GUIDELINES AND METHODS FOR THE USE OF SMALL UNMANNED AIRCRAFT SYSTEMS FOR MAPPING AND MONITORING

Photo: Oblique view of Coggeshall marsh on October 22, 2018 taken with a DJI Phantom quad-copter.

THE UNIVERSITY OF RHODE ISLAND

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INTRODUCTION

Unmanned aircraft system (UAS) technology has been around as a military application since the 1970s. Between recent advances in aircraft, battery and payload capabilities, and the FAA regulations published in August 2016 (which waived the requirement for traditional pilots license), UAS uses and potential applications are booming (Hogan et al., 2017). UAS are becoming a necessary tool for many government and academic organizations. Additionally, their use has surged within private industry ranging from professional surveyors, real estate marketing, structural inspections, crop assessments, to even wedding videography. A UAS allows for near real-time imagery surveys and other data capture for an area of interest in greater detail and reduced cost that is not feasible with currently available manned aircraft systems. A fully operational UAS Program can deploy its resources with very little advanced notice (hours).

This report is part of a project to evaluate the use of small Unmanned Aerial Systems (sUAS)[1] to map and monitor salt marshes at the Narragansett Bay National Estuarine Research Reserve on Prudence Island, Rhode Island. In addition to the aircraft itself, many other components must be considered as part of a full sUAS solution. A sUAS designed for mapping and monitoring habitats on sunny, low wind days is very different from one that is capable of real-time observation in more severe weather. These considerations include payloads (e.g. true-color, multispectral, and thermal cameras; LiDAR), global navigation satellite system (e.g. GPS, GLONASS, Galileo) compatibility, software (apps), supporting hardware, and the operations team itself comprised of operators, visual observers, and technicians who support roles including transportation, information technology, image processing, data analysis, and data distribution. The type of sUAS that is chosen will depend on your organization's mission and goals. For reference, it took us years (working part time) to develop our UAS program at the University of Rhode Island's Environmental Data Center (URI EDC). To date, three of our staff have passed a FAA aeronautical knowledge test and therefore are certified to fly sUAS commercially. In addition, the systems that provide the most functionally in terms of accuracy, flight times, and data quality typically require advanced training and have a considerable learning curve. For example, for the system we chose from BirdsEyeView Aerobotics, we participated in a three-day, on-site, professional flight instructor-led training before operating the aircraft on our own. Other systems, like the very popular DJI Phantom series, are easier to use but its data products may not meet the needs of a salt marsh monitoring program for example.

Our goals for this report are: 1) to document our methods to map salt marsh habitats at two sites on Prudence Island using a sUAS; 2) provide background information and suggestions for how to develop a new sUAS Program; and 3) provide some very basic guidelines on how to conduct a sUAS survey.

Operating a sUAS and processing the resulting data is an intensive process for which there are no legitimate "quick start guides". While this report certainly addresses important sUAS considerations, it

[1] As of the publication date of this document, the FAA defines as sUAS as an unmanned aircraft that weighs less than 55 lbs (25 kg).

by no means is intended to be a comprehensive document. sUAS technologies and regulations are changing rapidly, therefore the some of the information provided herein may change in the short term (months or year).

FAA sUAS PILOT CERTIFICATION

sUAS applications fall within four major categories defined by the FAA: recreational, commercial, government, and educational. This project was approached as a commercial application by the URI EDC. Commercial applications of sUAS are highly regulated by the FAA (https://www.faa.gov/uas/). Here is a sampling of the rules and regulations for the commercial operation of a sUAS (modified from https://www.faa.gov/uas/media/Part_107_Summary.pdf)[2]:

- Remote Pilot in Command must be present and have an FAA certification with sUAS rating
- Aircraft must be registered with the FAA
- Aircraft must weigh less than 55 lbs under full load
- Aircraft must remain within visual line of sight at all times
- Do not fly over non-participating people or at night
- Do not fly above 400ft above ground level
- Know the airspace restrictions - do not fly in particular types of airspace without authorization
- Yield right of way to other aircraft

In addition to commercial applications, a FAA remote pilot certification is also required to operate and fly a sUAS in a governmental capacity. And while recreational sUAS operators do not require certification, the rules referenced above still apply. In the case of the URI EDC, we have three Part 107 certified pilots on staff.

