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Advanced Photogrammetric Modeling of Dranoc Kullas Using Small Unmanned Aircraft Systems

George Gebert

Embry-Riddle Aeronautical University, GEBERTG@my.erau.edu

Liam Griffin

Embry-Riddle Aeronautical University, GRIFFIL6@my.erau.edu

Justin Lawlor

Embry-Riddle Aeronautical University, lawlorj@my.erau.edu

Lauren Davis

Embry-Riddle Aeronautical University, DAVISL27@my.erau.edu

Kylee Vander Velde

Embry-Riddle Aeronautical University, VANDERVK@my.erau.edu

See next page for additional authors

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Authors

George Gebert, Liam Griffin, Justin Lawlor, Lauren Davis, Kylee Vander Velde, and Sami Ali

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Dranoc, Kosovo

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By:

George Gebert

Liam Griffin

Justin Lawlor

Lauren Davis

Kylee Vander Velde

Sami Ali

Embry-Riddle Aeronautical University,
Daytona Beach, Florida
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In collaboration with:

U.S. Embassy in Kosovo

Cultural Heritage without Borders in Kosovo



EMBRY-RIDDLE
AERONAUTICAL UNIVERSITY

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Abstract

Small unmanned aircraft systems (sUAS), also known as drones, offer new capabilities for cultural heritage preservation activities. Student researchers from Embry-Riddle Aeronautical University have applied photogrammetric techniques based upon sUAS captured imagery to assist with historical site documentation and cultural heritage preservation in the Republic of Kosovo. Imagery from three locations -- Isniq, Dranoc and Junik -- highlight this work. Student researchers created georectified orthomosaics and 3D virtual objects. At each of these three locations the object of interest was a type of building known as a kulla. These kullas are fortified homes built for protecting large families and are unique to the region of Southeast Europe that was a former territory of the Ottoman Empire. A five-step process was followed during sUAS photogrammetric flights. These five steps are planning, preparing, conducting, analyzing and interpreting. Student researchers used two DJI Phantom 4 Pro V2s in order to conduct flights and gather images that were subsequently processed using Pix4Dmapper Pro to create virtual environments and high resolution georectified images. The efforts of this work can be used by non-governmental and governmental organizations for cultural heritage preservation purposes.

Keywords: unmanned aircraft system, UAS, orthomosaic, kulla, photogrammetry, point cloud, 3D mesh model, virtual object, drone, aerial imagery

Kulla Brief History

Construction of *kullas* typically started in the 18th century, during the Ottoman period, and lasted until the beginning of the 20th century. Throughout many years the kullas endured war and violence; they are a remnant of the Balkan's conflicted past. Kullas are a key element of the region's history and an important aspect of cultural heritage preservation. The word kulla in Albanian means tower. These were houses built for large families. They typically accommodated up to three whole families and consisted of three floors, three bathrooms which did not have plumbing and one or two kitchens (Backer & Elise, 2015). The structures included a large garden where animals were bred, as well as an open-sided outdoor covered area. Outer walls were constructed of stone while interior features were constructed with wood (e.g., stairs, flooring, etc) inner walls were made with mud bricks and occasionally wood. Doors and windows were built with an arching architecture, that was influenced from earlier Ottoman tower houses built during the middle ages (Rassam, 2001).

Kullas have walls that are over one meter wide at the base. This construction serves as a good insulator minimizing the need for heat in the winter and allowing the use of smaller fireplaces. Mud brick construction afforded a degree of elasticity that helped structures survive earthquakes that occur throughout the region. As an element of the construction planning, the architecture design included orientation toward Mecca for prayer purposes. This construction helps identify the Qibla (i.e., direction of prayer) for use by house residents.

The main reason for constructing kullas was for protecting large and extended families from violence often associated with blood feuds. Kulla sites were comprised of two separate buildings. Men occupied one building while women and children occupied the other. Kullas were built by wealthy owners that were often tax collectors and landlords (Verona, 2015).

