RESEARCH

udot.utah.gov
Utah Department of Transportation - Research Division
4501 South 2700 West - P.O. Box 148410 - SLC,UT 84114-8410

Report No. UT-12.08

EVALUATION AND DEVELOPMENT OF UNMANNED AIRCRAFT (UAV) FOR UDOT NEEDS

Prepared For:

Utah Department of Transportation
Research Division

Submitted By:

Utah State University
Utah Water Research Laboratory

Authored By:

Steven L. Barfuss
Austin Jensen
Shannon Clemens

July 2012

DISCLAIMER

The authors alone are responsible for the preparation and accuracy of the information, data, analysis, discussions, recommendations, and conclusions presented herein. The contents do not necessarily reflect the views, opinions, endorsements, or policies of the Utah Department of Transportation or the U.S. Department of Transportation. The Utah Department of Transportation makes no representation or warranty of any kind, and assumes no liability therefore.

ACKNOWLEDGMENTS

The research described in this report was supported by the Utah Department of Transportation (UDOT) and in part by mineral lease research funds available to researchers at the Utah Water Research Laboratory. The authors acknowledge the assistance from UDOT personnel Tim Ularich and Ken Berg for their support of the Southern Parkway flights. The authors also acknowledge the contributions of Bushra Zaman and Chris McGinty for their role in wetland classifications. In addition, the authors acknowledge the contributions of the UDOT Technical Advisory Committee (TAC): Mr. Michael Fazio, Mr. Daniel Hsiao, Mr. Abdul Wakil, Mr. Denis Stuhff, Mr. Rod Hess, and Mr. Terry Johnson.

TECHNICAL REPORT ABSTRACT

1. Report No. UT- 12.08	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A
4. Title and Subtitle EVALUATION AND DEVELOPMENT OF UNMANNED AIRCRAFT (UAV) FOR DOT NEEDS		5. Report Date May 2012 6. Performing Organization Code 17361G
7. Author(s) Steven Barfuss, Austin Jensen, Shannon Clemens		8. Performing Organization Report No. A22121-123500
9. Performing Organization Name and Address Utah State University Utah Water Research Laboratory 8200 Old Main Hill Logan, Utah 84322-8200		10. Work Unit No. UT-09.201 11. Contract or Grant No. 10-9119
12. Sponsoring Agency Name and Address Utah Department of Transportation 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410		13. Type of Report & Period Covered FINAL 14. Sponsoring Agency Code 5H0689H

15. Supplementary Notes

Prepared in cooperation with the Utah Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

This research involved the use of high-resolution aerial photography obtained from Unmanned Aerial Vehicles (UAV) to aid UDOT in monitoring and documenting State Roadway structures and associated issues. Using geo-referenced UAV high resolution aerial photographic imagery, the project documented the before, during and after stages of the Southern Parkway construction near the new Saint George International airport, in addition to photographing and classifying wetland plant species in the Utah Lake wetland mitigation bank on the NE corner of Utah Lake.

17. Key Words aerial imagery; unmanned aerial vehicle; plant classification; highway construction; geo-reference; photographic mosaic		18. Distribution Statement Not restricted. Available through: UDOT Research Division 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410 www.udot.utah.gov/go/research		23. Registrant's Seal N/A
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 49	22. Price N/A	

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

3D	=	Three-dimensional
AGL	=	Above Ground Level
AOI	=	Area of Interest
BBA	=	Bundle Block Adjustment
COA	=	Certificate of Authorization
DEM	=	Digital Elevation Model
DTM	=	Digital Terrain Model
ERDAS	=	Eastern Range Dispersion Assessment System (Leica Geosystems Geospatial Imaging, LLC)
FAA	=	Federal Aviation Administration
FOV	=	Field of View
FTP	=	File Transfer Protocol
GB	=	Gigabytes
GCS	=	Ground Control Station
GFoto	=	GhostFoto (AggieAir)
GIS	=	Geographic Information System
GPS	=	Global Positioning System
gRAID	=	Geo-spatial Real-Time Aerial Image Display
gVideo	=	GhostVideo (AggieAir)
IMU	=	Inertial Measurement Unit
JPG	=	Joint Photographic Experts Group (Image File Format)
KMZ	=	Zipped Keyhole Markup Language Files (Google Earth)
MB	=	Megabytes
Mhz	=	Megahertz
NAS	=	National Airspace
NAIP	=	National Agricultural Imagery Program
NASA	=	National Aeronautics and Space Administration
NDVI	=	Normalized Differential Vegetation Index
NIR	=	Near Infrared

RC	=	Radio Control
RGB	=	Red-Green-Blue
SITLA	=	School and Institutional Trust Lands Administration (State of Utah)
SOW	=	Scope of Work
TIFF	=	Tagged Image File Format
UA	=	Unmanned Aircraft
UAV	=	Unmanned Aerial Vehicle
UDOT	=	Utah Department of Transportation
USB	=	Universal Serial Bus
USU	=	Utah State University
UWRL	=	Utah Water Research Laboratory
VTOL	=	Vertical Takeoff and Landing (AggieAir)

EXECUTIVE SUMMARY

This project has focused on improving the performance and assessing the applicability of using an unmanned aerial vehicle (UAV) for highway related problems at the Utah Department of Transportation (UDOT). Two specific tasks were completed during the project. The UAV was used to take aerial images before, during and after the completion of the Southern Parkway Highway corridor project and images taken by the UAV were utilized to classify wetland plant species at the Utah Lake wetland mitigation bank. During both applications, the digital images taken by cameras onboard the UAV were post-processed so that stitched and geo-referenced images could be accurately utilized in UDOT GIS databases and as a UDOT plant species classification tool.

The Southern Parkway images allowed researchers to visualize the highway construction progress, construction staging areas, and cut and fill regions. The high-resolution imagery allows for immediate updating of UDOT GIS databases, documentation and inventorying of roadway signage and other highway structures and provides a historical record of the construction. It is apparent that the UAV can become not only a tool to learn from the past, but also a real-time tool to use during the construction process. It is expected that if an UAV were allowed in the future to traverse a construction zone at regular intervals during the construction process, additional benefits like determining the best methods for passing traffic safely through the construction zone would be realized.

During the Utah Lake wetlands mitigation bank phase of the project, it was determined that *Agrostis*, Baltic rush, *Phragmites* new, *Phragmites* old, and saltgrass were the most accurately classified plant species, while beaked sedge and narrowleaf/broadleaf cattail had the lowest classification accuracy. The accuracy errors seen during the classification process may have resulted from several possible causes: an insufficient number of ground samples, insufficient number of ground control points, the need for greater overlap in the aerial images, GPS ground sample data that was too course in relation to image pixel size, that the possibility of multiple plant species in many of the ground truthing polygons, the accuracy of the seeding tool

that was used, the potential misalignment of the NIR to the RGB images, and the time in the season in which the images were taken.

1.0 INTRODUCTION

The Utah Department of Transportation (UDOT) manages several thousands of miles of roads throughout the State of Utah. This management includes an inventory of the conditions of highway features to determine possible maintenance actions, planning for proposed highway corridors and the management of ongoing road construction. Their goal is to maintain highway infrastructure in its best possible condition, to mitigate wetlands appropriately when a proposed highway will displace certain plant species and to keep construction costs and public safety at acceptable levels. Most current highway assessment methods are expensive and time consuming, and consequently UDOT personnel are interested in pursuing highway management methods that are less costly and are more time efficient.

One method that has possible application to highway management is the use of unmanned aerial vehicles (UAV), and the UAV technology was utilized in part during this study. The UAV systems that are of most interest are those that are pre-programmed to fly designated routes using "smart" Global Positioning Systems (GPS) at defined altitudes and are commanded to take photographs so that the photos can later be uploaded, stitched together and geo-referenced to ground reference points. Much of the science behind this technology is in how the photos are handled after the plane lands so that they can be quickly utilized in a UDOT GIS database. An earlier USU study performed for UDOT using the UAV technology looked at inventoried culverts under Utah roadways that were capable of passing fish (UWRL 2008).

It has been proven that the UAV technology can be used to accurately define and monitor a multitude of highway issues using very high-resolution photography. These imagery data sets can then become important tools within a larger UDOT GIS database for UDOT personnel. The speed at which the images can be collected, the resolution of the images (a few centimeters), and the small relative cost of acquiring the images are all expected to be favorable to UDOT. Additionally, because images can be taken quickly and inexpensively, photos can also be taken at regular intervals to document important physical and environmental changes (that can only be seen from the air) on and near roadways over time.

1.1 UAV Technology

1.1.1 UAV Application to UDOT

Researchers at the Utah Water Research Laboratory have developed technology that will take high-resolution photographs of UDOT infrastructure and potential highway corridors from an unmanned aircraft (UAV) that is guided by satellite and given a predetermined course. This technology could potentially provide much of the information needed to inventory highway features, monitor ongoing road construction, evaluate existing road conditions, and classify plant species that may be removed when a future road is constructed. Additional benefits may include fast turn-around times from when the aerial photos are taken to when they are available on a UDOT GIS database. Satellite imagery is normally only updated every few years; however, geo-referenced UAV photographic images can provide high resolution aerial imagery to UDOT within hours instead of years in some cases. Other benefits include monitoring wetlands and noxious weeds along highway corridors, as well as inventorying highway structures, road paint reflectivity, bank erosion, and stream crossings.

1.1.2 The Future of UAV Technology

The potential of UAV technology described in the previous section is only a beginning. As the aircraft sensors become smaller and more accurate, the accuracy of the data collected will increase in quality and availability, while processing time will decrease. UAV platforms will also improve. Researchers at the Utah Water Research Laboratory are currently developing other UAV platforms that will fly longer and hold higher quality cameras. Other Vertical Takeoff and Landing (VTOL) UAV platforms are also being developed. These platforms will have the ability to take off and land vertically, hover, and fly at very low altitudes. The products generated from the imagery will also improve. In addition to generating orthorectified mosaics and classifying the imagery, work is being done on using the imagery and 3D photogrammetry to produce digital elevation models. Additional payloads are also being developed. Some of these include thermal imagery, air quality sensors, and radio fish tracking.

1.2 AggieAir

AggieAir is an autonomous, multispectral remote sensing platform. The purpose of AggieAir is to give more people greater access to aerial imagery in a way that is low-cost, versatile and easy to use. AggieAir requires only two people to operate it and is not dependent on a runway. The aircraft launches using a bungee, and it glides to the ground for a skid landing (see Figures 1.1 and 1.2).

Figure 1.1: Bungee Launch

Figure 1.2: Skid Landing

Figures 1.3 and 1.4 show the layout of AggieAir's components. In the front of the aircraft, the battery bays hold eight 12v batteries. These batteries supply enough power to keep the aircraft in the air for about one hour. The main bay holds the payload and the inertial measurement unit (IMU). In this case, the payload includes two cameras: one camera that takes pictures in the visual band of the spectrum and another that takes pictures in the near infrared band of the spectrum. The IMU and the GPS receiver are the aircraft sensors. They measure the orientation and the position of the aircraft, respectively. Data from the IMU and the GPS module are processed and sent to the autopilot by the Gumstix. The Gumstix is the on-board computer that not only sends data to the autopilot, but also controls the cameras and other payloads. While receiving position and orientation data from Gumstix, the autopilot navigates the aircraft according to a preprogrammed flight plan. The autopilot navigates the aircraft by using the elevons (to rotate) and the propeller (to accelerate). The winglets also help to navigate the aircraft by adding extra stability around the z-axis. Data collected from the autopilot such as position, orientation, status, etc. (telemetry) is transmitted through a wireless modem to the ground control station (GCS). Using this data, the GCS operator can watch the aircraft and give it commands. The pilot can also take manual control of the aircraft using a radio controlled (RC) transmitter. Different controls on the transmitter send different commands to the aircraft via the RC receiver. The RC receiver interprets the commands from the transmitter and moves the elevons and propeller accordingly. In addition, the pilot can use the RC transmitter to switch from autonomous flight to manual at any time.

