Precision Counting of Sandhill Cranes in Staten Island by FAA Approved Small Unmanned Aerial System Night Missions

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Abstract

One important challenge for Sandhill Crane conservation is the collection of regular, accurate counts of birds roosting in flooded areas at night. Estimates of roost site numbers are an important way to track population size over time and detect any changes in site selection that may be a function of management or changes in site conditions. Traditional methods for estimating roosting crane numbers are morning and evening counts of cranes as they arrive at or depart their roosting sites. The accuracy of these counts however is often hampered by poor visibility in foggy and/or low light conditions, variations between observers, difficulties in accurately estimating the number of birds when many are flying to or away from the site, and difficulties in pinpointing specific locations where birds are roosting. Use of small unmanned aerial systems (sUAS) equipped with infrared cameras provide a promising alternative for developing more accurate estimates of roosting population numbers efficiently and more frequently, as well as a method of mapping specific roosting locations relative to habitat features. sUAS could also assist in surveying new areas for roosting cranes, as even though these birds are often traditional, they are known to colonize new areas if habitat conditions are suitable. This paper presents a case study on how to get approval from the Federal Aviation Administration (FAA) for night flight missions, how to decide the mission parameters and timing, as well as initial post-processing workflows. From 11 night missions performed, we also will share in this paper our findings and lessons learned.

INTRODUCTION

The use of sUAS has grown significantly over the past several years as cameras and aircraft become more commonly available. The potential that they represent, providing on-demand high resolution imagery for remote sensing, has driven their adoption in research domains from archeology to wildlife conservation. However, as this new technology is adopted, there remains significant challenges for regular deployment and reliable measurements (Stark & Chen, 2016b). As early as 2006, researchers have investigated the use of sUAS for wildlife research to replace costly manned aviation expeditions (Jones, Pearlstine, & Percival, 2006).

In the case of the migratory Sandhill Crane, accurate counts of their roosting numbers are critical for conservation efforts. Their roosting sites in the Sacramento-San Joaquin River Delta are constantly threatened by human encroachment, changes in farming techniques and variable water usage rates. As the birds are only stationary at night, the current methods for estimating numbers involve on-site visual counts, in the early morning or evening. The combination of weather, low-light conditions, variations between volunteer observers and other difficulties pinpointing exact counts leads to a wide-range of errors. The potential exists for underreporting, missing roosting sites, or failure to detect site trends, all of which may hamper further conservation efforts.

A potential solution exists in the use of a sUAS with a thermal infrared (TIR) camera. TIR cameras measure infrared energy in the far infrared wavelengths (3 μm to 15 μm) and can be calibrated to provide a temperature measurement. Over the past several years, researchers have begun to utilize TIR cameras on sUAS for a variety of applications such as search and rescue, and in agriculture (Stark, Smith, & Chen, 2014). A sUAS could be flown at night while the Sandhill Cranes are roosting, and use a thermal infrared camera to identify the birds on the water, where the birds primarily roost. The temperature differential between the cranes and the water has been previously demonstrated, providing enough contrast to count (May, 2014). However, the use of small rotary-wing sUAS provides approximately 20 minutes of flight time, not enough to provide coverage for an effective census count. It has become important in the past several years to identify methods to improve optimization of sUAS-based remote sensing (Stark & Chen, 2016a). In this paper, a case study on the use of a small fixed-wing sUAS equipped with a thermal infrared camera is presented.

This project targeted the use of a sUAS for the identification of Sandhill Cranes through the use of a thermal infrared camera at the project site on Staten Island within the Delta. Four specific issues were identified as primary challenges to the successful completion of the project: Obtaining legal authorizations for flight operations at night, developing an effective methodology, determining the optimal data collection process and determining the optimal spatial resolution. The rest of the paper discusses each of these issues in detail, followed by a discussion of best practices and lessons learned.

FLIGHT OPERATIONS AT NIGHT

sUAS flight operations at night has been of increasing interest in the past couple of years. While the FAA typically prohibits the operation of sUAS at night, there are two processes in which an applicant may petition to enable it. The new regulations in 14 CFR 107 also known as Part 107, introduces a waiver process that a sUAS operator may present a safety case to the FAA for authorization to conduct sUAS flights at night. Similarly, Public Agencies are permitted to apply for a Certificate of Authorization (COA) that may include legal permissions to fly at night. Both processes require a significant effort on providing a safety case that the flight operations do not impact the safety of the national airspace system (NAS) nor does it pose a risk to any person or property on the ground. A detailed analysis of the process of obtaining authorization for flight operations at night can be found in (Stark, Smith, Navarrete, & Chen, 2015).

EXISTING REGULATIONS AND RELEVANT STATUTES

The regulations for manned aviation flight operations provide an effective starting point for addressing an effective safety case. A sampling of relevant statutes can be found in Table 1 from Title 14 of the Code of Federal Regulations (14 CFR). The regulations are focused around two major themes, visibility requirements and personnel requirements. The latest regulations 14 CFR 107 introduced a standardization of anti-collision lights (visible to 3 statute miles) and the waiver process that can be used for civil flight operations at night.

Table 1: Relevant Statutes for Flight Operations at Night.

