MONITORING PARKS WITH INEXPENSIVE UAVS:

COST BENEFITS ANALYSIS FOR MONITORING AND MAINTAINING PARKS FACILITIES

by

Mark C. Dustin

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DEDICATION

I dedicate this paper to my wife, children, and parents. Without your love, support, and understanding I could never have accomplished this.

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LIST OF ABBREVIATIONS

AUVSI	Association for Unmanned Vehicle Systems International
BLM	Bureau of Land Management
CMOS	Complementary Metal Oxide Silicon
DEM	Digital Elevation Model
DJI	Da-Jiang Innovations Science and Technology Co., Ltd.
Esri	Environmental Systems Research Institute, Inc.
DTM	Digital Terrain Model
FPV	First Person View
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
HP	Hewlett-Packard
KML	Keyhole Markup Language
KMZ	Keyhole Markup language Zipped
MP	Megapixel
MPH	Miles Per Hour
NAIP	National Agriculture Imagery Program
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
PC	Personal Computer
RF	Representative Fraction
RMSE	Root-Mean-Square Error

ROI	Return on Investment
SfM	Structure from Motion
SSI	Spatial Sciences Institute
SWOT	Strength, Weakness, Opportunity, and Threat
TIFF	Tagged Image File Format
U.S.	United States
UAV	Unmanned Aerial Vehicle
USC	University of Southern California
USGS	United States Geological Survey
WGS 84	World Geodetic System – 1984

ABSTRACT

UAVs are becoming more common in our modern world. UAVs are mostly associated with war due to the coverage of their use in the recent wars in Iraq and Afghanistan, but have the ability to do much more. UAVs are helpful tools in assessing damage after a disaster, keeping rescuers safe while they help those in need. UAVs are useful tools in monitoring crops to ensure the maximum yield is realized. The use of UAVs is also being used for monitoring remote land areas that are difficult to reach by foot. Amazon recently received approval from the FAA to research the use of UAVs for delivering packages. The uses of UAVs are endless.

Maintaining public parks is a time consuming task that requires a large staff and significant hours to accomplish in a timely fashion. Maintenance crews visit the parks on a regular basis to inspect the grounds and perform any necessary repairs and routine maintenance such as picking up trash, mowing lawns, and inspecting sprinklers, whether or not work needs to be performed at the park or not. City, county, state, and the federal government are responsible for maintaining these places for the public’s enjoyment. The Great Recession that occurred in the United States from 2007-2009 caused a decline in tax revenues for governments, forcing cutbacks in parks and recreation departments and requiring supervisors to develop alternative methods of completing the maintenance with smaller budgets and staffs. UAV technology is a possible solution to the problem. UAVs can be flown at any time, can capture high-resolution imagery, and require little labor to operate.

This paper examines the use of inexpensive UAV technology to monitor a park for maintenance purposes. A method for using the UAV for data collection is outlined and carried out at Deleo Regional Sports Park, a public park in Temescal Valley , an unincorporated area of western Riverside County in Southern California.. The results of the UAV data are used for digitization and creating Normalized Differential Vegetation Index (NDVI) output. The results of the digitization and NDVI output are compared to ground truth data collected with a GPS receiver and NDVI outputs created with United Stated Geological Survey (USGS) Landsat 8 imagery for accuracy. Lastly, the observations of the results of the study are examined to determine the cost benefit of using the UAV versus a GPS receiver and hiring manned aircraft.

CHAPTER 1: INTRODUCTION

Public parks provide an invaluable service to the community. They offer a place for residents to enjoy nature, spend time with family, and enjoy recreational activities such as soccer and running. Government agencies have a responsibility to maintain these public places, ensuring that they are free of graffiti, trash, and other hazards that can have a negative effect on the ability for the public to enjoy these places.

Park maintenance encompasses a wide variety of duties from removing trash and repairing fences to reseeding grass fields and painting picnic tables. Accomplishing these tasks requires maintenance crews to visit the parks on a regular basis and inspect the park grounds and amenities to ensure they are safe, clean, and in proper working order. This process takes a large staff and significant hours to accomplish in a timely fashion.

The goal of this study is to determine if unmanned aerial vehicle (UAV) technology can cost-effectively aid in the maintenance and supervision of parks. This will be accomplished by 1) determining if an UAV can capture aerial imagery with a high enough spatial resolution for monitoring the condition of park assets, 2) collecting near-infrared imagery for NDVI analysis to monitor vegetation health, and 3) determining if monitoring with a UAV takes less time to complete and is more cost-efficient than monitoring in person. Data for this study was collected at Deleo Sports Park in Temescal Valley, an unincorporated area of western Riverside County south of Corona in southern California (Figure 1.1). The 25-acre park, nestled at the base of the Santa Ana Mountains, offers a wide array of amenities for monitoring such as trails, trees, light poles, parking lots, and sports fields; assets similar to those found on other properties.

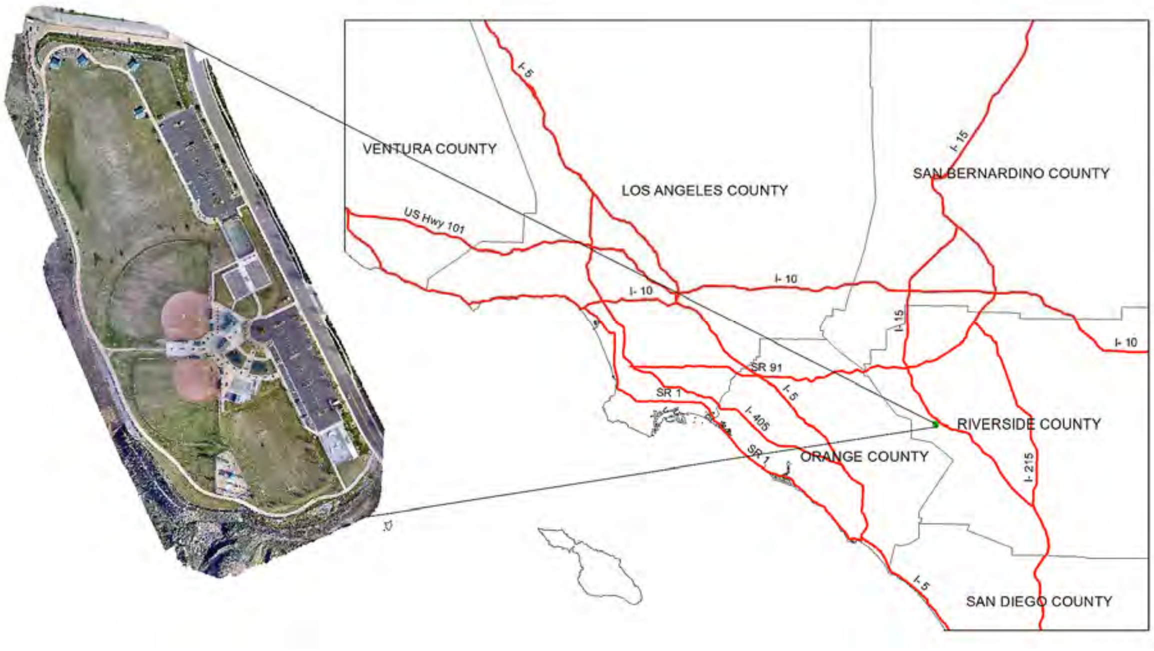


Figure 1.1 Deleo Regional Sports Park
Deleo Regional Sports Park, left is in Temescal Valley, an unincorporated area of Western Riverside County just south of Corona

1.1 Motivation

Aerial imagery needs to be up to date in order to be useful. Imagery captured a few years ago may show undeveloped land but today, that same piece of land may have been developed into a shopping mall or housing community. This unreliability in imagery makes it difficult to trust its accuracy. Imagery available through the Los Angeles County GIS Data Portal imagery, for example, is from 2011 as of the writing of this paper. Google Earth's imagery for the study site is more recent, having been captured in January 2013, but is still not up to date enough for monitoring purposes in 2015. A UAV, however, can be programmed and flown to capture imagery over a park, creating near real time imagery at the desired spatial resolution to properly monitor the condition of the park amenities.

Some parks have hiking trails through steep canyons and rough terrain to challenge experienced hikers. Monitoring the conditions of these trails can be difficult for maintenance crews who are older, in poor physical condition, or who may be monitoring the trail during high temperatures. Again, the UAV can be programmed to fly down into these canyons and capture imagery for monitoring purposes in safe and timely manner.

The monitoring and supervision of parks is costly expense for governments. The Great Recession of 2007-2008 reduced subnational government funding, resulting in cutbacks in staff and services (Jonas 2012). The use of UAV in the monitoring process has the ability to reduce the staffing and time required to complete monitoring the property and amenities, freeing up human resources that could be used in other areas within the government.

1.2 UAVs

1.2.1 History of UAVs

The first UAV can be credited to French brothers Joseph and Jacques Montgolfier during the development of the first hot air balloon in 1782. Joseph burned paper beneath an opening at the bottom of a silk balloon, which in turn caused the balloon to rise 70 feet before returning to the Earth when the air cooled inside the balloon (Karwatka 2002). Although the Montgolfier brothers achieved their ultimate goal of developing a hot air balloon large enough to lift people in November 1783, their successful prototype can arguably be considered the first UAV.

The use of hot air balloons equipped with incendiary devices can be traced back to Union and Confederate forces in the Civil War, where both sides launched balloons with the idea they would land in enemy supply or ammunition storages, ignite and wreak havoc (Garamone 2002). Japanese forces used a similar technique when they launched balloons equipped with explosives during World War II. The belief was that high-altitude winds would carry the balloons into the United States where they would fall and ignite fires (Garamone 2002). These attempts at using a UAV for attack proved to be ineffective.

The first UAV ordered by the United States military came when the country became involved in World War I in 1917 and the U.S. Navy placed an order for the Curtiss N-9 seaplane (Cook 2007). The Curtiss N-9 seaplane used an automatic control system that was developed by Elmer Sperry with Peter Hewitt, but this seaplane unfortunately was never used in battle as it was prone to crashes and engine failure during the Navy testing in late 1917 (Cook 2007). Despite the failures in the Navy trials, the US Army decided to continue the development of the UAV and awarded a contract to Charles Kettering in 1918 for his "Kettering Bug" biplane UAV (Cook 2007). Although there were successful tests sprinkled among the failures, the "Kettering Bug" UAV never saw combat (Cook 2007).

During World War II the Germans successfully developed a one-way unmanned aircraft called the V-1 "Buzzbomb", which reached speeds up to 400 mph and was unleashed on England in June of 1944 (Olson 1964). Although it was not a UAV in the sense that it was recoverable, the V-1 was the first successful unmanned aircraft used for combat.

In the late 1950s, the U.S. Air Force awarded a contract to Ryan Aeronautical Company for the development of the remote controlled BQM-34A "Firebee" drone for the purpose of performing photographic surveillance missions and returning to base (Cook 2007). The creation of the BQM-34A marks the beginning of the modern era of UAVs.

The Vietnam War is the first significant use of UAVs in military operations by the U.S. (Cook 2007). During the war, the "Firebee," "Lightning Bug," and "Buffalo Hunter" UAV's, all developed by the Ryan Aeronautical Company, were used to successfully fly several surveillance missions deep within enemy territory (Zaloga 1998; Cook 2007; Garamone 2002).

In 1982, the Israelis successfully used UAVs as decoys to draw missile fire from Lebanon during the Israel/Lebanon Conflict of the late 1970s and early 1980s (Cook 2007). The success of the UAVs led to the Israelis development of more sophisticated UAV systems that utilized lightweight video cameras to provide real-time surveillance on the battlefield (Zaloga 2008).

In the Gulf War of 1990-91, U.S. forces utilized the Pioneer UAV, an offshoot of Israeli UAV technology (Garamone 2002). The success of the UAVs in the war led the U.S. to invest in the development of the Predator UAV platform, a UAV equipped with color video cameras, radar, and the ability to be outfitted with missiles (Garamone 2002). The Predator UAV would be considered the “drone that changed the world” in that it allowed an operator to perform surveillance or attack a target on the other side of the planet with complete immunity (Terdiman 2014). This safety is attributed to the Predator’s ability to remain airborne for up to 40 hours, fly at an altitude up to 25,000 feet, and has the ability to hover over a specific area for up to 14 hours (Garamone 2002).

The wars in Afghanistan and Iraq brought about the next wave of UAV warfare by the U.S. military. Besides using the Predator, the U.S. military operated the RQ-170 Sentinel, a reconnaissance and surveillance UAV with stealth capabilities (Fulghum 2010). The RQ-170 drone was used to gather intelligence before, during, and after the raid on Osama bin Laden’s compound in Pakistan in May of 2011 (Ambinder 2011).

With the wars in Iraq and Afghanistan over, the civilian market is looking to capitalize on the UAV technology that has been so successful on the battlefield.

1.2.2 Domestic uses of UAV

UAVs have the ability to mitigate some of the problems involve with projects such as the collection of aerial imagery and monitoring land. Advanced, larger UAV’s are useful tools in emergency responses after natural disasters where it is difficult for workers to assess and monitor damage with the aerial imagery that is captured (Adams and Friedland 2011). Micro-UAVs equipped with digital cameras can deliver near real-time imagery for monitoring and mapping purposes (Grademer et al. 2009).

UAV’s come in a variety of shapes and sizes (Anderson and Gaston 2013). Large fixed-wing crafts that resemble airplanes require large areas for take-off and landing, and fly in long, straight paths, which is useful in monitoring pipelines. Small quadcopter crafts, on the other hand, do not need much room for take-off and landing, and have the ability to hover and turn in mid-flight, making them ideal for monitoring projects that require data collection in a variety of spots within a site. UAVs are an ideal tool for monitoring sensitive areas and subjects that may be threatened or destroyed if humans tried to monitor them manually (Jones IV, Pearlstine, and Percival 2006). The wide range of shapes and sizes also has an effect on the abilities of these crafts. Fixed wing aircrafts cannot stop and hover in one place like a quadcopter can, but the quadcopter cannot fly as long. These differences are determining factors in the selection of a UAV for a research project.

In recent years micro-UAVs have become popular due to their ability to give the user an instant bird’s-eye view (Anderson 2014). Other reasons for their popularity include their short learning curve to operate, ability to carry small cameras, and affordability due to advancements in technology. More people are experimenting with the aerial point of view--from realtors who want to gain a different perspective for marketing a property to hobbyists who may be looking to capture a unique video of some friends surfing. Social media has also helped fuel this interest with the ability of users to easily post and share the latest extreme sports action captured from the sky.

Prior to the wars in Iraq and Afghanistan, UAVs did not receive much attention in the public arena. Now, companies like Amazon.com are looking to use UAVs to deliver products to the customer's doorstep within hours of placing an order to provide faster service. The uses of UAV technology are endless.

1.3 Aerial Photography

Aerial photography is a form of remote sensing, which is a practice that encompasses the gathering of data with a sensor from a distance, that is an image of the surface of the Earth captured with a camera from an elevated position (Campbell and Wynne 2011). Aerial imagery captures what the surface of the Earth looks like at the moment the image is captured, and it is this temporal nature that makes this data useful.

Aerial photography is useful in the process of making maps. Aerial imagery that has been orthorectified, or geometrically corrected to account for the Earth's irregular surface, has a universal scale for the image, making it useful for mapping (Paine and Kiser 2012). Compilations of aerial imagery libraries can be of use to governments, businesses, and residents when distributed over the Internet (McKellar 2015). The ability to review aerial imagery sets from various points in time allows the user to look for the development of patterns such as bare dirt areas in a grass field or graffiti on park benches. The dirt areas could be the result of too much foot traffic or poor irrigation, while the benches with constant graffiti may be in poorly lit areas of the park. By examining the image library, park officials can identify such patterns and develop solutions to fix the problems.

Temporal data such as aerial imagery is useful in that it builds a historic, visual record of the area being monitored. It provides the users with the ability to travel back in time to see what the area looked like in the past, which is useful in restoration projects after natural disasters. In the United States there is a library of aerial imagery of the landscape that dates back to the 1930’s (Campbell and Wynne 2011). Analysis of such a record can yield insight into patterns such as black mangrove growth and contraction over a several decades (Everitt et al. 2010). The use of aerial imagery within a Geographic Information System (GIS), allows the user to digitize subjects of interest and easily analyze its change over time (Abbott 2004).

Aerial photography provides the user with a unique point of view of the subject area. This perspective can reveal information that may not be easily recognized from the ground, providing new ideas to solve a problem (Gilvear and Bryant 2003; Morrison 2011). Monitoring the conditions of a park at ground level may result in repairs being overlooked such as small tears or debris build up on canvas shade structures over children’s play areas.

This aerial perspective also makes it easier to collect large amounts of data within short period time. Depending on the resolution of the imagery, one frame of the surface can capture the locations and conditions of several square meters of land in a few seconds. Capturing the same data manually with a GPS unit could take a user several minutes.

The temporal nature of aerial imagery has its drawbacks. An act of nature can drastically alter the landscape within a set of imagery, rendering it obsolete for real-time decision-making. The necessity for current imagery, and the costs involved to obtain it, can make it unrealistic for agencies to keep image libraries up to date (Falkner and Morgan 2002).

1.4 Budgets

Government entities have the responsibility of maintaining public parks. The Great Recession of 2007-2008 reduced funding and forced governments to cut their budgets, reducing staffs and limiting services (Jonas 2012). In some instances, such as San Jacinto at the end of 2014, the city was forced to close the public parks due to budget constraints (Shin 2014).

Using the County of Riverside in California as an example, examination of the budget for fiscal year 2014-2015 shows that the Regional Parks and Open Space District has adopted revenues of approximately $23.5 million and expenditures of $25.6 million, resulting in a projected loss of $2.1 million if these numbers hold true to the end of the fiscal year (Orr 2014). Staffing for the department has been approved for 604 positions, an increase of 183 positions in comparison to fiscal year 2013-2014 (Orr 2014). While there are funds within the overall budget to help cover this loss, it is not sustainable to operate at loss on an annual basis, should the projections become reality at the end of the fiscal year. It is noted in the Budget Changes and Operational Impact section for the Regional Parks and Open Space District that the district has acquired new facilities and consuming more resources. It is also noted "in order to remain competitive, the District must develop adequate maintenance and programming plans" (Orr 2014, p.153).

The next chapter will discuss the background literature reviewed for the completion of this study. Vegetation monitoring, UAV mapping, aerial imagery acquisition, post-processing and feature recognition were all researched to develop the methods used to complete this study. Chapter three provides an outline for the methodology used, while chapters four and five are devoted to the results and conclusions from the study performed.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

UAV technology has been a useful tool in a number of research endeavors. The ability to capture near-real time aerial imagery has contributed to studies for monitoring land uses, such as agriculture; identifying changes in land, such as the progress and aftermath of a forest fire, and collecting data on wildlife without disturbing the habitat. This literature review will examine studies that have focused on the use of UAVs for collecting spatial data (Section 2.1), monitoring land cover and use (Section 2.2), managing property (Section 2.3), and conducting other research using UAVs that is related to the goals of this study (Section 2.4). The chapter will conclude with an overview of the different types of UAV platforms (Section 2.5) and cost/benefit analysis of using UAVs (Section 2.6).

2.1 Spatial Data Collection with UAVs

The process of capturing aerial imagery using conventional aircraft is a time consuming and costly task. A mission involves commissioning an aircraft and pilot, planning a flight, determining the optimal resolution of the imagery, and obtaining the necessary photographic equipment (Falkner and Morgan 2002). If weather conditions such as fog, wind, or rain appear on the day of the flight, much of the time and money expensed to that point might be wasted.

