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Comparison of Fixed-Wing Unmanned Aircraft Systems (UAS) for Agriculture Monitoring

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Introduction

Florida citrus growers need inexpensive methods to observe citrus plants to detect disease and plant stress consistently. Health vegetation indices, such as the Normalized Difference Vegetation Index (NDVI) collected from Unmanned Aircraft Systems (UAS), can be used to identify variation in plant health, which may be caused from disease or stress (Fan, et al., 2018, Hunt et al., 2010; Zhang & Kovacs, 2012;). Garcia-Ruiz et al. (2013) determined that UAS imagery taken by multispectral cameras can detect Huanglongbing (HLB), a common disease in Florida citrus groves. Cerreta, Hanson, Martorella, and Martorella (2018) suggested three-dimensional NDVI data taken from a UAS were more sensitive to less healthy levels of vegetation health values compared to two-dimensional NDVI values for citrus trees suspected with the HLB disease.

According to researchers at Purdue University (2008), U.S. farmers lose an estimated $20 billion annually from plant health problems. Many growers depend on precision agriculture specialists, such as crop scouts and agronomists, to help them determine the variability in their fields (Torres-Rua, 2017). The data from a UAS can also indicate where to apply variable rate treatments to minimize the impact on the environment (Duchsherer, 2018). UAS that are easy to operate may enable growers to inspect fields more frequently than with scouts, allowing more timely interventions to maintain crop health. Crop scouts or agronomists also use UAS as a part of their precision agriculture services. For either the producer or the crop scout, the key enabling features of UAS are their accuracy, ease of use, and low cost (Cao, et al., 2019).

Purpose

The purpose of this research was to compare two low-cost fixed-wing UAS to determine if there were differences in the NDVI reflectance values using the same multispectral camera.

Hypothesis

H1: There is no statistical difference between the NDVI reflectance values collected using the Parrot Disco Pro Ag and the senseFly eBee.

H0: There is a statistical difference between the NDVI reflectance values collected using the Parrot Disco Pro Ag and the senseFly eBee.

Materials and Methods

The same Parrot Sequoia multispectral camera was flown in both a Parrot Disco Pro Ag (Parrot, 2019) and a senseFly eBee (Geo Networking, 2017) to capture narrow-band multispectral images of a citrus grove in central Florida. The Parrot Disco Pro Ag and the senseFly eBee are shown in Figure 1. The same multispectral camera was used to minimize any variation caused by the camera. Between each flight, the Sequoia camera was unmounted from the Disco integration kit and mounted in the eBee integration kit. The red and near-infrared color bands were used to calculate a Normalized Difference Vegetation Index (NDVI) for the citrus grove for each flight.

Figure 1. Image comparisons between the Parrot Disco Pro Ag (left column) and the senseFly eBee (right column). De Leon Springs, FL. February 21, 2018.

Table 1 depicts the physical and performance characteristics between the Disco Pro Ag and eBee UAS. Both UAS are commercial UAS used in agriculture. As of March 2018, the configuration of the Disco Pro Ag is current; however, the senseFly eBee was several generations older and had been replaced with higher performing aircraft, including the $9,999 eBee SQ, which comes with the Parrot Sequoia camera (Parrot, 2019; senseFly, 2019).

Table 1

Physical and Performance Characteristics between the Disco Pro Ag and eBee

UAS Characteristic	Disco Pro Ag	eBee
Wingspan (Inches)	45.0	37.8
Weight (Pounds)	2.07	1.52
Datalink Range (Statue Miles)	1.24	4.97
Area Coverage at 400 Feet AGL (Acres)	200	350
Cruise Speed (Knots)	21	21 to 48
Endurance (Minutes)	30	50
Cost	$5,000 (includes Sequoia Camera)	$13,190 (eBee) + $3,500 (Sequoia)
Payload	Sequoia; nose camera	Multiple; including Sequoia; no nose camera
Flight Control Software	Parrot Freeflight Pro; Pix4Dcapture	eMotion 2; eMotion 3
Control Station Form Factor	Mobile device	Laptop
Launch Method	Hand	Hand
Landing Mode	Autonomous	Autonomous

Note. Characteristics from the respective Parrot and senseFly websites. The eBee comes with an RGB camera standard. The senseFly eBee SQ for $9,999 comes with the Sequoia camera and would be more of a direct comparison; however, was not available when data was collected in February 2018.