Statute	*Description*	*Notes*
§23.1385	Position Light System Installation	Applicable for sUAS Operations
§23.1387	Position Light System Dihedral Angles	Insufficient for sUAS operations. Dihedral angles should be expanded to 170° and tail light should be visible 360°
§23.1395	Maximum Intensities in Overlapping Beams of Position Lights	Insufficient for sUAS operations. Overlapping beams is necessary for orientation estimation.
§61.57 (b)	Recent Flight Experience	Applicable for sUAS Operations.
§107.29 (b)	Daylight Operation anti-collision lighting system	If operating during civil twilight, the aircraft must have anti-collision lighting visible to a distance of 3 statute miles.
§107.200	sUAS Waiver Policy and Requirements	Specifies the process to petition for a waiver for authorization for flight operations at night.

SAFETY CASE

The proponent must make a safety case to the FAA to petition for authorization to conduct flight operations at night. There are two major components to this safety case: Meeting necessary visibility conditions and implementing adequate operating procedures.

The sUAS must not only be visible to the operator, but to any potential intruding air traffic. The aircraft must be shown to be compliant with the regulations from Table 1 to meet this condition. However, this is not the only visibility requirement. Procedures must be documented and implemented to address any safety hazard that may arise when the lighting system fails or is insufficient. Mitigation strategies and other means of operational control must be documented. This may include requiring the area be fully secured before operation, the marking of any potential aircraft hazards and additional visual observers to monitor the aircraft and any other intruding aircraft.

PROJECT METHODOLOGY

The use of a TIR camera for the purposes of counting Sandhill Cranes has been previously demonstrated (May, 2014). However, in order to conduct a complete survey, the sUAS must cover larger areas. The goal of the project is to provide accurate survey counts in an area of greater than 3000 acres. The smallest area of coverage of value must be comparable to the existing field counts, done on plots which range from 100 to 500 acres. In order to cover this size of area, a fixed-wing sUAS was selected. In previous operations, it has demonstrated a capability to cover 1000 acres flying at 700 ft per flight, providing camera imagery at a 3" resolution. However, existing thermal cameras contain a 0.3MP sensor, or 3% that of a 10MP camera, and a narrower Field of View (FOV). Flight path adjustments must be made to cover the largest acreage while still providing the desired project goals.

The sUAS selected for this project is a custom-made battery-powered sUAS platform with a 7 ft wingspan and a total flight weight of 12 lbs. The aircraft has a total flight duration of 60 minutes, with a safe boundary of 30-minute mission time. It was designed to fly between 700 ft and 1300 ft and cover 1000 acres per flight. It was equipped with an ICI 9640P TIR camera and a payload computer provided by the TIR camera manufacturer. The camera has an image resolution of 640 x 480 pixels and is sensitive enough to measure temperature to 0.03° F.

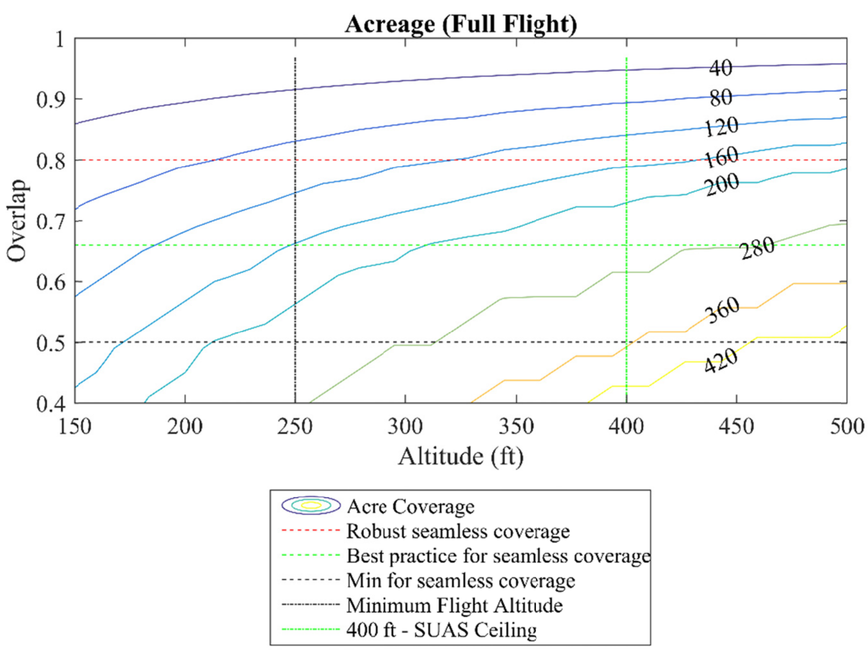

Figure 1: Flight coverage as a function of flight altitude and overlap ratio.

While the temperature resolution is sufficient, the low image resolution is a significant challenge. At a flight altitude of 400 ft and using the stock lens with a FOV of 44 x 33, the resulting image ground resolution or ground sampling distance (GSD) is 6 inches. This resolution is sufficient to detect an object of 2 ft, but not sufficient for accurate size measurements. At altitudes below 400ft, the coverage area dramatically decreases (Figure 1). Image overlap ensures that there is sufficient coverage between pictures for orthophoto reconstruction. In many flight operations, best practice is to ensure that each spot on the ground is imaged in at least 9 images which corresponds to 0.66 image overlap ratio (2/3rds of each picture is repeated both vertically and horizontally). Under these parameters, the fixed-wing sUAS is able to cover between 120-180 acres with robust coverage or up to 260 acres with best practice coverage. However, in practice, due to high wind conditions, robust coverage parameters were chosen, limiting coverage area.

A total of 11 flights were conducted on between October 2014 and March 2015: Two flights took place on October 5th, one on October 19th, one on November 13th, three on November 16th, two on December 18th, 2014, and two on March 5 2015.