Whether a plane, helicopter, or UAV is being used to capture aerial images, procedures in the mission planning process cross over between the different aircrafts for proper image acquisition. The user needs to define the spatial resolution of the data; the flight path needs to provide adequate image overlap, and the proper photographic equipment needs to be obtained. In *Aerial Photography and Image Interpretation, Third Edition,* by David P. Paine and James D. Kiser (2012) provides an excellent list of variables that need to be addressed before any aerial photo mission. The user needs to determine the size of the subject area and the degree of detail the imagery needs to capture in order to move forward. The next factor to be examined is the focal length of the photographic equipment. The focal length, in conjunction with the size of the area and desired detail in output determine the altitude of the mission and quantity of images required to produce imagery appropriate for the desired scale (Paine and Kiser 2012).

Depending on the terrain, the flight path for aerial photography requires that the coverage of the photographs overlap 60 percent for forward lap in the flight line and 30 percent on the sidelap of each flight line photographs. Consequently, the flight path looks similar to lawn mowing, going back and forth over the site. Achieving this coverage will ensure stereoscopic coverage of the site area. The flight lines and desired overlap of photographs determine the number of photographs that are taken during the mission (Paine and Kiser 2012).

The fore-mentioned variables require flight planning to be well thought out and precisely executed to ensure accurate results (Ahmad et al. 2013). This is where mission planning begins to differ between UAVs and traditional aircraft. Personal computer (PC) based ground stations and mission-planning software provide the UAV operator with preliminary aerial imagery to use as a basemap to select the area that needs to be updated. The user can then input the desired flight parameters such as altitude and overlap percentage, as well as the camera details like focal length. Then the software will create a flight path that covers the selected area. The flight is then uploaded to the UAV via data link from the computer to the UAV and the mission begins with the click of a button within the ground station interface on the computer. The progress of the mission can be monitored on the computer in real-time as the UAV completes the mission (Berteska and Ruzgiene 2013; Gademer et al. 2009).

Unlike UAVs, planes and helicopters need to go through safety checks, fuel up, and take off once clearance is granted. The aircraft then flies to the site and proceeds with the mission. It could be several hours before the first photograph is taken. UAVs, on the other hand, do not require these processes. Most kinds of UAVs can be taken to the site, easily assembled, and launched. Within minutes the UAV can be airborne taking aerial photographs.

Prior to the start of a mission in any type of aircraft, ground control points or GCP, need to be determined. GCP can be temporary markers or existing features on the ground that can be seen within the aerial photograph. The purpose of GCP is to provide locations on the image that can be precisely identified on the ground (Campbell and Wynne 2011). The coordinates of the locations can be obtained through the use of GPS receivers in the field before, during, or after the mission. The coordinates of the GCP are used during post-processing to georeference the images to the Earth's surface, making the imagery useful for mapping purposes.

In comparison to traditional aircraft, UAVs can be lightweight, which has its pros and cons. The light weight of the UAVs makes them easy to carry and transport to a site, but it also makes them more susceptible to winds during flight. These changes in winds can cause the UAV to pivot on its pitch axis, roll axis, or yaw axis, changing the angle of the camera from vertical to oblique (Watkins et al. 2006). In the event that wind has created an angle in the camera position the affected photographs need to be rectified to align the image orthogonally, bringing the X, Y, and Z axis' perpendicular to one another (Ladd et al. 2006). Once the image is rectified it can then be georeferenced, which is the process of using coordinates of known features to adjust the image to match these features' coordinates on the surface of the Earth (Falkner and Morgan 2002). This step is accomplished through the use of the GCP collected in the field on the day of the mission. The georeferenced images can then be mosaicked together to create one large image of the site. The process of mosaicking images together is to align and overlay two images using control points that are visible within both images. These control points can be common features within the images such as trees, benches, or even the GCP that were used to georeference the images (Ladd et al. 2006).

This section has provided insight into the methods for preparing, obtaining, and processing aerial imagery for mapping and monitoring purposes. Information on image overlap, sidelap, and the use of mission planning software and ground station ensure proper and complete image coverage of the site. This information will serve as reference in the preparation for the data collection for this study.

2.2 Monitoring Land Cover and Land Use Change with UAVs

Rangeland areas can found in remote locations that are difficult to access. Albert Rango et al. explore the use of UAV to capture high-resolution imagery for the purposes of monitoring rangeland in their study “Unmanned Aerial Vehicle-Based Remote Sensing for Rangeland Assessment, Monitoring, and Management.” In the study Rango et al. discover that when flying at a lower altitude (215m) the UAV was able to capture 5cm resolution imagery, which is much higher than imagery captured from satellites, 25cm resolution. Low-flying airplanes can capture comparable imagery, but are expensive to hire and flying at low altitudes increases the possibility of a crash. UAV technology lowers costs and improves operator safety for such missions. The results of the UAV imagery provided Rango et al. with the ability to detect individual plants that could be classified by vegetation type, bare soil in between vegetation, and patterns over the site that were not visible in normal remote sensed data (Rango et al. 2007).

When we think of UAVs we tend to think of them as radio-controlled aircrafts resembling airplanes and helicopter. Chapter one of this paper touches on the history of UAVs and identifies the first UAV as a hot air balloon. In “Mapping Two Competing Grassland Species from a Low-Altitude Helium Balloon”, Brenner Silva et al. use such an UAV to monitor the restoration of two grasses after a fire in the Andes Mountains of Ecuador. Silva et al. make note of the fact that radio-controlled UAVs with cameras attached have been successful in vegetation monitoring in other studies but decline to use a radio-controlled UAV in their own study. They feel the lighter weight of the UAVs makes them unstable in the unpredictable windy conditions of the Andes Mountains and opt to use a balloon tethered by a rope, manually guided by foot over the study site. Silva et al. discover that the balloon is not much more stable in the windy conditions. The lack of stability of the balloon in the winds requires more images to be collected during each flight in order to ensure proper coverage was attained. The balloon tethered UAV process used by Silva and et al. is able to successfully capture 1cm resolution imagery to identify individual plants. However, one of the drawbacks of such high-resolution aerial imagery that should be noted is shadowing, which is the effect of shadows from features that impedes the ability to identify or extrapolate information for features that are within the shadows (Silva et al. 2014).

While "Mapping Two Competing Grassland Species from a Low-Altitude Helium Balloon" is a one-time data collection endeavor, it is not uncommon for land monitoring studies to require several surveys over the span of months, years, or decades. In "Lightweight Unmanned Aerial Vehicles will Revolutionize Spatial Ecology," Karen Anderson and Kevin J. Gaston use a UAV to make the process of ongoing land monitoring easier. Mission flight paths are reused to collect data over the site at each survey interval. Having the mission plan stored allows Anderson and Gaston to make minor adjustments to the mission plan before uploading it to the UAV and collecting the data. Adjustments in altitude or camera settings to alter the spatial resolution of the imagery can easily be made in the mission planning software and saved for future use. This control ensures that the collected data will appropriate for the monitoring task and saves time when imagery is collected in intervals over the same site. The mission can be opened, adjusted, if needed, and uploaded to the UAV (Anderson and Gaston 2013) .

Field monitoring is another example of interval monitoring. Farmers have to monitor their fields regularly to ensure the crops are developing properly and to estimate the harvest. In “The Rise of Small UAV in Precision Agriculture,” Reza Ehsani and Joe Mari Maja explore the use of UAVs in field monitoring. Currently, farmers monitor for disease and pests by visually inspecting the plants, walking through the fields, a practice that increases the risks of damaging the crop. Not only is this method a time-consuming and expensive one, it is also not very accurate as it relies on the person performing the monitoring to identify and recognize all the signs of disease and infestation. Equipped with the proper sensors, the UAV can monitor a field in a shorter amount of time, with more accurate results at a lower cost (Ehsani and Maja 2013).

Looking down on a field can make it easier to identify the signs of disease, infestation, or maintenance issues. A farmer may overlook or ignore a brown spot in a field during a routine check of the fields at ground level. The larger view from above makes it easier to identify brown spots and determine if they are harmless or require further inspection. A pattern in the spots may indicate that the field was not evenly seeded, fertilized, or is not being properly watered. If a farmer suspects the irrigation system is the source of the problem, the irrigation system can be turned on and the UAV can be launched to capture more imagery or video. The footage can be reviewed in real-time and a course of action can be taken to fix the problem before any further damage can occur (Morrison 2011).

While changes in crops or fields on a farm occur quickly due to the time-sensitive nature of farming, land changes in natural settings can happen subtly over time or rapidly, in the blink of an eye. Erosion is one cause of land change that can happen gradually or instantly, by a severe storm for example. The inability to predict land change requires researchers and scientists to have the ability to capture data when change occurs to see if a threat exists to a nearby population. In “Unmanned Aerial Vehicle (UAV) for Monitoring Soil Erosion in Morocco,” Sebastian d'Oleire-Oltmanns et al. create a method for using UAVs to capture aerial imagery for creating Digital Terrain Model (DTM) in order to monitor gully erosion. The study by d’Oleire-Oltmanns et al. successfully created DTMs for the main gully at the site, and the high resolution (0.05 cm) of the imagery displayed the small lateral gullies that were forming off the main gully. This high level of detail was not visible with high-resolution Quickbird satellite imagery for the same site (d'Oleire-Oltmanns et al. 2012).

UAVs are a useful tool for monitoring land changes and use. This section provided insight into how to use UAV and sensors to obtain useful data. It is significant that a difference of 1 cm in spatial resolution can mean the difference in distinguishing vegetation type. Knowing how such a small difference in spatial resolution can be the determining factor in identifying a plant, it is crucial that the mission planning be precise. Consequently, high wind’s effects on UAVs is an important factor in the collection of data. Wind conditions need to be monitored closely during a mission so the proper corrections to the imagery are made during post-processing to ensure accuracy.

2.3 Managing Property with UAVs

Property management can be a laborious task that relies on the person performing the inspection and maintenance of the property to follow uniform procedures in order to maintain a constant level of quality. Large property management organizations may have a group of people in charge of a piece of property, a situation which may cause differences of opinion when it comes to judging the condition of the property under inspection. UAV imagery creates the ability for supervisors to see the conditions first hand and make decisions based on their observations and not potentially differing staff reports.

Crops are a farmer's most precious property and require close monitoring. Weeds steal valuable resources intended for crops, hindering the yield of the crop and reducing revenue. In "Configuration and Specifications of an Unmanned Aerial Vehicle (UAV) for Early Site Specific Weed Management," Jorge Torres-Sánchez et al. use UAV technology to detect weed infestations in a sunflower crop. The UAV captures imagery with RGB and multispectral cameras in an attempt to discriminate weeds from crops. This study successfully determined that spatial resolutions of 4cm or less, which required an altitude of 100m or less for the flight, was suitable for identifying individual weeds amongst the crop. Furthermore, spatial resolutions of 5cm or greater are sufficient for identifying weed patches. Identifying weeds, crops, and bare soil for spectral differences in the vegetation indices of the study were achieved at an altitude of 30m. At higher altitudes there was not a spectral difference between weeds and crops (Torres-Sánchez et al. 2013).

In "Gravel Road Condition Monitoring Using Unmanned Aerial Vehicle (UAV) Technology," Sabina Shahnaz (2010) uses high-resolution imagery from a UAV to monitor the condition of gravel roads in Brookings, South Dakota. The study utilizes the imagery to identify and measure 2-dimensional features on the roads such as dimensions of potholes and ruts, and road width. These results were compared to field measurement data to check for accuracy. Current methods in South Dakota require inspectors to perform field inspections of the roads in person only once a year due to the amount of time required to physically perform these inspections. The crews performing these inspections will also have differing opinions of condition and physical measurements of the roads. By comparison, the UAV can collect imagery suitable for identifying and measuring features on the roads in less time and can allow uniform standards of inspection for the road conditions (Shahnaz 2010).

In addition to surveying road conditions, governments need to monitor and maintain the other assets such as trees, parks, and bridges within the public domain. In Brian Ritter's thesis titled "Use of Unmanned Aerial Vehicles (UAV) for Urban Tree Inventories," Ritter uses UAV technology to build a tree inventory for the campus of Clemson University in Clemson, South Carolina. The tree inventory provides useful information on the species, location, size, condition, and diversity of trees for the campus. During the UAV missions imagery collected from an altitude of 90m was orthorectified and mosaicked. The imagery was analyzed to obtain tree inventories. The time spent to assemble this inventory from UAV methods was compared to the time required to obtain the data in the field with a GPS receiver. The UAV method saved 29 days of time in the collection process. The digital elevation model (DEM) created from the UAV imagery was considered accurate when compared to field measurements of tree heights, showing that the UAV method was capable of producing accurate output (Ritter 2014).

Like urban forests of Clemson University, the condition of man-made structures can be effectively monitored over time by using UAV technology. In "Monitoring Structural Damages in Big Industrial Plants with UAV Images," Thomas Moranduzzon and Farid Melgani (2014) explore the use of aerial imagery taken at different times to identify structural damage in an industrial building. The authors' hypothesize that analysis of aligned UAV imagery from different time periods can reveal damage that may not be seen from ground levels or from routine inspections. A UAV photographed an iron tube with visible corrosion at distances of 5m to 20m. The corrosion was purposefully enlarged to simulate the growth of the corrosion and photographed again at distances of 5m to 20m. The before and after images are aligned, and analysis of the corrosion on the tubes shows that the UAV imagery was within 3.5% of the ground truth data measurement for the simulated corrosion on the tube (Moranduzzo and Melgani 2014).

UAV technology can help make the management of remote areas more manageable. Large portions of the United States' borders with Canada and Mexico are too remote and difficult to monitor on a regular basis. In the report "Homeland Security: Unmanned Aerial Vehicles and Border Surveillance," Chad C. Haddal and Jeremiah Gertler demonstrate the benefits of UAVs for monitoring the land borders between the United States and Mexico. The UAV can cover remote areas and provide real-time imagery to a ground control station. Dispatchers can then deploy officers to the location of a suspected illegal border crossing. The UAV can also locate and track people illegally crossing in wooded areas through the use of thermal sensors, ultimately keeping officers safe and helping to position them to make an arrest when the illegal crossers emerge from the shrubs (Haddal and Gertler 2010).

This section has provided ideas on some of the assets that can be monitored and how to analyze them within aerial imagery. Methods for monitoring roads and building damage can be transferred to park management. Furthermore, the use of different sensor types such as thermal could be useful in the search for dangerous wild animals like mountain lions that could be roaming in the park.

2.4 Other Studies Using UAV Technology Related to the Proposed Work

Other studies, ones that do not deal specifically with land monitoring and management can offer insight into how UAVs can be mobilized or dispatched. The use of UAVs in different scenarios can provide useful information on some of the technical issues that could arise when using UAVs in the field, helping researchers to be prepared for the unexpected. Other studies also inform researchers of some of the limits experienced with UAV technology such as maximum altitudes of flight and payload.

In some instances, traditional methods of acquiring aerial imagery are not an economical decision, so UAVs can be a cost effective alternative. In the article “Low Cost Surveying Using an Unmanned Aerial Vehicle,” M. Pérez, F. Agüera, and F. Carvajal use a quadrocopter style UAV to survey a 5,000 square meter parcel of land. The use of the UAV for image acquisition is less laborious in comparison to manual land surveying techniques and traditional aircraft photogrammetry. Orthophotographs and DEMs created from the UAV imagery were checked for accuracy using the root mean square error (RMSE) method and were considered highly accurate with errors reaching no more than 7cm. Using the UAV method and inexpensive software to process the imagery produced accurate results with less labor, creating a cost savings in comparison to traditional survey methods (Pérez, Agüera, and Carvajal 2013) .

In some regions of the world accurate land maps may not exist, so UAV technology may produce a map quickly. In “Drones Help Word Bank Projects by Mapping Land,” Arthur Allen discusses the use of UAVs to map land parcels in developing countries. In developing nations the process of obtaining a map can be slow and expensive, which may in turn jeopardize a development project. The use of UAVs in these circumstances streamlines the mapping process and provides organizations such as the World Bank with the desired information required for funding a project. In this test funded by the World Bank, a UAV was able to capture aerial imagery over 34 properties in Albania in just twenty minutes. The same process would take several days for surveyors to complete in the field, thus revealing the comparative efficiency of collecting accurate data via UAVs (Allen 2014) .

UAV technology can make monitoring wildlife easier and produce more accurate results. Monitoring wildlife on foot requires surveyors to walk around in an animal’s habitat. These habitats can be in uneven terrain and require surveying to occur at night. These circumstances can result in injury to surveyors, animals being frightened into hiding, or cause an animal to attack the surveyor. Flying aircraft at altitudes low enough to accurately assess a species can be unsafe. In “An Assessment of Small Unmanned Aerial Vehicles for Wildlife Research,” George Pierce Jones IV, Leonard G. Pearlstine, and H. Franklin Percival use a small, fixed-wing UAV for the purposes of monitoring wildlife at various locations in Florida. The UAV proved to be a successful alternative to satellite and low-altitude aircraft in the tests. The study used two video cameras, one with a Complementary Metal Oxide Silicon (CMOS) chip and the other a progressive scan camera. Testing the two different types of video camera technology revealed that a CMOS chip camera, transmitting a live feed, was unsuitable for monitoring purposes due to blurry footage and dropped signals. Georeferencing the video footage was not instantaneous and required time-consuming backtracking to achieve. The progressive scan camera that recorded to media on the UAV was deemed suitable for monitoring (Jones IV, Pearlstine, and Percival 2006). This study shows that even though a UAV can provide the ability to monitor, the quality of the data being collected depends on the sensor technology.

The UAV used by Jones IV, Pearlstine, and Percival’s study provided useful footage for monitoring purposes and also provided insight into some of the mechanical problems that can occur when operating a UAV. The authors note that launching and landing the fixed-wing style UAV was difficult to achieve. The large amount of support equipment needed to operate the UAV hindered its portability. While the nitro-methane gas engine provided long flight times, the engine was difficult to run and unreliable as it eventually failed, causing the plane to crash land in salt water and be ruined (Jones IV, Pearlstine, and Percival 2006). Thus, UAV propulsion technology needs to be considered when deciding on what type of UAV to choose for a study.

UAV monitoring can be a useful tool in the wake of a disaster. The conditions after such an event can be unsafe for rescue personnel to monitor damage and perform search and rescue operations. A UAV can serve as the eyes of rescue crew members while they remain safe. “A Survey of Unmanned Aerial Vehicle (UAV) Usage for Imagery Collection in Disaster Research and Management,” by Stuart M. Adams and Carol J. Friedland looks at the use of UAVs for collecting data for damage assessment, rescue operations, and the monitoring and management of property loss. In large disasters such as Hurricane Katrina, the authors found that a helicopter UAV had the ability to produce still and video imagery suitable for inspecting and assessing building damage. UAVs were also successful in inspecting bridges, seawalls, and piers after Hurricane Wilma (Adams and Friedland 2011) .