The Part 107 remote pilot certification process begins by reviewing the eligibility requirements listed on the FAA website (https://www.faa.gov/uas/commercial_operators/become_a_drone_pilot/). If the requirements are met, the next step is passing an aeronautical knowledge test administered at an authorized FAA testing center. The exam cost is currently $150.

There are numerous in-person and online training opportunities for preparing for the FAA knowledge test. The cost for these tend to range from approximately $149 to $500. The URI EDC ultimately chose an online course for $149 that proved to be very useful.[3] The course included approximately 6 hours of pre-recorded instructional videos and featured test questions similar to what are found on the actual knowledge test. This particular course was taught by an instructor who is also a licensed manned pilot, which provided some valuable perspective. Additional references to other online resources and materials were provided that a new student may not necessarily find on their own.

[2] Please note that while we have summarized these rules for the purposes of this report, it is incumbent on future practitioners to fully understand and comply with all FAA rules and regulations.

[3] Remote Pilot 101, https://remotepilot101.com

There are also free study materials and sample tests online, including some offered directly by the FAA: (https://www.faa.gov/training_testing/testing/test_questions/media/uag_sample_exam.pdf).

CHOOSING A UAS

There are two fundamental types of aircraft currently in use by the sUAS industry: rotary and fixed wing. Other considerations include types of cameras (payloads) and GPS capability that comprise a fully functional sUAS. Please see Hogan et al. (2017) for a nice synopsis of the advantages and or disadvantages of each type of aircraft. Generally, rotary aircraft are highly stable and maneuverable but the battery life is usually much less than a fixed-wing aircraft. Conversely, a fixed-wing aircraft has a longer flight time and therefore can cover a larger study site. Fixed-winged aircraft tend to be more difficult to launch and recover.

BirdsEyeView Aerobotics FireFLY 6 Pro[4]

The URI EDC operates a sUAS that utilizes both rotary and fixed wing technologies. In rotary mode the aircraft takes off vertically, quickly transitions to forward flight mode for the vast duration of the flight, then transitions back to rotary mode for landing. We own two of these aircraft, which provides some redundancy in the event of equipment downtime. This system was used to collect the imagery for this project.

sUAS SETUP AND FLIGHT PLANNING

The steps that follow are somewhat specific to our BirdsEyeView FireFLY6. A photo of the set-up may be seen in Figure 1.

1. Define the area of interest.
2. Verify airspace. Apply for airspace authorizations as needed.
3. Decide on a survey type for your area of interest (Table 1)
4. In the field, find a good location for take-off and landing. A good location is a flat and clear of shrubs or vegetation that would impede the takeoff or landing of the aircraft. We have found that a clear area of around 300-400 ft^2 works well.
5. If you are using an RTK base station, install (or find one in the field) a temporary benchmark (wooden stake, re-bar, etc.) and survey the X,Y,Z coordinates. We used a survey-grade (cm) Trimble R10 dual-frequency receiver.
6. Track the weather and pick a day where the forecasted winds are light (5-15 kts).
7. Monitor Notices to Airmen (NOTAM) for temporary flight restrictions and other information that may impact flight operations.

[4] Specifications for the BirdsEyeView Aerobotics FireFLY6 Pro are available at https://www.birdseyeview.aero/pages/firefly6-pro.

