

High resolution remote sensing using UAS technology

Natalie Schultz

December 15, 2017

Summary

With the growing ubiquity of unmanned aircraft systems (UAS) and their applications for education and environmental research, it is important to understand the practical considerations of UAS use, and the relationship between image collection/analysis methods and data quality.

The overall objective of this project is to develop best practices and methods to collect and analyze high resolution UAS images for mapping and environmental applications. UAS flights were conducted around Connecticut between May 31 and November 29, 2017, ranging in location from a suburban park to a forested island. The UAS used in this project was a DJI Phantom 4 Pro that was equipped with an RGB and an R-G-NIR sensor. The digital images captured from the onboard cameras were used to create orthomosaics, digital surface models (DSMs) and 3D models of the landscape. Meant to lay the foundation for future UAS research, this report outlines a simple methodology for UAS image analysis and discusses the key findings for creating high-quality data products from UAS imagery. Future work will focus on continued analysis of the NIR data for vegetation monitoring purposes and compare classification methods for high-resolution imagery.

Introduction

Unmanned aircraft systems (UAS) are now widely used for a diverse range of scientific research applications, including wildlife monitoring, land surveys, forest inventories, and atmospheric sampling¹. Compared to traditional remote sensing products, such as satellite or aircraft-based imagery, images collected via UAS have many advantages, including high resolution, and greater flexibility and control in temporal resolution and spatial coverage². The recent updates to the Federal Aviation Administration's UAS regulations, coupled with rapid advances in lightweight UAS technology, helped fuel the rise in the use of UAS in environmental research in the United States and abroad³.

The challenges of UAS remote sensing are related to the practicalities of high resolution image collection/analysis and questions regarding data quality. As is required to create a single orthorectified image of the landscape, hundreds of images must be collected from the onboard UAS camera during the course of a flight. However, with the rapidly growing implementation of UAS technology in research applications and the diversity of purposes for which they are utilized⁴, it is presently unclear how image collection and processing methods affect the quality of the data produced from a UAS^{3,5}. Further, the analysis techniques that are typically used for moderate resolution images (satellite data) may not translate to the high resolution imagery obtained from a UAS⁶.

This research will test and evaluate image analysis methods for high resolution images, and evaluate the capabilities of UAS remote sensing for environmental applications. The overall objective of this project is to develop best practices and analysis methods for collecting and processing high resolution imagery from a UAS, specifically focused on land surveys from multispectral sensors. This project is devised to address the practical and methodological considerations of UAS operations and high-resolution image analysis. The lessons learned from this research will help build the foundation for understanding UAS capabilities and limitations for future UAS missions.

Methods

Remote pilot certification

Conducting research using a UAS requires understanding and compliance with UAS rules and regulations, from the federal to the university level. The Federal Aviation Administration (FAA) currently regulates under the small UAS rule (Part 107)⁷ that university researchers obtain remote pilot certification. Yale policy also requires this certification prior to research-related UAS operation from Yale staff, faculty, and students⁸. The process of obtaining a remote pilot certificate consists of passing an aeronautical knowledge exam at an FAA-approved testing center, registering and applying for the remote pilot certificate through the FAA Integrated Airman Certificate and/or Rating Application system (IACRA), and undergoing a TSA security background check⁹. I took and passed the aeronautical knowledge exam at Robinson Aviation, Inc. (Tweed Airport) on May 9, 2017. I received a temporary (120 days) certificate within a week of passing the exam, and the permanent (2 year) certificate about a month later. Renewal of the certificate requires a recurrent knowledge test.

UAS equipment

This research was conducted using a DJI Phantom 4 Pro (P4P). The P4P is a 1.38 kg quadcopter, with a velocity range of up to 31 mph and a maximum flight time of 30 minutes (per battery). The P4P comes equipped with a 20-megapixel red-green-blue (RGB) camera capable of capturing still images and videos, and the integrated GPS tags the images with latitude, longitude, and altitude information. The P4P can be controlled via a handheld controller or through a DJI or third-party iOS/android application. For flight mapping, we primarily used the iOS app, DJI Ground Station Pro, which allows the user to set the designated flight area, image overlap, flight altitude, speed, and various other flight/camera parameters. Using these settings, the software creates a flight route in order to capture images over the entire scene.