Historical Context

Balkan's History

The Republic of Kosovo is located in the Balkan region of Southeast Europe. The Balkans were part of the Roman Empire since the first century BCE. The progression of inhabitants where present-day Kosovo is located includes Neolithic peoples, peoples identified as Dardanians, Illyrians, Greeks, Romans, Byzantines, Albanians, Serbs and Ottoman-Turks (Judah, 2009; MacKenzie, 2005; McIlvaine, 2012). When the Roman Empire was at the height of its power, the Balkan region was the most united at any time in its history due to the Roman governmental structure (Crampton, Allcock, & Danforth 2019). In the 4th century, the Roman Empire was split between Rome and Constantinople. This divide between the east and west held different meanings throughout history, with each depriving the region of unity. Slavic speaking peoples began to migrate to the Balkans in the early 6th century (Judah, 2009). This has resulted in one of the more contentious regions on the earth regarding culture, politics and religion.



Figure 1. Extract of Map of the Ottoman Empire in the Balkans (Quataert, 2016).

The Ottoman Empire's conquest of the Balkans in the 14th century provoked widespread upheavals (see Figure 1). Centuries later the Serbs rebelled, inciting large movements of Serbs and non-Serbs (Judah, 2009). During the Balkans war in 1912 and 1913, nearly 2.5 million people across the southern Balkans fled because of the fighting. World War I began in the Balkan states when a Bosnian Serb nationalist assassinated the heir to the Austro-Hungarian throne in Sarajevo (Wachtel, 2008). After WWI, a state of Yugoslavia was formed. The Balkan states experienced the brutality of both World Wars and the Cold War, due to either their involvement or proximity of influential countries. The dissolution of Yugoslavia resulted in fighting, that led to the migration of peoples and the destruction of various historic sites, including kullas. The possibilities for economic prosperity, stability and peace are significantly growing for the people in the Balkans; North Atlantic Treaty Organization (NATO) and the European Union (EU) have already offered memberships to several Balkan states (The World Factbook: Kosovo, 2018).

Kosovo (Past and Present)

The Kosovo name comes from the Serbian word *Kos*, which means blackbird. Kosovo's history spans from the medieval era to the present. During the middle ages, the Kosovo region became the core of the Serbian empire; numerous important Serb religious sites were constructed in Kosovo, including Serbian Orthodox monasteries (The World Factbook: Kosovo, 2018). Just west of Prishtina, the Battle of Kosovo in 1389 was fought. The Turkish Ottoman Empire defeated a force of Serbs and their allies, which led to five centuries of Ottoman rule (The World Factbook: Kosovo, 2018). Serbia won its independence from the Ottoman Empire in the early 19th century.

Kosovo was granted the status of an autonomous region within the Republic of Serbia after World War II. In 1989, the president of the Serbian Republic removed Kosovo's autonomy, which prompted Kosovars to take nonviolent and violent action against the Serbs. The Kosovo Liberation Army (KLA) started attacking Serbian officials and police in Kosovo; this created a massive conflict between Serbians and Albanians until June of 1999 when a peace agreement was created. Kosovo formally declared independence in February of 2008. In July of 2010, the International Court of Justice decided to recognize Kosovo's declaration of independence (Lampe, Allcock, & Young, 2019).

Kosovo's period of Supervised Independence, run by the International Steering Group (ISG), which is comprised of 25 states including the United States, Russia and Germany, ended in 2012 (US Department of State, 2016). Serbia continues to reject Kosovo as an independent country. However, they both agreed in 2013 to communicate through aided talks by the EU (The World Factbook: Kosovo, 2018). Kosovo signed an agreement in conjunction with the EU in 2015 that encourages economic connections between the EU and Kosovo, as well as identify common political and economic objectives and promote cooperation in the region (European Commission, 2016). The EU identified Kosovo in a 2018 report as being able to join once it meets the criteria. Kosovo had recently held national and municipal elections in 2017. Albanians are the primary ethnic group of people in Kosovo representing 92.9% of the population.