8. Inventory, prepare, pack, and finally load equipment for transport to the work site.
9. In the field, set up the operations site. In our case, this consisted of:
    - Portable tables and stool
    - Ruggedized laptop
    - Various tripods for GPS base station antenna, radio antenna, anemometer.
    - Drone landing pad
    - Toolbox with supplies for in-the-field repairs
    - Generator, associated cables, battery chargers
    - Aircraft
    - Aircraft payloads, and associated accessories such as SD cards and batteries
    - Calibration panel for MicaSense RedEdge camera
    - Aircraft radio (for monitoring local manned air traffic, and communicating in a dire emergency)
    - Handheld radios for local person-to-person communication
    - Personal cell phones

Table 1. The types of survey styles available for the BirdsEyeView FireFLY6 PRO.

Survey Type	Horizontal Accuracy Category (WGS84)	Description
RTK Survey – In mode	Low	Imagery accuracy will be determined through averaging of the GPS base station position and corrections to the on-board GPS position of the aircraft
RTK Fixed mode	Medium	Imagery accuracy will be determined by a known position of the GPS base station and corrections to the on-board GPS position of the aircraft
RTK Fixed mode with surveyed ground control targets	High	Imagery accuracy will be determined by the known base station and ground control targets positions and base-aircraft RTK GPS

10. Establish a flight plan
    - Load pre-defined flight area
    - Assess local wind direction and speed
    - Assess local flight hazards, and impact on potential takeoff and landing approaches
    - Configure for sensor being flown (e.g. Sony A6000 vs MicaSense RedEdge)
    - Set altitude, overlap, sidelap, overshoot, lead-in, lane skip, and other values
    - If necessary, determine when the flight will be paused to swap batteries
11. Assemble the aircraft.
12. Conduct pre-flight checklist
    - Aircraft pre-flight
    - Payload pre-flight
13. Conduct flight
14. Conduct post-flight checklist

IMAGERY POST-PROCESSING

Upon returning from Prudence Island, the original image data were copied to an image processing workstation[5], and a backup copy of the data were placed on a networked file server. We used the *Pix4D Pix4Dmapper* software product to align the images, generate an initial point cloud, generate a digital terrain model, and ultimately generate the orthomosaics used for vegetation interpretation. We followed instructions provided by Pix4D to process the true color A6000 imagery, and followed instructions provided by MicaSense to process the multispectral RedEdge imagery.

There are other software products on the market that perform similar functions, such as Agisoft Metashape, DroneDeploy, MicaSense Atlas, Esri Drone2Map for ArcGIS, and PCI Geomatica. We initially purchased Pix4Dmapper based upon a good balance of features, performance, and cost. We are now experimenting with Agisoft Metashape as it offers some more freedom on customizing workflows and may be more lenient when processing image data consisting mostly of water features. The cloud-based software solutions we have looked at to date do not offer the functionality or customizability that we need, or are simply too expensive given the volume of image data we collect.

IMAGE ACQUISITION AT PRUDENCE ISLAND

Airspace Authorizations

Prudence Island, RI is located within controlled airspace associated with T.F. Green Airport (airport identifier KPVD), and controlled airspace associated with Quonset State Airport (KOQU). FAA airspace authorizations are required to conduct UAS flights within each of the types of airspace. In anticipation of a lengthy approval process, we proactively submitted the following applications for the sUAS surveys:

- Coggeshall Marsh, KPVD Class E Surface, application number 2017-P107-ESA-24865, submitted November 11, 2017.
- Coggeshall Marsh, KOQU Class D, application number 2017-P107-ESA-25636, submitted December 4, 2017.
- Nag Marsh, KPVD Class E Surface, application number 2017-P107-ESA-25791, submitted December 5, 2017.
- Nag Marsh, KOQU Class D, application number 2017-P107-ESA-25907, submitted December 6, 2017.

We received an initial response from the FAA on March 6, 2018. The FAA had since determined that authorizations were not necessary for extensions to Class E surface areas, negating the need for applications 2017-P107-ESA-24865 and 2017-P107-ESA-25791. We agreed with FAA specialist who was reviewing these applications to proceed with cancelling these applications outright. 2017-P107-ESA-25636 was quickly approved afterwards on March 15, 2018.