Additionally, we integrated a sensor capable of capturing near-infrared radiation (NIR) on the P4P. As opposed to a typical red-green-blue camera, the MAPIR Survey 3W RGN (Survey3) captures light in the green (550 nm), red (660 nm), and near-infrared (850 nm) wavelengths. The Survey3 was mounted to the P4P using a plastic mounting plate and positioned in such a way that it did not interfere with the operation of the drone or obstruct the view of the original

camera. Images were captured at two second intervals and were calibrated using a ground target calibration target (MAPIR Calibration Target V1) with known reflectance values in the MAPIR Calibration Control application. The Survey3 was used to calculate the normalized different vegetation index ($NDVI = [R_{NIR} - R_R]/[R_{NIR} + R_R]$), where R_{NIR} is the reflectance of near-infrared radiation, and R_R is the reflectance of red light.

UAS flights

We conducted flights between May 31 and November 29, 2017 at various locations in Connecticut. A select number of flights are included in this analysis (Table 1). We created a flight checklist (Appendix A) which we followed for each flight to ensure a safe operation. Multiple flights were conducted at Brooksvale Park in Hamden, CT. We chose this location because of its open access, relative seclusion, and the heterogenous nature of the land cover in the area. Using images captured at Brooksvale Park, we created orthomosaics, digital surface models (DSMs), and 3D models of the landscape. It is also here that we tested various flight settings for the creation of orthomosaics, conducted an accuracy assessment of the images, and compared classification methods on the high-resolution imagery. We additionally flew the P4P at the top of East Rock Park in New Haven, CT for the purposes of creating a 3D model of the Soilders' and Sailors' Monument. Finally, we flew the P4P at Horse Island, Branford, CT and Great Mountain Forest, Norfolk, CT to capture imagery and videos. The flight speed and altitude varied between flights, but was generally between 8 to 13 mph and 200-400 ft, resulting in images with spatial resolution between 2-3 cm pixel⁻¹.

Date	Location	Purpose
6/21/2017	Brooksvale Park, Hamden, CT	- Orthomosaic, DSM, 3D model of landscape - Accuracy assessment using GCPs
6/29/2017	East Rock Park, New Haven, CT	- 3D model of Soldiers' and Sailors' Monument
7/6/2017	Brooksvale Park, Hamden, CT	- Orthomosaic, DSM, 3D model of landscape - Image overlap test for forested landscape
7/17/2017	Horse Island, Branford, CT	- Orthomosaic, DSM, 3D model of landscape - Video footage
7/25/2017	Great Mountain Forest, Norfolk, CT	- Orthomosaic, DSM, 3D model of landscape - Video footage
11/29/2017	Brooksvale Park, Hamden, CT	- MAPIR Survey 3 (red, green, NIR) flight - NDVI

Table 1. The dates, locations, and general purposes of each of the UAS flights.

Image processing

We primarily used the photogrammetry desktop software, Agisoft PhotoScan, to create orthomosaics, DSMs, and 3D models from the UAS images. Briefly, the process of constructing 2D and 3D products using PhotoScan consists of four main stages¹⁰. The first stage is the alignment of the images (Figure 1a). At this stage, PhotoScan uses the location of the images and searches for common points in the overlapping images to create a sparse point cloud. Using the aligned image locations, a dense point cloud is created in the second stage (Figure 1b). In the third stage (Figure 1c), a 3D polygonal mesh (geometry) is created which represents the surface of the object or landscape. In the fourth stage (Figure 1d), the texture (color) is applied to the mesh and it can be used as a 3D model or for orthomosaic or DSM generation. Post-processing, the orthomosaics and DSMs were exported as GeoTIFFs for further analysis in ENVI.