The style of the UAV can determine its usefulness in a study. For example, in “An Evaluation on Fixed Wing and Multi-Rotor UAV Images using Photogrammetric Image Processing,” by Khairul Nizam Tahar and Anuar Ahmad, two different types of micro-UAVs, one UAV a fixed-wing, the other UAV a multi-rotor, capture aerial imagery over a slope area. The resulting imagery from both UAV outfits was highly accurate and therefore, considered acceptable for mapping purposes. The multi-rotor UAV produced imagery was slightly more accurate and contained more detail. This accuracy is a result of the multi-rotor UAV’s flying at a lower altitude (80 M) compared to the fixed-wing UAV’s altitude (320 m). These results suggest the multi-rotor UAV is more useful for low-altitude, small area missions where high spatial resolution data is required. The fixed-wing UAV, flying at higher altitudes, is best suited for larger areas that do not require high spatial resolution results (Tahar and Ahmad 2013)

Smaller UAV require lighter payloads in order to get airborne. This weight restriction necessitates the use of smaller cameras mounted on the aircraft. These smaller cameras utilize wide-angle lenses that can create distortion in the collected image, requiring correction in post-processing. In an “Investigation of Fish-Eye Lenses for Small-UAV Aerial Photography,” by Alex Gurtner et al. explore the use of fish-eye lenses, which provide a wide-angle view without adding heavy weight to the payload of the UAV. The lighter weight makes fish-eye lenses an attractive option for a camera on a small UAV. However, the use of a wide-angle lens comes at a cost, image distortion. In the study it is noted that small, lightweight UAV with camera mounted directly to the body of the craft has difficulties staying aligned with the target area and experience vibrations in flight that blur and add distortion to images. The authors suggest that a gimbal mount could help, but ultimately opt for the use of a fish-eye lens to try and eliminate these issues. The fish-eye lens did vibrate in flight, but the distortion caused by the vibration was not visible in the imagery. Distortion created by the wide-angle view of the fish-eye lens did however require rectification before being suitable for mapping purposes (Gurtner et al. 2009) .

This section looked at the use of UAVs and sensors in other studies. It was discovered that UAVs are used to in situations when traditional aerial imagery capture is too costly and that UAVs can produce results that are highly accurate. UAVs are capable of making quick maps when time is of the essence and can provide users with the ability to monitor wildlife without disruption. Using a wide-angle fish-eye lens can reduce the effects of UAV vibration during a mission. The information presented has provided insight into the mounting of the camera to a UAV and other monitoring uses.

2.5 UAV Platforms

UAVs come in a variety of designs making it difficult to classify them. UAVs can be classified by their size or flying abilities. Information collected in the studies of this section has been used to create a table to break down the different UAVs, listing the largest and most expensive first.

Table 2.1 UAV Platforms and Their Advantages and Disadvantages

Size	Payload	Characteristics	Advantages	Disadvantages
Large	Up to 1000kg	Fixed wing	Fly continuous up to 2 days at altitudes up to 20km Flown by flight software via ground station	Expensive to purchase and operate. Large size requires a hanger for storage
Medium	50kg	Fixed wing	Fly up to 10 hours at altitudes around 4km Flown by software via ground station	Expensive to purchase and operate.
Small	Less than 30kg	Fixed wing and copter	Easy to launch and transport. Flown by direct radio control or software	Up to 2 hr. flight time at altitudes less than 1km
Micro	Less than 5kg	Copter and fixed wing	Inexpensive, easy to operate, store and transport. Flown by direct radio control or software	Less than 1 hr. flight time at altitudes less than 250m

Source: (Anderson and Gaston 2013; Everaerts 2008)

The UAVs in the studies all used flight planning software and a ground station to operate the UAV during data collection. Examinations of the UAV platforms used in the studies reveal that the majority of them utilize a small, fixed-wing UAV to perform data collection. The fixed-wing has its advantages, endurance and the ability to glide for long distances, which is useful for monitoring pipelines. The micro-copter style UAVs, while not used as often, has the advantage of being able to hover over a site and take off/ land vertically (Everaerts 2008).

2.6 Cost/Benefit Analysis of Using UAV

A common theme discovered throughout the literature reviewed for this study is that UAVs are a cost effective tool for collecting aerial imagery. Traditional means of collecting imagery with planes costs substantially more time and money. In terms of military use, UAVs possibly save the lives of the pilots that would be in the line of fire during a mission. In terms of business use, the costs involved with the initial purchase of the UAV, support equipment, post-processing software, and labor need to be considered when comparing to traditional aerial imagery collection methods.

Information presented by Chris Mailey, a former member of the Association for Unmanned Vehicle Systems International (AUVSI), in his blog post “Are UAS More Cost Effective than Manned Flights?” provides figures in regards to the costs for completing aerial imagery collection missions for the Bureau of Land Management (BLM). One of Mailey’s examples is the BLM’s Sandhill Crane Population Survey, where the population of the Sandhill Crane within a wildlife refuge needed counting. Using government-manned aircraft cost $4,300 for direct costs; a contractor-manned aircraft cost $35,000 for the job; and the RQ-11A Raven UAV supplied by the United States Army cost $2,600 for the imagery plus two hours for post-processing. Two other BLM projects cited by Mailey, both in Mesa County, Colorado, required flights over the landfill and gravel pit on a quarterly basis to provide volume data for these areas. Contracting a manned aircraft carried a price of $10,000 each for the landfill and gravel pit inspections while the UAV cost $300 for the landfill and $120 for the gravel pit (Mailey 2013). The figures from these BLM projects show that UAV technology provides huge cost savings in comparison to manned aircraft.

Precision agriculture relies on aerial imagery to properly monitor and manage crops to reduce costs and maximize profit. In “Drones Evolve into a New Tool for Ag,” Laurie Bedord interviews Roger Brining, a Kansas farmer that has used different forms of aerial imagery for his farming needs. He discusses the costs he has incurred for acquiring imagery. According to Brining, traditional aerial imagery captured by plane cost him approximately $3.50 per acre, produced results that were not of a high enough resolution and took too long to receive. Brining’s UAV system is estimated to cost between $5,000 and $7,000 and is predicted to provide him with high-resolution imagery of specific areas almost instantly (Bedord 2013)

In some cases, farmers cannot obtain complete coverage of their fields. In “The Good Drones: Industries Eagerly Await FAA Rules to Allow Them to Fly,” Ucilia Wang interviews California farmer Cannon Michael who uses aerial imagery to monitor the crops on his 11,000-acre farm. Michael states that satellite data from the U.S. Geological survey costs $0.25 to $0.30 per acre after it has been downloaded and processed for use. The cost is low but the satellite flies over his farm once every two weeks, producing low-resolution photos that lack the detail Michael requires for monitoring his crops. Hiring a pilot to collect aerial imagery costs $2.00 to $4.00 per acre, which is much more expensive than the satellite imagery. Manned aircraft imagery produces the resolution Michael desires but is only achievable over 10-15% of his crops (Wang 2014).

The figures stated in this section make it obvious that UAV is a cost-effective alternative to traditional aerial imagery acquisition. Prices will always vary depending on the job and desired resolution but it appears that UAV have the advantage in terms of cost and turnaround time of a useable product.

This chapter covered the literature reviewed in researching a methodology to perform the proposed study. Previous studies have provided insight into the development of a methodology to carry out the data collection and analysis of the proposed work that will be outlined in chapter three.

CHAPTER 3: METHODOLOGY

This chapter will cover the methodology used for this study. The study area will be introduced (Section 3.1), followed by a description of the equipment used to complete the study (Section 3.2). The following are data acquisition (Section 3.3) by UAV and post-processing data (Section 3.4) for data analysis (Section 3.5). The following flowchart (Figure 3.1) is a visual representation of the processes used to complete this study.

3.1 Study Area

The study area for this project is Deleo Regional Sports Park, a 25-acre park operated by the County of Riverside Parks and Recreation Department (Figure 1.1). Deleo Regional Sports Park is located in the Sycamore Creek housing community in Temescal Canyon, an unincorporated area of Riverside County along the southern border of Corona, California. Corona is located in western Riverside County, approximately 50 miles southeast of Los Angeles in Southern California.

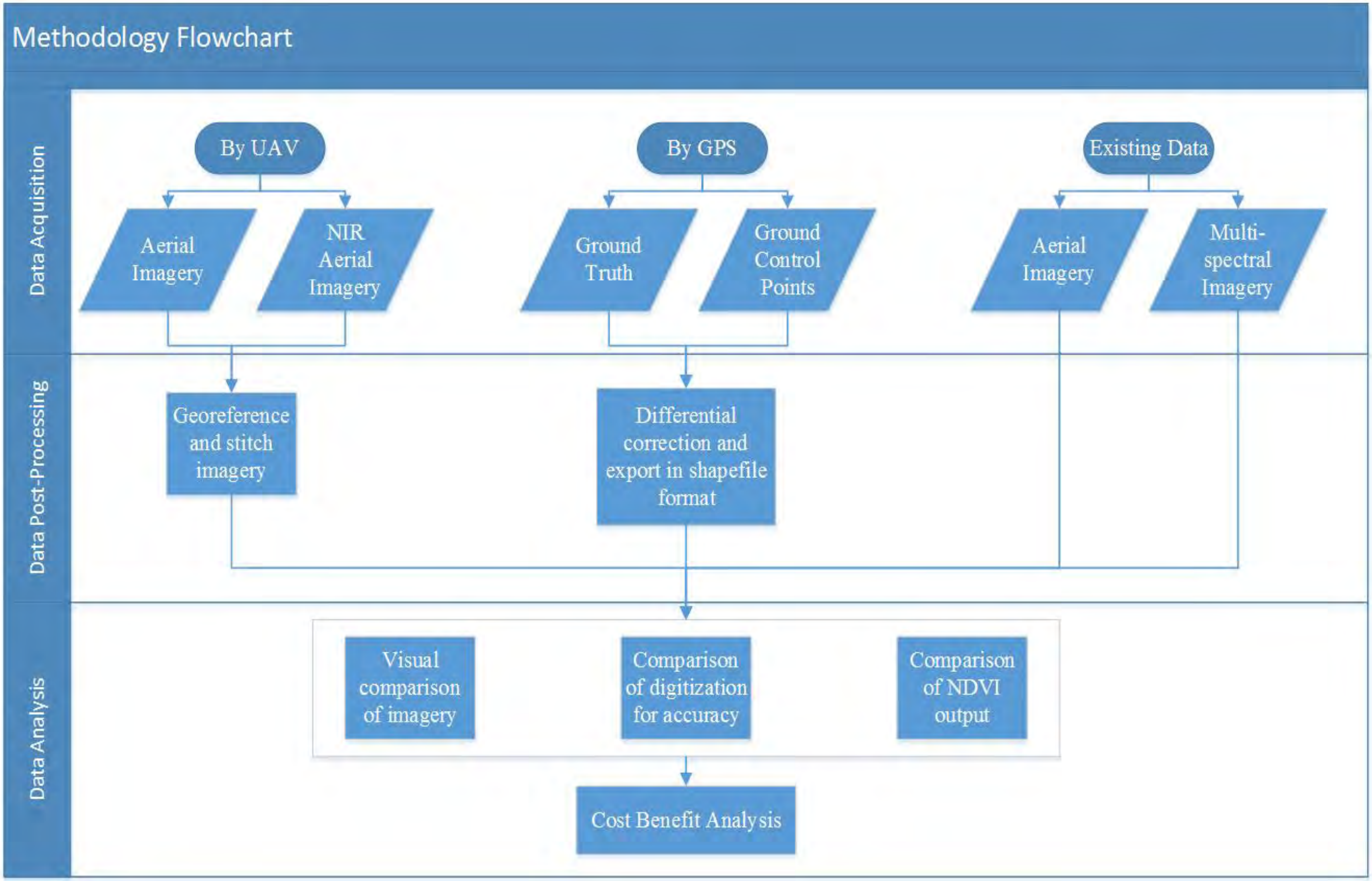


Figure 3.1 Flowchart of methodology

3.2 Equipment

Several pieces of equipment, enumerated in the following sub sections, were used to complete this study. There is necessary equipment for data acquisition by UAV (Table 3.1).

Table 3.1 List of Necessary Equipment

System	Equipment
UAV System	Phantom 2 by DJI
	Zenmuse H3-3D Gimbal by DJI
	FlySight First Person View (FPV) transmitter and Black Pearl Display
	2.4 Ghz Datalink by DJI
	PC Ground Station Software by DJI
Camera System	GoPro Hero 3+ Black Edition cameras (2)
	Sunex DSL945D 5.5 lens
	IRpro Hybrid Flat 5.5 InfraBLU22 5.5 lens
GPS Receiver	Trimble GeoExplorer 2008 Series GeoXH
	Trimble TerraSync 5.0 Software
Computers, Systems, and Other Software	ASUS TP300LA laptop computer
	HP EliteBook 8540w laptop computer
	Trimble GPS Pathfinder Office 5.60 software
	Esri ArcGIS 10.3 software
	Google Earth Pro 7.1
	Maps Made Easy mapping service

3.2.1 UAV

The Phantom 2 UAV (Figure 3.2) by Da-Jiang Innovations Science and Technology Co., Ltd. (DJI) was chosen for this project due to its ability to carry a small camera, compatibility with a three-axis gimbal for mounting the camera to the UAV, its compatibility with mission-planning software, and its affordability.

Figure 3.2 Phantom 2 UAV by DJI
(Source: http://www.dji.com)

Micro and small UAVs are available in hobby stores and online retailers. The Phantom 2 UAV is considered a micro UAV due to its size. It weighs approximately 1000 g with battery and propellers and has a diagonal length of 350 mm. According to DJI, the Phantom 2 is listed with a flight time of 25 minutes with a fully charged lithium polymer battery. The included remote control unit operates on a 2.4GHz ISM frequency and has the ability to communicate with the Phantom 2 up to 1000 m from the remote control (DJI 2015).

The Zenmuse H3-3D (Figure 3.3) by DJI is a 3-axis gimbal camera mount that secures the camera to the Phantom 2 UAV, providing stabilization for the camera should the UAV experience movements in “pitch”, moving front to back; ”rolling”, moving side to side; or “yaw”, moving left to right (Figure 3.4). Without stabilization, such movements on a camera would cause the camera to tilt, roll, and pan (Figure 3.5).

Figure 3.3 Zenmuse H3-3D by DJI with GoPro Hero3+ camera (Source: http://www.dji.com)

Figure 3.4 Pitch, Roll, and Yaw on a DJI Phantom Vision. (Source: https://luminous-landscape.com/landscape-aerial-photography-using-unmanned-aerial-vehicles/)

Figure 3.5 Tilt, Roll, and Pan movements in relation to a camera.
(Source: https://luminous-landscape.com/landscape-aerial-photography-using-unmanned-aerial-vehicles**)**

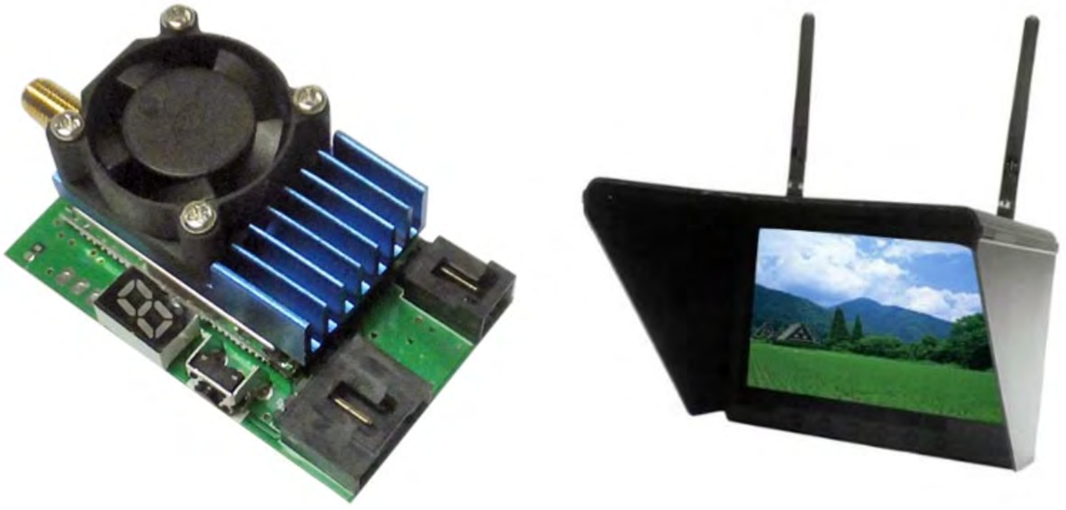


Figure 3.6 FlySight TX5812 FPV Transmitter and FlySight Black Pearl 7” display
(Source: https://www.dronesmadeeasy.com**)**

The Zenmuse gimbal is motorized and therefore provides the operator of the UAV with the ability to adjust the tilt of the camera from vertical to horizontal via the remote control unit (DJI 2014b).

The FlySight First Person View (FPV) Transmitter added to the UAV system wirelessly sends real-time footage to the FlySight Black Pearl display so that the operator may monitor the orientation of the camera during flight (Figure 3.6) (Drones Made Easy 2015).

The DJI PC Ground Station 4.0.11 runs on a Windows based personal computer and allows the operator with the ability to plan a mission, upload it to the UAV wirelessly, launch the UAV, monitor the progress of the UAV, and instruct the UAV to land all through the software interface. The Photogrammetry tool within the software handles the mission planning process. When opened, a preliminary aerial image of the site to be photographed is displayed through Google Earth, where the user enters the specifications of the camera and the desired altitude of the flight. The user then draws a square/rectangle over the site. This produces a preview of the proposed flight path with waypoints, which mark the turning points of the UAV for the mission (Figure 3.7). No waypoint zones built into the software prevent the user of creating flight paths within a five-mile radius of major airports, helping to avoid flight into the restricted airspace of the airport. If the flight path is acceptable it can be uploaded to the UAV wirelessly via the DJI 2.4Ghz Datalink (Figure 3.8). The datalink creates a wireless communications bridge between the computer and Phantom 2. Once the mission is successfully uploaded, the user can launch the UAV and watch its progress in real time as it travels along the flight path to each waypoint in the Ground Station interface. When the mission is complete, the user can then tell the UAV to auto land through the Ground Station software on the computer (DJI 2014a).

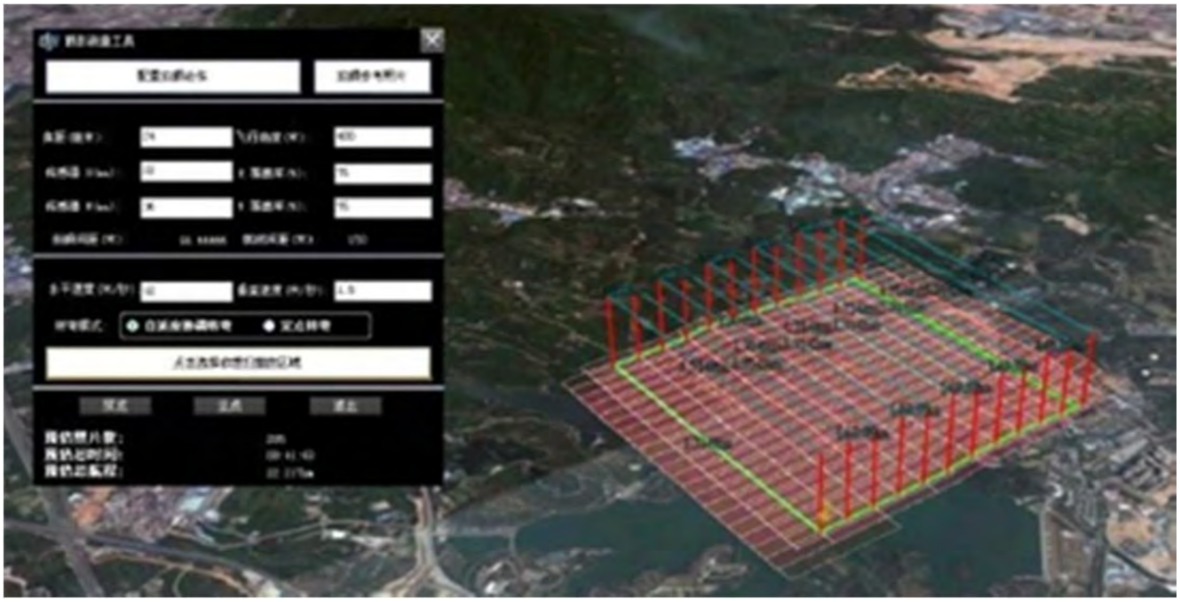


Figure 3.7 Photogrammetry Tool in DJI PC Ground Station software
(Source: http://www.dji.com**)**

Figure 3.8 DJI 2.4Ghz Datalink
(Source: http://www.dji.com**)**

3.2.2 Camera System

GoPro Hero 3+ Black Edition cameras (Figure 3.9) were used for image collection due to their compatibility with the Zenmuse H3-3D gimbal. The cameras can collect images with a resolution up to 12 megapixels and can be programmed to capture images using the preprogrammed intervals.