Geography

The Republic of Kosovo is a landlocked region, with multiple mountain ranges along the borders. Mount Gjeravica to the west, is the highest point at 8,714 feet (see Figure 2). In historical terms, its geography makes Kosovo rich with natural resources and precious metals that helped build empires throughout history (Vukovic & Weinstein, 2002). Kosovo covers a

total of 10,887 square kilometers. The majority of the population resides within eastern Kosovo near Prishtina.



Figure 2. Geographic map of Kosovo (Lampe et al., 2019).

Equipment

All flights were conducted using two DJI Phantom 4 Pro V2s in an autonomous mode controlled by the third-party software Pix4Dcapture. The Phantom 4 Pro V2 is a multirotor aircraft controlled via 2.4 or 5.8Ghz from a linked ground controller using DJI Go 4.0 to measure and provide telemetry to the operator including a camera feed. DJI Go 4.0 allows the pilot to set restrictions on the aircraft such as max altitude, max flight distance and a return to home altitude in order to avoid obstacles. Once the aircraft's onboard Global Positioning System (GPS) receives information from more than eight satellites it can enter geopositioned stabilized flight

allowing the aircraft to hold position when not receiving inputs from the ground controller or third-party software. DJI's Flight Autonomy sensor system is adapted into the Phantom 4 Pro V2 which includes two rear visual sensors using infrared sensing allowing for five directions of obstacle sensing and four directions of obstacle avoidance. A 1" complementary metal oxide semiconductor (CMOS) 20MP sensor is mounted below the fuselage on a semi-adjustable, three-axis stabilization gimbal allowing the sensor to tilt -90 to +30 degrees (DJI, 2016).

Embry-Riddle Aeronautical University student researchers, studying abroad in Kosovo, used Pix4Dcapture to autonomously fly a variety of flight plans over the kullas in order to capture all the imagery. These flight plans include grids, double grids and circles which are uploaded through Pix4Dcapture into the aircraft and monitored by the pilot as the mission is ongoing through the app. When creating a flight plan the pilot has the option to manipulate the orientation, altitude and projected ground sample distance (GSD) in order to achieve the most optimal result. Pix4Dcapture allows the operator to download maps in advance where there is Internet access. Once in the field, or at a remote launch location where Internet access is not available, the operator can use the downloaded map via a cache. Once the images have been captured and the aircraft is safely landed the pictures are uploaded into Pix4Dmapper Pro to begin post processing.

Pix4Dmapper Pro

After student researchers gather the images, they are imported from the aircraft's internal micro SD card onto a computer and uploaded into Pix4Dmapper Pro to be processed. The software creates a point cloud (see Figure 3) that is based upon keypoints (see Figure 4), or common pixels identified among multiple images, to enable the stitching of pictures (see Figures 5 & 6). The point cloud serves as the basis for orthomosaic images and 3D virtual objects (see

Figure 6). Using the point cloud, a digital surface model (DSM) is generated. The digital surface model is the foundation of two further processes. The first process is the creation of an orthomosaic. An orthomosaic is a high-resolution georectified image of the area mapped and is often 10-30 times more detailed than satellite imagery. The second process is the creation of a triangle mesh that is comprised of vertices with specific x, y and z locations. The vertices are the foundation of the triangle mesh and are the basis of any 3D virtual object. This process is done through photogrammetry, which is “the art and science of obtaining useful information from the environment by processing imagery and then applying exacting measures that can provide 3D characteristics” (Macchiarella, Robbins, & Cashdollar, 2019).