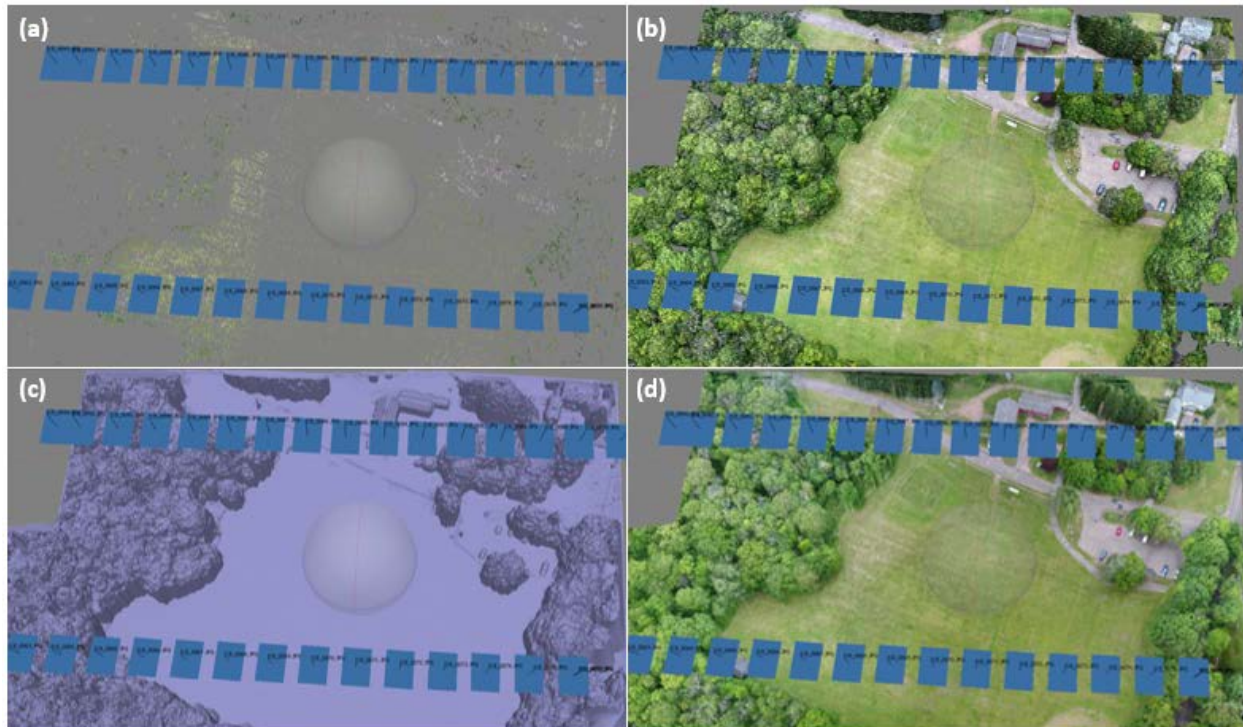


Figure 1. The four main stages of image processing in PhotoScan: (a) image alignment, (b) dense cloud, (c) polygonal mesh, and (d) image texture. The blue rectangles represent the individual image locations taken during the flight of the P4P. This example is showing a scene of Brooksvale Park, Hamden, CT.

Accuracy assessment

While images from the P4P are tagged with latitude and longitude information from its onboard GPS, we were interested in examining the positional accuracy of the orthomosaics. Ground

control points (GCPs), points of known coordinates, may be used to improve the scale, orientation, and accuracy of an image. We created GCP targets (white 18” particleboard squares with black crosses in the middle), placed them throughout our planned flight route, and measured their ground locations using handheld GPS devices. After constructing the orthomosaic, we compared how closely the location of the targets lined up with their actual locations as measured on the ground. We additionally integrated the locations of the GCPs into the image processing workflow to examine whether image accuracy was improved.

Results

Accuracy assessment

The location accuracy of the orthomosaics produced using PhotoScan was examined during two flights at Brooksvale Park, Hamden, CT on 6/21/17. Without incorporating GCPs into the photo processing workflow, the accuracy of the location of the ground targets in the orthomosaic images compared to their locations as measured by handheld GPS devices was 7.75 ± 1.95 m (\pm 1s.d.) and 6.00 ± 1.44 m. Repeating the process and incorporating the coordinate information from the GCPs into the PhotoScan processing workflow improved the accuracy to 0.36 ± 0.20 m and 0.41 ± 0.19 m.

	Location Accuracy	
	w/o GCPs	w/ GCPs
Brooksvale #1	7.75 ± 1.95 m	0.36 ± 0.20 m
Brooksvale #2	6.00 ± 1.44 m	0.41 ± 0.19 m

Table 2. The location accuracy of two flights conducted at Brooksvale Park on 6/21/17. The average distance to the five GCPs as measured by the handheld GPS is shown (± 1 s.d.).

Further qualitative analysis by exporting the images to Google Earth confirmed that the accuracy of the location of the orthomosaics was improved through the incorporation of GCPs (Figure 2). It is especially evident when following the path of the road and the parking lot.