The 2.77 mm focal length of the GoPro lens creates an extremely wide angle of view that causes distortion at the edges. In order to mitigate this issue, the original GoPro lenses were replaced with a Sunex DSL945D and an IRpro Hybrid Flat 5.5 InfraBLU22 5.5 Rectilinear lenses (Figure 3.10). Both lenses have a 5.5 mm focal length that reduces image distortion in comparison to the images produced by original 2.77 mm lens on the GoPro cameras. In order to ensure proper camera and lens function Drones Made Easy in San Diego, CA performed the lens modification when the DJI Phantom 2 kit was purchased.

Figure 3.9 GoPro Hero 3+ Black Edition camera
(Source: www.gopro.com)

IRpro in Brea, California performed the modification on the second GoPro Hero 3+ Black Edition with an IRpro Hybrid Flat 5.5 InfraBLU22 5.5 Rectilinear lens. According to IRpro, the InfraBLU22 lens is fitted with a BLU22 filter that offsets the effects of the GoPro's CMOS sensor in order to effectively capture the near infrared spectrum on the blue channel of the camera's sensor, providing the ability to process the imagery for NDVI interpretation (IRpro 2015).

Figure 3.10 Sunex DSLR945D, left, and IRpro Hybrid Flat 5.5 InfraBLU22 5.5 Rectilinear lenses
(Source: http://www.sunex.com and http://www.ir-pro.com**)**

3.2.3 Trimble GPS Receiver

A Trimble GeoExplorer 2008 Series GeoXH GPS receiver was used to collect the coordinates of the site amenities and ground control points for the aerial imagery (Figure 3.11). The GeoExplorer XH unit is lightweight and can provide sub-foot data accuracy after differential correction in post-processing (Blickenstorfer 2012). This level of accuracy was deemed sufficient for the purposes of this study.

Trimble's TerraSync 5.0 software installed on the GeoExplorer 2008 Series GeoXH GPS receiver provides the unit with the ability to communicate with GPS receivers and record positional data. The interface allows the user to collect point, line, or area data, add attributes to the data, and store it in files for download.

Figure 3.11 Trimble GeoExplorer 2008 Series GeoXH GPS receiver with TerraSync software
(Source: http://www.hydrosurvey.cn/)

3.2.4 Computers, Systems, and Other Software

Two different computers, an ASUS TP300L and an HP EliteBook 8540w were used for this study.

The ASUS TP300LA is a 13.3” laptop computer with Windows 8 operating system (Figure 3.12). This computer is lightweight, has a touch screen, and has a 360-degree rotating screen to essentially turn into a tablet (ASUS 2015). These features made this computer ideal for using in the field with the DJI PC Ground Station software to operate the DJI Phantom 2 UAV for data collection.

The HP EliteBook 8540w is a 15.6” laptop computer equipped with Windows 8 operating system (Figure 3.12). This computer, owned by the Spatial Sciences Institute (SSI) at the University of Southern California (USC), was used for data analysis of this project.

Figure 3.12 From left, ASUS TP300LA and HP EliteBook 8450w
(Source: http://www.asus.com/us/, http://www.engadget.com)

Trimble’s GPS Pathfinder Office version 5.60 is a specialized software platform installed on the HP EliteBook for use with the Trimble GPS receiver. The software provides a communication interface between the GPS receiver and computer, allowing data to be downloaded from the GPS receiver to the computer. GPS Pathfinder Office is used to perform differential correction by acquiring positional data from local base stations and improving the positional accuracy of data collected with the GPS receiver. GPS Pathfinder Office also transforms data files into shapefiles for use in Environmental Systems Research Institute, Inc. (Esri) ArcGIS 10.3 software (Trimble Navigation Limited 2015)

Environmental Systems Research Institute, Inc. (Esri) ArcGIS 10.3 software is used to perform analysis on the data acquired for this study. ArcGIS and GPS Pathfinder Office are highly specialized software titles and were used on the HP EliteBook computer mentioned earlier in this section.

Google Earth is used in the PC Ground Station software as mentioned in section 3.1.1 and provides preliminary basemap imagery for mission planning. Google Earth is used to analyze existing imagery for comparison. Google Earth is also used within the Maps Made Easy web service for georeferencing images.

Maps Made Easy (www.mapsmadeeasy.com) is a web-based mapping service that allows users to georeference images. It stitches these images together to create maps (Maps Made Easy 2015). This service is used to create maps of UAV collected imagery and process the imagery into a GeoTIFF formatted file. A GeoTIFF file is a tagged image file format (TIFF) image with georeferenced information embedded into the metadata of the file. This embedded georeference information, such as map projection and coordinate system, allows the image to be opened in ArcGIS 10.3 in the proper spatial orientation.

3.3 Data Acquisition

The Data acquisition process occurred from February to April of 2015 at Deleo Regional Sports Park. Data collection included the use of the UAV to collect aerial imagery data and a GPS receiver to collect ground truth and ground control point data. Existing data is collected electronically via the internet.

3.3.1 UAV Data Acquisition

UAV data collection occurred at Deleo Regional Sports Park in March and April of 2015. Prior to any flights the ideal spatial resolution of the imagery needs to be determined, followed by verification of the new technical specifications of the cameras after modification.

The 5.5 mm lens modifications on the GoPro Hero 3+ Black Edition cameras create the equivalency of a 28mm field of view in terms of 35mm format according to Drones Made Easy, who performed one of the lens modifications. Using the formula: Altitude = (Pixel Resolution x Focal Length)/Pixel Dimension, it is possible to calculate the spatial resolution for the imagery at a given altitude. The pixel dimension of the GoPro is 0.00155mm according to the GoPro technical specs (Mailey 2014). Starting with a 50 m altitude the calculation is: 50m = (Pixel Resolution x 28mm)/0.00155, resulting in a projected pixel resolution, or spatial resolution of 2.77mm. This calculation is completed for altitudes of 50 m, 75 m,, 100 m, and 125 m (Table 3.2).

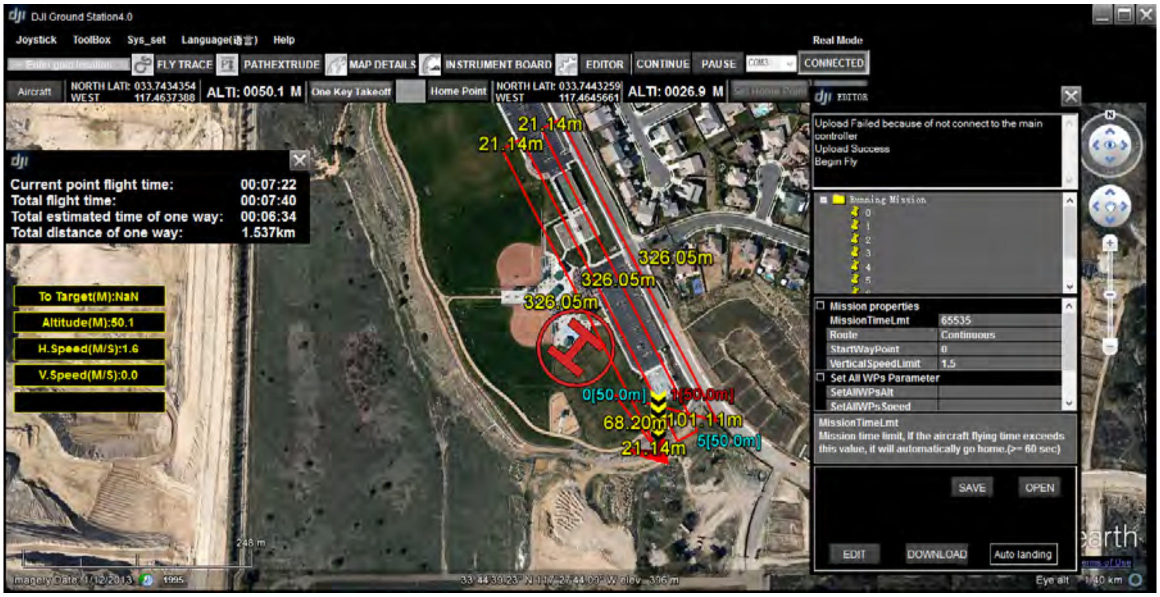
Table 3.2 Pixel resolutions at various altitudes considered for UAV data collection

Altitude (m)	Pixel Resolution (mm)
50	2.77
75	4.15
100	5.54
125	6.92

Orange soccer cones placed within the area of the flight serve as ground control points (GCP) for the aerial imagery. Permanent, flat features such as utility and manhole covers also served as GCPs where available. The positional data for the GCPs are collected using the Trimble GPS receiver (Figure 3.13) for georeferencing during post-processing.

Figure 3.13 Collecting positional data for an orange soccer cone being used as a GCP at Deleo Regional Sports Park

In order to prepare the UAV for data collection, the photogrammetry tool in the PC Ground Station software is opened and the camera and flight parameters are entered in the tool. The data for this study is collected at an altitude of 50 m to avoid collisions with light poles in the park. Next, a rectangle is drawn over a portion of the park, producing a preview of the flight path (Figure 3.14). Then the flight path is created and uploaded to the UAV. Before the UAV is launched, one of the GoPro Hero 3+ Black Edition cameras is attached to the DJI Zenmuse H3-3D gimbal mount (Figure 3.15) and set to automatically capture a 12-megapixel (MP) image every two seconds. Finally, a home point is for the UAV is established in the ground station software and the UAV is launched via the software. The UAV uses the home point for auto landing at the end of the flight. This process is repeated using the saved flight paths to capture imagery for NDVI processing using the GoPro with the InfraBLU22 lens modification (Figure 3.16).



NORTH LATI: 033.7434354 WEST 117.4637388 ALTI: 0050.1 M

NORTH LATI: 033.7443259 WEST 117.4645661 ALTI: 0026.9 M

Current point flight time:	00:07:22
Total flight time:	00:07:40
Total estimated time of one way:	00:06:34
Total distance of one way:	1.537km

To Target(M):NaN
Altitude(M):50.1
H.Speed(M/S):1.6
V.Speed(M/S):0.0

Upload Failed because of not connect to the main controller
Upload Success
Begin Fly

☐ Mission properties

MissionTimeLmt	65535
Route	Continuous
StartWayPoint	0
VerticalSpeedLimit	1.5

☐ Set All WPs Parameter

SetAllWPsAlt	
SetAllWPsSpeed	

MissionTimeLmt
Mission time limit, If the aircraft flying time exceeds this value, it will automatically go home.(>= 60 sec)

Figure 3.14 DJI Ground Station software during a flight at Deleo Regional Sports Park.

Figure 3.15 GoPro Hero 3+ Black Edition camera attached to DJI Zenmuse H3-3D Gimbal on DJI Phantom 2 prior to flight

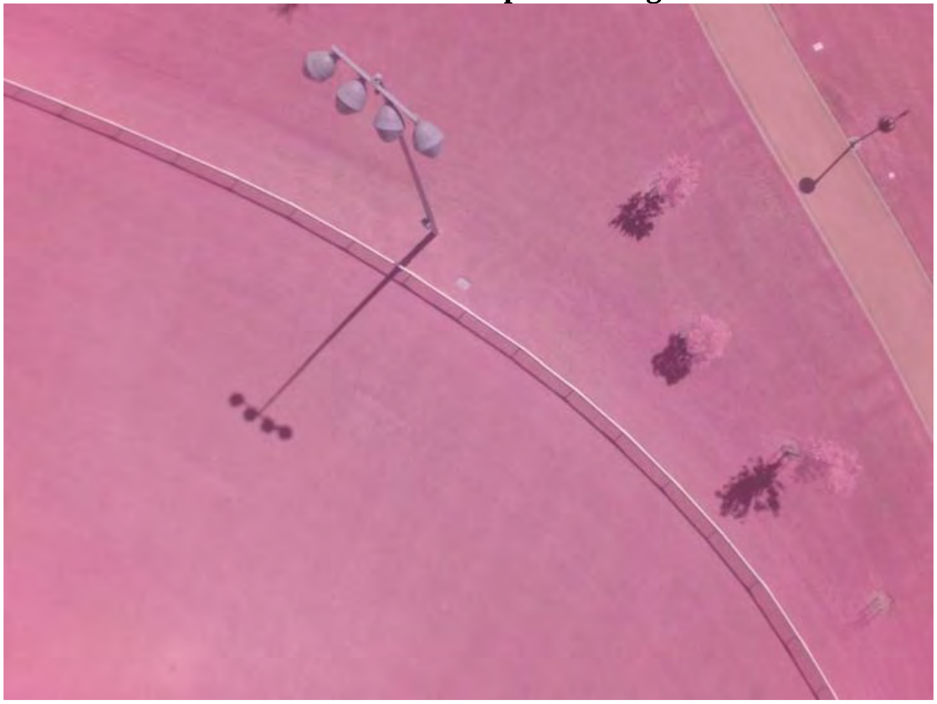


Figure 3.16 Image taken with GoPro equipped with InfraBlu22 lens modification. Pink shades are grass and trees. The walking trail, light poles, and fence appear less pink.

3.3.2 GPS Data Acquisition

Ground truth data for this study is collected with the Trimble GPS receiver. The coordinates for trees, light poles, fences, and buildings were recorded over several days in February and March of 2015 due to the volume of data being collected.

Data folders were created for each feature type for organizational purposes and then recorded. The process of recording coordinate data with the GPS receiver involved positioning the receiver adjacent to the feature at a height of one meter and collecting a minimum of 15 readings per feature for increased locational accuracy (Figure 3.17). This process is repeated until all feature locations have been recorded.

Figure 3.17 Collecting positional data for a tree at Deleo Regional Sports Park

3.3.3 Bing and Google Earth Imagery Acquisition

Bing Maps aerial imagery is available via ArcGIS Online and can be accessed in ArcGIS 10.3 software. Google Earth imagery is acquired via a location search in Google Earth Pro 7.1. The two different imagery data sets are used for comparison with the UAV imagery due to their popularity, ease of acquisition, and expected relevancy.

3.3.4 USGS and NAIP NDVI Data Acquisition

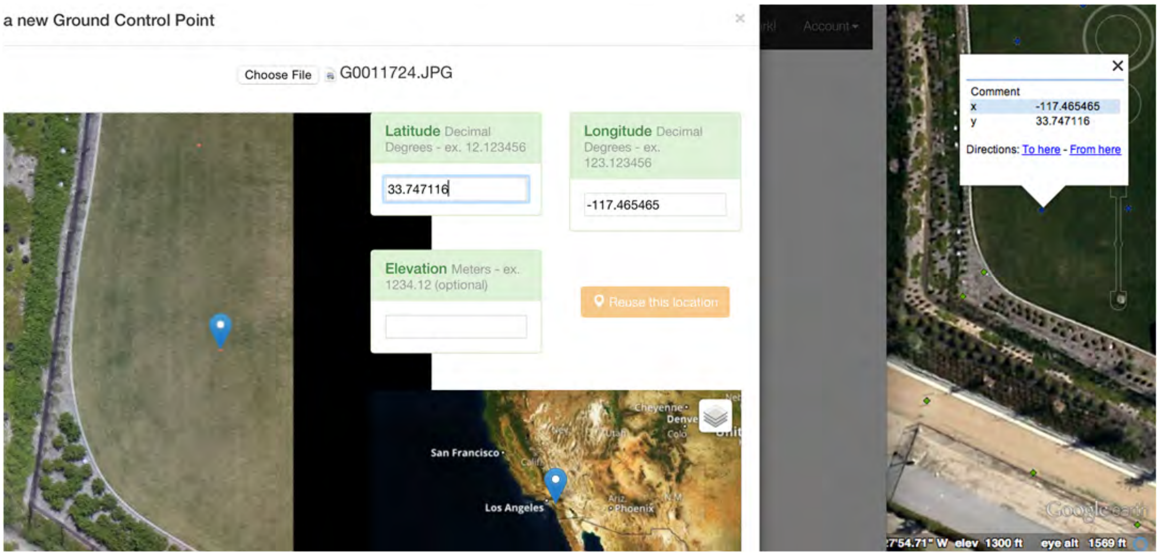
NDVI data for the area is collected from the United States Geological Survey (USGS) and through ArcGIS Online. The EarthExplorer service on the USGS's website is used to select and download NDVI data files for the study area collected from March 31, 2015. The National Agriculture Imagery Program (NAIP) imagery is available via ArcGIS Online and accessed through ArcGIS 10.3 software.

3.4 Post-Processing Data

3.4.1 UAV Post-Processing

The UAV data consists of several hundred images that need to be georeferenced and stitched together in order to be useful. Maps Made Easy (www.mapsmadeeasy.com) is a web service that allows users to stitch and georeference aerial imagery into maps. The purchase of the UAV used for this project came with an account, free points, and a monthly subscription to process images on the Maps Made Easy service. The Maps Made Easy service allows users to create an account for free, but points need to be purchased to process images and produce a final image file for download. Users can choose between a monthly subscription or one time point purchase when signing up and adding points. The maps used for this project required 2,960 points, costing $89.98 to purchase 3,000 points. The purchased points combined with the free points supplied with the free subscription provided plenty of points to process and download the imagery.

Georeferencing, as mentioned in chapter two of this paper, is the process of assigning geographic coordinates to features in an image to make it useful for mapping. The addition of coordinate data to features within an image adjusts the image to match these features' coordinates on the surface of the Earth (Falkner and Morgan 2002). Processing images with geographic information and stitching them together into a larger image requires computers with powerful processing abilities. Maps Made Easy service has the capabilities to process images in as little as few hours (Maps Made Easy 2015)The Maps Made Easy surface handles the georeferencing process by requiring the user to identify a location in the image with a marker and enter the latitude and longitude data for the point (Figure 3.18). The coordinates of the point are then stored in a table that associates the data to the specific pixel location in the image. When this information is stored the coordinate data is referenced to Google Elevation Service in order to attach elevation data for the point, which is used in the mosaicking process. The Maps Made Easy interface uses the WGS 84 geographic coordinate system used in Google Earth and requires the coordinate data entered for georeferencing to be in the same system to ensure accuracy.


a new Ground Control Point

G0011724.JPG

Latitude Decimal Degrees - ex. 12.123456: 33.747116

Longitude Decimal Degrees - ex. 123.123456: -117.465465

Elevation Meters - ex. 1234.12 (optional):

Comment	
x	-117.465465
y	33.747116

Directions: To here - From here

Figure 3.18 Georeferencing in Maps Made Easy interface

The images are stitched together using a proprietary process that uses a Structure from Motion (SfM) method for stitching the imagery together based on the color and shape of features in the imagery identified by the system (Maps Made Easy 2015).). SfM is a method of using several overlapping images to create a three-dimensional surface, relying on the three-dimensional location of the camera or control points on the surface (Westoby et al. 2012). The points are located and matched throughout the uploaded imagery to triangulate their positions in a manner that minimizes error between the points. If the imagery has GPS information in the Exchangeable Image File Format (Exif) file, georeferencing occurs during the reconstruction of the imagery. If the imagery does not have GPS information in the Exif file, such as that of the GoPro, the georeferencing occurs after reconstruction (Maps Made Easy 2015. This results of the Maps Made Easy processes produces a final image that is properly aligned with the Earth's surface.