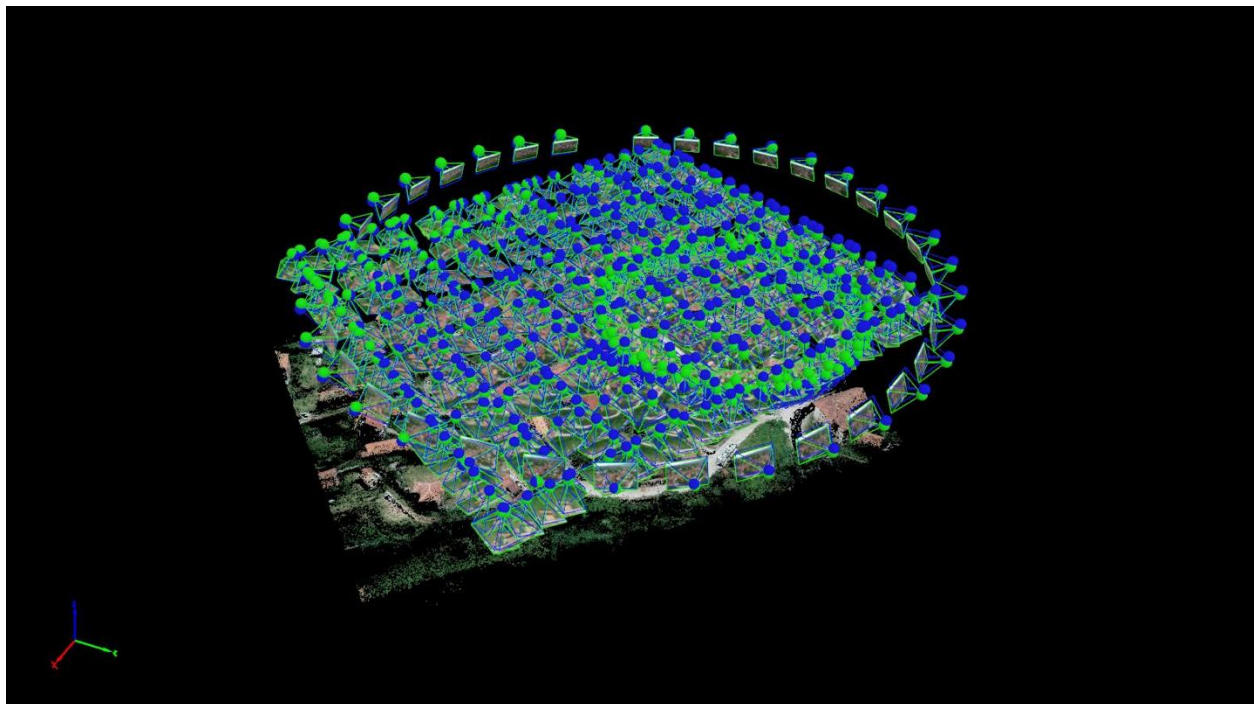


Figure 3. Camera positions of three circles and one double grid over Dranoc (Pix4D, 2018).