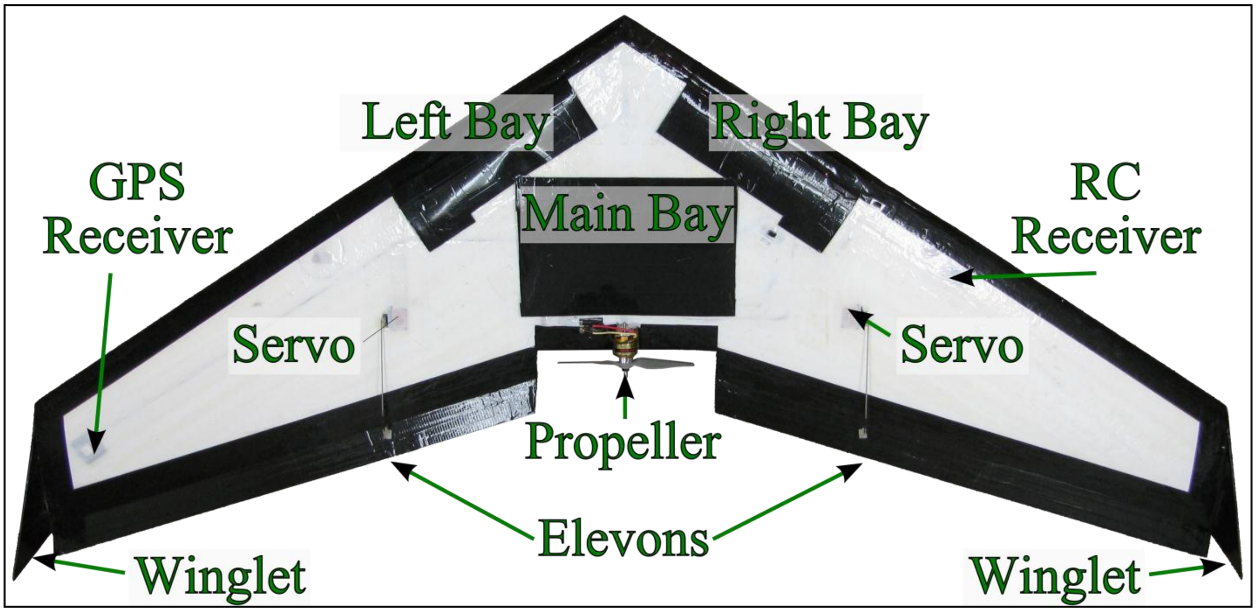


Figure 1.3: Aircraft Layout

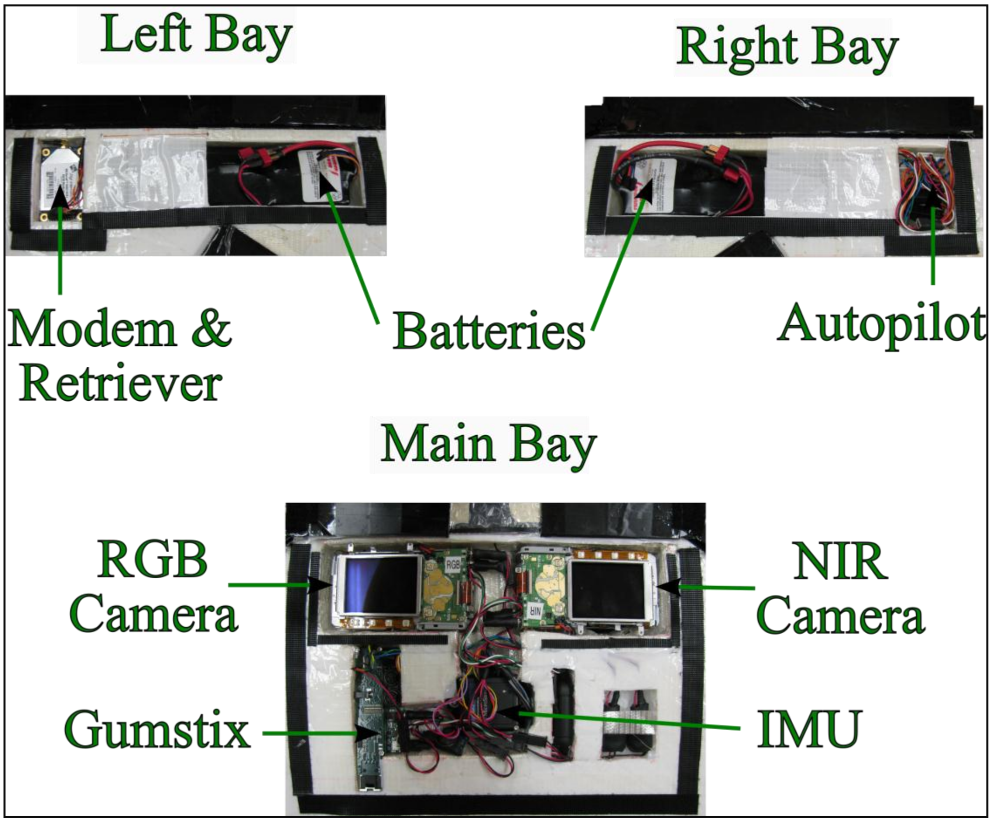


Figure 1.4: Bay Layout

1.2.1 Aircraft Payloads

AggieAir is designed to hold many different payloads; however, the only payload currently developed for AggieAir is GhostFoto (GFoto). GFoto is a Canon camera that is controlled via USB from the on-board Gumstix computer. The Gumstix tells the camera when to take a picture and then records the aircraft position and orientation. GFoto also sends status messages down to the GCS so the operator can make sure everything is functioning correctly. After the flight, the images and a datalog can be downloaded from the aircraft into the Geo-spatial Real-Time Aerial Image Display (gRAID) plug-in for World Wind. gRAID orthorectifies the images with the respective telemetry data and displays the images on the earth. After this process, gRAID can also export the images into world files that can then be used in other Geographic Information Systems (GIS) software. GPS software can be used to increase the accuracy of the orthorectification and to make a mosaic. gRAID can also be used with another payload called GhostVideo (GVideo). GVideo uses a low resolution video camera to send streaming video down to the ground station through a video transmitter. On the ground, gRAID is used to orthorectify the video stream with the telemetry data and display the images in real-time. One problem, however, is GVideo's low resolution and contrast, which produce low quality images. Another drawback is that the aircraft must always be within communication range to receive the images.

1.2.2 Ground Station Equipment

Figure 1.5: AggieAir Ground Station

Figure 1.5 shows the ground station used to operate AggieAir. The trailer has tables for working on the aircraft, cabinets for storing the equipment, mounts for antennas, and a generator to power the equipment and charge batteries. The trailer also provides heating and cooling for the aircraft and crew.

Figure 1.6: Ground Station Equipment: (a) backup box, (b) RC transmitter, (c) toughbook computer, (d) tools, (e) battery charger, (f) GPS receiver, (g) two way radios, (h) 900Mhz antenna, (i) 900Mhz modem, (j) tracker, (k) bungee

Figure 1.6 shows additional ground station equipment. The following list describes the equipment functions.

1. The backup box is used to store extra batteries and extra parts for the aircraft. If a part goes bad on the aircraft, the equipment from the backup box can be used to replace the bad part.
2. The RC transmitter is used by the pilot to take manual control of the aircraft if needed.
3. The toughbook computer contains the ground station software and is used to monitor the aircraft during flight.
4. Basic hand tools are used to perform maintenance on the aircraft if needed.

5. Battery chargers are needed to recharge batteries after they have been used in order to fly the aircraft multiple times.
6. A handheld GPS receiver is used to record takeoff and landing locations for the flight plan.
7. Two way radios allow the GCS operator to talk with the pilot.
8. The 900 Mhz antenna and modem plug into the ground station computer so the computer can monitor and talk with the aircraft.
9. The tracker is used, in combination with a transmitter on the aircraft, to find the aircraft if it goes down during flight.
10. The bungee is used to launch the aircraft.

1.3 Research Objectives

The goal of this study was to use high-resolution aerial photography obtained from Unmanned Aerial Vehicles (UAV) to aid UDOT in monitoring and documenting State Roadway structures and associated issues. The research summarized in this report encompasses two specific objectives.

1. Use the UAV to take high-resolution photographic images to monitor an ongoing highway construction project pre-construction, during construction and after construction of the highway was completed.

2. Use the UAV to take digital photographic images in RGB and NIR in an effort to classify wetland plant species.

The funding from this project was used to investigate the applicability of using the UAV under these two objectives and to look for ways to improve the functionality and efficiency of the UAV as it applies to these UDOT applications. Several UAV flights were made at both the Southern Parkway construction project near the new Saint George, Utah airport (objective #1) and at the Utah Lake wetlands mitigation bank located on the northeast corner of the lake (objective #2).

The initial draft of the SOW for the project included another objective to fly and map the SR-6 highway corridor to update its aerial imagery after road construction. However, this project was abandoned due to some safety concerns and replaced with the Utah Lake Wetlands Mitigation Bank project. Some of the safety concerns included distracting drivers during takeoff and landing and disrupting traffic due to our slow moving ground station.

1.3.1 Southern Parkway

The objective of the Southern Parkway project was to fly over the Southern Parkway three times over the course of its construction to evaluate the benefit of using AggieAir to gather aerial imagery multiple times during construction. The tasks associated with the Southern Parkway project were as follows:

1. Establish the area of interest (AOI) over the highway.
2. Build flight plans over the AOI.
3. Get permission from landowners to access land for takeoff and landing.
4. Work with the UDOT construction manager to determine when to fly over the highway.
5. Fly over the highway three times over the course of the construction.
6. Process RGB orthorectified mosaics for all three flights.

1.3.2 Utah Lake Wetlands Mitigation Bank

The objective of the Utah Lake Wetlands Mitigation Bank project was to fly over a UDOT mitigation wetland to map different types of vegetation. The intent was that this data could be used to help manage the mitigation wetlands. In addition, it was also hoped that the UAV technology could be used to classify wetland plant species in regions where future roads may be constructed to improve and accelerate the wetland mitigation permitting process. The tasks associated with the wetlands classification portion of this project are as follows:

1. Establish the area of interest (AOI) over the wetlands.
2. Build flight plans over the AOI.
3. Get permission from landowners to access land for takeoff and landing.
4. Work with UDOT biologists to figure out when to fly over the wetland.

5. Sample six different types of vegetation (Phragmites, Baltic Rush, Saltgrass, Hardstem, Beaked Sedge, and Spikerush) within the AOI and within a week of the flight.
6. Acquire visual and NIR imagery over the area of interest.
7. Process visual and NIR orthorectified mosaics for the wetland.
8. Process classification maps based on both visual and NIR mosaics.