NIGHTTIME FLIGHT OPERATIONS

The six flights conducted in November and December of 2014 generated the best data and are summarized in Table 2. The average flight time was 43 minutes, including roughly 27 minutes of mission time. Other air traffic in the site was minimal and there was no threat of intruding air traffic.

Table 2: sUAS Nighttime Flights in 2014.

Flight	*Date*	*Start Time*	*Flight Time*	*Mission Time*	*Images*	*Sunset*	*Air Temp*
Flight 1	Nov 13th, 2014	7:20 PM	0:38	0:23	413	4:55 PM	59° F
Flight 2	Nov 16th, 2014	6:50 PM	0:46	0:35	634	4:53 PM	58° F
Flight 3	Nov 16th, 2014	8:30 PM	0:47	0:31	687	4:53 PM	54° F
Flight 4	Nov 16th, 2014	10:02 PM	0:44	0:29	413	4:53 PM	46° F
Flight 5	Dec 18th, 2014	9:52 PM	0:42	0:18	507	4:47 PM	51° F
Flight 6	Dec 18th, 2014	11:26 PM	0:41	0:28	593	4:47 PM	49° F

BIRD DISTURBANCE

The birds were disturbed by the presence of the sUAS, though no determination on whether they are disturbed by the sUAS lighting system or the sound. Launches were more successful at distances greater than 100 meters from the desired plots and launching away from the roosting sites.

The initial flights at 400 ft disturbed the birds moderately, although it did not appear that the cranes were flying off. Smaller geese were more commonly seen flying off after being disturbed. Flying at a lower altitude was attempted on flight 5, on Dec 18th, in which the flight altitude was initially reduced to 250 ft, however, it was observed that it was disturbing all birds significantly. The altitude was increased for the remainder of the flight, and the second flight was delayed to allow the birds to recover.

THERMAL IMAGE ANALYSIS

Examples of the imagery collected during these flights can be found in Figure 2 and Figure 3. The imagery depicted several successes and several challenges. In the following figures the contrast has been artificially adjusted for visibility.

The first sUAS nighttime flight on Nov 13th, 2014 was conducted at 7:20 PM, only a short time after sunset and only minimally after twilight. This resulted in poor imagery as seen in Figure 2. The ability of the TIR camera to detect and identify birds relies on the temperature contrast between the water and the birds. During the day, the water in the flooded fields will be warmed from the sun, and will slowly cool at night. The smaller objects such as vegetation and the birds will cool with the ambient air temperature and the soil will cool rapidly due to evaporative cooling.

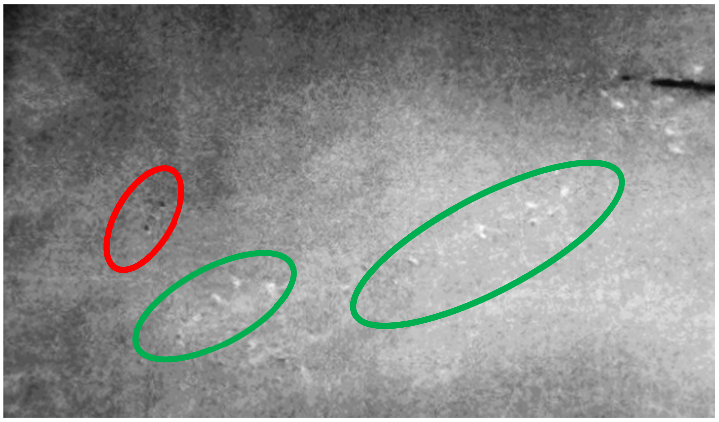

Figure 2: Thermal imagery from Nov 13th, 2014. Birds appeared as both colder and warmer than the surrounding water.

However, if the ambient air temperature is a similar temperature to the water, the birds become challenging to detect. In Figure 2, birds appear as colder as well as warmer than the water. When the birds are disturbed, their observable body heat is slightly elevated due to movement and exposure of areas covered by wings while at rest. This scenario is not satisfactory for detection or identification purposes as it decreases the observability of the birds. The spatial temperature variability of the water is also apparent in Figure 2, which further complicates the detection process.

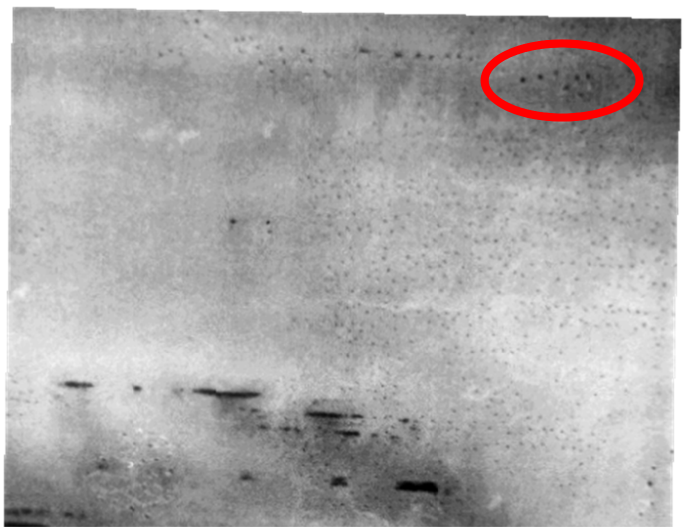

Figure 3: Thermal Imagery from Nov 16th, flight 3. Circled in red are a set of cold dots that could be either large birds or small clumps of vegetation. The resolution is insufficient to make an identification.

