Unmanned Aircraft Systems for Archaeology Using Photogrammetry and LiDAR in Southwestern United States

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Unmanned Aircraft Systems for Archaeology Using Photogrammetry and LiDAR in Southwestern United States

Jemez, Coronado, and Creekside Tularosa
New Mexico
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Unmanned Aircraft Systems for Archaeology Using Photogrammetry and LiDAR in Southwestern United States

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**Abstract**

Researchers can use small unmanned aircraft systems (sUAS), also known as drones, to make observations of historical sites, help interpret locations, and make new discoveries that may not be visible to the naked eye. A student team from Embry-Riddle Aeronautical University gathered data for historical site documentation in New Mexico using the DJI Phantom 4 Pro V2, DJI Mavic Pro 2, DJI M210 and DJI M600, and senseFly eBee. Utilizing these drones, student analysts were able to take the data gathered and create georectified orthomosaic images and 3D virtual objects. At Tularosa Canyon, at a site known as the Creekside Village, work aimed at imaging an amphitheater like structure (i.e., kiva) that dates back to 600 AD. The team used photogrammetry and LiDAR to determine the location of other manmade structures at the same location. Images were processed with Pix4Dmapper Pro. Team members generated LiDAR point clouds and post processed data in search of undiscovered features and structures.

*Keywords*: UAS, sUAS, photogrammetry, LiDAR, drone, orthomosaic, Pix4Dmapper Pro
Introduction

A team of students and faculty traveled to New Mexico during the summer of 2021 to conduct UAS (unmanned aircraft system) flights for collecting data to support archeology and cultural heritage preservation. The aim of the flights was to help create new knowledge about know historical locations and assist with the discovery of new sites. This work occurred during a summer study away program.

Brief Site Histories

New Mexico has an interesting and long history of human habitation ranging from Paleo-Americans dating back more than 10,000 years through the arrival of Europeans and their descendants. Three locations visited during the summer highlight New Mexico’s history and people. These locations are the Coronado Historic Site, Jemez Historic Site and Tularosa Creekside Village.

The history of Coronado starts approximately two thousand years ago when Native Americans arrived to hunt game and collect wild plants (New Mexico Department of Cultural Affairs, 2003a). As these people started to settle, they constructed pithouses along the Rio Grande River. At approximately 1300 AD the village of Kuaua was created at the location. The village was large, consisting of over one-thousand rooms and ten kivas (underground ceremonial rooms). These ancient peoples were adorned the kivas with murals on the walls. New layers of plaster would be placed over previous murals to create canvas for replacement art (New Mexico Department of Cultural Affairs, 2003a).

In 1540, Vásquez de Coronado and his group, consisting of 500 soldiers and 2000 native allies, came across this village and eleven others while searching for treasure (New Mexico
Coronado dubbed the native people Los Indios de los Pueblos, or Pueblo Indians (New Mexico Department of Cultural Affairs, 2003c). Coronado would visit all these villages within two years. It is thought that one reason he and his men survived is that they obtained food from the villages. After conflicts with village inhabitants Coronado’s group left and returned to Mexico in 1542.

The northernmost site, known as Kuaua (evergreen in the Tiwa language), was abandoned less than one century after Coronado made first contact. The residents of the village were exploited, and many died due to foreign diseases brought by the European colonists during this time. Native people finally abandoned in 1680 after the Pueblo revolt (New Mexico Department of Cultural Affairs, History 2003). The village then remained unoccupied until 1935 when the site New Mexico State designated it as its first state monument (New Mexico Department of Cultural Affairs, 2003c).

The history of Jemez dates to approximately 600 BC. Archaeologists found evidence of hunting camps and traces of agriculture found in a cave on the Jemez River (Village of Jemez Springs, 2015). The discovery of ceramics and pueblos of various sizes indicated population growth. Around the late 13th century, ancestors of the present-day Jemez Pueblo (known as Walatowa) constructed a large pueblo in a San Diego canyon and dubbed it Giusewa (a Towa word referring to the hot springs) (New Mexico Department of Cultural Affairs, 2003b). By the time of first European contact, the Jemez nation was one of the largest and strongest Puebloan cultures. (Whatley, 1993).