2.0 RESEARCH METHODS

2.1 Overview

The following were the project's major tasks. Each of these tasks was completed for both the Southern Parkway flights and the Utah Lake mitigation bank flights.

1. Determine the geographical land area that needed to be covered
2. Prepare a flight plan for these areas.
3. Fly the UAV to collect the data
4. Process the photographs and data
5. Prepare mosaic image files that could be imported into Google Earth or GIS database.
6. Analyze the data

The following sections describe in more detail the procedure for each of these tasks.

2.2 Flight Procedures

2.2.1 Pre-Flight Preparations

For each flight, a flight plan was prepared according to the area of interest (AOI), desired ground resolution, available ground features, terrain, and available flight time. These determined the path and altitude of the aircraft to ensure coverage over the AOI and appropriate overlap between images for post processing. Each flight plan was simulated using a ground station software to work out any potential bugs.

Areas for takeoff and landing were determined. Takeoff required a clear strip of land 500 yards long and 100 yards wide. Landing required an area 500 yards by 500 yards.

Additional planning was done before the flight to determine when the flight would take place. Weather was the largest factor that determined when the flight would take place. The aircraft cannot fly in rain, snow or strong and gusty winds (AggieAir can fly in a maximum wind of 25 miles/hr). The elevation of the sun also affected flight planning. If the AOI contained any water, the cameras would capture the reflection of the sun at over 50 degrees elevation. In Utah this only occurs around solar noon during the summer. During the winter the sun does not rise over 50 degrees elevation.

After the flight plan was built and a flight time determined, the aircraft was checked by the crew using a pre-mission checklist. This took place at the Utah Water Research Laboratory and included cleaning and balancing the aircraft, testing radio connections, testing the cameras, and making sure the autopilot was functioning correctly.

2.2.1.1 Southern Parkway

Figure 2.1: Area of Interest for Southern Parkway

Figure 2.1 shows the AOI for the Southern Parkway. It was determined using a centerline for the highway (red line), which was provided by UDOT. The centerline was displayed on Google Earth Pro, and its drawing tools were used to plan the flight. Two parallel lines were drawn around the centerline such that the centerline was always contained within the two parallel lines, and the least number of vertices were used with the parallel lines. Figure 2.2 shows these two parallel lines in white. The distance between the two parallel lines was determined by the field of view (FOV) of the camera used and flight altitude above the ground. This flight required maximum resolution so a flight altitude of 600ft above ground (AGL) was used. For the camera used, the width between the two parallel lines was approximately 550ft. After the two outer parallel lines were drawn, an additional parallel line was drawn directly between the outer two. This middle line is the actual flight line of the aircraft and is displayed in green in Figure 2.2. If the aircraft follows this line, the area within the two outer parallel lines is guaranteed to be captured by the cameras during flight.

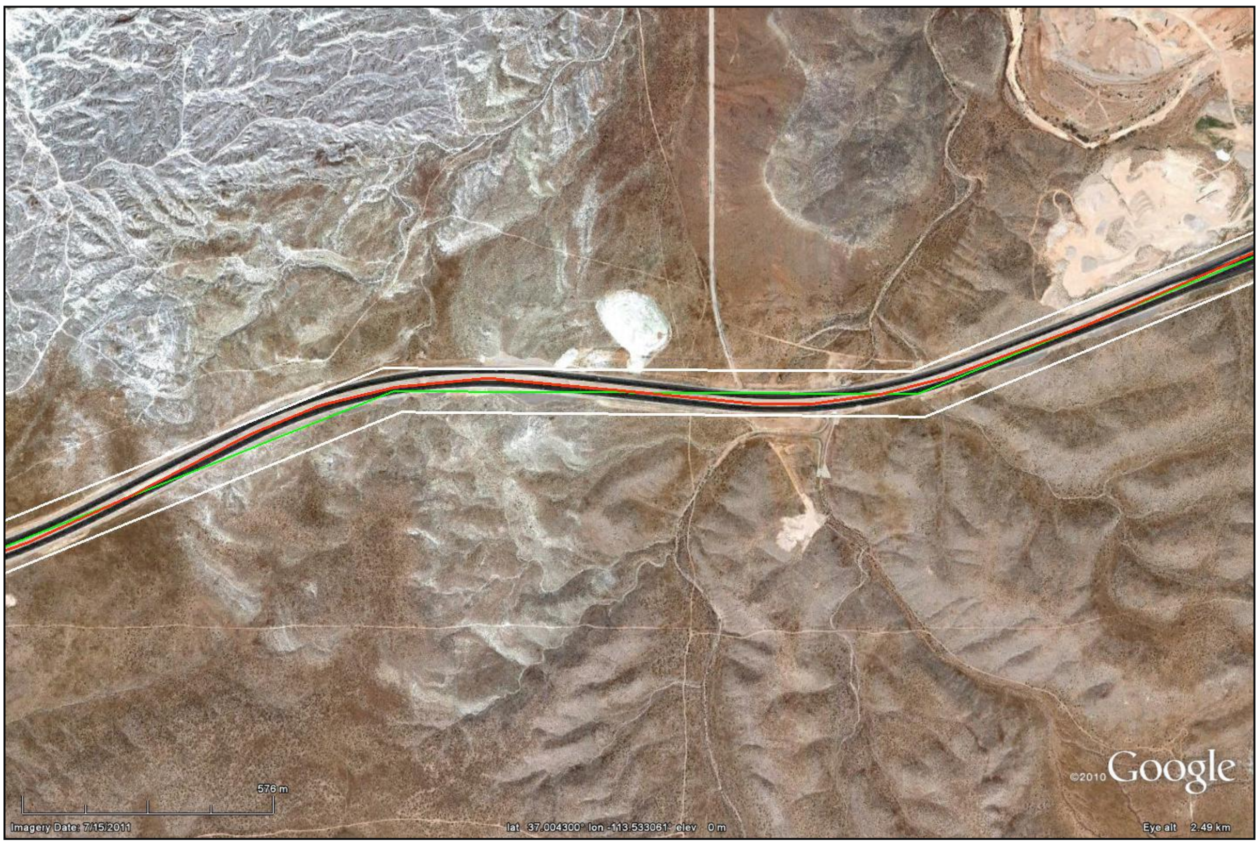


Figure 2.2: Southern Parkway Flight Planning

After simulating the flight plan, it was determined that the flight would take approximately 30 minutes to fly. This was within the flight time of the aircraft; however, there would not be enough time to fly the area and come back to the launch location. Therefore there aircraft was launched at the beginning of the flight, and followed to the end by the crew. Once the aircraft was finished, it was landed near the end of the flight line.

Planning the takeoff and landing areas was also done before the flight. The land around the Southern Parkway was open, clear and managed by the State of Utah School and Institutional Trust Lands Administration (SITLA). An area at the beginning and end were selected and approved by SITLA before the flight.

2.2.1.2 Utah Lake Wetlands Mitigation Bank

Figure 2.3: AOI for Utah Lake Wetlands Mitigation Bank

Figure 2.3 shows the AOI for the Utah Lake Wetlands Mitigation Bank (red polygon). For this area, a different flight plan was built that only required the vertices of the polygon (AOI) instead of each individual flight line. With this flight plan the aircraft automatically covered the entire area by sweeping back and forth along the area. The green lines in Figure 2.3 show an example of the flight lines automatically generated by the aircraft. The distance between each sweep was determined by the flight altitude of the UAV and the cameras used. To ensure overlap and sufficient features in the FOV of the cameras, the aircraft was programmed to fly at 1500ft. Therefore, the sweep spacing for this flight was 750ft. The simulation time of this flight plan was 20 minutes.

A large open space on the east side of the AOI was chosen for takeoff and landing. This area is owned by the city and permission was obtained by UDOT to use the area.

2.2.2 Flight Day

On the day of the flight, the crew drove the ground station to the designated takeoff area, set up the equipment, made last minute changes to the flight plan, went through a pre-flight checklist, and launched the plane. The changes made to the flight plan included the exact takeoff and landing locations and their altitudes. These locations need to be changed right before flight since the exact location of the takeoff and landing locations are not known until the crew is on site. After the aircraft was launched, it flew into a Standby mode where it loitered above the ground station so the crew could go through another checklist to ensure the aircraft was behaving correctly during flight. Once everything passed this checklist, the ground station operator sent the aircraft into the main flight plan. If something on the checklist had failed, the crew could have landed the aircraft and fixed the problem.

Once the aircraft finished the flight plan, it flew back in to Standby mode and waited for the crew to give the landing instructions. Upon landing, the crew downloaded the images and checked the quality and overlap. If there were gaps or other issues with the images, the flight plan could have been reflown before the crew left the site.

2.3 Post Processing

2.3.1 Southern Parkway

Southern Parkway was flown on three separate dates – March 3, 2010; May 26, 2010; and August 26, 2010. Color visual imagery and near-infrared imagery were captured for all three flights, however, only RGB imagery was mosaicked. Ground control points were collected in the field on July 24, 2010. The vertical precision ranged from 3.81-4.76 inches and the horizontal precision ranged from 3.62-3.86 feet.

2.3.1.1 NASA World Wind

After the UAV had completed a flight mission and successfully landed, JPG imagery and flight information was downloaded from the cameras and GPS unit. The imagery was captured approximately every four seconds, while a positional coordinate and roll, pitch and yaw were recorded for each frame. This imagery information was entered into NASA World Wind, which is a customizable geographical information system. Flightlines were arranged by headings, and necessary flight images were exported for readability in EnsoMosaic UAV.

2.3.1.2 EnsoMosaic UAV

EnsoMosaic UAV, developed by Mosaic Mill of Finland, is an image-processing software that reads aerial images captured with compact digital cameras used onboard UAVs and processes the images into seamless orthorectified image mosaics (MoasicMill Ltd, Finland). An RGB mosaic was created with EnsoMosaic UAV. In EnsoMosaic UAV, adjoining image pairs were manually linked together with common tie points between most image pairs. Next, automatic tie point iteration was run with large residuals removed manually.

After the number of tie points was sufficient between all image pairs, the bundle block adjustment (BBA) was run. BBA is an "iterative mathematical process to solve the orientation of the images and the location of the perspective centers simultaneously for a large image block" (MosaicMill User's Guide 2009: 2). After each iteration, an estimation of the global accuracy of the image rectification, called adjustment error, was reported. Adjustment error is the mean error of unit weight, a function of all the residuals and all the weights (MosaicMill User's Guide 2009: 43). After each round of the BBA, erroneous tie points with large residuals were manually removed, and the BBA rerun. This continued until the largest residuals were deleted and the accuracy of the mosaic was considered satisfactory, which was when the total adjustment error was at its best.

After the BBA, a Digital Terrain Model (DTM) with 33-foot ground resolution was generated for orthocorrection of the mosaic (this default ground resolution is coarse). The DTM was created based on the elevation values generated for each tie point during the BBA (MosaicMill User's Guide 2009: 54). Lastly, the mosaics were created by rotating and rectifying each image to the ground coordinate system. The resulting Southern Parkway mosaics had a pixel resolution of 4 inches. Due to the large area that the final mosaics covered, the TIFF image was divided into pieces so that each piece was no greater than 2 GB in size.