3.4.2 GPS Post-Processing

Ground truth and GCP data collected with the Trimble GPS receiver is subject to positional errors that can be attributed to atmospheric interference or satellite position. Differential correction performed in Trimble's GPS Pathfinder Office software can correct these errors. The differential correction process uses positional data from base station providers in the area that is downloaded by the software. The base station records its location at fixed intervals and compares it to the position of the control location to calculate the positional error for the reading at that specific time. The time of day the data collected by the GPS receiver is cross-checked with the positional error data, applying positional error corrections to data that were collected at corresponding times of day. The data files are converted to shapefile format in GPS Pathfinder Office after differential correction.

3.5 Data Analysis

All the data collected is imported into ArcGIS 10.3 for analysis. Imagery in Google Earth cannot be imported into ArcGIS 10.3 and will be analyzed within Google Earth Pro 7.1. The inability to transfer Google Earth's imagery into ArcGIS is not an issue due to the software's interface having analysis abilities such as measuring distance, area, and digitizing.

3.5.1 Visual Comparison of UAV, Bing, and Google Earth Imagery

The UAV imagery is in WGS 84 and is projected to NAD 83 State Plane California Zone IV US Feet using the Project tool in ArcGIS. The conversion of the data from a geographic coordinate system to a projected coordinate system allows measurements to be calculated on the data. The UAV, Bing, and Google Earth imagery of the study site is opened and visually examined (Figure 3.19). Observational inspections of the three imagery sets is performed, making note of differences that can be seen in each such as differences in landscape, vegetation maturity, and feature condition. The dates the imagery sets were collected is noted along with map scale when the maps are zoomed in to their maximum zoom level.

3.5.2 Comparison of Features from UAV, Bing, and Google Earth Digitization

The features of the park visible in the UAV, Bing, and Google Earth imagery are digitized (Figure 3.20). Features in the UAV and Bing imagery are performed in ArcGIS 10.3. Digitization of the Google Earth imagery is performed in Google Earth Pro 7.1 and imported into ArcGIS for comparison purposes.

Digitizing in Google Earth Pro produces a Keyhole Markup language Zipped (KMZ) file that can be converted in ArcGIS using the KML to Layer tool and used for analysis in ArcGIS. Displaying the latitude/longitude in decimal degrees in Google Earth Pro produces six significant digits in the latitude/longitude data during digitization, the same number of significant digits in the GPS receiver data and digitization performed in ArcGIS. Having the same number of significant digits ensures continuity in the precision of the data points. Digitized features from Google Earth are converted from WGS 84 to NAD 1983 State Plane California Zone VI using the Project tool in ArcGIS.

The locations of the digitized features are compared to the ground truth data using the Near tool in ArcGIS in order to determine the accuracy of the data sets. The light pole data set is chosen to measure the accuracy of the datasets since it is a stand-alone feature that is a permanent feature in the park that is easily identifiable for digitization purposes. Other features such as trees or fences may differ in location and size in the imagery sets and could create inaccurate accuracy results.

The measure tool in ArcGIS measures the width and length of features. The measurements from the UAV, Bing, and Google Earth imagery are then compared to the measurements captured with the GPS receiver in the ground truth data. A tape measure is used to collect measurements of features that were feasible in order to check the accuracy of the ground truth data.


UAV
1:960

Bing
1:960

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Google
Earth
1:960

Figure 3.19 Comparative Imagery of Deleo Regional Sports Park

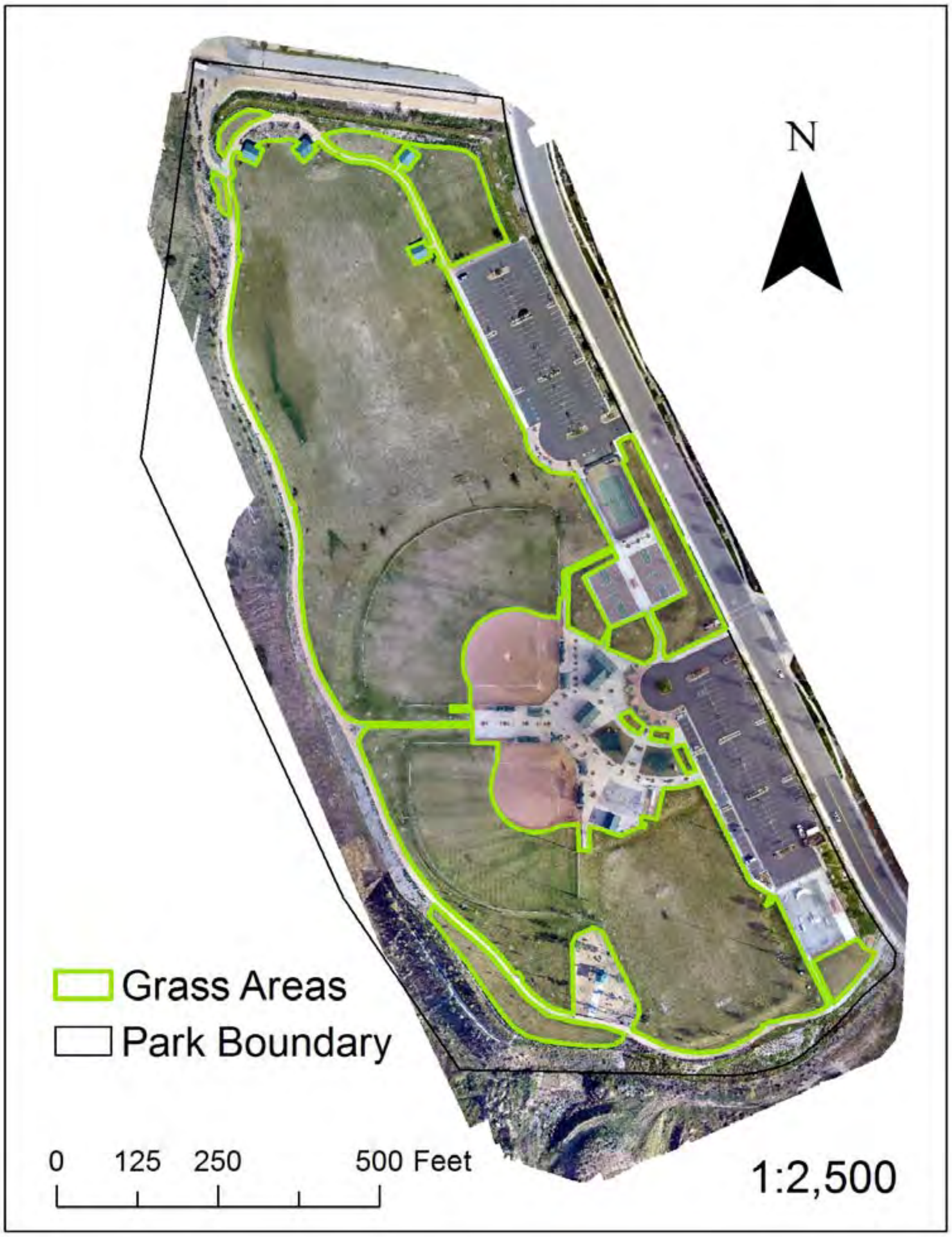


Figure 3.20 Grass Fields Digitized Using UAV Imagery as A Guide

3.5.3 Comparison of NDVI between UAV, NAIP, and USGS

Normalized Difference Vegetation Index (NDVI) uses visible and near-infrared spectrums of light reflected off the surface of the Earth to determine the level of photosynthesis occurring in the vegetation (NASA 2015). The NDVI data derived from the imagery after processing can monitor the health of vegetation in an area. The index has numerical range of -1.0 to 1.0, with -1.0 characteristic of dead or no vegetation, and 1.0 being healthy, green vegetation. NDVI output is generated from the UAV imagery using the Image Analysis window in ArcGIS 10.3. In the Image Analysis Options window the red band, band one in the imagery, is designated as the infrared band, and the blue band, band three, is designated as the red according to specifications from IRpro about the Hybrid InfraBlu22 lens. This process is applied to the USGS imagery in order to generate NDVI output from the Landstat 8 imagery acquired from the USGS..

NDVI 2012 imagery of California from the National Agriculture Imagery Program (NAIP) by Esri is available through ArcGIS Online and obtained in ArcGIS for comparison. The three NDVI data sets are visually examined for similarities and differences. The NDVI results of the UAV and USGS output are visually compared with the UAV imagery to determine if the index information is representative of the park’s vegetation conditions.

3.5.4 Cost/Benefit Analysis

The literature review in chapter two of this paper revealed that significant cost savings exists between UAV and manned aircraft imagery acquisition. Quotes for custom aerial imagery acquisition with manned flights and purchasing existing color and multi-spectral imagery are obtained and compared to the price of the UAV system used for this study. These monetary costs are compared to determine the financial benefit of the UAV.

The total hours spent collecting and processing data collected with the UAV and GPS receiver are tallied in order to determine total labor cost for each method of data acquisition. These figures are compared to arrive at the potential labor savings benefits of the UAV.

A strength, weakness, opportunity, and threat (SWOT) analysis is performed using the results of the financial and labor benefits to arrive at a final conclusion on the use of UAV technology. Information discussed in the literature review of chapter two in this paper is also considered in the SWOT analysis.

This chapter covered the equipment and methodology utilized for the data collection portion of this study. The results of the analysis performed in this chapter are enumerated in the next chapter.

CHAPTER 4: RESULTS

This chapter articulates the results of the methodology used in chapter 3 to capture data using a UAV. The results of the UAV data will determine if the UAV is a cost efficient method for monitoring and maintaining a park. The findings regarding the accuracy of the UAV with existing data sources (Section 4.1) are presented first, followed by the cost-benefit analysis of using the UAV versus employing manned aircraft and manual data collection (Section 4.2).

4.1 Accuracy of UAV and Existing data

The UAV-collected imagery is visually compared to Google Earth and Bing imagery available through ArcGIS Online in ArcGIS 10.3. The dates of the imagery sets are collected and then compared for relevance (Table 4.1).

Table 4.1 Dates imagery data was collected by the sources reveals a significant difference in the age of the Bing imagery in comparison to the UAV and Google Earth imagery

Imagery Source	Date Collected
UAV	March/April 2015
Google Earth	January 2013
Bing	May 2010

The UAV imagery is collected at an altitude of 50 m over four days in March/April of 2015, and is the most accurate visual representation of the park at the time this paper is written. The Google Earth imagery, collected January 2013, is relevant to the extent that it shows the park and most of the features as they look today. The most obvious features missing are vinyl fencing on the grass fields near the parking lots and fences in the outfield of the Little League fields, which are present in the UAV’s more recently collected imagery.(Figures 4.1 and 4.2).

UAV
1:192

Bing
1:192

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Google
Earth
1:192

Figure 4.1 Comparative Imagery Zoomed in on Vinyl Fencing

UAV
1:192

Bing
1:192

Google
Earth
1:192

Figure 4.2 Comparative Imagery of Little League fence

The Bing imagery acquired from ArcGIS Online is from May 2013 and shows the park as a graded dirt field prior to the beginning of park construction to begin (Figures 4.1 and 4.2). In comparison to the UAV imagery (Figures 4.1 and 4.2), the Bing imagery is least relevant of the imagery data sets and, consequently, is useless for further analysis.

Zooming in on the imagery increases the amount of detail that can be seen on the Earth's surface in a map. The resolution of the imagery determines how much detail can be seen at a zoom level before the imagery appears blurred or pixelated. In order to test visible detail of the imagery sets, the UAV, Google Earth, and Bing imagery sets are zoomed to their maximum zoom levels on the handicapped parking spots at the park and compared. First, the Google Earth imagery is zoomed in to resulting in a representative fraction (RF) scale of 1:60 (Figure 4.3). The imagery is very pixelated and difficult to see much detail in the writing of the handicapped parking areas. Next, the UAV imagery is zoomed in further than the Google Earth imagery to a RF scale of 1:5 (Figure 4.3). Bing imagery is zoomed in to a scale of 1:25 (Figure 4.3). The UAV imagery is pixelated, but the lines and writing of the parking spot recognizable in comparison to the Google Earth imagery of the same location. The Bing imagery shows dirt and moving in to a scale of 1:24 produces a white screen, showing that the maximum zoom of the Bing imagery set is 1:25. The results of the zooming in on the UAV imagery has a higher resolution than the Google Earth imagery, allowing for finer inspection of the park.

Figure 4.3 Maximum Zoom in of imagery

The results of precision of the ground truth data points are examined after differential correction is performed on the data. The results provide the horizontal accuracy that is used to create four categories to classify the results (Table 4.2). The overall average of error is calculated along with the average error in each category. The digitized features from the UAV and Google Earth data are compared with the light pole ground truth data using the Near analysis tool in ArcGIS to determine the accuracy of the UAV and Google Earth data. The ground truth data is symbolized by the degree of precision based on the categories in Table 4.2. A multi-ring buffer is created around each ground truth point to display the distance of error ranging from 15 cm to 1 m (Figure 4.4).

Table 4.2 Precision of Ground Truth Data and Accuracy of UAV and Google Earth Digitized Data in Comparison to Ground Truth Data Light Pole Points

Category	Ground Truth	Number of Ground Truth Points	UAV	Google Earth
Overall Average	26.50 cm	140	58.52 cm	90.83 cm
5-15 cm	10.91 cm	63	10.79 cm	9.98 cm
15-30cm	23.04 cm	34	23.95 cm	19.33 cm
30-50cm	38.95 cm	24	37.70 cm	41.51 cm
.5-1m	0.67 m	19	0.73 m	0.72 m
1-2m	N/A	0	1.35 m	1.32 m
2-5m	N/A	0	2.1 m	2.80 m

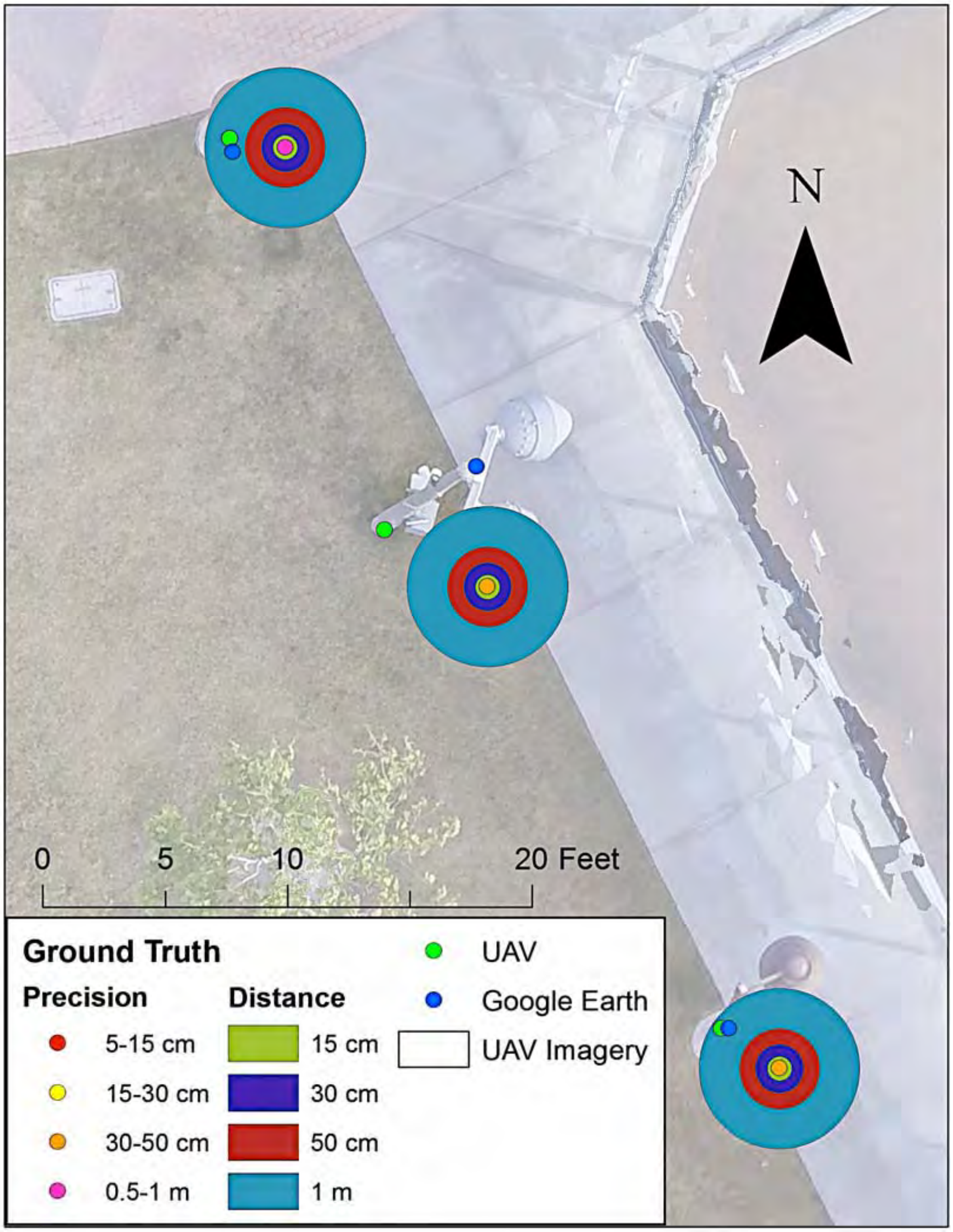


Figure 4.4 Comparison of light pole locations at Deleo Regional Sports Park UAV and Google Earth points were digitized from the respective imagery. The ground truth points were collected with a GPS receiver

Two-dimensional measurements (length and width) and the area of selected features in the park are compiled to further check the accuracy of the UAV data in comparison to the ground truth data. Accurate measurements are necessary in order for the UAV imagery to be useful in park maintenance. If the area calculation using the UAV imagery is not accurate, supply orders will be wrong and could result in spending too much on materials or labor. Table 4.3 shows the results of the measurements of six features within the park using the data sources of this study (Table 4.3).

Table 4.3 Measurements for features in park to determine accuracy of UAV data. The UAV and ground truth data are almost identical in all but one measurement test.