First European contact at Jemez was in 1541, when Captain Francisco de Barrionuevo led an expedition through the area (Village of Jemez Springs, 2015). After the initial expedition,
there were other expeditions in 1581 and 1583, known as the Rodríguez-Chamuscado and Espejo Expedition respectively (Whatley, 1993). The colonizers brought along priests with the intention of converting natives to Christianity. These activities led to conflict (New Mexico Department of Cultural Affairs, 2003). In 1598, a Franciscan named Alonozo de Lugo was assigned to convert the Jemez people, and under his direction the first church in the area was built between 1621 and 1625 (New Mexico Department of Cultural Affairs, 2003b; Village of Jemez Springs, 2015). Known as San José de los Jemez, this church was located at the Jemez Pueblo of Giusewa and was built using Pueblo labor. After much conflict, the church was abandoned in 1640 (New Mexico Department of Cultural Affairs, 2003b). The final major conflict was the Great Pueblo Revolt in 1680; this was the first and only time in United States history where the native peoples were able to fully, although temporarily, remove European colonialists (Whatley, 1993).

However, in 1688 the Spanish, under General Pedro Reneros de Posada, resumed the conquest and returned. The final revolt of the Jemez people was in 1696 at the Guadalupe Mesa (Village of Jemez Springs, 2015).

Tularosa Creekside Village had signs of human activity in 688 AD (Greenwald, 2018). However, the date that Creekside Village had its first human activity is still undetermined, and predicted to be even earlier. Through radiocarbon dating of objects and analyzing artifacts, it is known that the site had activity during the Mesilla Phase that spanned to approximately 1100 AD. These years are also known as the formative period (Greenwald, 2018). Archeologists believe that the settlement possessed a complex and organized political and social structure. Based on the physical characteristics of the site, archeologist theorize that the people residing in Creekside Village relied on intensive agriculture for their main food supply rather than hunting or rearing livestock (Greenwald, 2018). A cultural resource survey discovered the site in 2004 as
a part of an initial investigation at Creekside Village during March of 2014 (Greenwald, 2018). The *Great Kiva*, a large ceremonial room, was also discovered at this location. The depression underwent testing. The testing was found that it shared similar characteristics with other kivas, and the title *Great Kiva* was given to it due to its great size at over 88 meters$^2$ of floor space (Greenwald, 2018). Creekside Village is unique. There are odd patterns of vegetation present revealing the accumulation of fine sediments. Archeologist theorize that a reservoir served as the source of sediments (Greenwald 2018).

Greenwald (2018) states four possible hypotheses addressing why ancient inhabitants would construct a reservoir. Especially since they had access to Rio Tularosa water:

1. Slow runoff from higher altitudes to protect areas of the site and capture runoff for use in fields. An apparent flash flood may have been the reason for this decision.

2. Ability to get water from a different site known as Twin Kivas, and it could have been because this was a more reliable source to get water from, or to supplement an existing water source.

3. The reservoir would have been fed by multiple water sources, allowing for mixing and improving the water quality. The spring waters possessed a high amount of gypsum and saline, which would negatively impact crops; mixing this water with another source would minimize the damage.

4. The reservoir could create an environment where bacteria and algae could grow and reduce the number of carbonates in the water, and the filling process of the reservoir would have plants to help filter the water to improve its quality. The sediments carried from this reservoir via ditches would supply the agriculture
fields with nutrients and increase the soil quality. This theory is expressed within terraced fields at the Creekside village site. (p.72)

Since this site is still relatively new, Greenwald states, “a need exists for additional dateable samples from most contexts… (146)”. UAS flights at Tularosa Creekside Village possess incredible potential to assist archeologists.

**Equipment and Software**

**DJI Phantom 4 Pro V2 & Mavic 2 Pro**

The team primarily used DJI UAS for its research flights conducted in New Mexico. DJI provides an easy-to-use interface, GPS stability, and reliable flight characteristics. These platforms are excellent options for both novice and experience pilots. In New Mexico, the team primarily used the Phantom 4 Pro V2, as well as the Mavic Pro 2 multirotor UAS to collect photographic data. These multirotor aircraft are suitable for consumer and professional level use. When flown with autopilot software that is specialized for data collection, these models are ideal for photogrammetric and video projects.