Figure 2. Incorporating GCPs qualitatively improved the accuracy of the orthomosaics when they were overlaid on Google Earth. The (a) Google Earth image is compared to (b) the orthomosaic without GCPs and (c) the orthomosaic with GCPs. Images in (b) and (c) are from Brooksvale Park, Hamden, CT 6/21/17.

Orthomosaic and DSMs

During the course of this project, we tested the impact of various flight parameter settings on the quality of the maps, including flight altitude, speed, and image overlap percent. We found that by using the default image overlap percent settings in DJI Ground Station Pro (90% front overlap, 60% side overlap), our image mosaics were consistently missing data that should have been collected from the flight. More often, PhotoScan had difficulty finding a sufficient number of tie-points in overlapping images over forested regions of the flights. Two flights were conducted at Brooksvale Park, Hamden, CT on 7/6/17 to examine the importance of image overlap percent on creating a complete orthomosaic (Figure 3). Each flight was conducted using the same flight boundary, covering an area of 25.37 acres. The P4P was flown at an altitude of 399 ft at 13.6 mph, capturing an image every two seconds, resulting in images with a spatial resolution of 3.3 cm pixel⁻¹. For the first flight, the image overlap settings were set as default, whereas in the second flight, the side overlap was increased to 80%. This increase in overlap increased the flight time from 6.5 to 12 minutes, and the number of images from 130 to 268.

From Figure 3, which also displays the boundary of the flight route, it is clear that with the recommended flight settings, a significant piece of the forested region of the scene was not able to be constructed. By increasing the side overlap to 80%, the entire scene within the flight boundary was produced. Although neither battery life nor computational time were significant issues in these relatively short flights (each flight was well within the battery limit, and image processing time increased by ~1 hr), these results highlight the preparation and trade-offs that should be considered when trying to maximize data quality with equipment/computational limitations.

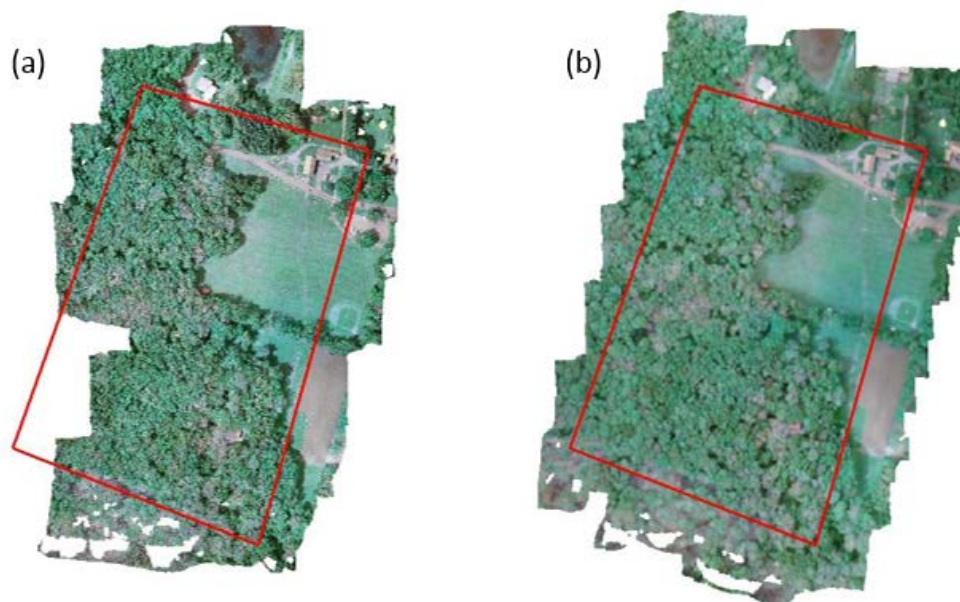


Figure 3. Orthomosaics created from Brooksvale Park, Hamden, CT on 7/6/17 with (a) 60% side overlap and (b) 80% side overlap. The boundary of the flight route is shown by the red box.