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[5] The image processing workstation used for this project was Dell Precision Tower 7810 with an Intel Xeon E5-2660 CPU, 64 GB of RAM, SSD-based RAID 0 local data storage.

However we did not learn the fate of 2017-P107-ESA-25907 until May 24, 2018 when after multiple inquiries, we were notified that the application was cancelled outright. The FAA specialist who assisted us in March intended to combine this application with 2017-P107-ESA-25636, but they did not. Thus, we were granted airspace permission to fly only over Coggeshall Marsh. We followed up on March 24, 2018 requesting advice on how to proceed. We were advised on June 6, 2018 to re-submit our application to fly in the Quonset Class D airspace encompassing Nag Marsh. This led to our submitting a new airspace authorization application:

- Nag Marsh, KOQU Class D, application number 2018-P107-ESA-22985, submitted June 6, 2018.

This follow-up application was ultimately approved on September 13, 2018, thus finalizing the permit process for this project with the FAA. Overall, we found the authorization application process at the time to be quite cumbersome and inefficient. We had to re-submit our applications and nearly ten months later we finally had our authorizations. We found that since TF Green is part of the Low Altitude Authorization and Notification Capability (LAANC) system, these applications were processed much more quickly[6]. We hope that these authorizations will become easier when Quonset State Airport adopts the LAANC system.

We did not expect our airspace authorization to fly at Coggeshall Marsh would be limited by the FAA to operations not exceeding 200ft above ground level. This constraint was dictated by the new UAS Facility Map in effect at the time for this airspace. Per the FAA, "UAS Facility Maps show the maximum altitudes around airports where the FAA may authorize part 107 UAS operations without additional safety analysis[7]." Thus, we were precluded from collecting multispectral data at this site because the shutter speed of the MicaSense camera simply cannot operate quickly enough to collect sufficiently overlapping images at this altitude using the FireFLY6 Pro platform. We did not have enough time to submit another Part 107 airspace authorization request that sought approval to exceed the altitudes defined in the UAS Facility Maps (which were being publicly rolled out while our initial airspace applications for this project were under review).

If we wanted to fly at Coggeshall Marsh this year (2019) at 200ft above ground level, we would submit an airspace application via the FAA Drone Zone[8] and expect an answer from the FAA in three months. This three month wait period should drop to a matter of hours or even minutes once Quonset State Airport becomes part of LAANC. If we wanted to fly at Coggeshall Marsh higher than 200ft above ground level, we would not be able to use LAANC and instead submit an airspace authorization application via the FAA Drone Zone, and expect at least three months to pass due to the more stringent safety requirements to fly above the altitudes defined in the FAA UAS Facility Maps.

[6] More information about LAAANC is available at https://www.faa.gov/uas/programs_partnerships/data_exchange.
[7] More information about FAA UAS Facility Maps is available at https://www.faa.gov/uas/commercial_operators/uas_facility_maps.
[8] https://faadronezone.faa.gov

We expect the FAA to continue requiring more stringent reviews of Part 107 airspace authorization requests that involve exceeding the parameters described by the UAS Facility Maps. These reviews will most likely take at least three months to complete. It certainly is possible to be awarded an authorization that exceed these parameters on flight altitude, but we are not currently familiar with what additional requirements (communications with air traffic control e.g.) may need to be in place by the sUAS flight team before the FAA would be willing to approve such proposed work.

In addition to requesting FAA authorization, the University of Rhode Island requires URI employees and contractors to apply for a sUAS flight permit issued by URI, a process that is coordinated by the URI Department of Public Safety. Part of this permit process is obtaining written land owner permission to acquire imagery of the properties in question. We worked with Narragansett Bay National Estuarine Research Reserve to get these necessary approvals.