Measurement of Feature						
Data Source	**Walking Trail Width (ft.)**	**Total Length of Vinyl Fence (ft.)**	**Area of Picnic Structure (sq. ft.)**	**Area of Grass Fields (sq. ft.)**	**Area of Play Grounds (sq. ft.)**	**Area of Little League Diamonds (sq. ft.)**
UAV	8.79	2739.89	781.9	547799.34	7511.56	37993.12
Google Earth	9.16	2084.30	744.22	545486.01	6965.17	37901.53
Ground Truth	9.80	2761.82	888.89	550252.74	7563.68	37962.4
Tape Measure	8.95	N/A	806.6964	N/A	N/A	N/A

The measure tool in ArcGIS is used to measure the width of the walking trail in the UAV and ground truth data. Next, the width of the trail is also measured of the Google Earth digitized data for added comparison (Figure 4.5). In addition to obtaining measurements within ArcGIS, a tape measure is used to manually collect the measurement of the trail width to serve as an added control measurement (Figure 4.6). The result of the tape measure width can be compared to the ground truth data to check the accuracy of the GPS receiver.

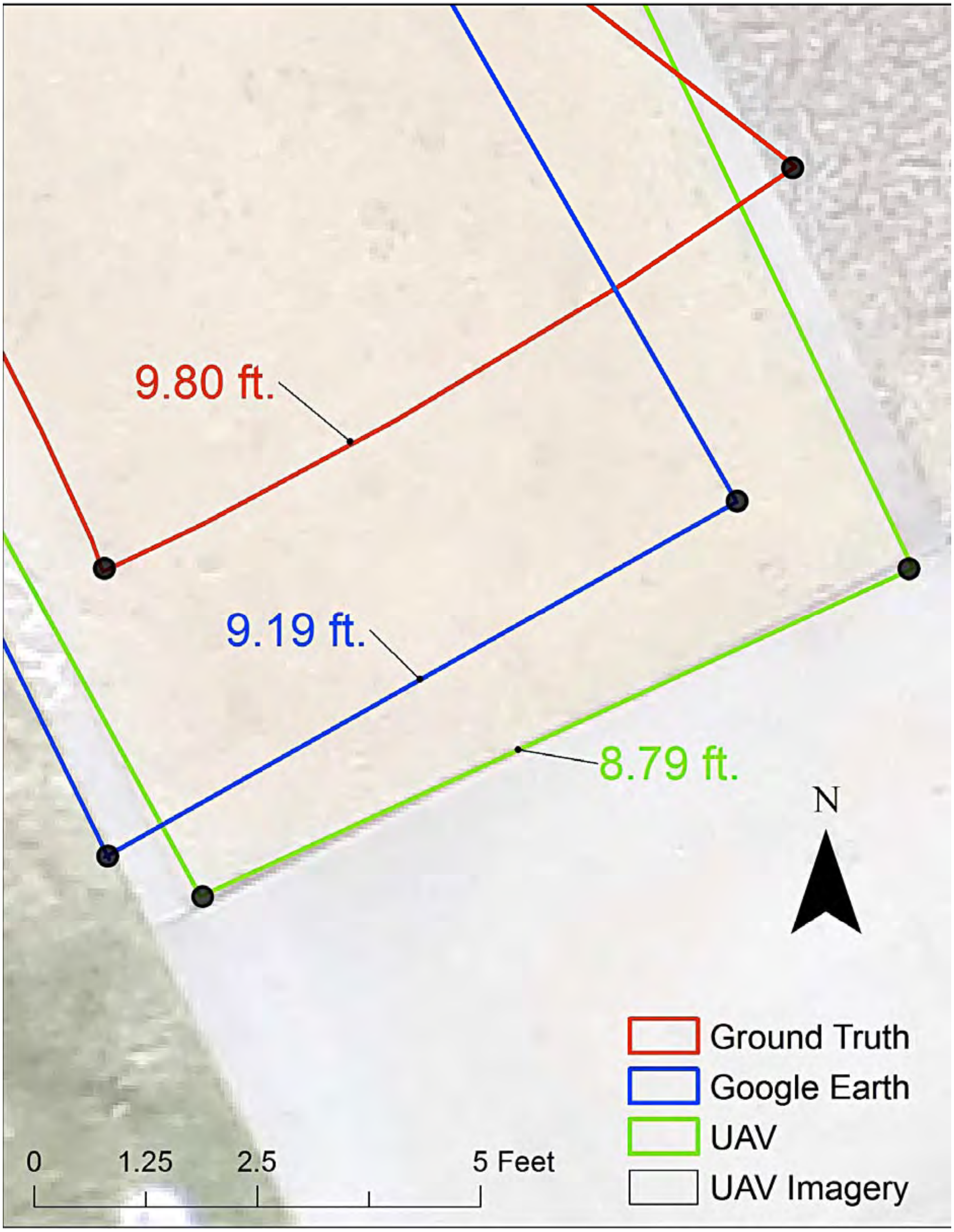


Figure 4.5 Map of width of walking trail.
Detail map showing the width of the walking trail at the north end of the park as collected from the data sources.

Figure 4.6 Tape measure being used to measure the width of the dirt trail to compare to ground truth data for accuracy purposes

The length of the entire vinyl fence in the park is calculated using the calculate geometry feature in ArcGIS to obtain the length of the line segments representing the fencing (Figure 4.7). These figures are added up using the statistics function the field in the attribute table of the data sets. This serves as another accuracy check of the UAV data in comparison to the ground truth data (Table 4.3) and to obtain data that would be of use for maintenance purposes, such as having to order fencing to replace the existing vinyl fence that has deteriorated in the hot weather conditions of the area. The vinyl fence is approximately four feet tall, and checking measurements of this feature can determine if the height of a feature has any effect on the accuracy of the measurement.

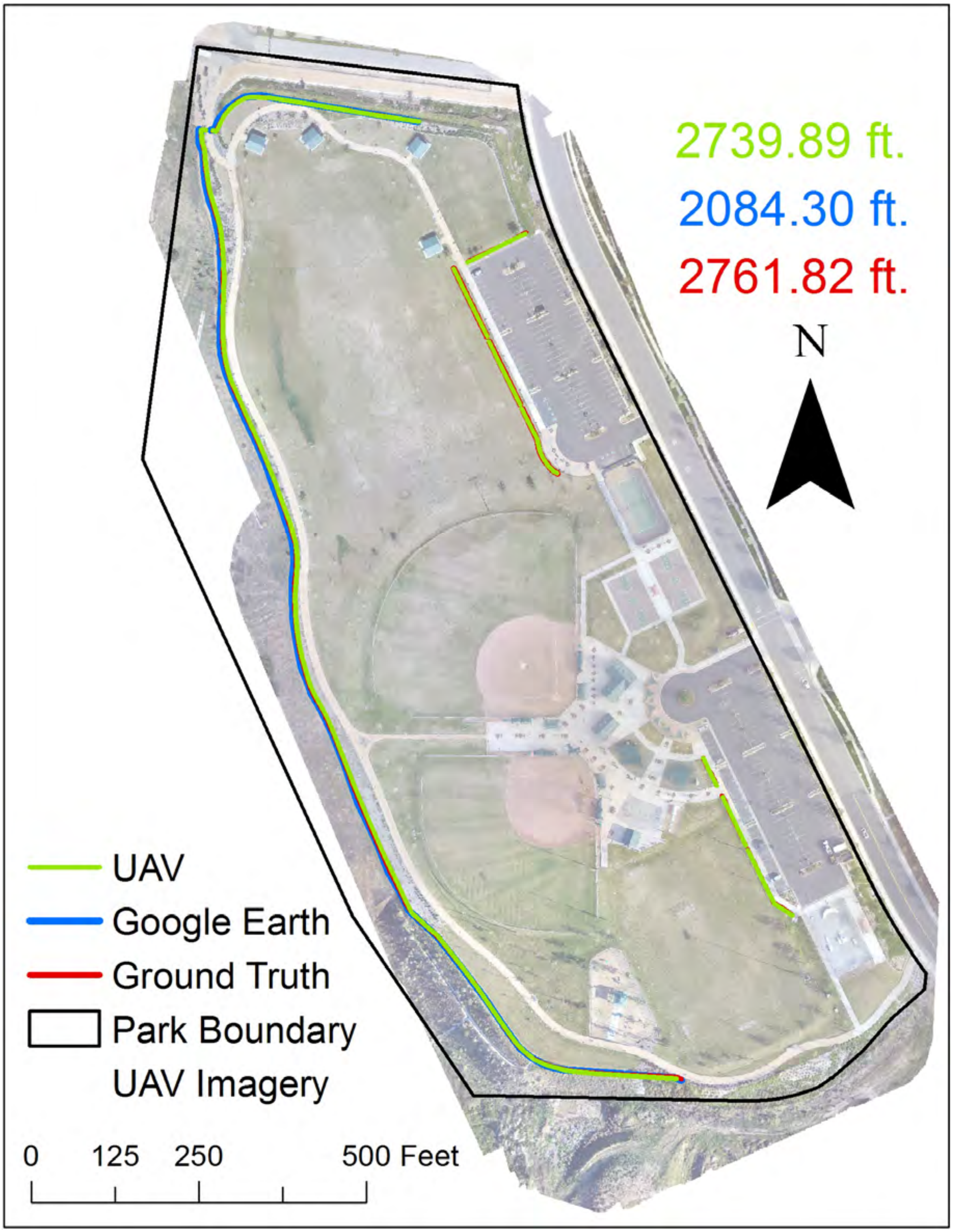


Figure 4.7 Map of the vinyl fencing in the park.
The map shows the location of the vinyl fencing and the total length.

The concrete pad of a picnic structure is the next featured measured for comparison. The area of the concrete pad is calculated by using the Calculate Geometry tool in ArcGIS to calculate the area in the UAV, ground truth, and Google Earth data sets. Once again a tape measure is used to measure the sides of the pad to serve as a control to check the accuracy of the ground truth data (Figure 4.8). The length and width measurements obtained with the tape measure are multiplied in order to calculate the area of the pad using the tape measure data. This process is repeated to calculate the total area of grass in the park (Figure 4.9), the area of the playground areas with rubberized coating (Figure 4.10), and the Little League diamonds (Figure 4.11). This is done to serve as a test for calculating data for ordering supplies for maintaining these amenities and further accuracy comparison.

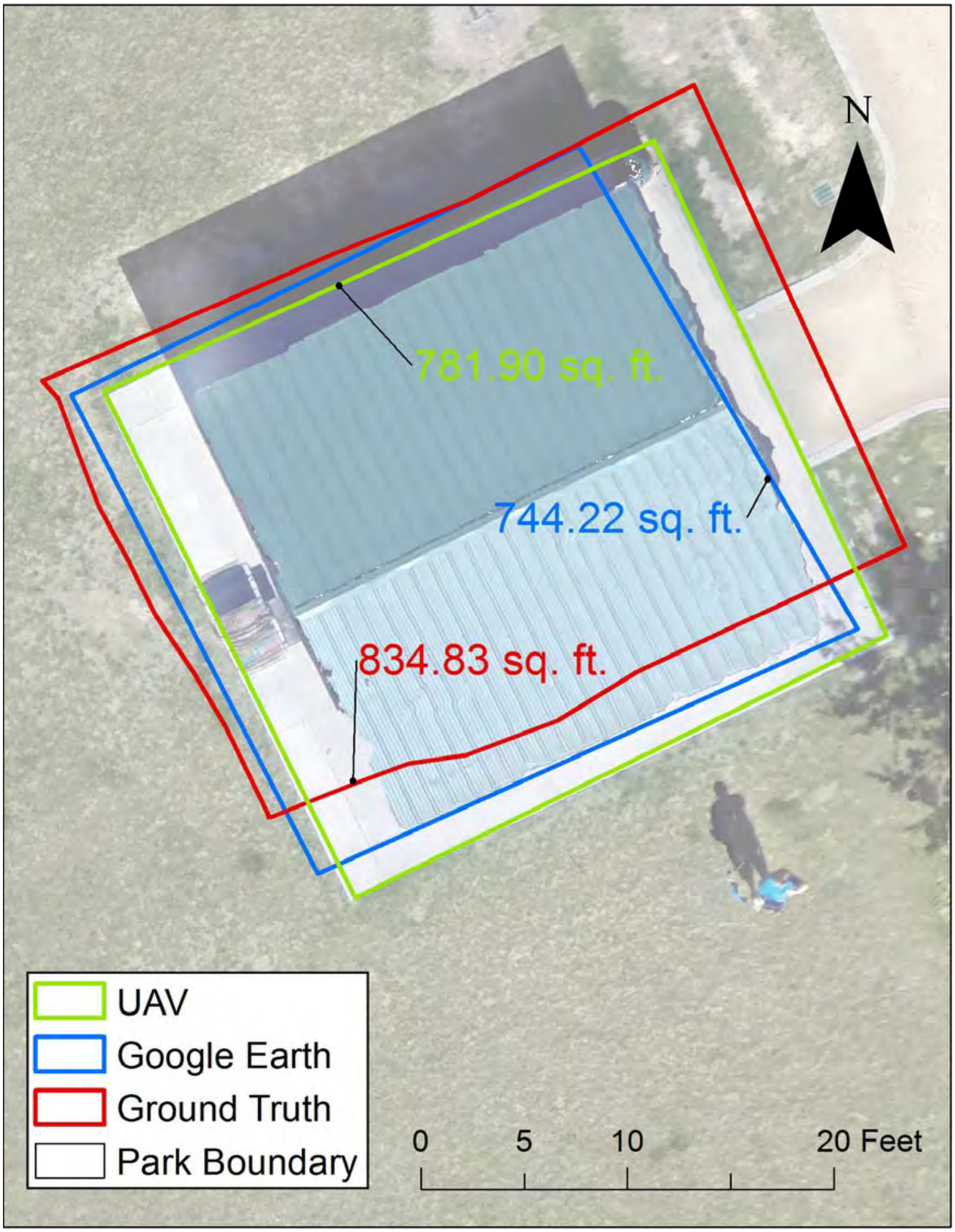


Figure 4.8 Map comparing size of picnic area.
A picnic area in the northern end of the park is analyzed for its conformity of shape and size.

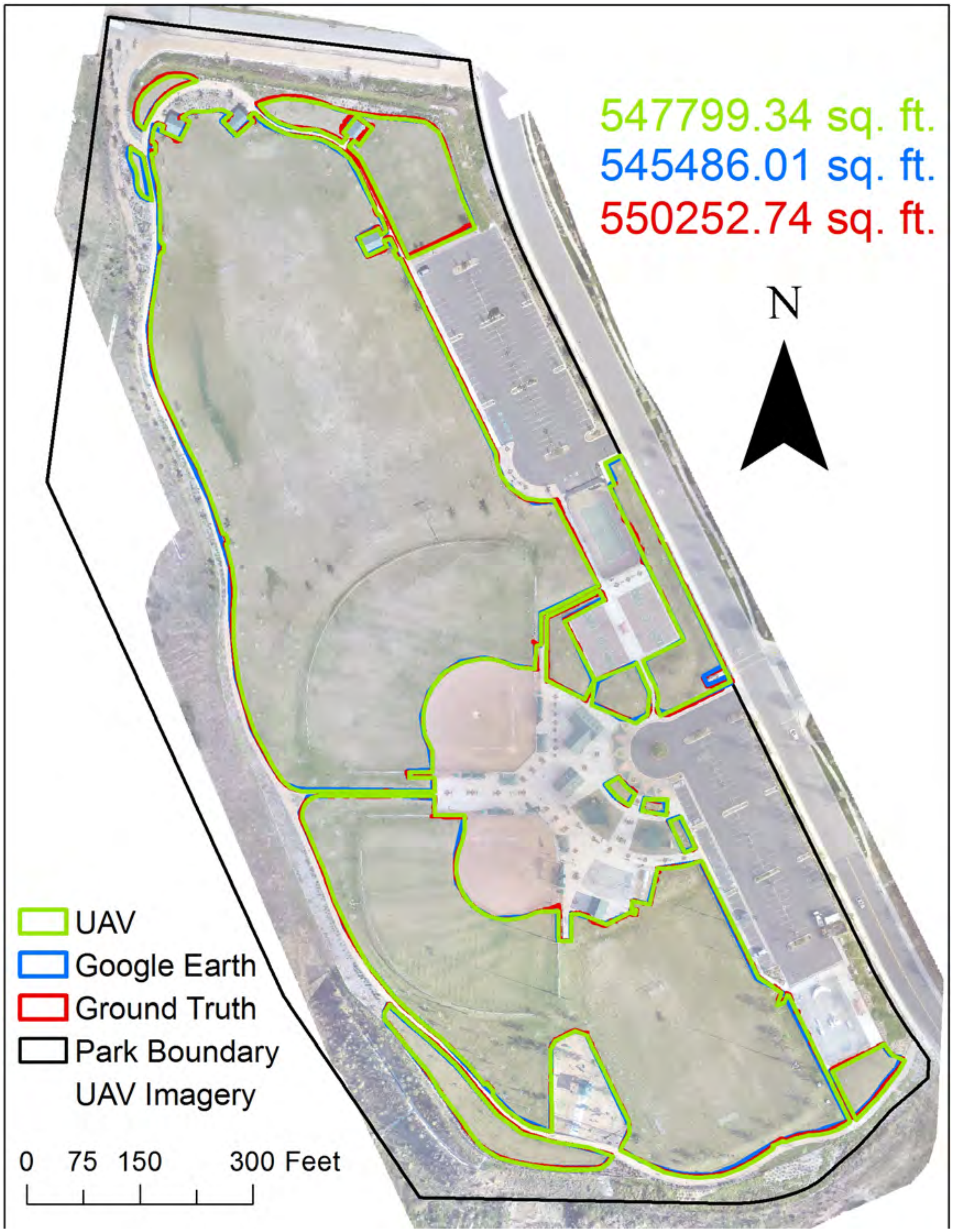


Figure 4.9 Map comparing total grass areas of park.
Map shows the digitized grass fields from the UAV and Google Earth imagery sources. These features are compared to ground truth data collected with the GPS receiver for the same grass fields. The area of each feature is added together to derive the total area of grass fields at the park.