Study Area

The study area consisted of a 255-acre orange grove, located in De Leon Springs, Florida, United States. This area comprised of a humid subtropical climate with an average of 54 inches of rainfall per year (Zipdatamaps.com, 2019). The field elevation was 48 feet above mean sea level.

Sample Population

The area consisted of a 30-acre section containing 3,258 citrus trees. A 45-sample set of randomly-selected locations in the sample area yielded a *post hoc* achieved power of 0.91, using a confidence level of 95%, and assuming a medium effect size of 0.50. The NDVI values were recorded from the NDVI data for the 45-sample pairs between both the Disco Pro Ag and eBee datasets. A paired t-test was used to examine the mean difference between the two data sets. The alpha level was set to 0.05. Condition 1 (pre-treatment) was the NDVI dataset from the Disco Pro Ag, while Condition 2 (post-treatment) was from the eBee NDVI dataset. Both conditions were of the same location within the sample area.

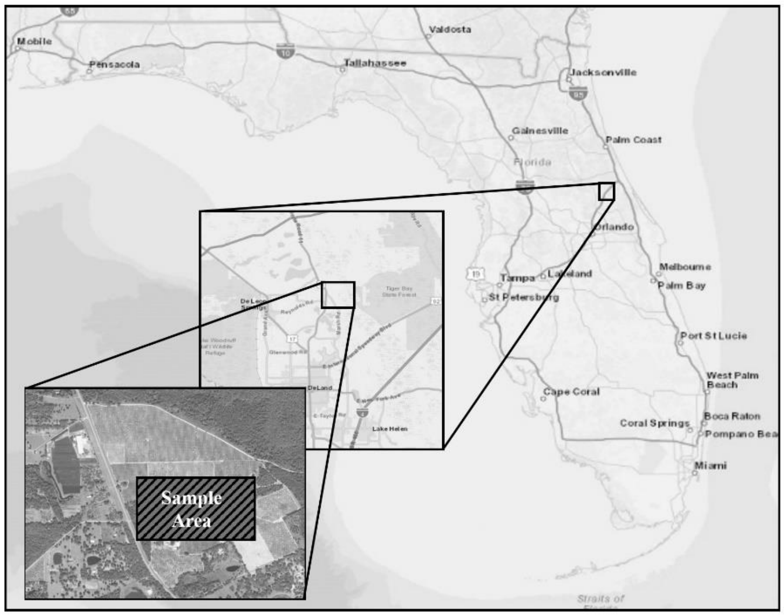

Figure 2. Geographical location of the study location and sample area.

Limitations

This research compared differences between NDVI values collected from the same multispectral camera over a citrus grove in Florida. Each flight was flown sequentially with the Disco Pro Ag first, then the eBee second. There was a period of time between flights to change the Sequoia camera from one aircraft to the other. Although the altitude, overlap proportions, and area of interest were similar between the two flights, the sun angle did change. A radiometric calibration was performed before each flight to minimize this variation; however, there may still be effects of the sun angle change not accounted for between flights.

Remotely Sensed Data Collection

Data collection took place on February 21, 2018 using a single Parrot Sequoia multispectral camera (firmware version 1.4.1) flown from the Parrot Disco Pro Ag UAS (firmware version 1.5.2), then a senseFly eBee (firmware version 2.4.13 7964). The same multispectral camera was used on all flights to minimize any variation caused by the camera. Between each flight, the Sequoia camera was unmounted from the Disco integration kit and mounted in the eBee integration kit. A radiometric calibration was performed using an AIRINOV calibrated reflectance target before each flight (AIRINOV reflectance target, 502-38-01, AIRINOV

Corporation, Paris, France). The reflectance values were calibrated within Pix4Dmapper Pro (Pix4D, version 4.3.31) to account for sunlight angle differences between each flight. For both flights, the wind was from 310 degrees magnetic at 4.0 knots.

Ground Control Points (GCPs) were emplaced and measured with a GNSS system. The GNSS system had an accuracy of 0.02 meters. Ten GCPs were located throughout the sample area. Three GCPs were imported to Pix4Dmapper Pro and used as control points to determine the accuracy of each dataset. The remaining seven GCPs were used to improve the accuracy of each dataset. GCPs increased the absolute location accuracy of the geo-located Disco Pro Ag and eBee NDVI datasets. The radiometric calibration increased the reflectance accuracy of the Sequoia camera. The flight-specific comparison is depicted in Table 2.