Image Acquisition

For the study sites, we used a FireFLY6 Pro aircraft flown at an average speed of approximately 20 knots at 120 meters above ground level at Nag Marsh, and 60m at Coggeshall. At Coggeshall marsh, imagery was collected using a true-color Sony a6000 digital camera with a 16mm lens. The site was flown over two days (October 7 and 22). Winds on both days were light to moderate (5-15 kts) and tides were low. At Nag marsh, imagery was collected in two separate flights on the same day (October 22). One flight utilized the true-color Sony a6000, while the second set of imagery was collected using the MicaSense RedEdge multispectral camera. The MicaSense camera collects five visible spectral bands concurrently (blue, green, red, red edge, and near infrared). A mission plan was created by uploading the study area polygon (shapefile) into the FireFLY6 Planner software which was installed on a ruggedized field laptop. Also included as input to the mission plan are the: camera type, altitude, angle, overshoot and lead-in distance, % overlap and % sidelap of the photos, and number of lane skips. Once generated, the mission plan creates the flightlines and waypoints for the aircraft to follow during autonomous (autopilot) data collection and the estimated total area and distance covered, distance and time between images, ground resolution, number of pictures, number of flight lines and flight time required to collect the imagery. Our mission plan included 80% sidelap and overlap for the Sony A6000, and 75% overlap and sidelap for the MicaSense RedEdge cameras. All image acquisitions were done utilizing "RTK Mode" whereby real-time differential corrections are sent to the aircraft from the GPS base station. The X, Y, Z coordinates of the GPS base station location were previously measured using a survey-grade (cm) GNSS dual frequency receiver. In total and over two days, we collected over 62 GB of imagery covering ~135 hectares.

Results

After the mosaic and ortho creation process was completed in Pix4D, all the imagery datasets were aligned and tied to the RI DEM/USGS 2011 6in (15cm) statewide orthophotography found on RIGIS (http://www.rigis.org/pages/2011-ridem-imagery). This step insures that all features and imagery data are consistent and comparable. These data have a listed accuracy at the 95% confidence interval of 0.76m NSSDA (0.31, 0.44m XY RMSE). Common features were identified on each dataset and then resampled using 1st order polynomial transformation in ArcGIS (Table 1). Once the accuracy tests were completed, all data sets were published and shared publicly to the URI-EDC ArcGIS Online data portal (Table 2).

Potential for supervised classification

sUAS imagery has great potential for mapping and monitoring salt marsh habitats in Rhode Island. sUAS imagery has the ability for consistent and rapid monitoring of sites to measure a variety of environmental metrics including vegetation cover, type, erosion, accretion, and condition. During the summer of 2018, URI- EDC along with the R.I. Coastal Resources Management Council mapped several marshes along the south shore of Rhode Island with a sUAS. We conducted an image analysis to map the vegetation cover at each of these sites using a supervised classification. In addition, we calculated accuracy metrics for the vegetation cover classes (Table 3).

Table 2. The date, resolution, transformation results (RMS) and data page link for the Prudence, RI UAS imagery.

Image Name	Date	Pixel resolution (m)	RMS (m); n	Data Page
Coggeshall (south)	10/07/18	0.05	0.029; 7	https://tinyurl.com/y5ksxt6h
Coggeshall (north)	10/22/18	0.05	0.034; 4	https://tinyurl.com/y3jugynd
Nag True Color	10/22/18	0.10	0.07; 4	https://tinyurl.com/yxu4gt2o
Nag Multispectral	10/22/18	0.08	0.07; 4	https://tinyurl.com/yxtnhgz2

Table 3. Accuracy assessment and analysis (producers, users, and overall accuracy) for the salt marsh cover type mapping of sites along the south shore of Rhode Island (From Claver, 2018).