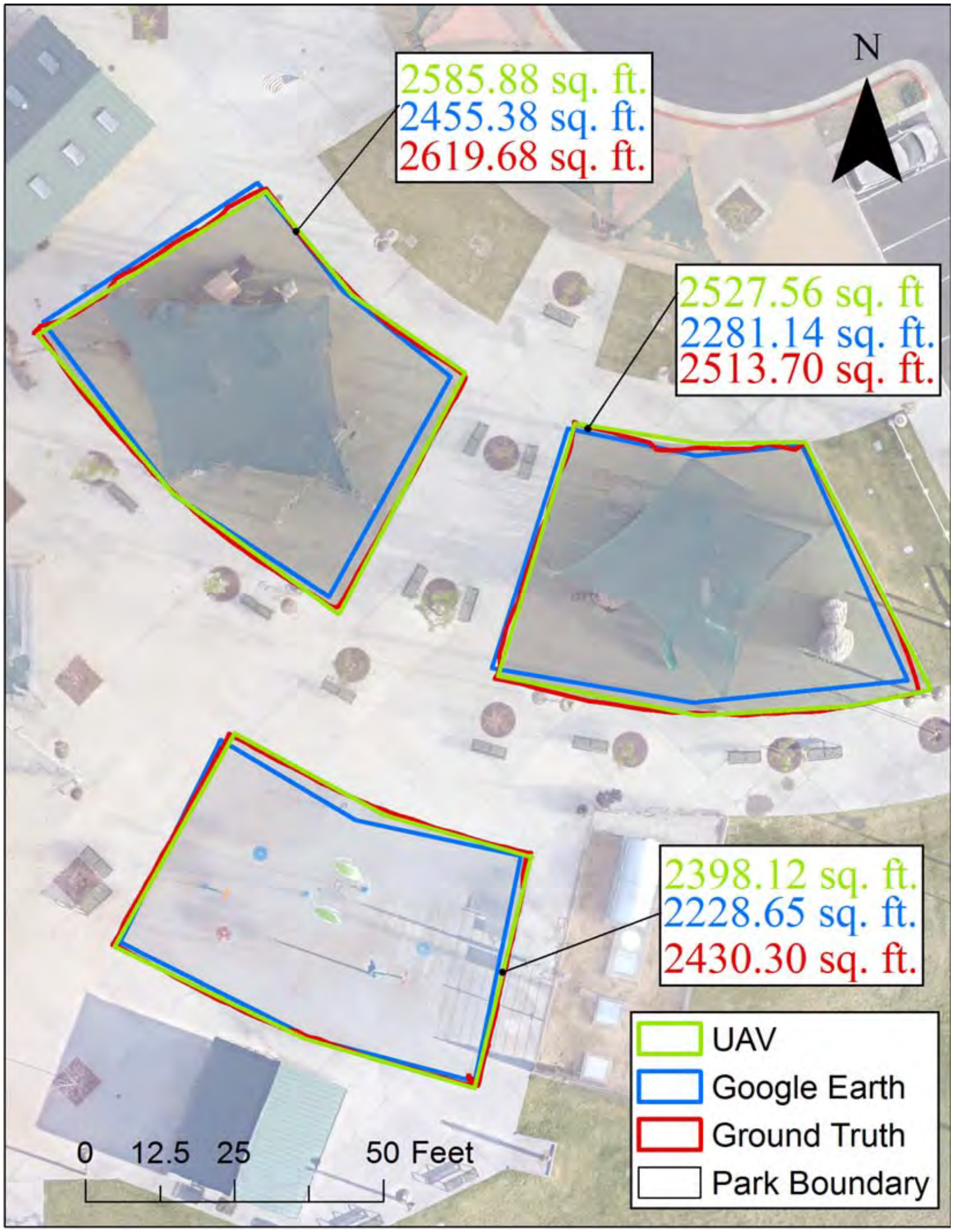


Figure 4.10 Map of play areas.
Map of play areas at Deleo Regional Sports Park. The areas have a specialized rubber surface that protects children in case of falls. The features are digitized using the UAV and Google Earth imagery as a guide and compared to the ground truth data collected with a GPS receiver. The area from each source for each section is seen in the map.

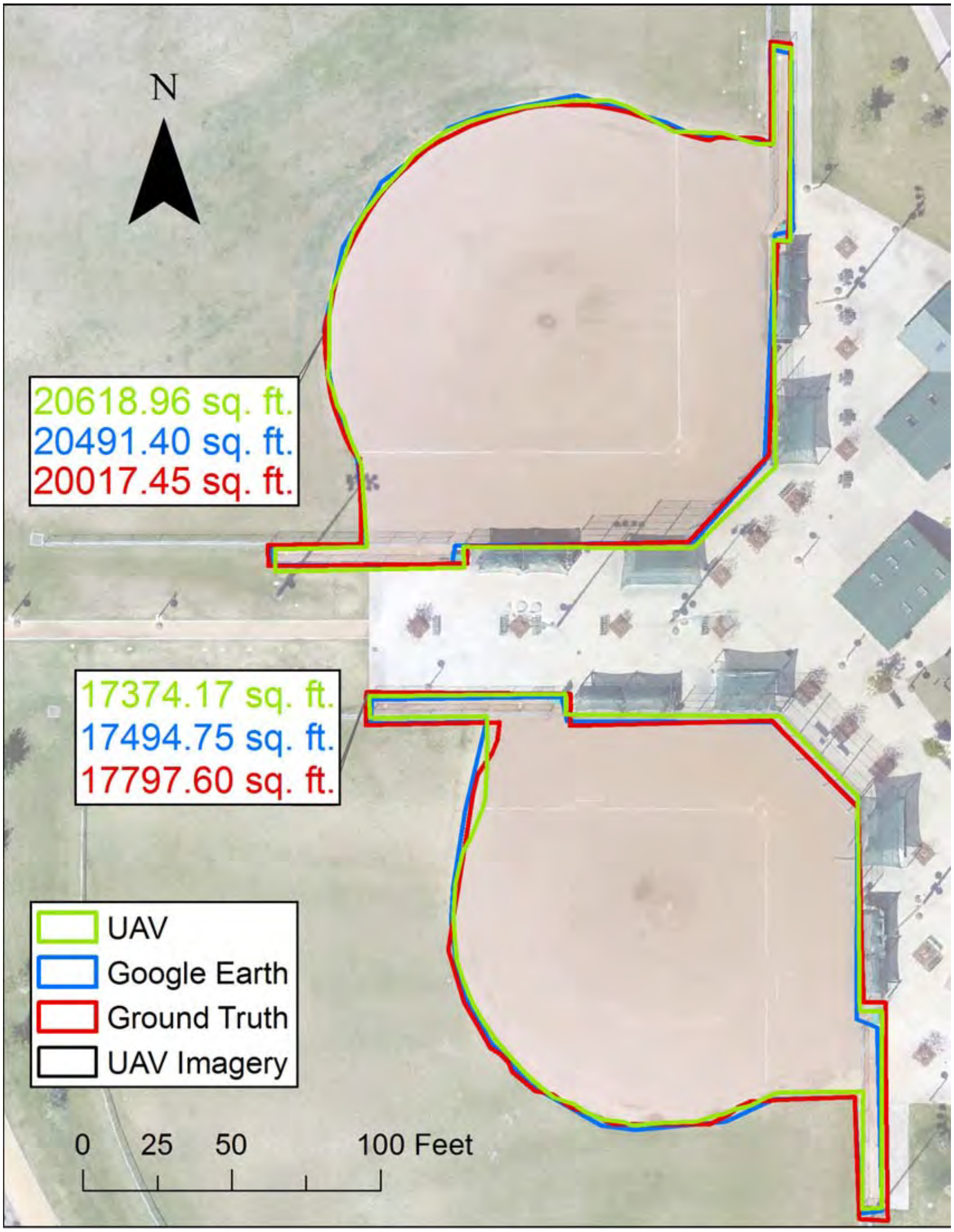


Figure 4.11 Map of area of Little League baseball diamonds.
Map shows the digitized baseball diamonds created from the UAV and Google Earth Imagery. The size and shapes of the diamonds are compared to the ground truth data collected with a GPS receiver. The area of each diamond is displayed for each data source.

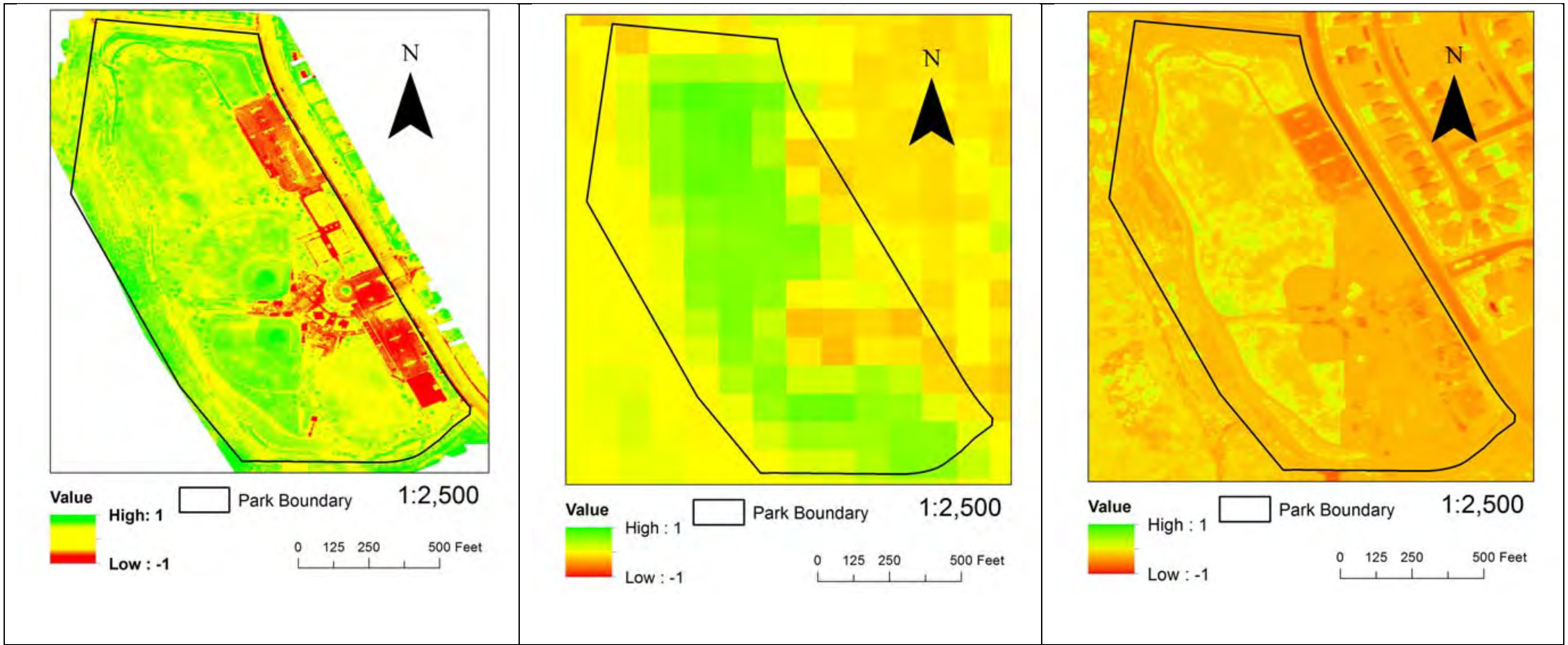
4.2 NDVI Comparison

The Normalized Difference Vegetation Index (NDVI) output derived from multispectral UAV imagery and United States Geological Survey (USGS) using ArcGIS are visually compared with National Agriculture Imagery Program (NAIP) NDVI data to determine if there are similarities between the data sets (Figure 4.12).

The NDVI outputs of the UAV and USGS imagery show the park area with high levels of photosynthesis activities as indicated by the green colors. The finer resolution of the UAV NDVI output is able to offer finer details of the vegetation in comparison to the USGS NDVI output. The USGS NDVI output has a 30 m resolution and provides an overall assessment for the park.

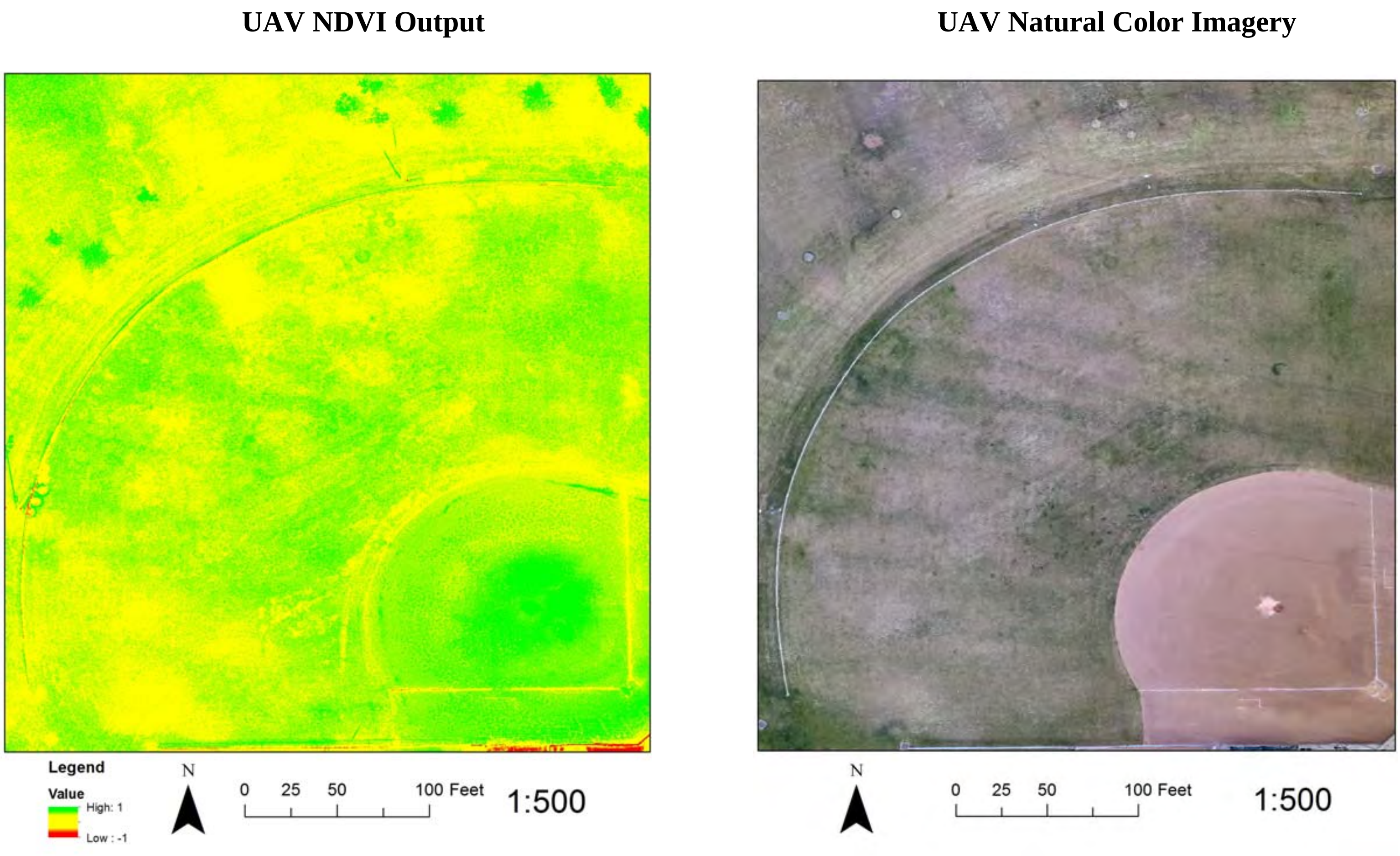
The UAV NDVI data is compared to 2012 NAIP NDVI data acquired through the ArcGIS Online service in ArcGIS (Table 4.5). The NDVI output of this data is mostly yellow and orange, indicating very little photosynthesis activity. This data is from 2012 and could be representative of the park during construction, which may explain the lack of vegetation. This data may not be useful in making assessments of the vegetation today, but it is useful for analyzing vegetation change over time.

Comparing the UAV NDVI output with the natural color UAV imagery from the same day (Figure 4.13), shows that the detail of the UAV NDVI data is highly representative of the conditions of the park's vegetation. Therefore, this shows that the inexpensive GoPro camera and lens modification can produce accurate NDVI data for monitoring vegetation health.



UAV (April 2015)	USGS (March 2015)	NAIP (2012)

Figure 4.12 Results of NDVI Outputs from Imagery



UAV NDVI Output

UAV Natural Color Imagery

Figure 4.13 Comparison between UAV and NDVI Data and Natural Color Imagery

4.3 Cost-Benefit Analysis of UAV Data Acquisition

The time required completing the processes for working with the GPS receiver and the UAV were tallied separately and broken down into three categories, acquisition, processing, and analysis. Table 4.4 shows the total time required for each category using the GPS receiver and the UAV system in this study. The final tally shows a significant savings in labor hours can be achieved using the UAV (Table 4.4).

Table 4.4 Time required to acquire, process, and analyze data collected with GPS receiver and UAV.
The total tally of hours shows the UAV can save time in labor hours.

	GPS Receiver	UAV
Acquisition	60 hours	30 hours
Processing	2 hours	12 hours
Analysis	6 hours	8 hours
Total	68 hours	50 hours

Eagle Aerial, a local aerial survey company, was contacted to obtain a quote for flying a custom mission to acquire color and multispectral imagery over the study site. The option to purchase recent imagery was also explored. Table 4.5 shows the costs of contracting a custom flight, purchasing existing imagery, and the total cost of the UAV system used in the study. Comparison between the costs of one custom flight and purchasing the UAV system shows that a cost savings exists (Table 4.5).

Table 4 5 Costs of imagery acquisition sources. Comparing the costs of the UAV versus one custom flight show there is a savings to be realized.

Source	Cost
Custom Flight	Starting at $4000
Existing Imagery	$1195
UAV System	$3200

The quotes obtained for a custom flight and purchasing existing high-resolution imagery show that using the UAV conserves monetary costs in a single data acquisition project. Even greater savings can be realized if the UAV is used in multiple projects since the cost of the UAV system has already been realized in the initial monitoring project. Increased efficiency in UAV operation will be realized once the staff becomes more familiar with the UAV system, further reducing labor costs.

A return on investment (ROI) cost-benefit approach evaluates and compares the baseline costs, operational costs, and quantifiable benefit of a system over a period of time (Croswell 2011). Using a ROI cost-benefit analysis approach for the UAV system and manned-aircraft image acquisition, Table 4.6 shows an example of collecting imagery for the park on a quarterly basis using the UAV and manned-aircraft. The labor cost of $1000 ($20/hour times 50 hours) and the cost to process the imagery $89.98 (cost to purchase 3000 points on Maps Made Easy service) is rounded to $90 and both costs are added into the cost of UAV imagery acquisition and analyzed (Table 4.6). The additional costs associated with the manned-aircraft cost were not available and are not figured in with the analysis. The results of the analysis show that the UAV has the potential to save $8440 per year for a 25-acre park such as Deleo Regional Sports Park. Currently, there are 15 parks similar to the study site in Riverside County and the use of UAV technology on all 15 parks could save $126,600 a year with a UAV system purchased for each park. Purchasing eight UAVs for the purpose of monitoring the park could increase annual savings by an additional $22,400. An additional $3200 in savings would be realized in each of the following years as the UAV does not need to be purchased again.

Table 4.6 Projected ROI Cost Benefit Analysis of UAV versus Manned Aircraft Data Acquisition

	Q1	**Q2**	**Q3**	**Q4**	**Total Cost**
UAV	$3,200	0	0	0	$3,200
UAV Labor/Processing	$1,090	$1,090	$1,090	$1,090	$4,360
Manned-Aircraft	$4,000	$4,000	$4,000	$4,000	$16,000
Savings	-$290	$2,910	$2,910	$2,910	$8,440

This chapter revealed the results of the methods used to complete this study. Chapter five will discuss and draw some conclusions from these results in order to determine if using a UAV system is an accurate, cost-efficient method for monitoring and maintaining a park.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

This chapter will discuss the results of this study and come to conclusion of the use of inexpensive UAV technology for monitoring a park. The findings from this study will be discussed first, followed by the successes and failures of the methodology used in the study. Next, sources of error will be discussed followed by a SWOT analysis to determine if the UAV technology is a feasible method for monitoring the park. The chapter will end with thoughts on the future developments of UAV technologies and future studies that could be completed using UAV technology.

5.1 Findings

The methodology utilized in this study provided three significant findings: 1) details of the imagery, 2) the timeliness of the imagery, and 3) the cost benefits of using UAV technology.

The level of detail in the UAV imagery is higher than the detail found in imagery from Google Earth, Bing, USGS Landsat 8, and NAIP imagery examined in this study. Looking at the NDVI output of the UAV and the USGS, the UAV NDVI data provides much more detail and allows the user to see that the health of the park's vegetation differs throughout. The USGS NDVI data, with a spatial resolution of 30 m, provides a broader picture of the vegetation's health that is not entirely accurate. Using the USGS data would lead the user to believe that the entire park is healthy, but in reality it was not.