Digital surface models (DSMs) of the landscape were also created during image processing. Although they are sometimes used interchangeably, a DSM is different from a digital terrain model (DTM) in that it represents the height of the surface including surface objects such as trees and buildings, rather than the ground surface itself. [Figure 4](#) presents a DSM and RGB orthomosaic of the Yale Camp at Great Mountain Forest in Norfolk, CT on 7/25/17. This flight covered an area of 31.3 acres, and was flown at a height of 350 ft, producing images with a spatial resolution of $2.9 \text{ cm pixel}^{-1}$. The height of the surface in this scene ranges from 352 m at low ground elevation to 472 m at the tree tops at higher elevation. Although it was not explored in much depth in this analysis, options exist within Photoscan and other photogrammetry programs to classify the dense point cloud into, for example, ground points and “other” points, so that the elevation of the ground itself (DTM) is reconstructed, rather than the height of the elements in the scene. By constructing both the DSM and DTM geometries, the height of landscape features (e.g. canopy height) can be determined simply as the difference between the two.

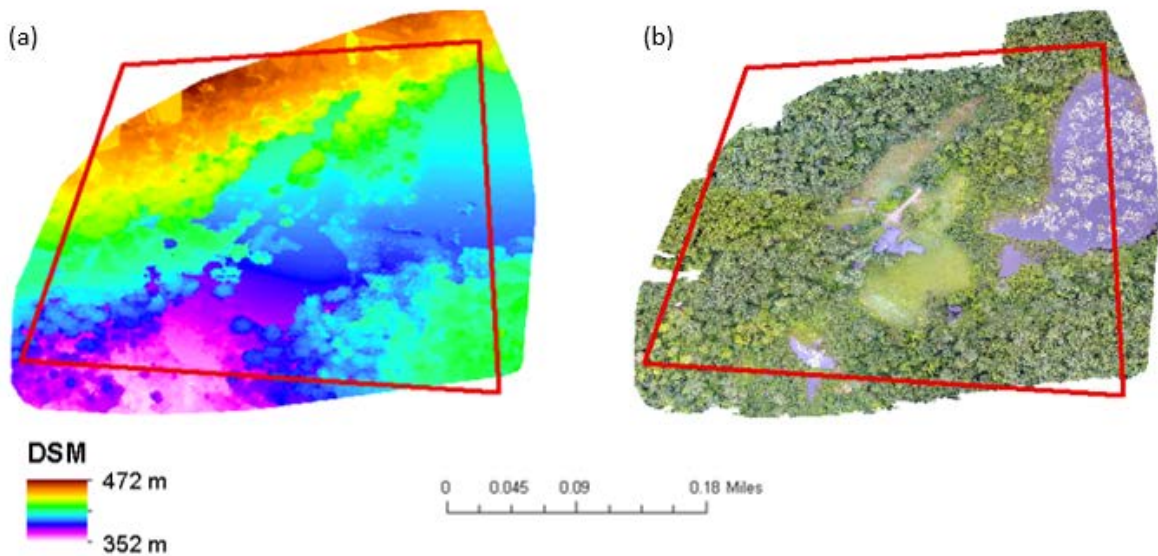


Figure 4. The (a) DSM and (b) RGB orthomosaic of Yale Camp at Great Mountain Forest, Norfolk, CT from 7/25/17. The camp buildings are in the center of the scene. The red box shows the boundary of the flight.

3D models

A 3D model of the Soldiers' and Sailors' monument at East Rock Park, New Haven, CT was constructed by circling the monument as shown in [Figure 5a](#). Setting the flight path mode as circular around a point of interest, the P4P circled the monument, starting at 3.3 ft above the ground and reaching a height of over 130 ft. Due to the proximity of the UAS to the monument, the spatial resolution of the imagery is estimated to be $0.3 \text{ cm pixel}^{-1}$. The 3D model is shown in its entirety in [Figure 5b](#) and zoomed-in for detail in [Figure 5c](#). An interactive view of the monument can be accessed online here: <https://skfb.ly/6s6vY>.

Three-dimensional models of the landscape can also be created using UAS imagery. An aerial survey was conducted over Horse Island, Branford, CT on 7/17/17. The area of the flight was 18.2 acres, and the UAS was flown at a height of 354 ft, producing images with a spatial resolution of 30 cm pixel^{-1} . The results of the 3D reconstruction of the Island using P4P images are shown in [Figure 6](#) and may be accessed for interactive online viewing here: <https://goo.gl/vAh2Hc>. All images were taken with a gimbal pitch angle of -90° (nadir), which is why the more horizontal view as shown in [Figure 6b](#) has holes and is missing some detail. The 3D reconstruction can be improved by including oblique angle images in addition to nadir images during the flights.