The relative small size of the birds is still an issue as evidenced in Figure 3. While there are clearly many birds in the image, it becomes challenging to distinguish them from soil and vegetation. Circled in red five large dots that may or may not be birds or clumps of vegetation or soil. In this picture, the spatial temperature variation may be linked to water depth or water flow.

The collection of the thermal imagery was successful, however there are several challenges need to be overcome. In the imagery, birds are visible when the temperature contrast is significant enough. Flights done early in the evening before the ambient air has cooled result in a poor temperature contrast. The small size of the birds in the imagery due to poor spatial resolution introduces significant challenges in bird detection and prevents successful bird identification. The water exhibits significant temperature variation that will also challenge bird detection. In a following section, a simple bird detection algorithm is presented to demonstrate the feasibility.

THERMAL IMAGE ORTHOMOSAIC

While the imagery demonstrated the ability to detect birds and the sUAS provided adequate overlap, the lack of regularly spaced features introduced a significant challenge in generating a seamless orthomap.

The first set of sUAS nighttime flights were designed as described previously to ensure significant overlap in anticipation of generating seamless maps with commercially available software. While the images are all tagged with GPS and orientation information, the data is not always accurate due to a variety of issues. Compensation for these inaccuracy utilizes image feature recognition and fitting to solve for the correct locations as well as correct for surface elevation. However, as much of the desired target area is water with sparse vegetation and features, the use of an automated feature-based stitching algorithm was unsuccessful as seen in Figure 4. Several commercially available stitching software was evaluated including Agisoft Photoscan, Pix4D, EnsoMosaic, DroneMapper, Microsoft ICE, Kolar Autopano, and Hugin. The processing found in Figure 4 took 13 hours of processing to generate, and similar processing times were experienced with the other commercially available software. The combination of the lack of features and the significant processing time indicated that a fully stitched image was likely infeasible under these constraints. It should be noted that there is nothing inherently challenging to stitching thermal imagery. The failure of the stitching experienced is due to the lack of features found in the covered area.

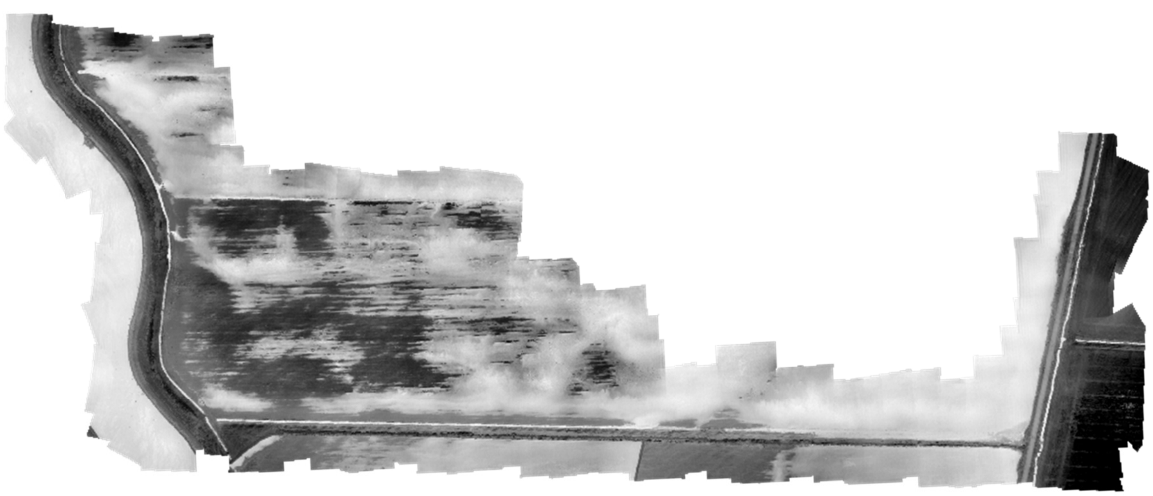

Figure 4: Attempted feature-based stitching of the imagery from flight 3 on Nov 16th.

As a result of the failures of the automated processes, a simple script was developed to generate a KML file (a file containing georeferenced data and map overlays) that overlaid each image using the GPS and orientation information without applying any fitting. The result can be seen in Figure 5. The result was generally successful when the aircraft was level and flying with minimal disturbances and also enabled clear visual confirmation of that the imagery collected was seamless. The greatest advantage of this process is that it can be generated quickly (under 5 minutes) and possibly in the field for data collection verification. As each image is processed separately, the process can be streamlined with parallel computing and additional capabilities such as the implementation of a bird counting algorithm could be accomplished easily as introduced in the following section.