2.3.2 Utah Lake Wetlands Mitigation Bank

The Utah Lake Wetlands were flown on August 24, 2011. Color visual imagery and near-infrared imagery were captured and both RGB and NIR were mosaicked. The goal of this task was to perform supervised classification of wetland species. The Utah Department of Transportation (UDOT) collected ground truthing samples of wetland species from within the Utah Lake Wetlands prior to the UAV flight. GPS ground truthing data ranged from 3-10 feet in vertical precision and 2-7.5 feet in horizontal precision. Hand drawn polygons on maps were also provided for additional ground truthing data.

2.3.2.1 NASA World Wind

After the UAV had completed its flight mission and successfully landed, JPG imagery and flight information were downloaded from the cameras and GPS unit. The imagery was captured approximately every four seconds, while a positional coordinate and roll, pitch and yaw were recorded for each frame. This imagery information was entered into NASA World Wind, which is a customizable geographical information system. Flightlines were arranged by headings and necessary flight images were exported for readability in EnsoMosaic UAV.

2.3.2.2 EnsoMosaic UAV

Similar to the Southern Parkway work, EnsoMosaic UAV was utilized to create the orthorectified mosaics. For the task of supervised classification, the RGB and NIR mosaics were both required. Each camera logged separate flight information, so RGB and NIR images could not be combined into a single EnsoMosaic UAV project.

EnsoMosaic UAV generated orthorectified mosaics as described in section 2.3.1.2. The resulting RGB and NIR Utah Lake Wetlands mosaics had a pixel resolution of 7 inches. Each mosaic created was under 2 GB so the entire site was contained into one TIFF image. The size of the RGB TIFF image was 553 MB and the NIR TIFF was 525 MB.

2.3.2.3 Calculate Reflectance Values

Reflectance values were necessary to perform quantitative remote sensing tasks such as supervised classification of wetland species. Standard digital cameras record values in digital numbers ranging from 0-255. Reflectance value conversion was performed due to different land surfaces having different responses in specific spectral bands. The reflectance is "the ratio of the radiant flux reflected by a surface to that reflected into the same reflected-beam geometry by an ideal, perfectly diffused standard surface irradiated under the same conditions" (Nicodemus et al. 1977), or the fraction of electromagnetic radiation that was reflected by the surface being analyzed.

Digital photos of a barium sulfate white reflectance panel were taken before and after the flight mission while in the field using the same RGB and NIR cameras on-board the UAV. After returning to the UWRL, reflectance factors of the white panel using the zenith angle of the sun at the time of the photo were derived using a formula from Dr. Christopher Neale. A "reflectance mode" method used by Miura and Huete (2009) with modifications aimed to reduce reflectance value conversion bias were added to this method by AggieAir Flying Circus. The goal was to derive corrected brightness values and to correct for vignetting and other non-uniformities for the digital imagery. The result of the modified "reflectance mode" method was reflectance valued images for each band – red, green blue, and NIR. The bands were then stacked in ERDAS (Leica Geosystems Geospatial Imaging, LLC) to create a single four-band image.

2.3.2.4 Supervised Classification

For the Utah Department of Transportation wetland study, a fifth band was added. This was the normalized differential vegetation index (NDVI), which is the most widely accepted vegetation index for agricultural and vegetation studies (Schmaltz 2005). It uses the red and NIR bands. NDVI is robust and requires no atmospheric correction. It also reduces the impact of sunlight intensity variations, which is ideal for post mosaic classification. Calculation of the NDVI is shown in Equation 1:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \tag{1}$$

Using ERDAS Imagine, supervised classification was performed using the ground truth points and polygons of wetland plant species provided by UDOT on the five-band reflectance image. The plant data was divided into training and testing sets. The training set was used to create spectral signatures unique for each plant species, while the testing set was used for accuracy assessment. Although some species were spectrally similar (see Figure 2.4), and by ERDAS standards could have been merged, the classes were left unmerged. Otherwise, the suggested threshold merging value of 1700 for the Transformed Divergence separability function (ERDAS Field Guide 2010) would have merged all vegetation categories subsequently into one category. See Table 2.1 for the separability matrix for the wetland plant species.

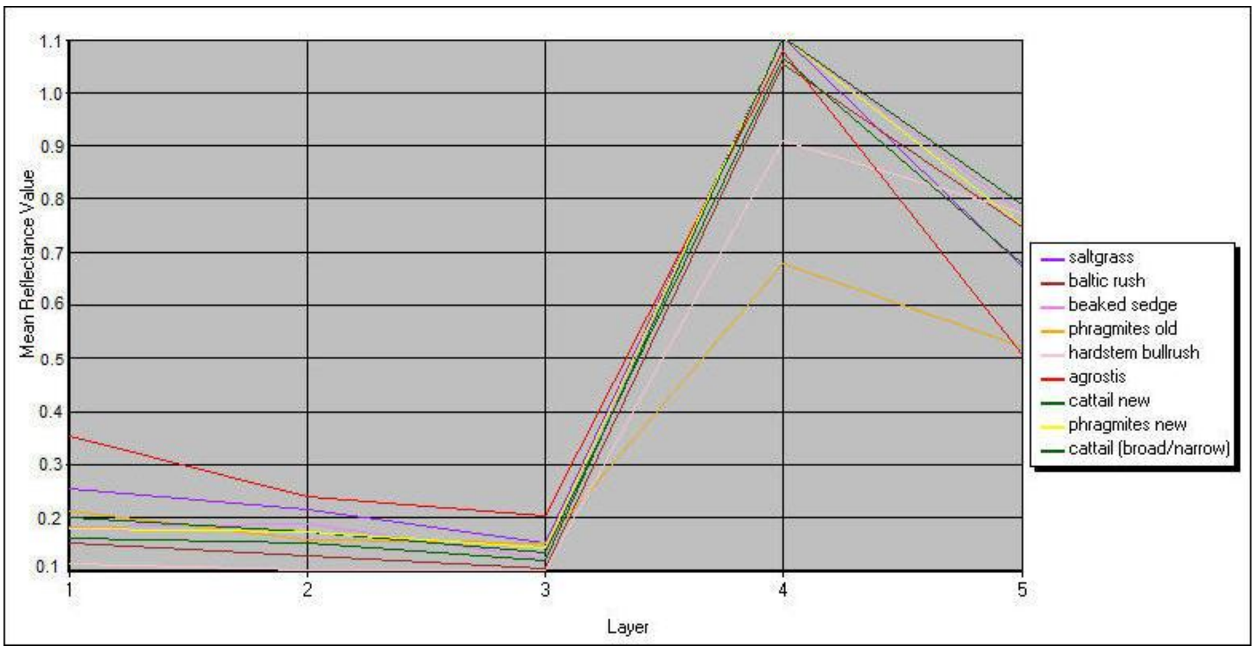


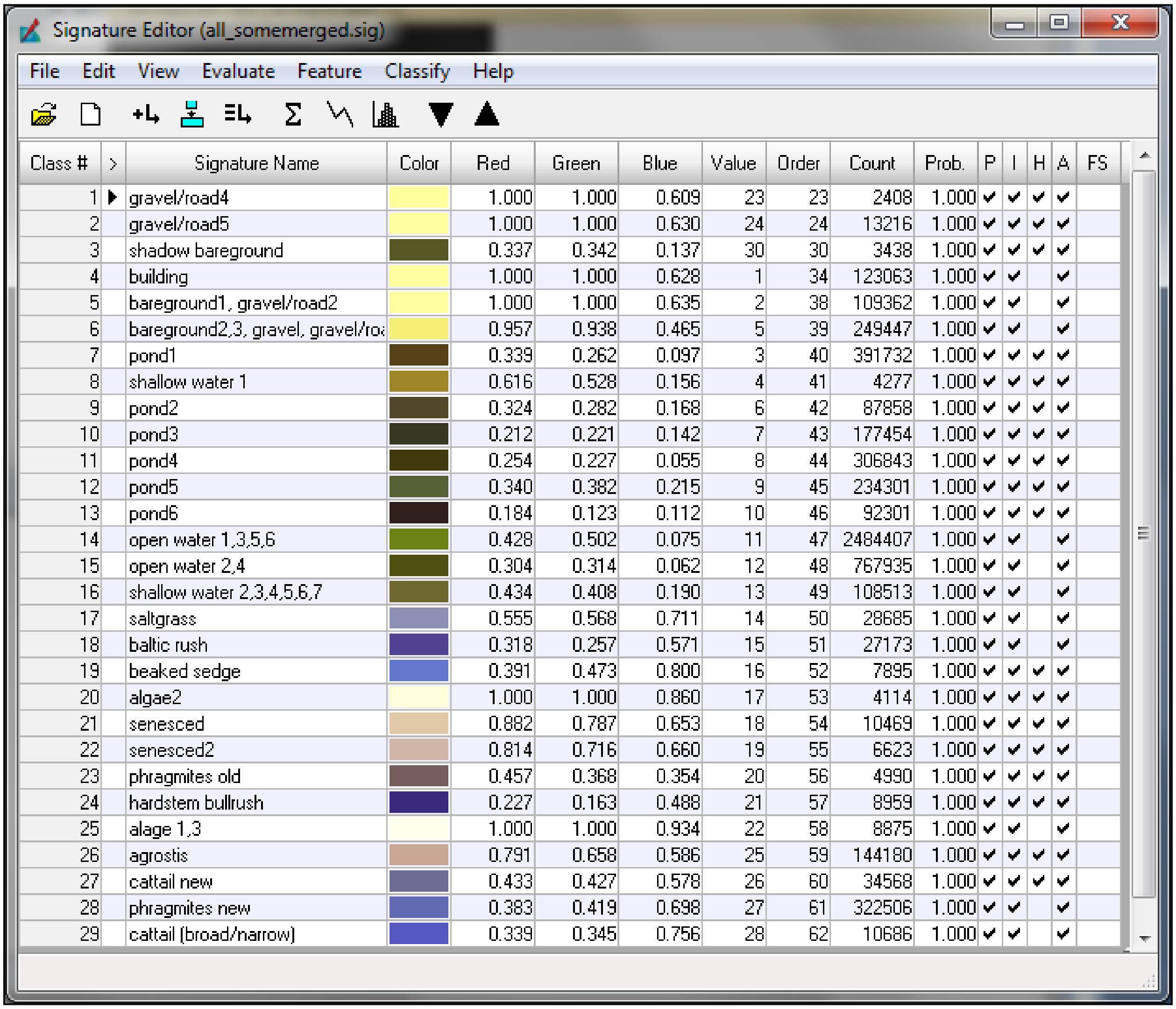
Figure 2.4: Mean reflectance value of defined wetland species used for supervised classification: red 1, green 2, blue 3, NIR 4 and NDVI 5

Table 2.1: Signature separability using transformed divergence for wetland plant species

Signature Name	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. saltgrass	0	1966.18	1642.32	2000.00	2000.00	1986.35	1678.65	1814.36	1713.56
2. Baltic rush	1966.18	0	1768.65	2000.00	1495.04	2000.00	1177.86	1554.86	1623.71
3. beaked sedge	1642.32	1768.65	0	2000.00	1995.98	2000.00	1838.26	1065.14	844.14
4. *Phragmites* old	2000.00	2000.00	2000.00	0	1999.71	1998.87	1999.88	2000.00	2000.00
5. hardstem bullrush	2000.00	1495.04	1995.98	1999.71	0	2000.00	1949.92	1871.31	1920.25
6. Agrostis	1986.35	2000.00	2000.00	1998.87	2000.00	0	1987.78	1999.97	2000.00
7. cattail new	1678.65	1177.86	1838.26	1999.88	1949.92	1987.78	0	1498.36	1872.76
8. *Phragmites* new	1814.36	1554.86	1065.14	2000.00	1871.31	1999.97	1498.36	0	637.90
9. cattail (broad/narrow)	1713.56	1623.71	844.14	2000.00	1920.25	2000.00	1872.76	637.90	0

Additional signatures were added to represent roads, water, ponds, gravel, bare ground, and buildings.