The relevance of existing imagery sets varies from source to source. The Bing imagery and NAIP NDVI data available for the study site via ArcGIS online in ArcGIS 10.3 was collected in May 2010 and May 2012 respectively. The land cover and use has changed dramatically since the data sets were collected and their only use is to serve as a record for analyzing the change.

The Google Earth and USGS Landsat 8 imagery are more useful for monitoring the conditions of the park. Google Earth imagery collected in January 2013, roughly six months after the park opened, shows the park almost how it looks today (Wells 2012). The absences of fences on the Little League fields and along the parking lots are the noticeable differences that could cause issues in maintenance of the park. The Landsat 8 imagery was collected on March 31, 2015, three days prior to the collection of NIR imagery with the UAV. The NDVI output derived from the multispectral imagery has a spatial resolution of 30-meter and provides insight into the overall health of the study site. The NDVI output from the UAV imagery provides significantly more detail resulting in a better understanding of the health of the park's vegetation.

The cost savings benefits of using UAV technology for park monitoring are significant in two areas. First, the UAV saved 18 hours in comparison to using a GPS receiver to collect data for the entire park. This savings in labor time alone could accelerate the turnaround time of having usable data in hand by up to a week. Second, the cost of purchasing the UAV system used in this study is 20% less than the starting price of hiring a manned aircraft to collect data one time. Collecting data on the same site on a regular basis would not require the purchase of another UAV; however, using a manned aircraft would require the similar monetary costs each time data needs to be collected. Purchasing existing imagery equivalent to the level of detail provided by the UAV is an available option, but there is not a guarantee that the data will be relevant.

5.2 Successes and Failures of Methodology

The inexpensive UAV used to collect data for this study performed better than expected. The UAV platform is extremely user friendly and can be operated by an inexperienced operator in a short period of time. The ground station software has a user-friendly interface and provided no issues in the programming and upload of data collection missions. Operating the UAV in ideal weather conditions, i.e. low wind speeds, provided smooth flights and quick data collection.

The lens modifications on the GoPro Hero 3+ Black Edition cameras performed as described by the manufacturers and businesses that performed the lens modifications. Lens distortion that is expected with the GoPro factory lens was minimal; the aftermarket lenses produced sharply focused images and did not require further focusing calibration in the field.

Georeferencing and stitching images together using the Maps Made Easy web service worked smoothly most of the time. The process of uploading the images and georeferencing them are easy to perform, however, receiving the final output of the stitched imagery was difficult to obtain. Maps Made Easy was in the process of a server upgrade during the georeference and stitch process the first three attempts of processing the imagery. The upgrade process resulted in the map output to be missing portions of imagery and not being properly georeferenced. An email to the support team at Maps Made Easy explained what had happened and the issue did not occur again on subsequent processing attempts.

Deleo Regional Sports Park was chosen as the study site due to its accessibility, ability to fly the UAV without any known restrictions, and the variation of park features. This made data collection with the UAV convenient to schedule during the course of this project. Unfortunately, the accessibility of the park made it difficult to collect data with the UAV when scheduled. Missions were desired to be flown at times when the park was less crowded to reduce the chances of injury should control of the UAV be lost and result in a crash. Predicting these times was difficult and ultimately resulted in multiple visits to the park to collect data.

Weather conditions in the months of February, March, and April forced data collection to be rescheduled. The UAV is not capable of safely being operated in rain and the UAV is difficult to control in winds of 15 mph or greater. Attempts at data collection in winds of 10-15 mph resulted in the UAV crashing into a tree on one occasion (Figure 5.1).

Figure 5.1 UAV caught in a tree while landing in gusty winds before a storm

Technical specifications for the UAV claim that the UAV can be flown for 25 minutes on one battery. This was found to be true about half the time. Winds force the UAV to compensate to keep the flight in line draining the battery sooner than expected. Extra batteries were required to efficiently collect the data as a result.

5.3 Sources of Error

Errors were found in the results of the ground truth data collected with Trimble GPS receiver as previously mentioned in Chapter 4 of this document. The precision of the light pole ground truth GPS data can be found in the horizontal accuracy field after differential correction is performed and the file is exported Pathfinder Office as a shapefile. The horizontal accuracies are categorized, resulting in the different symbolization of the light pole points to show the precision of the data point (Figure 4.4). Buffer rings around the points display the distances of the possible error to see how accurate the ground truth data for the light pole is in comparison to the UAV and Google Earth light pole data points.

The precision of the light pole ground truth data did not have a universal effect on the accuracy of the UAV and Google Earth light pole data as stated in Chapter 4 of this document. Ground truth data points with high and low precision resulted in both high and low accuracy of UAV and Google Earth data points. One explanation for these differences can be human error using the GPS receiver and digitizing. The position of the GPS receiver in relation to the feature can alter the recorded points, i.e. the user is moving during recording or the receiver is not properly placed adjacent to the feature or the offset is not properly calculated in the GPS receiver. Similar issues can occur in the digitization process. The person performing the digitization may not accurately digitize a feature based on the base imagery due to heavy shadows or lack of detail from low-resolution imagery.

In addition to the precision errors of the ground truth data for the light poles, errors were noticeable in data collected for features for the entire park. These errors were noticeable in data collected while walking in shaded areas along fences and under canopies. The results of the data in ArcGIS do not resemble the features they are supposed to represent and require further correction in ArcGIS (Figure 5.2). These errors are the result of insufficient satellite communication with the GPS receiver. Using an external antenna with the GPS receiver or collecting the data at a different time of day could resolve the issue.

Figure 5.2 Polygons Collected with GPS Receiver

Second source of error is in the mosaicked UAV imagery. The natural color imagery from the UAV was collected on different days and times. The imagery captured on each day was georeferenced and stitched and later compiled into one image in ArcGIS. Displaying the imagery in ArcGIS shows that the imagery does not line up properly as seen in Figure 5.3. This difference did not affect the digitization process, but is noticeable under close observation, along with the differences in color due to the different conditions of each flight. The error in alignment could be the result of the differences in time and day the imagery was collected or slight discrepancies in assigning coordinates with ground control points in the georeferencing process. This issue could be resolved by collecting the data in one visit, improving the accuracy of assigning coordinates to ground control points in the Maps Made Easy system, or using a different software program that provides more control over the mosaic and georeferencing processes.

The last source of error is in the NDVI output from the UAV near-infrared imagery. Highly accurate imagery for NDVI output requires a camera with the ability to set custom white balances. The GoPro used in this study does not have that ability and could be the reason there are false readings in the NDVI output from the UAV. The dirt of the walking track and baseball diamonds are prime examples of this. In the NDVI output of the UAV these areas are green, representative of healthy vegetation, when they should be orange or red to represent no vegetation.

Figure 5.3 Misaligned Imagery Collected by UAV

5.4 SWOT Analysis

SWOT analysis of the observations during this study reveal that the use of inexpensive UAV for maintenance and monitoring has its strengths and weaknesses (Table 5.1). The UAV provides the user with the ability to collect site specific, near real-time data, with high detail and accuracy.

However, the weather conditions have to be favorable, i.e. not too windy, and several batteries are required if the site is large and requires high detail data.

Table 5.1 SWOT analysis for use of inexpensive UAV for monitoring a park using the results from this study

Strengths	1. Provides up to date imagery A. High Detail and accuracy 2. Control of parameters A. Site area B. Scale C. Sensor type 3. Low start up cost 4. Easy to transport 5. Short learning curve, easy to use 6. Emerging technology that is growing
Weaknesses	1. Weather can limit use 2. Short range 3. Limited sensor types available at this time 4. Advanced UAVs can be expensive
Opportunities	1. Can be used to monitor other asset types 2.Technology advancements will increase range and improve sensor types
Threats	1. Government regulations 2. Privacy concerns 3. Future technology that may make the UAV inefficient

The biggest threat to the use of UAVs for monitoring is government regulations. The Federal Aviation Administration (FAA), by order of the United States Congress, has been given the task of developing regulations for the use of UAVs. The FAA is expected to develop regulations by 2017 and this will determine the use limitations of small UAVs. Currently, local governments and agencies are issuing regulations on UAVs. In California there is a ban on using “camera drones” to capture audio and visual data of person without permission (Perry 2015). In June of 2014 the National Park Service issued a press release announcing the ban of flying recreational UAVs within park boundaries to ensure the safety of the public and allow people to enjoy the park without disruption that UAVs can cause (National Park Service 2014).

The Riverside County Parks Permits department was contacted prior beginning this study to determine if the UAV could be used in a public park and if a permit would be required. A phone conversation with a park representative on February 25, 2015 revealed that the UAV could be flown in the park and a permit was not needed at the time or in the foreseeable future. The representative did ask to use caution when operating the UAV and try not to prohibit the enjoyment of the park by others.

Inexpensive UAV technology is an emerging market and the results of the FAA regulations on small UAVs will have great impact on further development. If the FAA issues tight restrictions on small UAVs, manufacturers may find it unprofitable to further develop the technology, making UAV technology less attractive for monitoring purposes.

UAVs require fewer hours to collect data and cost less than one custom flight to collect data with an airplane. This makes the UAV an attractive option however, the pending FAA regulations leave future use and developments of inexpensive UAV technology undetermined. Pending FAA regulations aside, the results of this study show that an inexpensive UAV is a cost effective method for monitoring a park.

5.5 Future Developments and Work

Tough regulations on citizens being able to fly small UAVs will make it difficult for manufacturers to justify spending on research and development of the technology. No matter the FAA decisions on UAVs, government agencies will have the ability to use the technology. Should the FAA impose very few regulations the industry could explode with development.

Improvements in technology could trickle down to small UAVs and improve performance. GPS locations could be more accurate and possible be recorded in intervals while in flight. Improvements in battery technology and electronic motor efficiency would result in longer flight ranges for the UAVs or the option to carry larger payloads. Larger payloads would mean more advanced sensors.

Future work with inexpensive UAVs will involve urban landscapes and continued work with imagery for NDVI data output. GPS receivers can only produce data that is as good as the satellite coverage the receiver can obtain. In highly developed areas buildings can make it difficult to obtain accurate readings and collect data due to high concentrations of people and vehicles. The UAV might be able to collect imagery in these areas more efficiently. The GoPro cameras used in this study have preset white balances that can be further explored to see if one of the presets have the ability to improve accuracy during NDVI data collection.

Advancements in the technology should be closely monitored and examined to see if improvements could be made. Future GoPro cameras may have the ability to set custom white balances, improving the accuracy of data collected for NDVI processing. Improved battery technology could increase efficiency by extending flight range. Improved technology could make UAVs smaller and more mobile. Future developments will only make UAVs more attractive for monitoring purposes.

The results of the data collected with the UAV are highly accurate and acceptable in comparison to the ground truth data collected with a GPS receiver. Coupled with the return on investment cost/benefit analysis performed on the use of the UAV and manned-aircraft data collection, the UAV is cost-effective tool for monitoring a park. The features analyzed in the park and the methods used to perform these analysis’ can be used in the monitoring for other projects such as habitat restoration or road conditions. These results also demonstrate that inexpensive tools such as the UAV and camera sensors used in this study can produce results comparable to methods and tools that are significantly more expensive. This creates possibilities for improved data collection for projects with smaller budgets, projects that may have use labor-intensive data collection methods due to the high costs associated with manned-aircraft data collection. Studies that rely on aerial data collection with little funding have an opportunity to be realized. The customization of data collection with the UAV increases the quality of the data, improving the results of the study.

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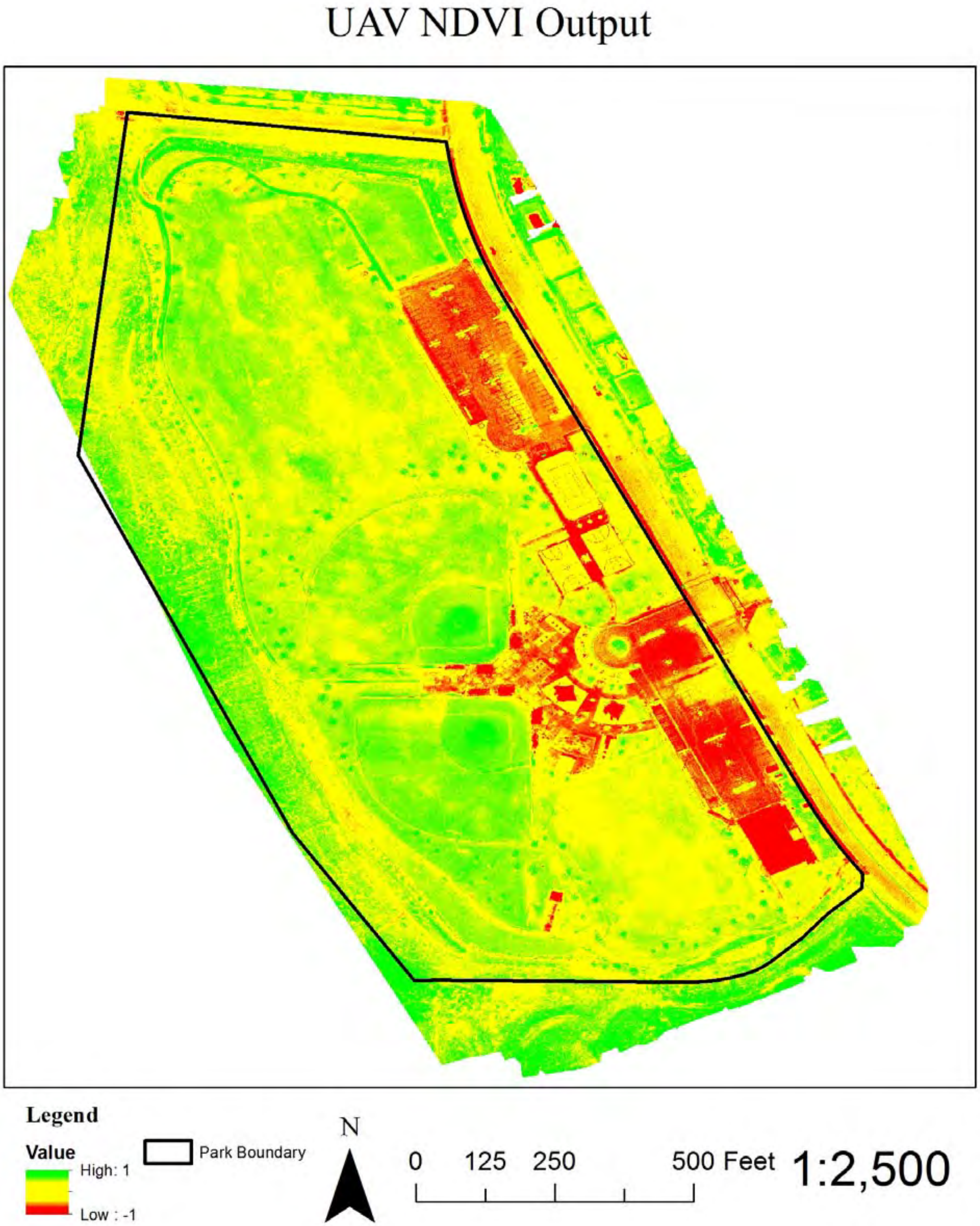
APPENDIX A: UAV IMAGERY

APPENDIX B: BING IMAGERY

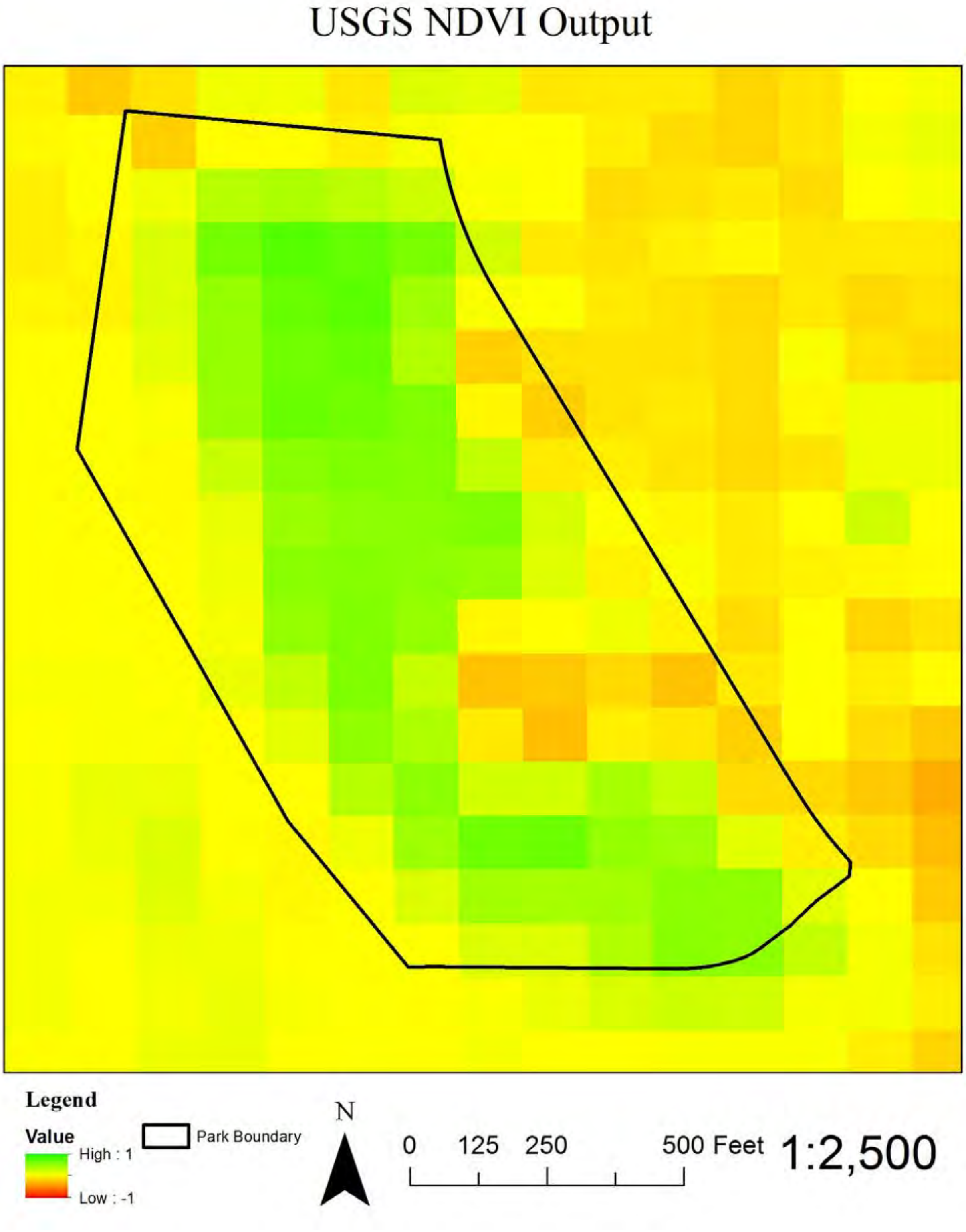
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

APPENDIX C: GOOGLE EARTH PRO IMAGERY

APPENDIX D: UAV NDVI OUTPUT



APPENDIX E: USGS NDVI OUTPUT



APPENDIX F: NAIP 2012 NDVI OUTPUT