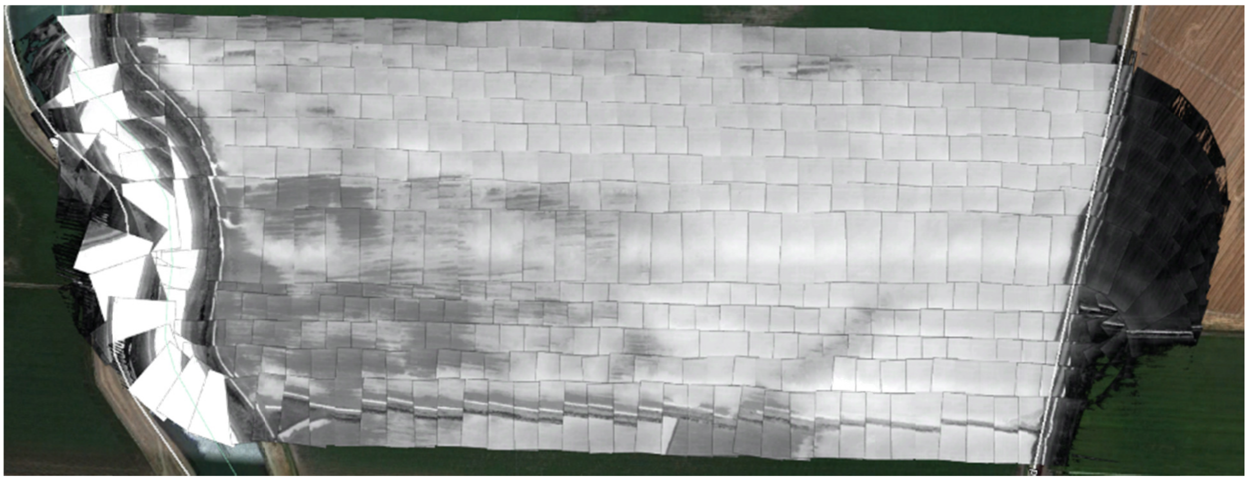

Figure 5: Overlaid images from flight 3 on Nov 16th.

The use of the overlaying image process provided a feasible solution to visualizing the thermal imagery, however it does not provide an accurate orthomap. The advantages of fast processing and the potential for parallel computing may make it a more efficient process than stitching. Better results could be obtained by applying *a priori* knowledge constraints such as aligning the roads, however, due to the lack of features, it may be hard to implement across all images.

BIRD DETECTION ALGORITHM

The process of detecting and counting birds in the collected thermal imagery is challenging, but doable. A simple bird detection algorithm was developed, but additional challenges were revealed. Figure 6 depicts a sample result from the bird detection algorithm. While some birds were obvious, many appeared simply as small round dots. Looking at the temperature difference was unreliable as well. The temperature difference between the birds and the water at the time of flight is roughly 4° F. The vegetation is slightly colder than birds, but within a margin of 2° F. While many of the spots were detected, it is difficult to determine the accuracy of the algorithm due to the poor resolution of the images.

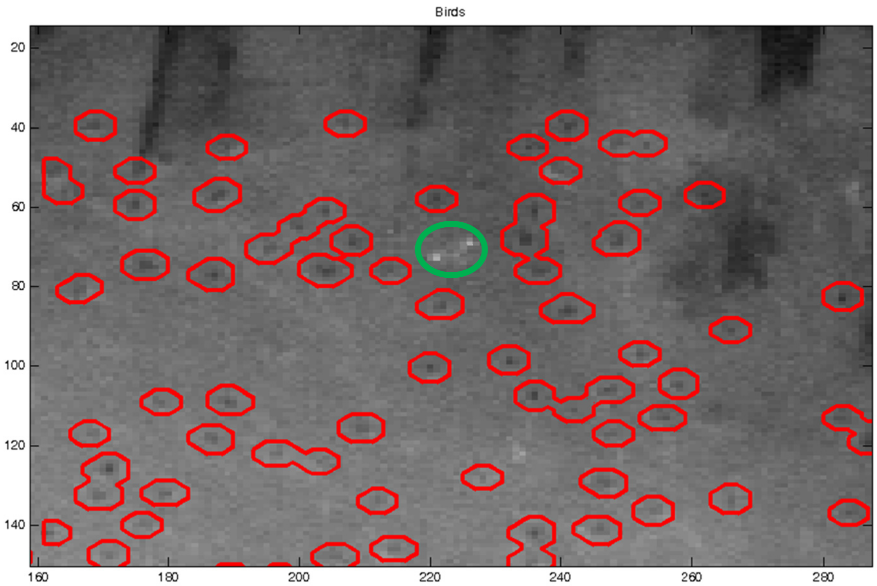

Figure 6: Results of the bird detection algorithm.

Zooming in on the image, the bird counting algorithm demonstrates that it can circle the small black dots that we are assuming to be birds. It did miss the bird in the center of the image, circled in green. This is because at the time of the image, the bird had spread its wings, releasing trapped heat, and thus appearing as a warm spot instead of a cold spot.

Birds are still difficult to see due to the contrast of the image. However, as described previously, contrast is a human eye limitation, not a sensor limitation. Figure 7 depicts a comparison between the original contrast map and an enhanced contrast map.