Figure 2.5 for the Signature Editor ERDAS tool that is used for the supervised classification process. After the spectral signatures were defined, the classified image was generated using the five-band reflectance mosaic with a Maximum Likelihood classifier. A Fuzzy Convolution filter (7x7) was run to eliminate the “salt and pepper” effect of misclassified pixels. Section 4.1.2.2 shows the results for the supervised classification.


Signature Editor (all_somemerged.sig)

File Edit View Evaluate Feature Classify Help

Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	▶	gravel/road4		1.000	1.000	0.609	23	23	2408	1.000	✔	✔	✔	✔	
2		gravel/road5		1.000	1.000	0.630	24	24	13216	1.000	✔	✔	✔	✔	
3		shadow bareground		0.337	0.342	0.137	30	30	3438	1.000	✔	✔	✔	✔	
4		building		1.000	1.000	0.628	1	34	123063	1.000	✔	✔		✔	
5		bareground1, gravel/road2		1.000	1.000	0.635	2	38	109362	1.000	✔	✔		✔	
6		bareground2,3, gravel, gravel/ro		0.957	0.938	0.465	5	39	249447	1.000	✔	✔		✔	
7		pond1		0.339	0.262	0.097	3	40	391732	1.000	✔	✔	✔	✔	
8		shallow water 1		0.616	0.528	0.156	4	41	4277	1.000	✔	✔	✔	✔	
9		pond2		0.324	0.282	0.168	6	42	87858	1.000	✔	✔	✔	✔	
10		pond3		0.212	0.221	0.142	7	43	177454	1.000	✔	✔	✔	✔	
11		pond4		0.254	0.227	0.055	8	44	306843	1.000	✔	✔	✔	✔	
12		pond5		0.340	0.382	0.215	9	45	234301	1.000	✔	✔	✔	✔	
13		pond6		0.184	0.123	0.112	10	46	92301	1.000	✔	✔	✔	✔	
14		open water 1,3,5,6		0.428	0.502	0.075	11	47	2484407	1.000	✔	✔		✔	
15		open water 2,4		0.304	0.314	0.062	12	48	767935	1.000	✔	✔		✔	
16		shallow water 2,3,4,5,6,7		0.434	0.408	0.190	13	49	108513	1.000	✔	✔		✔	
17		saltgrass		0.555	0.568	0.711	14	50	28685	1.000	✔	✔		✔	
18		baltic rush		0.318	0.257	0.571	15	51	27173	1.000	✔	✔		✔	
19		beaked sedge		0.391	0.473	0.800	16	52	7895	1.000	✔	✔	✔	✔	
20		algae2		1.000	1.000	0.860	17	53	4114	1.000	✔	✔	✔	✔	
21		senesced		0.882	0.787	0.653	18	54	10469	1.000	✔	✔	✔	✔	
22		senesced2		0.814	0.716	0.660	19	55	6623	1.000	✔	✔	✔	✔	
23		phragmites old		0.457	0.368	0.354	20	56	4990	1.000	✔	✔	✔	✔	
24		hardstem bullrush		0.227	0.163	0.488	21	57	8959	1.000	✔	✔	✔	✔	
25		alage 1,3		1.000	1.000	0.934	22	58	8875	1.000	✔	✔		✔	
26		agrostis		0.791	0.658	0.586	25	59	144180	1.000	✔	✔	✔	✔	
27		cattail new		0.433	0.427	0.578	26	60	34568	1.000	✔	✔	✔	✔	
28		phragmites new		0.383	0.419	0.698	27	61	322506	1.000	✔	✔		✔	
29		cattail (broad/narrow)		0.339	0.345	0.756	28	62	10686	1.000	✔	✔		✔	

Figure 2.5: Signature Editor tool from ERDAS

3.0 RESEARCH NOTES AND OBSERVATIONS

3.1 Flight Safety

Flight safety is a very important consideration when using UAVs. Some potential issues include collisions with ground obstacles, collisions with airborne obstacles, losing link, and losing control of the aircraft. One other issue with respect to flying over a highway includes the impact of the UAV on traffic and distracting drivers.

3.1.1 Approving Flight Plans and Permits

A solution to mitigating risk with regards to collisions with airborne and ground objects is applying for a certificate of authorization (COA) with the federal aviation administration (FAA). This gives us official permission from the FAA to fly in the national airspace (NAS). Included in the application for a COA is information about the aircraft, the proposed flight plan, and when the flights will take place. However, this information does not guarantee that the COA will be accepted. Under FAA regulations, flights of an unmanned aircraft (UA) cannot take place over a populated area, at night, or in many classes of airspace, and the aircraft must remain in eyesight at all times. If the COA is granted, the user must inform various aviation organizations about when and where the flight operations will take place. After the initial submission, it may take six to nine months to get a COA.

3.1.2 Flight Safety over Highways and Roads

A proposed highway route was evaluated for possible UAV monitoring, but was later abandoned due to safety concerns. The proposed route was SR6 from the mouth of Spanish Fork Canyon to Soldier Summit. These safety concerns include having to drive slowly on a one lane highway while following the aircraft, getting stopped on the highway due to construction and being unable to keep up with aircraft, distracting drivers during takeoff and landing, and not having enough area for takeoff and landing.

4.0 DATA EVALUATION

4.1 Image and Data Analysis

4.1.1 Southern Parkway

As mentioned previously, the Southern Parkway imagery was flown on three dates: March 3, 2010; May 26, 2010 and August 26, 2010. Both color visual and near-infrared imagery were captured by AggieAir, but only the color mosaics were produced. The imagery was displayed over a 2019 NAIP 3.2-foot basemap. These mosaics were produced in TIFF format as well as Google Earth tiles.

4.1.1.1 Image Mosaics

Figure 4.1 shows the full Southern Parkway mosaic overview with a 2009 NAIP 3.2=foot basemap. However, displaying all three mosaics individually would not provide much information since the scale is fairly zoomed out. Figure 4.2 through Figure 4.4 show zoomed in examples of a bridge on the Southern Parkway site.