Table 2

Flight-specific data between the Disco Pro Ag and eBee

Flight Characteristics	Disco Pro Ag	eBee
Area of Interest (Feet x Feet)	1315 x 2626	1314 x 2626
Start Time (Eastern Standard Time)	10:58 a.m.	11:22 a.m.
Land Time (Eastern Standard Time)	11:11 a.m.	11.39 a.m.
Total Flight Time (Seconds)	817	1019
Flight Altitude (Feet Above Takeoff)	354	351
Battery Consumed (%)	71	49
Distance from Landing Spot (Feet)	44	4
Images Calibrated (Images)	1320	1108

Note. Landing distance measurements were taken with a rolling measuring wheel.

The Pix4Dcapture mobile application software (Pix4D, version 4.3.31) was used to plan the Parrot Disco Pro Ag flight and is shown in Figure 3. Flight planning parameters were set with a 75% longitudinal and 65% lateral overlap ratio. The camera was set to trigger automatically.

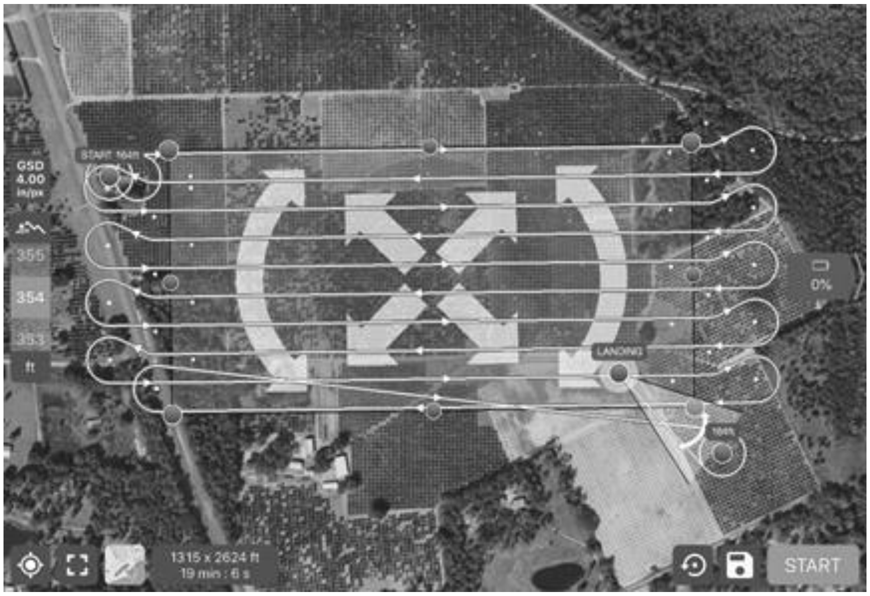

Figure 3. Pix4Dcapture mission plan for the Disco Pro Ag before flight.

Mission planning for the eBee was done using eMotion 2 (senseFly, version 2.4.13, rev 8551). This flight altitude was the closest selectable altitude to the Disco Pro Ag. Flight planning parameters were set with a 75% longitudinal and 65% lateral overlap ratio. The camera was set to trigger automatically. The eBee flight was also oriented using a grid with an East-West pattern as depicted in Figure 4.

Figure 4. eMotion 2 mission plan for the senseFly eBee while in flight.

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Image Processing

Each set of images was processed in Pix4Dmapper Pro separately. Table 2 reflects the Pix4Dmapper Pro processing options for both datasets. A shapefile of the sample area boundaries was created and imported from Global Mapper (Global Mapper, Version 19.1, Blue Marble Geographics, Hallowell, Maine) and selected as a processing area. Using the same shapefile between both datasets enabled the exact geolocation extents of the processing area for both datasets.

Table 3

Pix4Dmapper Pro processing options.

Processing Option	Setting
Keypoints Image Scale	Full
Image Matching Pairs	Aerial Grid or Corridor
Targeted Number of Keypoints	Automatic
Calibration Method	Alternative
Pointcloud Image Scale	Half Image Size
Pointcloud Density	Low
Pointcloud Minimum Matches	3
Generate Textured Mesh	No
DSM and Ortho Resolution	Automatic
DSM Filters	Noise Filtering and Surface Smoothing (Sharp) On
Radiometric Processing and Calibration	Camera and Sun Irradiance for Each Color Band
Index Calculator Resolution	Automatic
Reflectance Map	GeoTIFF
Indices	NDVI
Export Products	Index Values as Points, Rates, and Polygon Shapefiles (12 cm/ grid)

Note. Processing options in Pix4D originated from the Ag Multispectral template, then altered to export the 12 cm/grid index values as a shapefile.