	Site	Bare	Water	Low Vegetation	Sa High Marsh	Sa Low Marsh	Meadow High Marsh	Salt Shrub	Upland	Algae	Wrack	Overall Accuracy (%)
Producer's	Quonochontaug	96.67	100.00	100.00	100.00	-	100.00	-	-	83.33	86.67	95.24
Accuracy	Ray	80.00	100.00	90.00	95.00	-	90.00	90.00	-	95.00	75.00	89.38
(%)	Latham	90.00	100.00	78.95	89.47	-	85.00	-	-	70.00	80.00	84.78
User's	Quonochontaug	90.63	93.75	96.77	90.91	-	96.77	-	-	100.00	100.00	95.24
Accuracy	Ray	94.12	95.24	100.00	79.17	-	72.00	94.74	-	90.48	100.00	89.38
(%)	Latham	85.71	80.00	88.24	68.00	-	89.47	-	-	100.00	94.12	84.78

DJI Phantom 4 Pro Oblique Video

In addition to collecting planimetric imagery, we also collected a handful of cinematic oblique videos with our Phantom 4 Pro quadcopter. A sample of these videos can be seen at the links below:

https://youtu.be/dqxQgLCiIbk https://youtu.be/3WvKTxuIPeo (note if the videos don't play with your default browser, try Chrome or Firefox).

These videos were flown manually without the use of a mission planning application that operates on a phone or tablet. For scientific studies, we'd recommend the use of a mission planning application as it would ensure complete coverage of a study site. In addition, the direction and altitude of the flight lines can be pre-programmed thus insuring data consistency.

CONSIDERATIONS FOR FUTURE WORK

For this project we were able to collect the field and imagery data over approximately 8-10 days (2 person team). While this level of intensive surveying is not feasible for large regional mapping efforts (statewide e.g), it is very economical and practical for a sub-selection of around four sites. Yearly monitoring of these sites would certainly provide a solid interpretation of the status and trends of salt marsh habitats in the State.

The delineations of salt marsh cover types at Nag and Coggeshall for this project were done by photo-interpretation and by manually analyzing the photo-signatures of the ortho-mosaics from the sUAS. However, a supervised classification of cover types (or some combination of automated and manual techniques) would increase the repeatability and consistency of these data which is a critical consideration for monitoring and discerning status and trends over time.

After some testing, the RTK system on our FireFLY6 Pro system did not produce the horizontal accuracy we were expecting (+/-50 cm). If we were to fly these study sites again, we would place traditional ground control targets and utilize RTK GPS equipment prior to flying these sites. Such ground control during imagery processing would increase our horizontal and vertical accuracy substantially.

The multispectral image data are critical for interpretation of salt marsh cover types and the lack of these data at Coggeshall made for more difficult photo-interpretation particularly when discerning vegetated vs non-vegetated areas of the marsh. In addition, the multispectral data are less susceptible to glare reflecting off of water bodies and are vastly superior when interpreting vegetation extent and types. The true color imagery we collected had more variable color throughout the ortho-mosaic, which is very noticeable for the two imagery datasets collected at Coggeshall. The October 7 acquisition was done with overcast skies and during the growing season, while the October 22 acquisition was done under sunny skies and near the end of the growing season. This variation and the lack of additional bands in the traditional true color imagery, despite its higher spatial resolution, made it more difficult to interpret salt marsh vegetation. However, true color imagery is still useful for accuracy assessments due to its higher spatial resolution.

After the field season for this project closed, we explored other approaches to how we might have been able to collect multispectral imagery at Coggeshall Marsh. We found a custom 3D-printed solution[9] that allows us to mount a multispectral MicaSense RedEdge camera onto a DJI Phantom 4 Pro. We purchased the integration kit and have since used it at Napatree Point in Westerly, RI with great success. The system allows for simultaneous true color and multispectral image data collection at the cost of reduced flight times of 12 to 15 minutes. We believe that this system may work well at 200ft AGL.

REFERENCES

Claver, J. 2018. Mapping Salt Marsh Land Cover Using Unmanned Aerial Vehicle Imagery of Southern Rhode Island Coastal Ponds. Major paper submitted in partial fulfillment of the requirements for the degree of Master of Environmental Science and Management. University of Rhode Island, Kingston, RI.

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FIGURES

Figure 1. sUAS field set up for the FireFLY6 PRO.

[9] More information about this integration kit is available at https://skyflightrobotics.squarespace.com/phantom/4/pro/micasense/rededge/camera/intergration/kit.