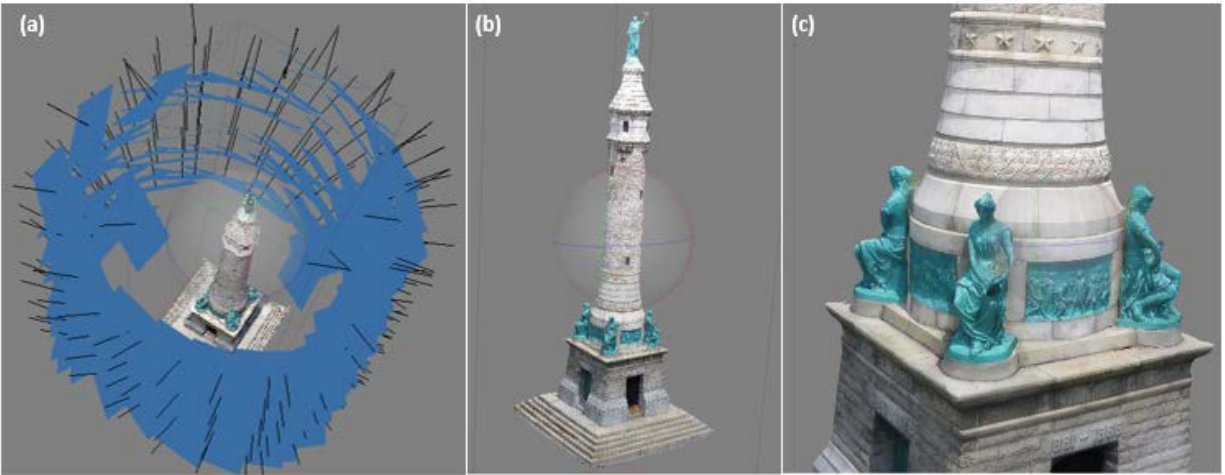


Figure 5. The (a) image locations surrounding the dense point cloud of the East Rock monument, and the completed 3D model, shown (b) in its entirety and (c) zoomed in on detail. This flight was conducted 6/29/17.

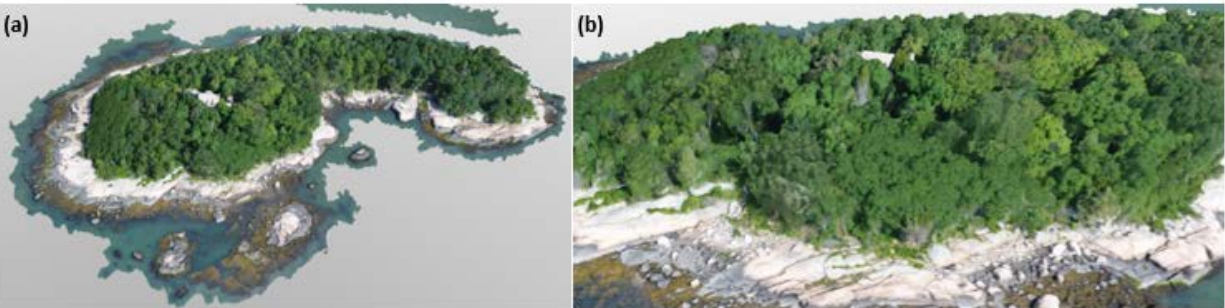


Figure 6. The (a) full and (b) zoomed-in 3D reconstruction of Horse Island, Branford, CT. The images were taken on 7/17/17.

High resolution NDVI

The Survey3 (R-G-NIR) was mounted to the P4P and flown over Brooksvale Park, Hamden, CT on 11/29/17. The Survey3 was programmed to take images at 2 second intervals, while the drone was flying at a speed of 12.2 mph at 359 ft (altitude). The resulting images were captured with a spatial resolution of $2.7 \text{ cm pixel}^{-1}$. The Survey3 images were used to create an orthomosaic (Figure 7a), which was calibrated via a ground calibration target. In this image, the NIR band is set to display as blue (red = red, green = green). Much of the image appears blue/teal because of the green vegetation in the scene, which is highly reflective in the NIR wavelengths. The NDVI was calculated with the red and NIR bands, producing the image

shown in [Figure 7b](#). Although November was not the most ideal time to begin operation of a vegetation sensor, the preliminary NDVI results appear reasonable. The green vegetation (displayed as blue trees or grass in [Figure 7a](#)) generally has NDVI values ranging from 0.4 to 0.55, while the brown patches of grass and sparse canopy areas have NDVI values in the range of 0.15 to 0.25. The roads and buildings have the lowest NDVI values, ranging from approximately -0.1 to 0.1.