The team flew Mavic Pro 2 primarily for aerial video and still image documentation of operations. This compact UAS comes equipped with a Hasselblad 4K, 20-megapixel camera utilizing a 1-inch CMOS sensor. The camera is mounted to the front on the underside of the aircraft using a three-axis gimbal. Smooth photography and videography are possible due to stabilization. Combined with GPS and GLONASS global navigation satellite systems (GNSS), omnidirectional obstacle sensing for collision avoidance, and a maximum flight time of 31 minutes, the Mavic 2 Pro is a capable aerial camera system. (DJI. 2018)
The Phantom 4 Pro V2 was the aircraft used for collecting much photogrammetric data. Its 20-megapixel, 1-inch CMOS camera mounted via a three-axis gimbal is ideal for this work. The small size of the aircraft, 350 millimeters diagonally from motor to motor, makes it ideal for use in where the terrain is constrictive. Flight time of 30 minutes, resistance to winds up to 22 miles per hour, GPS and GLONASS, flight stabilization, and forward, reverse, and downward vision positioning sensors allow the Phantom to provide accurate imagery (DJI, 2016).

**senseFly eBee and eBee+**

The eBee and eBee+ are autonomous flying wing platforms developed for mapping and surveying operations. Weighing 0.67-0.71 kilograms the eBee airframe is constructed from lightweight EPP foam, structural carbon, and composite components for a total wingspan of 96 centimeters. A brushless electric motor propels the lightweight airframe that produces 0.63 kilogram-force or 6.2 newtons of force. The lightweight construction and brushless motor allow the eBee to achieve flight times of 45-50 minutes fully loaded. The payload of the eBee includes a 3-cell Lithium polymer battery, S.O.D.A (Sensor Optimized for Drone Applications) camera, and airframe. With a maximum take-off weight of 0.75 kilograms, the eBee can still obtain operational speeds of 40-90 kilometers per hour and wind resistance of up to 45 kilometers gusts. The eBee’s speed allows the aircraft to achieve a max flight coverage of 12 km² on a single
charge allowing the S.O.D.A to capture an abundance of pictures for post-processing using Pix4Dmapper Pro (eBee Extended User Manual, 2016).

The eBee+ is the larger variant of the eBee and features a 110-centimeter wingspan of the same construction as its smaller counterpart. It weighs 0.62 kilograms without its combined payload. The eBee+ is powered by a 1 kilogram-force or 9.8 newton brushless electric motor which is more than capable of pushing the max take-off weight of 1.4 kilograms through the air. The eBee+ also carries the S.O.D.A onboard and can fly for up to an hour at operational speeds of 40-110 kilometers per hour. Like the smaller variant, the eBee+ can withstand wind gusts of 45 kilometers per hour and function in operational temperatures of ranging from -15 to 35 degrees Celsius. The larger wingspan and propulsion system allow for greater flight endurance than its smaller counterpart and allow for longer missions. Longer missions equated to more data for post processing (eBee Plus Drone User Manual, 2018).

Fixed wing aircraft, like their multirotor counterparts, have advantages and limitations that define mission roles and uses during operations. Multirotor aircraft are great for collecting precise datasets on specific points of interest and fixed wing aircraft are better at collecting data over more areas that are expansive. Knowing an aircraft’s role and limitations is important when planning operation to enable the collection of data in the most efficient way. The fixed wing
eBee and eBee+ take high quality photos with the on-board S.O.D.A camera and are better suited for long duration mission flights over larger (e.g., multi-square kilometer) areas. The photos gathered from these missions can then be stitched together in Pix4Dmapper Pro to create orthomosaic images and images for 3D modeling. One technique that Archaeologists can use is to add point of interest photosets that are taken from multirotor aircraft and then blended into orthomosaics and 3D models using eBee and eBee+ captured images. This technique enables the creation of orthomosaics and 3D models of larger sites with very precise data around points of interest.