After processing in Pix4D, NDVI dataset shapefiles were imported into Global Mapper GIS software (Global Mapper, Version 19.1). Each point contained an NDVI reflectance value for the same location in the sample area. Forty-five random pairs were selected, and the NDVI reflectance value for both the Disco Pro Ag and eBee were recorded.

Results

Paired-t testing was performed on the Disco Pro Ag and eBee NDVI datasets using Minitab statistical software (Minitab, version 18). Sampling consisted of 45-matched pairs using condition 1 as the NDVI dataset from the Disco Pro Ag, while condition 2 was from the eBee NDVI dataset. The distribution of matched pairs is depicted in Figure 5. There was no significant difference between the NDVI values for the dataset collected using the Parrot Disco Pro Ag and the senseFly eBee, as shown in Table 4.

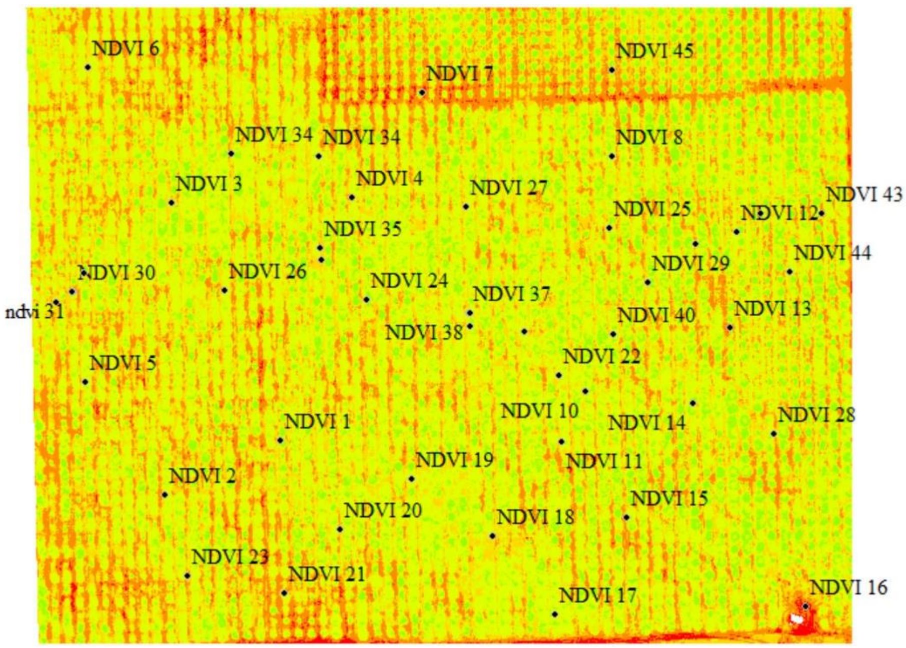

Figure 5. Post-processed NDVI image and distribution of 45-match pairs.

Table 2

Paired-t testing of NDVI datasets between the Disco Pro Ag and eBee.

Sample	N	Mean	SD	SE Mean
Disco Pro Ag	45	0.6184	0.1486	0.0222
eBee	45	0.6000	0.1586	0.0236
Mean Difference	SD	SE Mean	95% CI for Difference	
-0.00933	0.4314	0.00643	(-0.02229, 10.00363)	
T-Value		*p*-value		
-1.45		0.154		

Note. Mean, SD, and SE Mean values are in NDVI index values. $p > 0.05$.

A Pearson's correlation was performed between the 45-sample pairs of the Disco Pro Ag and eBee NDVI reflectance values. The correlation measured the strength and direction of the association between the two datasets. Pearson's correlation indicated a strong positive relationship (0.963, $p = 0.00$).

Although both the Disco Pro Ag and eBee had outliers, the data were normally distributed. These data had similar means and confidence intervals. Figure 6 depicts a boxplot and 95% CI within each dataset for comparison. The dataset from the eBee indicated a higher mean value for all samples combined; however, was not a significant difference.