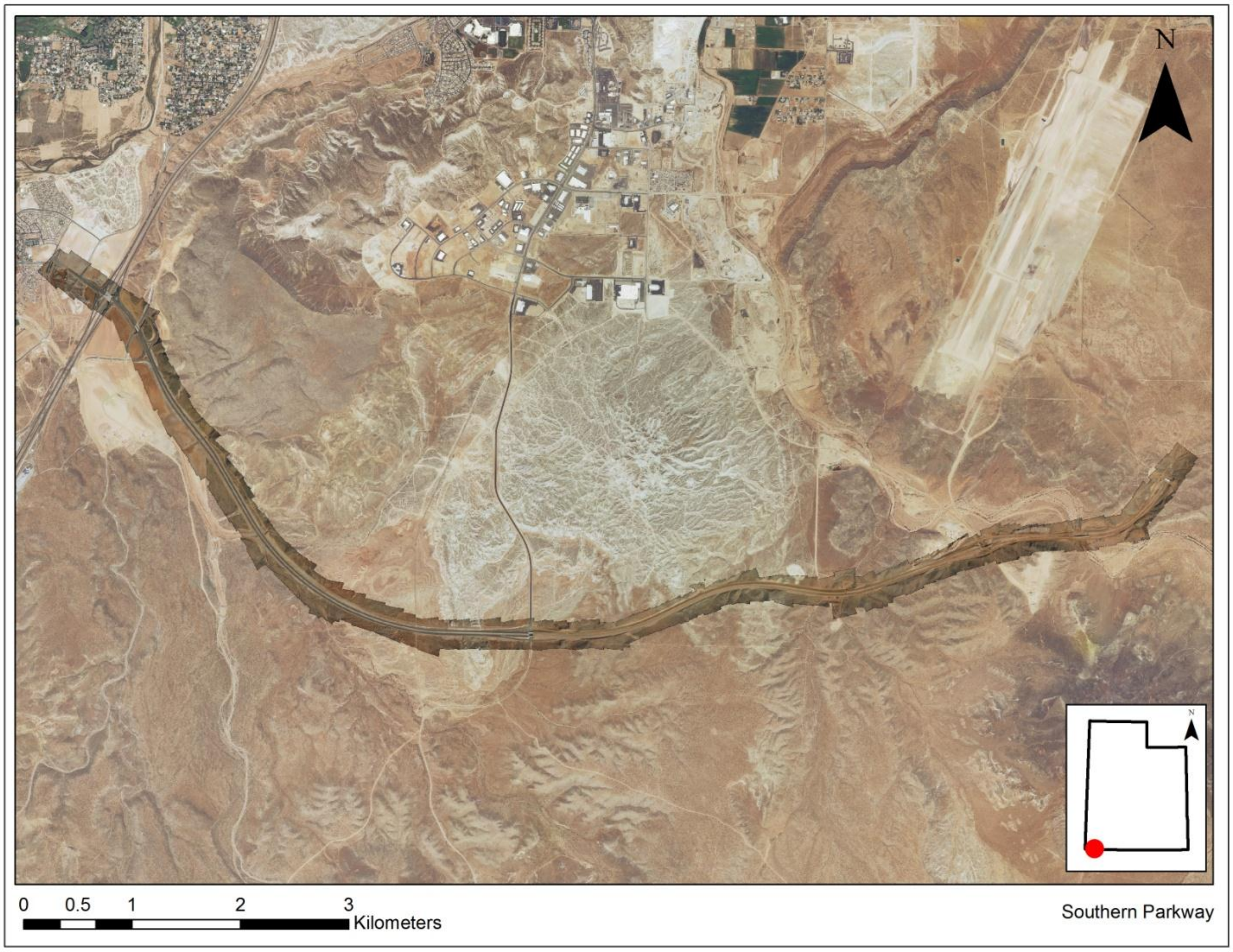


Figure 4.1: Overview of flight mission for Southern Parkway

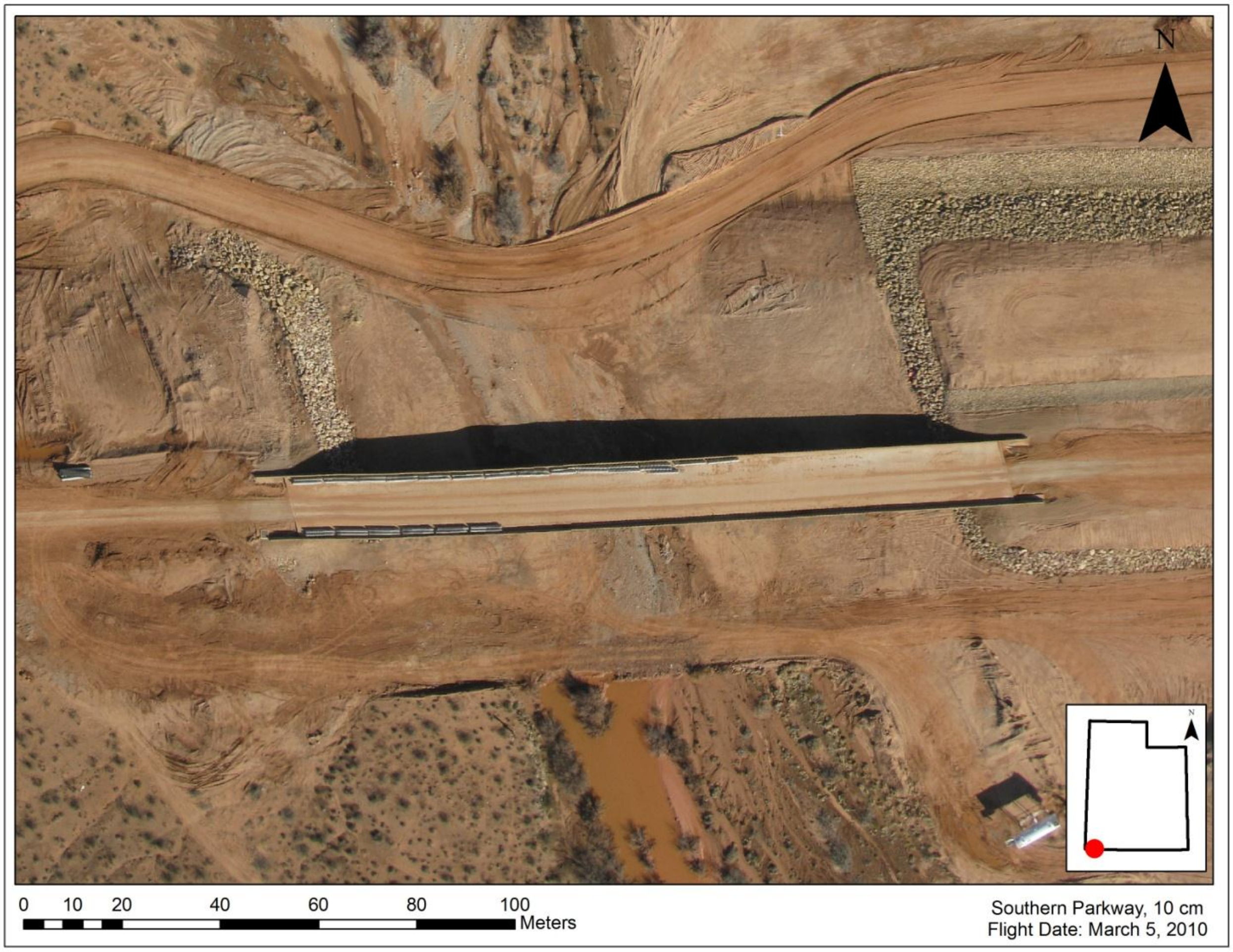


Figure 4.2: A bridge at Southern Parkway flown March 5, 2010

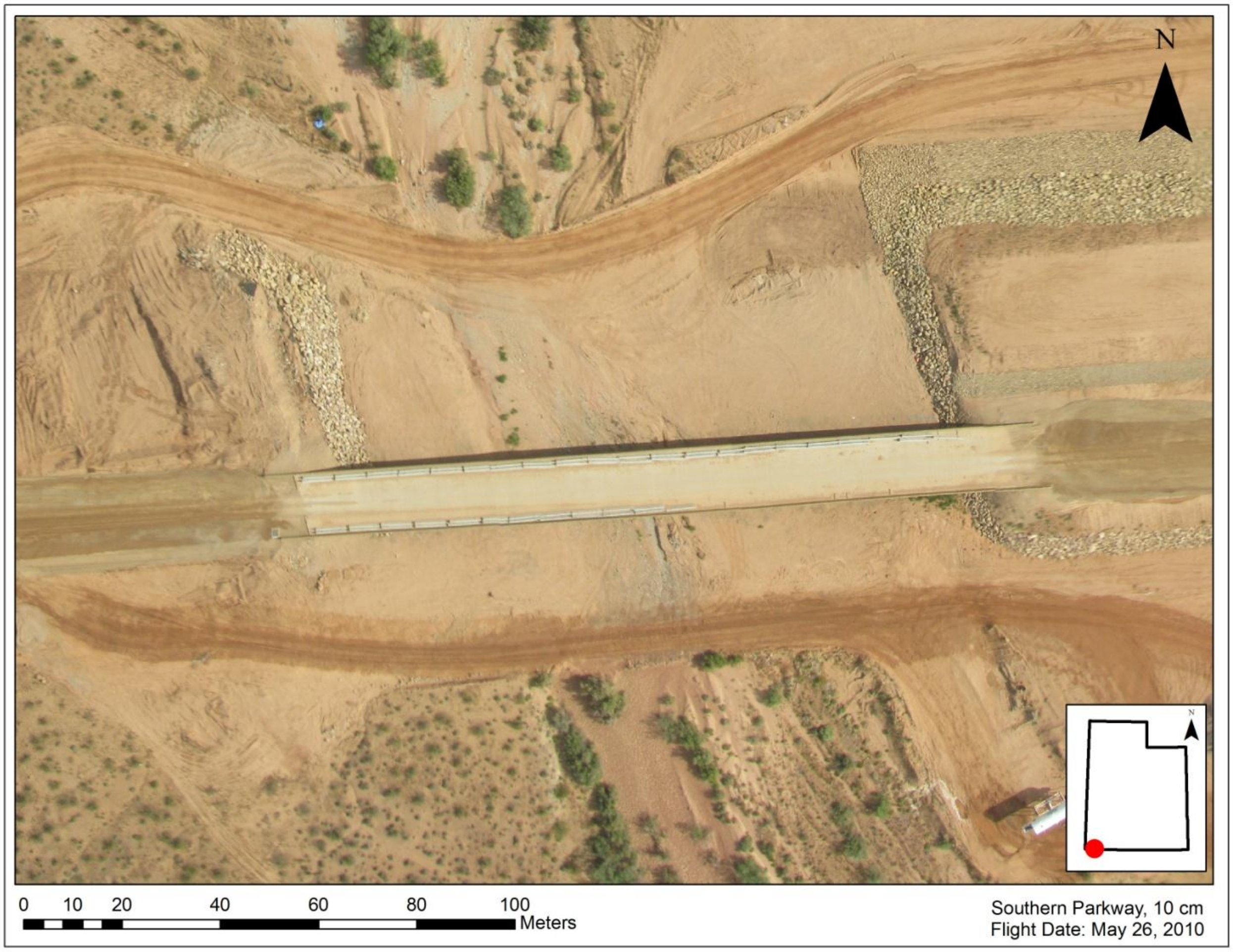


Figure 4.3: A bridge on Southern Parkway flown May 26, 2010

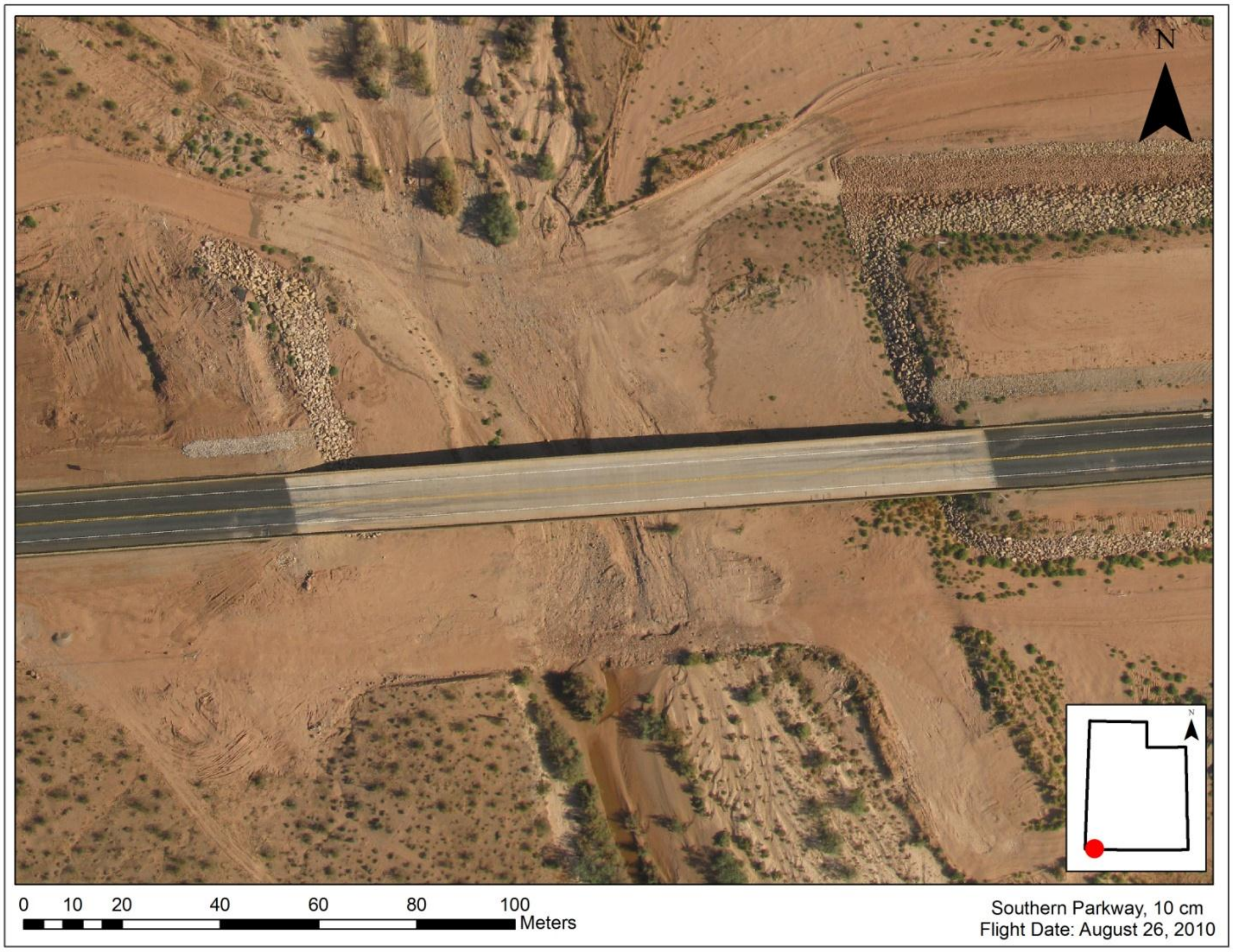


Figure 4.4: A bridge on Southern Parkway flown August 26, 2010

4.1.2 Utah Lake Wetlands Mitigation Bank

The Utah Lake Wetlands Mitigation Bank imagery was flown on August 24, 2011. Both color visual and near-infrared imagery were captured by AggieAir (see Figure 4.5 and Figure 4.6). The imagery was displayed over a 2011 NAIP 3.2 foot basemap. These mosaics were produced in TIFF format, as well as Google Earth tiles.