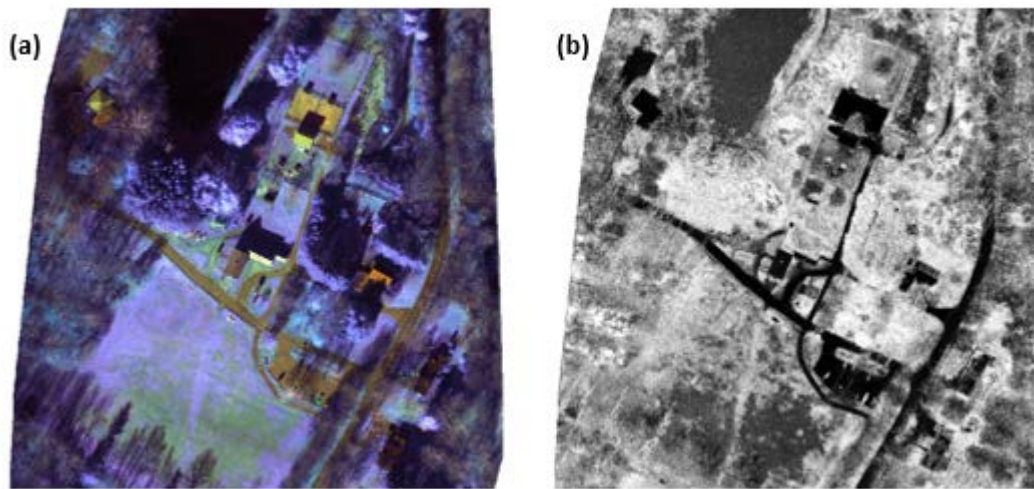


Figure 7. The (a) R-G-NIR (set as R-G-B) orthomosaic of the Survey3 camera, and (b) NDVI. The images were captured over Brooksvale Park, Hamden, CT on 11/29/17. The NDVI ranges from -0.1 (black) to 0.6 (white) in this scene.

Conclusion

The overall objective of this project was to develop best practices and methods to collect and analyze high resolution UAS images for mapping and environmental applications. Using a DJI Phantom 4 Pro equipped with an RGB and R-G-NIR sensor, flights were conducted around Connecticut between May 31 and November 29, 2017. In this report, the methods and considerations of using the digital images captured from the onboard cameras to create orthomosaics, digital surface models (DSMs) and 3D models of the landscape was discussed. A preliminary assessment of the UAS as a vegetation monitoring tool was conducted using an R-G-NIR sensor. The initial NDVI results were reasonable, ranging from -0.1 for non-vegetated surface to 0.6 for green vegetation in the scene.

Although the P4P has integrated GPS which automatically geo-tags the RGB images, we found that the location accuracy of the orthomosaic was improved by 5-7 m by incorporating ground

control points (GCPs) into the image processing workflow. During the course of this analysis, we tested various flight settings and parameters to understand their impact on the quality of the data produced. One of the important parameters in creating a complete image was the overlap percent setting. While the default setting of 90% front overlap and 60% side overlap consistently produced enough tie-points for image mosaicking with heterogeneous images (i.e. many unique features), the side overlap needed to be increased to 80% over forested regions. This increased overlap nearly doubled the flight time and the number of images captured.

This project was designed to lay the foundation for future UAS research, documenting practical and methodological considerations for mapping and environmentally-related UAS operations. Future work will focus on continued analysis of the NIR data for vegetation monitoring purposes and compare classification methods for high-resolution imagery. The results of this project may be incorporated into remote-sensing courses at Yale, and help build the foundation for understanding UAS capabilities and limitations for future UAS missions.