**eMotion 3**

Autonomous flight is achieved by the eBee and eBee+ through uploaded flight plans produced by the pilot in senseFly’s eMotion 3 software (eMotion 3, 2021). eMotion 3 software controls all aspects of a planned flight to include operational height and distance, flight path shape, and cruising speed. This software allows the pilot to plan a mission that the eBee or eBee+ can fly autonomously without manual interaction from the pilot. The eMotion 3 software also includes the ability to run a simulation of the flight that includes factors like wind speeds to see how the eBee/eBee+ will operate in that kind of an environment. The eBee/eBee+ is hand launched for its missions gathering pictures. The eMotion 3 software keeps track of where the pictures are taken to ensure overlap and exchangeable image file format (EXIF) is encoded so that images can be georectified in post-processing. Once the flight is completed images captured by the S.O.D.A, can be downloaded to Pix4Dmapper Pro (eMotion 3, 2021).
**DJI Matrice 600**

The DJI Matrice 600 (M600) carried the LiDARUSA Revolution 120 payload. The M600 is one of DJI’s largest UAVs and the first “heavy lifter” introduced by DJI. The M600 boasts a max payload weight of 13 pounds and the aircraft can comfortably carry the 3.81-pound LiDAR (light detection and ranging) unit without compromising flight time. The M600 has a max speed of 40 mph in no wind conditions, with a maximum wind resistance of 18 mph. The M600 also has a retractable landing gear, to allow the LiDAR to collect point cloud data without interference. In calm winds and standard elevation, the M600 can have a flight time of about 25 minutes with the LiDARUSA Revolution 120 payload and cover upwards of 100 acres (DJI, 2016).

**LiDAR**

LiDAR is a method of remote sensing in which LASER pulses of Infrared Radiation (IR) are beamed to targeted areas on the ground. When a pulse hits an object, it reflects back to the sensor that records a range. Combining pulse with orientation and positioning obtained from an integrated GPS and Inertial Measurement Unit (IMU), each LiDAR return will have a specific XYZ position, scan angle and calibration value (NOAA, 2012). These values can then be processed and generated into a dense group of elevation points, referred to as a “point cloud.”
GPS base station provides positional data used in post processing to make the point cloud more accurate. The technique is now as post processing kinematic (PPK). This process can make each LiDAR point accurate to the centimeter level. LiDAR point clouds can be used for numerous applications, such as creating digital surface models, digital terrain models, identifying man-made structures and measuring micro elevation changes. LiDAR point clouds can also be combined with orthomosaic images to create highly detailed and accurate 3D images.

**LiDARUSA Revolution 120 and North Base SmarTK PPK Receiver**

DJI Matrice 600’s payload is the LiDARUSA Revolution 120. Weighing 3.81 lbs with a size of 11.75 x 4.4 x 3.5 inches, the Revolution 120 mounts comfortably underneath the Matrice 600. The Revolution 120 is built with a Quanergy M8 LiDAR sensor, Snoopy A-Series inertial navigation system (INS), and on-board GPS receiver that are powered with a 3-cell LiPo battery. The Quanergy M8 has a 360-degree field of view with a 200-meter range that allows for 3 layers of returns. Data outputs include angle, distance, intensity, and a time stamp (Quanergy, 2021). The Snoopy INS combines all the data from the Quanergy M8 sensor, GPS position and inertial measurement unit (IMU). The LiDAR unit writes data to an external USB drive (LiDARUSA, 2019).

The Revolution 120 can be upgraded with multispectral and RGB cameras to create colorized point clouds. At an altitude of 50 ft, it has the capability to capture over 200 points per square meter with a 3.8 cm resolution. In standard applications, an altitude of 265 feet, with a
A North Base SmarTK PPK receiver collects GPS positional data. PPK enables location accuracies to the centimeter level. The LiDAR unit does not use the receiver during flight, but rather its positional data are post processed for the LiDAR point cloud. The base station is set up before flight and records exact latitude, longitude and ellipsoid height positional data from Global Navigation Satellite System (GNSS) satellites that continuously fly overhead. While post processing positional data, the file from the base station can correct the positional values from the integrated GPS on the Revolution 120 and “tighten up” the point cloud creating a positional accuracy down to one centimeter.