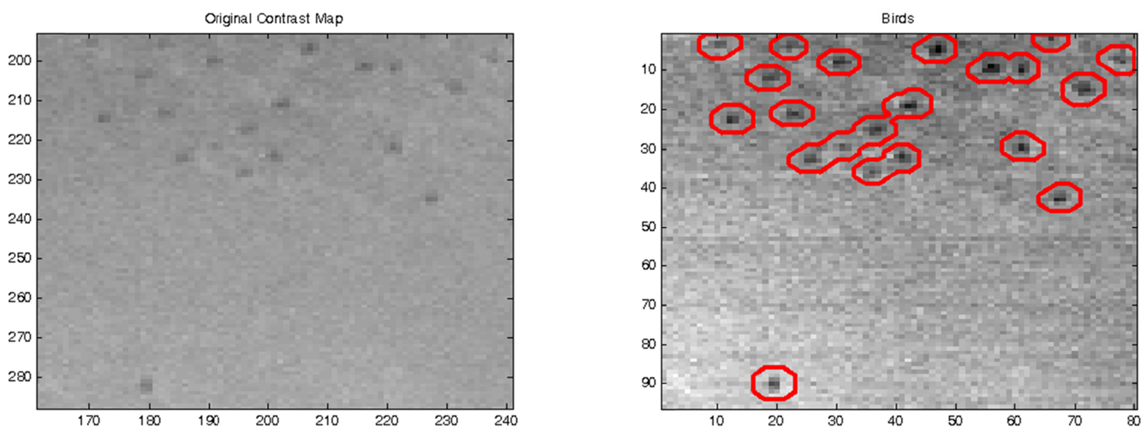

Figure 7: Comparison of original contrast map and enhanced contrast map.

DATA VISUALIZATION

The use of a fully stitched orthomap was unlikely due to the challenges previously described. However, the bird detection algorithm could be applied individually to each image. Rather than counting all the birds in the area, the following approach could be used to estimate the population by generating a bird distribution map.

Figure 8 depicts the spatial distribution of the detected birds across the imagery in flight 3 on Nov 16th. The number of birds detected in each image is proportional to the size of the red dot. While the bird detection algorithm is not perfectly accurate, it enables a spatial view of the bird populations and relative population size.

The small size of the birds and the limited contrast in temperature between the birds and the water introduces significant challenges in automatic detection of birds. A simple coarse algorithm was developed to demonstrate the feasibility of an automatic detection of birds, however the current algorithm is far from accurate. The similarity in temperatures between birds and vegetation necessitates the use of an object detection algorithm rather than a thresholding approach. Compounding the challenge is the small size of the birds, often on the order of 3-6 pixels that are easily mistakable for sensor noise or small vegetation. It is unlikely that the current resolution of the imagery is sufficient for species identification, though a more refined algorithm may be capable of better bird estimates. The spatial and temporal temperature variation in the water is apparent in the aerial imagery and introduces further challenges, however it may also provide information on water depth.

The spatial visualization of the number of birds detected in each image could be further improved upon to generate high quality population estimates.

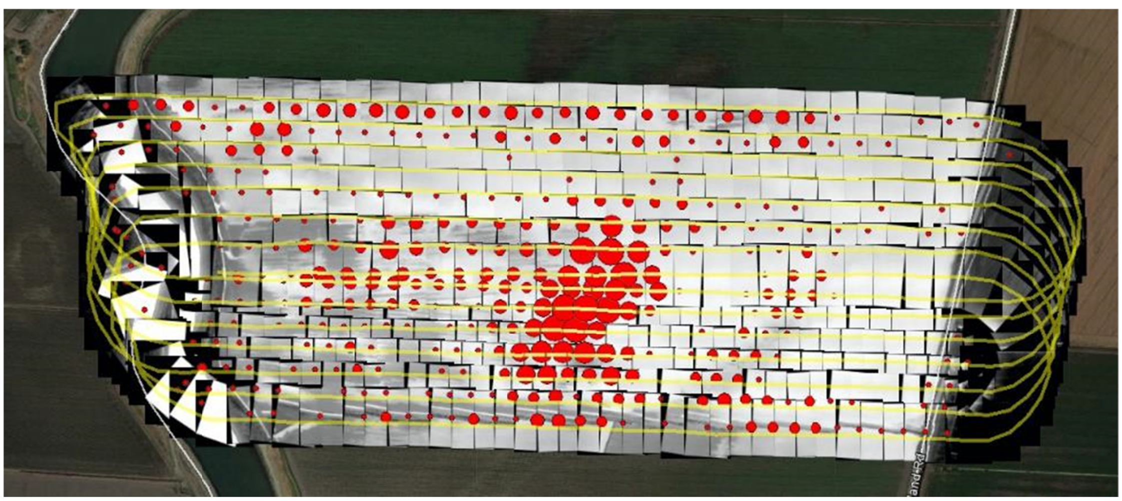

Figure 8: Spatial distribution of bird counts per image from flight 3 on Nov 16th. Bird counts were estimated with automatic detection algorithm.

OPTIMIZING TIME OF DATA COLLECTION

Previous data collection depicted a temperature difference between roosting birds and the surrounding environment in which the standing pools of water had a warmer temperature than that of the roosting birds. However, the temperature of the birds was unknown and the thermal effects of the standing water was unmodeled prior to the project. The understanding of the temporal and thermal characteristics proved to be an important aspect to the successful completion of the project.

Given the logistical challenges and the time constraints of collecting thermal imagery, an investigation into the optimal time to take thermal imagery is recommended, however it is outside the scope of this project. In the following section, some observations and correlations are presented to guide potential future investigations.

TEMPERATURE CORRELATIONS

The temperature contrasts between the birds, water, soil and vegetation are paramount to the project's success. A sampling of the various temperatures found during the flights as measured by the TIR camera can be found in Table 3. The average temperature of positively identified objects (typically 3-5 instances per image) was compiled across 10-15 images per flight.

Table 3: Various average temperatures found during sUAS operations.