References

- 1 Watts, A. C., Ambrosia, V. G. & Hinkley, E. A. Unmanned Aircraft Systems in Remote Sensing and Scientific Research: Classification and Considerations of Use. *Remote Sensing* **4**, 1671-1692, doi:10.3390/rs4061671 (2012).
- 2 Salamí, E., Barrado, C. & Pastor, E. UAV Flight Experiments Applied to the Remote Sensing of Vegetated Areas. *Remote Sensing* **6**, 11051-11081, doi:10.3390/rs61111051 (2014).
- 3 Dandois, J., Olano, M. & Ellis, E. Optimal Altitude, Overlap, and Weather Conditions for Computer Vision UAV Estimates of Forest Structure. *Remote Sensing* **7**, 13895-13920, doi:10.3390/rs71013895 (2015).
- 4 Whitehead, K. & Hugenholtz, C. H. Remote sensing of the environment with small unmanned aircraft systems (UASs), part 1: a review of progress and challenges. *Journal of Unmanned Vehicle Systems* **02**, 69-85, doi:10.1139/juvs-2014-0006 (2014).
- 5 Harwin, S. & Lucieer, A. Assessing the Accuracy of Georeferenced Point Clouds Produced via Multi-View Stereopsis from Unmanned Aerial Vehicle (UAV) Imagery. *Remote Sensing* **4**, 1573-1599, doi:10.3390/rs4061573 (2012).
- 6 Feng, Q., Liu, J. & Gong, J. UAV Remote Sensing for Urban Vegetation Mapping Using Random Forest and Texture Analysis. *Remote Sensing* **7**, 1074-1094, doi:10.3390/rs70101074 (2015).
- 7 Federal Aviation Administration. *Summary of Small Unmanned Aircraft Rule*, <https://www.faa.gov/uas/media/Part_107_Summary.pdf> (2016).
- 8 Yale Environmental Health and Safety. *Unmanned Air Systems (Drones)*, <<https://ehs.yale.edu/unmanned-air-systems>> (2016).
- 9 Federal Aviation Administration. *Becoming a Pilot*, <https://www.faa.gov/uas/getting_started/part_107/remote_pilot_cert/> (2017).
- 10 Agisoft PhotoScan. *Agisoft PhotoScan User Manual, Professional Edition, Version 1.3*, <http://www.agisoft.com/pdf/photoscan-pro_1_3_en.pdf> (2017).

Appendix A – Flight Checklist

BEFORE LEAVING

Airspace	Unrestricted or authorized by ATC (Airmap, B4UFLY) Potential obstructions identified
Weather	Visibility \geq 3 miles Wind \leq 20 mph No precipitation/fog Distance from clouds: \geq 500 ft (vert), \geq 2000 ft (horz)
Firmware	Up to date
SD Card	Installed w/ enough free space
USB Cables	Controller to phone/tablet Controller to drone
Controller	Fully charged Firmware up to date Calibrated
Batteries	Two, fully charged
Tablet/phone	Fully charged DJI GO 4 and flight mapping apps installed
Propellers	Minimum of 8 (4 black, 4 silver)
Gimbal lock	On
Inspection	Check for any damage/defects (do not fly if yes)
Documents	Binder with pilot certificate & UAS registration Log book
Flight plan (if applicable)	Created, saved to tablet/phone
Ground control points (if applicable)	GPS devices Targets

PRE-FLIGHT

Install battery, verify fully charged	
Install propellers (2 silver, 2 black), double check they're secure	
Remove gimbal lock	
Connect tablet/phone to controller	
Open flight app	
Turn on controller	
Turn on drone (battery)	
Transfer flight plan to drone (if applicable)	
Set GCP targets (if applicable)	
Record in logbook	Date/time Location Weather conditions People involved

BEFORE TAKEOFF

Verify GPS mode

Start motors (no abnormal noise)

Check for warning messages (*status lights should be flashing green*)

Compass calibration (if necessary)

Make sure home point & altitude set

AFTER TAKEOFF

Hover, verify systems OK, no abnormal noise

Check flight controls and operation

During flight

Maintain visual contact

Be aware of potential obstructions

Notify non-participants (if necessary)

Monitor flight via phone/tablet

POST-FLIGHT (FIELD)

Turn off drone (battery)

Turn off controller

Remove propellers (check for any damage)

Install gimbal lock

Remove battery

Pack everything in DJI box

Check area for forgotten items

POST-FLIGHT (LAB/OFFICE)

Record details in Excel flight log

Transfer photos to folder

Charge battery

Charge controller