**DJI Ground Station Pro**

Collecting LiDAR data accurately is essential. Hand flying the M600 is not ideal during LiDAR missions. Autonomous flights are preferred. The M600 uses the DJI Ground Station Pro application for mission planning and flight control (DJI, 2017). Proper mission planning is critical for collecting LiDAR data. Planners place a mission start point for missions. Two 90-degree turns are
added before the data collection pattern begins. The turns allows the IMU in the Revolution 120 to initialize and calibrate. The flight path is a standard “lawnmower” pattern over the area of interest. Depending on the desired resolution of the project, the spacing used between each row needs to be about 150-300ft, for 30-50% side overlap. Flight speed and altitude are also be determined by the project resolution, with a standard flight being 15 mph at 265 feet above takeoff altitude. Each corner of a flight leg is “rounded off” to a radius of 50 feet. This allows the aircraft to fly its pattern more efficiently since there is little need to slow during turns. This technique saves aircraft battery and reduces flight time. Corners of the flight plan must be outside the desired mapping area. This technique protects the integrity of the LiDAR returns.

After the mission ends, the M600 returns home and lands autonomously (DJI, 2017).

LiDAR Post Processing with TerraPos and ScanlookPC

After LiDAR data are obtained, processing is necessary for visualization. Several programs were in use during the trip, these include Online Positioning User Service (OPUS), TerraDrone, TerraPos and ScanlookPC. Before processing can begin, the GPS positioning file must be downloaded from the North Base SmarTK PPK receiver. This file is then converted to Receiver Independent Exchange Format (RINEX). This is a standard data exchange format for raw satellite positioning data. Once converted, operators uploaded the position file to NOAA’s OPUS website. OPUS provides access to the National Spatial Reference System and uses software that computes coordinates using the NOAA Continuously Operating Reference Stations (CORS) stations. OPUS refines the position provided in the RINEX file and returns a report to the submitter that includes latitude, longitude and ellipsoid height of the base station that is highly accurate (NOAA, 2010).
Using TerraDrone is the next step of the LiDAR visualization process. TerraDrone is a simplified graphic user interface (GUI) for TerraPos (LiDARUSA, 2021). TerraDrone integrates North Base SmarTK PPK receiver base station positional data, LiDAR unit IMU and GPS data from Snoopy INS, and the Quanergy M8 LiDAR point data returns together. Very accurate latitude, longitude, and ellipsoid height from the OPUS report are entered for the base stations location. TerraDrone then verifies and compares the positional data from the Snoopy INS and OPUS values to correct the LiDAR point returns. TerraPos enhances accuracy of data and processes it into files for the next step using the ScanlookPC program (LiDARUSA, 2019).

ScanlookPC creates control points from the TerraDrone data and uses a control point adjustment algorithm. The result is a control point adjusted georeferenced point cloud. The user can “crop out” undesired data to clean up the point cloud even more. Once all is complete, users can export the final point cloud into numerous file types for viewing and editing (LiDARUSA, 2021).
LiDAR Operations at Coronado Historic Site

The first operation conducted in New Mexico was at Coronado Historic Site in Bernalillo, New Mexico, on the west bank the Rio Grande River. Planned as a training day, Coronado became one of the trip’s most complete sites in terms of data collection. Both LiDAR and photogrammetry operations were conducted at this site. The buildings in the LiDAR point cloud show ancient kivas and agriculture, as well a modern visitor center. The raised areas (inside the black rectangle) are where an ancient structure once stood. These features are not readily visible by satellite or orthomosaic imagery. The footprint of the village of Coronado is clearly visible using LiDAR. The team identified an area of interest (circled in blue) for further processing. Future studies can help determine what this location may be.

One of Several Raw Point Clouds from LiDAR Flights Conducted at Coronado Historic Site
LiDAR Operations at Tularosa Creekside Village

Planned to be the major focus of the New Mexico collection effort, the Tularosa location presented challenges due to GPS signal degradation emanating from a local U.S. Government site. The original plan was to conduct LiDAR flights over the entire mapping area, with areas of archaeological interest flown in high-level detail. GPS interference prevented this from occurring. Fortunately, the team was still able to fly several flights and cover areas of archaeological interest. Initial processing is complete. Detailed analysis is ongoing to search for new information about the site. The aim is to find evidence that will show ancient kivas, aqueducts, irrigation, terraced agriculture, and various other structures. Archeologists have not mapped these features before.
Photogrammetry