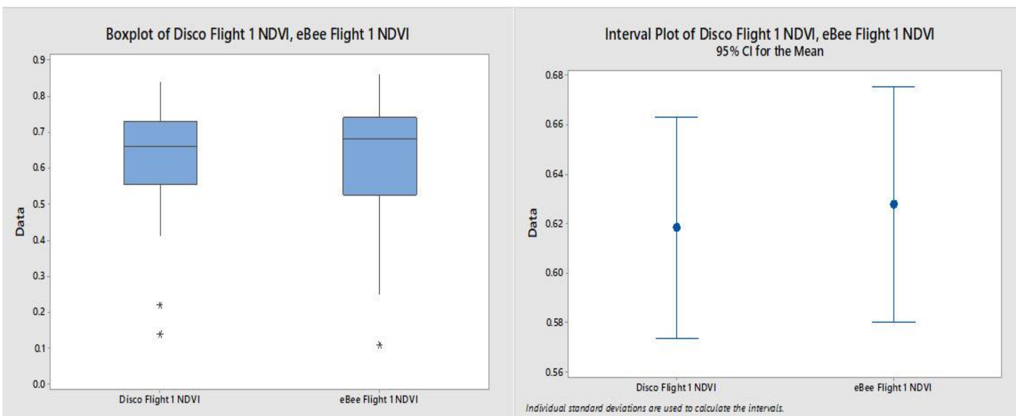

Figure 5. Boxplot and CI Distribution of Disco Pro Ag and eBee sample datasets. $p = 0.15$.

Each Pix4Dmapper Pro project created a quality report to indicate key measurements about the dataset, which was calculated by the software. Although the area of interest was of the same dimension, altitude, and overlap percentage, the quality report results of the two Pix4D projects differed.

Discussion

There were no statistical differences between the Disco Pro Ag (M = 0.62, SD = 0.15) and the eBee (M = 0.60, SD = 0.15) conditions; $t(45) = -1.45$; $p = 0.15$ regarding the NDVI reflectance values. Additionally, there was a significant strong positive correlation between the datasets (Pearson = 0.963, $p = 0.00$). These data show that there was no difference between the data gathered using the Disco Pro Ag and senseFly eBee.

The Parrot Disco flew the area of interest in 25% less time than the eBee, indicating a higher ground speed during the image acquisition; however, the Disco Pro Ag also consumed 31% more of its battery capacity compared to the eBee. It is possible the eBee would have greater endurance and cover a larger area of interest compared to the Disco Pro Ag than the sample area. Although the Parrot Sequoia used a global shutter for its multispectral camera, the quality report results indicated the Disco Pro Ag had 5% fewer median keypoints per image; however, it had negligible differences in minimum keypoints per image and 1.6% more keypoints in the maximum keypoints per image. Keypoints are recognizable features in an image. More keypoints are generated with less blurry images. This difference in keypoints per image suggested the difference in groundspeed had no effect on resolution.

Both UAS were easy to use in terms of setup and operation. The Parrot Disco Pro Ag used a mobile device with Pix4Dcapture software connected to a hand controller. All mission waypoint planning was performed on a mobile device. The eBee used a laptop with an externally-connected modem to perform waypoint mission planning. See Figure 7 for a depiction of the differences between the Disco Pro Ag and eBee control station It was noted that during the flight, the remote pilot operating the Parrot Disco Pro Ag required less dependence upon a Visual Observer compared to the remote pilot of the eBee. Due to the nature of the ground control station, the remote pilot of the eBee was less mobile, requiring more assistance from the Visual Observer when the aircraft was as it greatest distance away from the control station, even though the aircraft remained within visual line of sight of the pilot.

Figure 6. Parrot Disco Pro Ag (left; in the remote pilot's left hand) and senseFly eBee (right; laptop) remote pilots and control station configurations. De Leon Springs, FL. February 21, 2018.

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Conclusion

Both the Disco Pro Ag and eBee were equally capable of monitoring agriculture with similar results. In the grove surveyed, no plant disease or stress was detected. However, this research supports the efficacy of low-cost platforms in collecting NDVI data that could detect disease in an afflicted grove. Through this research, the cost of the Disco Pro Ag at $5,000 (Parrot, 2019) may be a more affordable option compared to the senseFly eBee's cost of $16,690 (Geo Networking, 2018) with comparable results. Differences in mobility and method of waypoint planning may also provide remote pilots with different styles of operation. As growers continue to adopt UAS technology to understand their fields better, the characteristics of each system will be necessary for quick setup time and ease of use.

Future research should concentrate on the radiometric accuracy of multispectral data collected from a UAS. Although differences between the Disco Pro Ag and eBee were not significant, there were differences. The causes of differences were not investigated in this research. A better understanding of the causes of radiometric variances can lead to improving the accuracy of the data.

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