separate models, we created a combined model using all the images from the three flights that occurred over each field on the same day. With the three individual models and the one combined model for the eight different trails, there were total of 32 models. The results for all four processes can be found in tables 3 and 4.

The RMSE of the GCP's is a local indicator of how well Pix4Dmapper fits the model to the GCPs. It represents the consistency between the geolocation measured in the field and the geolocation Pix4Dmapper estimates when processing the model. The goal is to minimize this value. To calculate RMSE, the error between the actual location of each GCP and its location in the model is divided into directional errors (X, Y, and Z-components). All of the directional errors for all the GCP's in a model are combined through the root-mean-square calculation to provide an RMSE for each direction. Then, to provide a single value for a model, the three directional RMSE values are averaged to create the Model RMSE.

The GSD is a measure of the spatial resolution of the 3D model. It is defined as the distance between two neighboring pixels. A larger value indicates a model with less detail. Higher flights at higher altitudes generally have higher GSD values. The GSD is calculated separately for every pair of neighboring pixels in the model. To provide a GSD value for the entire model, all of the individual GSDs in the model are averaged together to produce the Model GSD.

Camera optimization varies based on lens type. However, it can generally be defined as the percentage difference between the initial and optimized parameters of the camera. This is best kept under 5%.

While flying faster at a higher altitude completed the missions quickly, it was the 30 m (~98 ft) flights that gave us an average Model RMS error of 0.016 m (~0.63 in) and an average Model GSD of 0.773 cm (~0.30 in).

Out of the 32 models, only two failed during processing. The Model RMSE and other descriptors of model quality indicated that these models had unusually large errors. They were excluded from further processing and not included in the descriptive statistics in Tables 3 and 4.

Applied Data Processing

Photogrammetry Processing – Pix4Dmapper

The most noteworthy settings we used in Pix4Dmapper are listed below.

- Coordinate System: World Geodetic System 1984 (EGM 96 Geoid)
- Processing Options Template: 3D Model
- Initial Processing: Keypoints Image Scale = Full
- Point Cloud Mesh: Export = LAS (a file format for saving point clouds)
- DSM (Digital Surface Model), Orthomosaic and Index: Resolution = Automatic, Use Noise Filtering (box is checked), Use Surface Smoothing (box is checked) - Type = Sharp.

The GCPs were imported using the GCP/MTP Manager. See Figures 4-6 for examples of a finished model.

Figure 4. An isometric top view of a portion of a fully processed alfalfa field model flown on June 4, 2019, using Flight 1 parameters. Only part of the nearby barn is modeled as the flights only recorded one side of the building.

Figure 5. A side view of the alfalfa canopy from a portion of a fully processed model flown on June 4, 2019, using Flight 1 parameters. Although the UAV did not take pictures from this angle and this close to the ground, the photogrammetry process captured the transition from the short grass bordering the field to the taller growing alfalfa plants.

Table 3. The descriptive statistics of the Model RMS Error of 24 unique flights.

Height (m)	Gimbal Angle	Minimum of Model RMS Error (m)	Maximum of Model RMS Error (m)	Average of Model RMS Error (m)	Standard Deviation of Model RMS Error (m)
30	90°	0.005	0.025	0.016	0.007
50	75°	0.010	0.022	0.018	0.004
50	90°	0.006	0.057	0.022	0.015
30 & 50	75° & 90°	0.005	0.052	0.019	0.015

Table 4. The descriptive statistics of the Model GSD of 24 unique flights.

Height (m)	Gimbal Angle	Minimum of Model GSD (cm)	Maximum of Model GSD (cm)	Average of Model GSD (cm)	Standard Deviation of Model GSD (cm)
30	90°	0.740	0.790	0.773	0.021
50	75°	1.370	1.460	1.409	0.030
50	90°	1.280	1.380	1.348	0.032
30 & 50	75° & 90°	0.770	1.350	1.098	0.257

Figure 6. An aerial view of the alfalfa canopy and tractor tracks from a portion of a fully processed model flown on June 4, 2019, using Flight 1 parameters.

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