Date	*Flight*	*Ambient (F)*	*Water (F)*	*Bird (F)*	*Soil (F)*	*Max Day Temp (F)*	*Bird vs Water (F)*	*Difference (Max-Flight)*	*Start Time*
11/16/2014	2	58.0	52.17	51.43	49.25	65.00	-0.74	7.00	6:50 PM
11/16/2014	3	54.0	49.47	47.97	38.53	65.00	-1.50	11.00	8:30 PM
11/16/2014	4	45.0	50.49	48.74	46.27	65.00	-1.75	19.00	10:02 PM
12/18/2014	6	49.0	47.50	46.91	44.86	60.00	-0.59	9.00	11:26 PM

The assumption that bird temperature follows or correlates to the ambient air temperature is not validated in the data compiled from the sUAS nighttime flights. On the other hand, there is a strong correlation between bird and water temperature. These results may be indicative of poor resolution where pixel mixing between birds and the water may create an artificial correlation.

However, the temperature difference between the birds and water showed a strong correlation between the temperature difference of the daytime temperature and the temperature at the time of flight ($R^2 = 0.7749$). This matches the assumption that the daytime sun heating up the water generates the temperature contrast of the birds on the water and validates the assumption that flying later in the night will result in better contrast than early in the evening.

ANALYSIS

The temperature correlations found prompt further investigation into the optimal time for thermal data collection. Intuitively, the warmer the day is and the colder the night is, the better the temperature contrast between the birds and the water. However, there does not seem to be a strong correlation between ambient air temperature and the bird temperature as was previously assumed.

Additionally, the thermal capacitance of the flooded fields is likely also influenced by the size of the pooling of water. The river on either side of the island had a significantly higher temperature than the standing water in the pool. It could be assumed that the thermal imagery process of detecting birds may not be effective in small areas of water or in areas that do not get significant sunlight.

IMPROVING RESOLUTION FOR SPECIES IDENTIFICATION

Staten Island is host to several species of roosting birds, however, only the roosting population of Sandhill Cranes is of interest. Accurate counts of the cranes require identifying these cranes from other species of birds which may roost in the same area. Whereas daylight counts can use a variety of features such as color and body shape for species identification, the only source of information available from the aerial images is a silhouette of the birds in a sleeping position. Most common sources do not list the size of a bird in a sleeping position, leading to a lack of information that can be used to identify parameters that can be used in bird species identification.

POPULATION DISTRIBUTION ESTIMATION

To develop a data set, a population simulation was developed that estimated the size distribution of each population based on some rough initial estimates (Table 4). These initial estimates displayed a significant overlap in species size distribution, especially amongst Sandhill Crane, Canadian Geese and Tundra Swan that will make species identification difficult (Figure 9).

Table 4: Estimated Bird Species Characteristics.

Bird Species	*Length*	*Population Variance*	*Sleeping length compared to bill to tail length*	*Sleeping Width*
Crane	40 – 46”	2”	50%	8-9”
Canadian Geese	30 – 43”	3”	66%	8”
Small Geese	20 – 25”	2”	66%	7”
Tundra Swan	55”	2”	62.5%	9-12”
Mallard	20-26”	1.5”	87.5%	5”

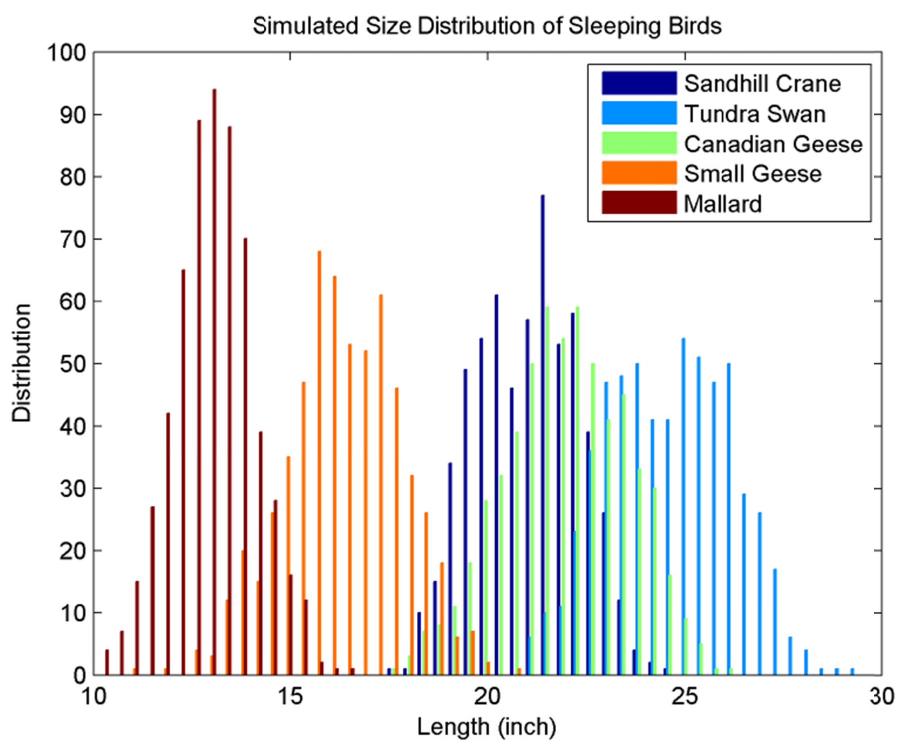

Figure 9: Simulated size of sleeping birds. The estimated simulation displays significant overlap between the Sandhill Crane, Canadian Geese and Tundra Swans that will reduce species identification accuracy.

However, it is advantageous that Tundra Swans and Canadian Geese are not common on the island. If the abundance of these birds are considered within the expected accuracy tolerance, then the degree of separation is more feasible between the large birds (Sandhill Cranes) and the smaller birds (smaller geese and mallards).