4.1.2.1 Image Mosaics

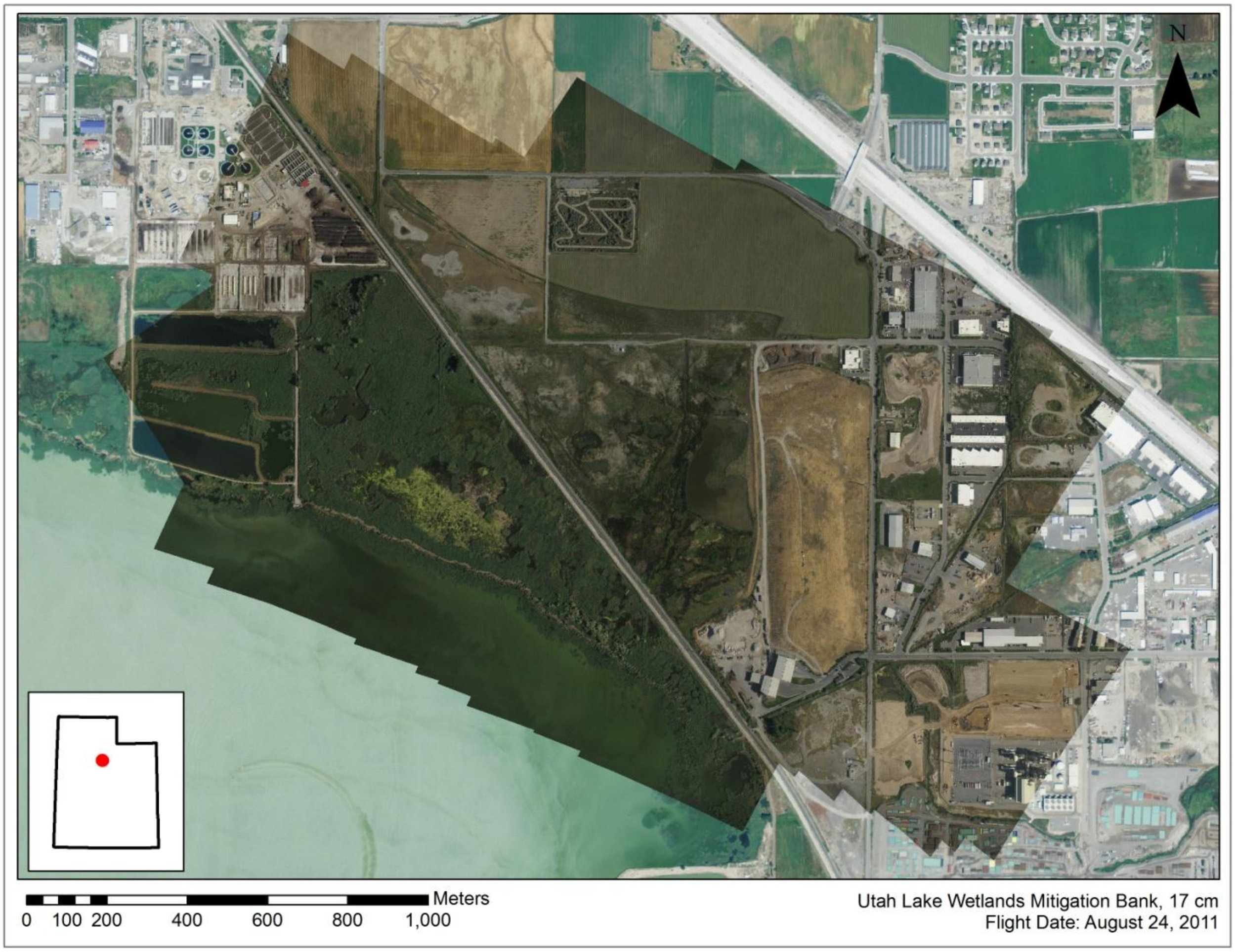


Figure 4.5: Color mosaic for Utah Lake Wetlands Mitigation Bank flown August 24, 2011

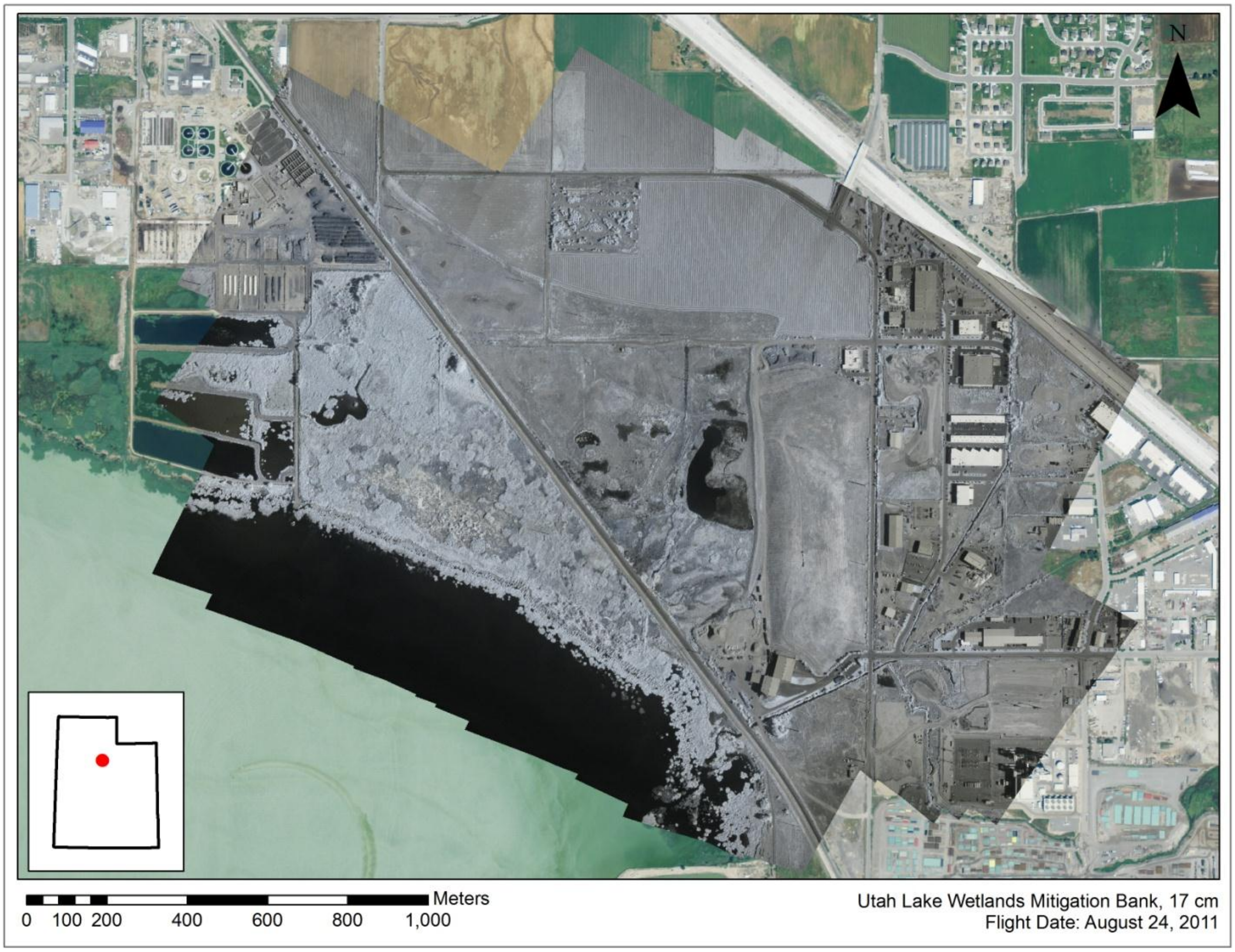


Figure 4.6: Near-infrared mosaic for Utah Lake Wetlands Mitigation Bank flown August 24, 2011

4.1.2.2 Classification Results

The results of the supervised classification can be seen in Figure 4.7. A classified raster image and an accuracy assessment table were generated (see Table 4.1).

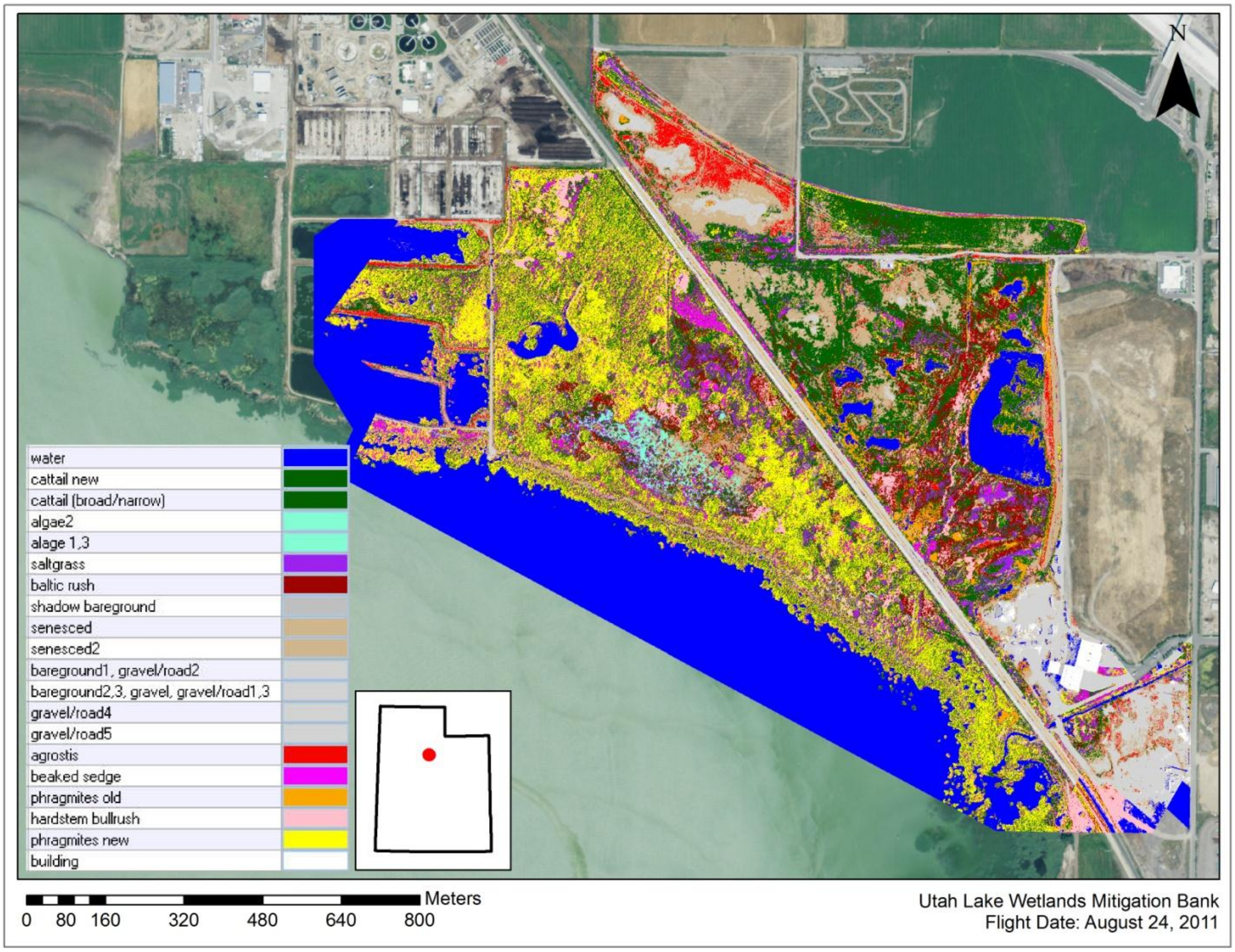


Figure 4.7: Supervised classification results of the Utah Lake Wetlands Mitigation Bank

"Accuracy assessment" is a general term for comparing the classification data to spatial data that are assumed to be true. The purpose of this comparison is to determine the accuracy of the classification process (ERDAS Field Guide 2010). The testing data set was used to determine how each pixel was defined and how it should be classified. The results produce a *producer's accuracy* and a *user's accuracy*. The producer's accuracy is the total number of correct points in a class divided by the number of points of that class, as derived from the ground truthing data, and represents the probability that a pixel in a given class will have been classified correctly on the image. The user's accuracy is the total number of correct points in a class divided by the total number of points of that class, as derived from the classification data, and represents the probability that a pixel classified as a particular class on the image is actually that class. The Kappa statistic indicates how well the classification results agree with the ground truth data (ERDAS Field Guide 2010). Table 4.1 shows the results of supervised classification.