Photogrammetry is the art and science of making measurements from pictures. UAS carried cameras are inherently capable of conducting photogrammetric flights. Pix4Dcapture and eMotion 3 are mobile applications designed for these purposes. These applications allow the pilot to optimize flight planning for 3D mapping, point cloud creation and virtual modeling. The flight paths ensure adequate image overlap, on both the sides and ends, to produce parallactic angles for key point identification allowing the stitching of images. Precise determination of vertices (i.e., x, y and z locations of points in a cloud and/or key points) for virtual object creation. The data can then be used to generate digital surface and terrain models, orthomosaic images, and textured models.

Leonardo da Vinci in 1942 first conceptualized the ideas behind photogrammetry with principles of perspective and projective geometry. A current interpretation and definition, “the art and science of obtaining useful information from the environment by processing imagery and then applying exacting measures that can provide 3D characteristics” accurately describes the processes (Macchiarella, Robbins, & Cashdollar, 2019). Originally, photogrammetry occurred on a 2-D plane using had written measurements in ratio for a viewer to see. Today digital photogrammetry, with software like Pix4Dmapper Pro, can auto-generate and “match-up” overlapping pictures to create accurate digital versions of objects and areas. Advancements of photogrammetric software are importantly providing capabilities allowing engineers, archeologists and others to analyze measure and inspect areas and objects of interest efficiently and effectively. These advancements, and evolutions, in the field of photogrammetry are showcased by examples including urban planning and cultural heritage preservation (Macchiarella, Adkins, & Wallace, 2020).
One mission that displays the capabilities and benefits UAS generated photogrammetry occurred at the Coronado Historic Site. The goal was to use photogrammetry, controlling flight with Pix4Dcapture, to document old structures (e.g., Kivas) for cultural heritage preservation. Archeologists searched for large circular dirt mounds that could indicate a Kiva location. Since Coronado Historic Site is well preserved and excavated it served as an ideal location to practice photogrammetric techniques while providing products for cultural heritage preservation. Both multirotor UAS, Phantom 4 Pro V2, and fixed wing UAS, eBee were used. At Coronado the eBee captured images across the entire site. The Phantom4 Pro V2 focused collection upon specific points on the ground and reconstructed structures (e.g., kivas).

**Pix4Dmapper Pro**

Once the data has been safely gathered from the aircraft’s internal micro-SD card post-flight, data is then uploaded to the desktop version of Pix4Dmapper Pro for further processing. Pix4Dmapper Pro can create virtual objects and high-resolution images that are georectified for accurate analysis and measurements. Taking the images, Pix4Dmapper Pro will create a point cloud based on unique keypoints (i.e., uniquely identifiable pixel patterns) between images, to allow the stitching of the images. The software also creates a point cloud is then used as a foundation to create a digital surface model (DSM) that enables orthomosaic and 3D virtual objects creation. The DSM is foundational for generating vertices for a triangle mesh (see Figure *Triangle Mesh of Coronado Historic Site* below). Compared to satellite and GPS, an orthomosaic can often be upwards of 30 times more detailed.
Triangle Mesh of Coronado Historic Site

Orthomosaic of Coronado Historic Site
Conclusion

Archeology and historical site preservation are important to society as it catalogs the past and documents knowledge for future generations. The data collected from this project proved to be very useful for archeology and cultural heritage preservation. The aim of this effort was to conduct UAS operations over sites of historical importance and map the layout of the sites via LiDAR and photogrammetry. Using a variety of UAS including the Mavic Pro2, Phantom4 Pro V2, M210, M600, and the eBee/eBee+ the team was able to fly a multitude of flights and gather a plethora of data. The data collected will help archeologists further their research of these sites and help expand knowledge of these historic settlements. Flights focusing on LiDAR also produced data and maps that gave insight into the unseen by the naked eye, examples include the footprint of the Coronado village and possible canal and terrace systems at Tularosa Creekside Village. Through hard work and dedication, the team was able to produce quality data sets for the archeologists and their preservation operations. The data and research methods for this project are not only specific to historic New Mexico sites. Preserving history is important for future generations, and with every advancement in UAS technology, these efforts become more detailed and widely used.
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