RESOLUTION ANALYSIS ON SPECIES IDENTIFICATION

There exists a narrow window for species identification physically, however spatial resolution constraints may adversely affect the process. To visualize the difference in resolution, a set of simulated images were generated: Crane / Mallard. In Figure 10, a silhouette of a Crane and Mallard are simulated and rendered at 1”, 2.5”, 4” and 6”. While they are clearly different sizes at the 1” and 2.5” resolution, they become less distinguishable at the higher resolutions.

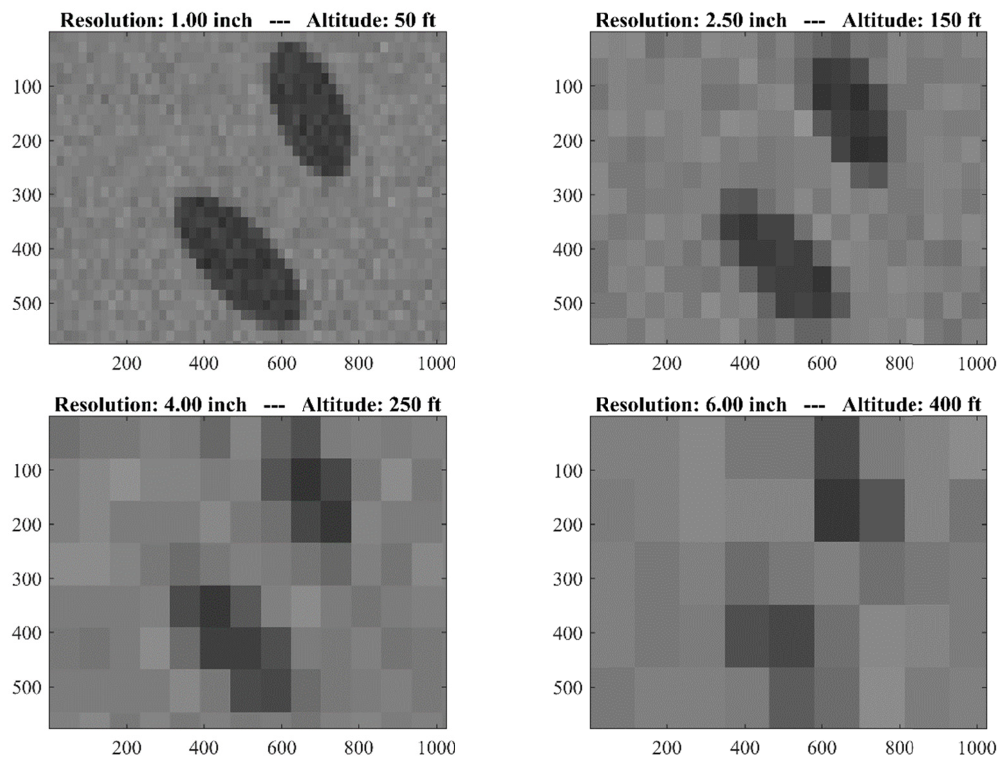

Figure 10: Set of simulated images of a mallard and a crane at different resolutions.

The relative size difference between the species of birds are not very distinguishable from a silhouette in a sleeping position. The simulations in this section demonstrate that the current 6” resolution is insufficient for any species identification. However, it is also apparent that perfect identification of the bird species in this manner is unlikely unless additional parameters are used to positively identify bird species. Bird width may be useful, however, the minute differences in bird width would require an even higher resolution to be useful.

BEST PRACTICES AND LESSONS LEARNED

Despite the difficulty of species identification, there were many successes behind the project. The project was able to obtain legal authorization for flight operations at night by developing a thorough safety case. Once airborne, the use of a TIR camera to detect roosting birds was accomplished with a fixed-wing aircraft. Though the species were unidentifiable, the work uncovered new research potential on optimizing the time of the data collection flight and identified new challenges in image processing. The challenges of the time-varying water temperatures, both due to atmospheric change and non-uniform water temperature distribution will require additional research to overcome. Through analysis of the simulated silhouettes of the bird species, it is evident that more work is necessary for species identification.

Among the lessons learned:

- The sUAS must be visible enough to enable an operator to pilot it and visible to other air traffic up to 3 statute miles.
- The sUAS must be able to fly high enough as to not disturb the roosting birds. In this project, birds were disturbed when flying at 400 ft.
- Data should be collected after the soil has cooled but before the stagnant water cools.
- The resolution should be sufficient enough to discern large roosting birds from small roosting birds, preferably with an ability to generate accurate measurements.
- The sUAS should be equipped with a TIR camera with a lens with sufficient zoom to improve the resolution while still enabling the aircraft to fly above 400 ft.

FUTURE RECOMMENDATIONS

The use of small unmanned aerial systems for the identification of Sandhill Cranes through the use of a thermal infrared camera was a challenging project. The desired coverage area was large, the birds are relatively small and thermal cameras have a very limited resolution. There may be a place for sUAS to improve the roosting counts for Sandhill Cranes, however, there remains much development to be effective and cost efficient.

Further investigation is needed on

- The optimal time to collect thermal imagery to provide the highest temperature contrast.
- Optimizing the balance between spatial resolution, coverage area and flight altitudes.
- Preventing sUAS from disturbing the roosting birds.
- Improving microscale object detection in thermal imagery.
- Developing a bird classifier for thermal imagery.

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