Table 4.1. Supervised classification results of wetland species

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa Statistic
Agrostis	25	19	19	76.0%	100.0%	1.0000
Baltic rush	35	23	18	51.4%	78.3%	0.7406
cattail new	25	19	16	64.0%	84.2%	0.8214
beaked sedge	11	22	8	72.7%	36.4%	0.3295
Phragmites new	50	26	22	44.0%	84.6%	0.7998
Phragmites old	19	24	19	100.0%	79.2%	0.7716
cattail (broad/narrow)	16	43	10	62.5%	23.3%	0.1712
hardstem bullrush	15	19	13	86.7%	68.4%	0.6606
saltgrass	19	11	8	42.1%	72.7%	0.7010
Totals	216	216	133			
Overall accuracy = 61.57%						
Overall Kappa Statistic = 0.5703						

The classes that had the best classification and Kappa were *Agrostis*, Baltic rush, *Phragmites* new, *Phragmites* old, and saltgrass. Hardstem bulrush had a moderate Kappa at 0.6606, while beaked sedge and narrowleaf/broadleaf cattail had the lowest Kappa. Cattail new, which was added to the data set later as a polygon, and the original narrowleaf/broadleaf cattail were spectrally different enough (1872.76) despite both being cattails species. UDOT asked that the narrowleaf and broadleaf cattail be merged for the study, although they were originally two separate cattail species at the beginning of the project. *Phragmites* new had a fairly decent Kappa of 0.7998; however its producer's accuracy was low at 44.0%. *Phragmites* old was clearly distinguishable between other vegetation types, including *Phragmites* new, and produced a 100% producer's accuracy.

4.2 Observed Errors

4.2.1 Southern Parkway

4.2.1.1 Errors/Issues

EnsoMosaic UAV software uses ground control points to aid in the mosaic creation. Ground control points can be identified one of two ways: take GPS locations of ground control points while in the field or use digital maps (NAIP, etc) and DEMs (Google Earth) to locate XYZ. For the March and May flights, only digital map based ground control targets were used. However, this proved to be problematic as the construction and earth moving in the area made even the most recent year's NAIP imagery invalid for collecting ground control points via a map. In July 2010, field crews visited the Southern Parkway site to collect field based on fixed features (culverts, telephone boxes, etc). However, not all control features could be identified in the imagery or could be seen in all three flights so providing useful ground control data had some difficulties.

In addition, the Southern Parkway flights were flown at 200 meters above ground level producing overlap of about 55% between frames. Ideally, 70% or greater overlap is desired for the mosaicking process. Even on a perfectly calm day, 55% overlap doesn't provide enough similar features between frames to make the mosaic process run smoothly, but some wind was evident in all three flight dates, resulting in obtuse frames. Additionally, the sage brush/desert landscape was very homogeneous which also made automatic tie point recognition a challenge. Overall the mosaics were produced, but had errors that were difficult to remedy.

4.2.2 Utah Lake Wetlands Mitigation Bank

4.2.2.1 Ground Sampling Errors

UDOT field crews collected ground truth sample points of known wetland species with a Global Positioning Service (GPS) on August 15, 2011. The horizontal precision of the GPS points ranged from 2-7.5 feet with an average of 3.47 feet; and the vertical precision of the points ranged from 3-10 feet with an average of 4.84 feet. For imagery that had a pixel resolution of 6.7 inches, the GPS collected data could have been too coarse for the imagery resolution. For example, if a GPS point were near the edge of a species cluster, the error could possibly have pushed it outside of the actual species boundary leading to inaccurate spectral signatures.

Also, variations in the collection of ground truthing data may have lead to errors. The hand drawn polygons sketched from Google Earth were fairly broad compared to the GPS locations. It was very likely that the polygons included species other than those identified. Polygon data was entered into the signature editor in its original shape, while the GPS points were added to the signature set with a seeding tool, which was a far more intricate method compared to the polygons. The GPS collected data was also clustered into one area and not very well distributed among the 1.23 square miles of the study site, which may have introduced some bias.

In addition, the areas of interest (AOIs) that were created (for the signatures) from the GPS points were generated using the seeding/growing tool in ERDAS, which searched for spectrally similar pixels based on a set of parameters. The seeding tool was quite sensitive to slight parameter modifications. Since seeding parameters were determined successful by visual interpretation, one technician could have chosen one set of parameters for the seeding while another technician could have picked different settings which could lead to some bias in the AOI creation. Error also may have been introduced in the AOI process while using highly sensitive seeding parameters and 1+ meter accuracy GPS points.

4.2.2.2 Other Errors

The overall accuracy of the classification was 61.57%, which indicated room for improvement (an overall accuracy of 75-100% or higher would have been ideal for a classification study). Wetland classification studies are usually a challenge due to the spectral similarities of wetland species. Although the spectral classes for each wetland species were left unmerged, according to the ERDAS Transformed Divergence suggestion of merging anything with a separability less than 1700, species could have been merged. However, after a few merges, everything would have been in one class according to the 1700 threshold. Perhaps allowing for a lower threshold for this study which would have merged some species (ie. three lowest separabilities) and others left unmerged could have improved some of the error. A few of the species had relatively low separabilities: separability for *Phragmites* new and narrowleaf/broadleaf cattail was 637.90, beaked sedge and narrowleaf/broadleaf cattail was 844.14, and *Phragmites* new and beaked sedge was 1177.86. In additional, there was other factor that may have contributed to the overall accuracy of this study.

Another factor that may have contributed to the overall accuracy could have been the misalignment of the NIR and RGB imagery. Due to having separate cameras and camera logs from the UAV, the NIR and RGB raw imagery cannot be combined, and each camera's imagery must be mosaicked separately in EnsoMosaic UAV. Although the unprocessed RGB and NIR imagery could not be combined into one EnsoMosaic project prior to the mosaicking process, the mosaicked product can be combined or stacked due to having spatial projection which is independent of the cameras. The RGB reflectance value images were stacked with the NIR layer using ERDAS, but the actual pixel corners were not identical, causing misalignment. Despite having the same ground control points to orthorectify both the NIR and RGB mosaics in EnsoMosaic UAV, the end mosaics inherently would not be exact, as each EnsoMosaic project has its own algorithmic results. Although the alignment in the Northing was accurate, there was a 2.36-inch misalignment in the Easting which could have attributed to error.

The August 24, 2011 flight represented just one snapshot of time in this wetland's growing season. Some wetland species have different spectral responses based on whether the species are emerging or receding. A multi-temporal study, having flown the UAV at other times within the growing seasons, could have aided in providing more in depth spectral signatures for some species, which could lead to greater accuracy in the overall classification project.

4.3 Resulting Image Files

Many samples of the images developed in this project have been included throughout the report. An FTP server is available to download the mosaics and the raw images taken from the aircraft. In addition, Google Earth KMZ files have been made so the mosaics can be viewed on Google Earth. Please contact Austin Jensen (Austin.Jensen@usu.edu) to obtain access to this data.

5.0 CONCLUSIONS

5.1 Benefits and Application

The results from this project illustrated the value of the UAV as a tool for UDOT applications. Having the ability to acquire high-resolution digital aerial images over sites of interest is both informative and enlightening. The fact that aerial images can be collected and viewed within a matter of a few hours is extremely valuable to many UDOT applications such as road construction and road damage; inventorying roadway structures; and noting the range, classification, diversity and incremental seasonal change in plant species located along roadway easements. Although the purpose of this project was to evaluate the applicability of the UAV for UDOT purposes, this project was also carried out to aid in improving the function of the UAV to more closely match the needs of UDOT. For example, new safety concerns were discovered when flying around and over highways that will now be addressed in development and flight planning.

It was concluded from this project that UDOT would benefit specifically when using the UAV for tasks that include the need for immediate aerial images of Utah roadways. These may include roadways that are being proposed, roadways that are under construction, roadways that are in need of repair and the structures of roadways that are in existence. Regularly updating aerial images on UDOT's GIS database would improve many functions of the organization and would allow more current images to be viewed as decisions are made throughout the state.

It was concluded from this project that UDOT would also benefit from images taken from the UAV in regards to wetland plant species classifications and monitoring. Although the accuracy results of this study were not as high as desired, the potential classification errors were identified and it is expected that the results could be significantly improved with further research to lower the expected errors during the classification process. It is expected that the UAV could be an economic tool for wetland mitigation permits as there is great potential for time saving and more accurate classification with the UAV. Additionally, if image post-processing improves for plant classification, mitigation ratios may be reduced and the total cost for mitigation projects may be reduced.

It was concluded that UDOT would also be able to benefit from the UAV images in several other ways that were not specifically investigated during this project. Some of these include the possibility of using the UAV to monitor invasive plant species along Utah's highway corridors, using the UAV to evaluate and monitor erosion or hillside damage near roadways, using the UAV to measure paint reflectivity on roadway surfaces, using the UAV to inspect snow covered mountain roadways prior to opening the road for travel in late spring, using the UAV to inspect damage immediately after a flood, rockslide or earthquake, and using the UAV to provide historic timelines of specific roadway corridors for the purpose of evaluating environmental changes due to human impact.

REFERENCES

Leica Geosystems. 2010. ERDAS Field Guide™, (7th ed.) Atlanta, Georgia.

Miura T, Huete A. Performance of Three Reflectance Calibration Methods for Airborne Hyperspectral Spectrometer Data. Sensors. 2009:9:794-813.

MosaicMill Oy. EnsoMOSAIC Image Processing User's Guide. Version 7.3. Mosaic Mill Ltd., Finland, 2009.

Neale CMU. Spring 2009. BIE 6250 - Remote Sensing of Land Surfaces, Utah State University, Logan, UT

Nicodemus FE, Richmond JC, Hsia JJ, Ginsberg IW, Limperis T. Geometrical Considerations and Nomenclature for Reflectance. U.S. Department of Commerce, National Bureau of Standards: Washington, D.C., 1977.

Schmaltz J. 2005. Visible Earth: A catalog of NASA images and animations of our home planet. Washington, D.C.: NASA.

Utah Water Research Laboratory, 2008, Development of a fish passage culvert inventory in the state of Utah, prepared for Utah Department of Transportation