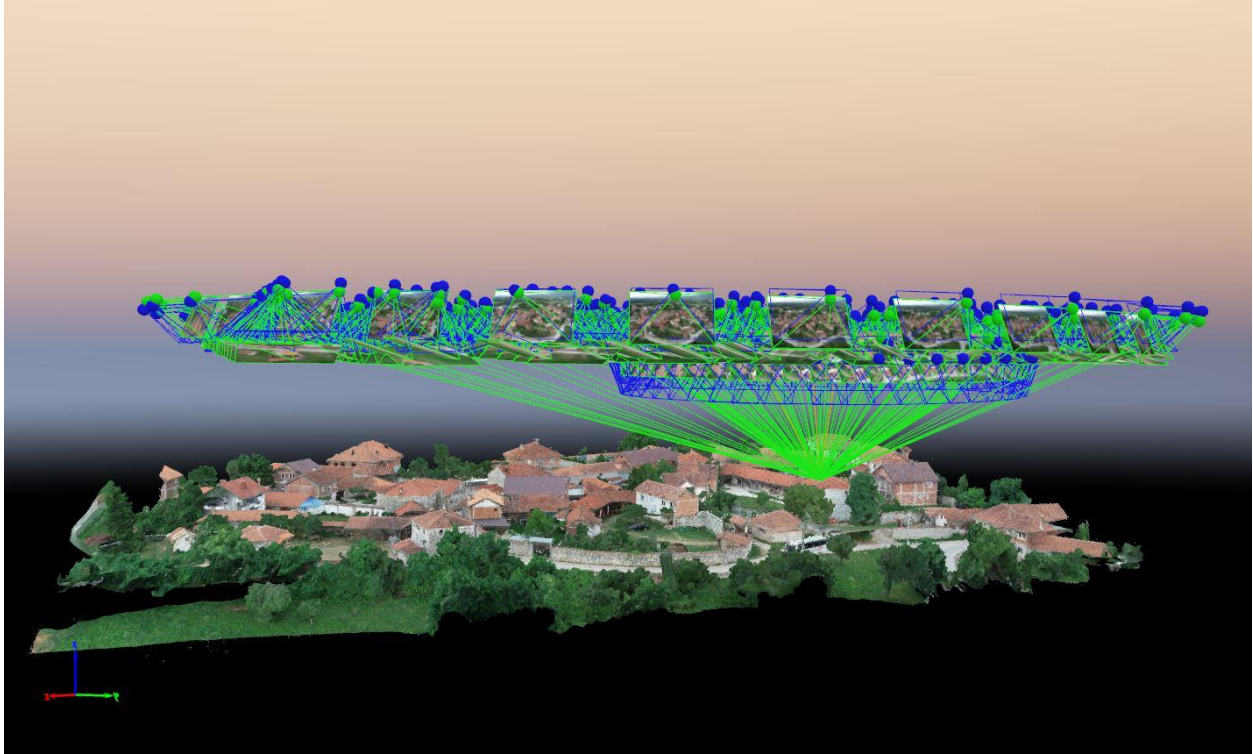


Figure 4. Images for an identified keypoint at Dranoc kulla with the point cloud (Pix4D, 2018).



Figure 5. The virtual Dranoc as created within Pix4Dmapper Pro.



Figure 6. The point cloud through a creation of tie points (Pix4D, 2018).

Locations

Student researchers visited and imaged three kulla locations near the western border of Kosovo (see Figure 7). These kullas are located in Isniq, Dranoc and Junik. The main focus of the work is the Dranoc kullas. However, the kullas in Isniq and Junik are notable and worthy of further documentation (see Figures 8 & 9).



Figure 7. Isniq, Dranoc and Junik kullas' locations in Kosovo (Google Earth Pro, 2019).



Figure 8. Pix4Dmapper Pro 3D virtual representation of Isniq kullas and surrounding area.



Figure 9. Pix4Dmapper Pro 3D virtual representation of Junik kullas and surrounding area.

Workflow

In order to safely and properly conduct operations to obtain the aerial imagery for interpretation, five main steps were followed. These steps were planning, preparing, conducting, analyzing and interpreting. The first task of planning begins with a selection of the site to be imaged and a study of the area utilizing Google Earth Pro. A preliminary survey is completed of the nature of the area, its hazards and subsequently a site survey document is completed. The site survey is a formal document listing estimations of minimum safe flight altitudes, a satellite picture of the area including terrain trends, airspace and weather information and more. With the site survey information, a preliminary flight plan will be created using Pix4Dcapture that will be adjusted on site if necessary.

Preparing is the second step and primarily consists of preparing paperwork and aircraft equipment. Each aircraft being used has an associated logbook with flight logs, risk assessment forms and a printed version of the site survey. After all aircraft batteries, controllers and smart phone/tablets are charged, all aircraft equipment is accounted for and properly secured in the aircraft case. Support equipment such as a laser range finder, anemometer, orange cones and radios are also accounted for.

Upon arrival to the operation site, the third step of conducting begins. It is vital to conduct an on-site survey that validates the site survey previously performed using Google Earth Pro. After setting up the operational site, student researchers assemble the aircraft and associated equipment and modify the flight plan as necessitated by the on-site survey (see Figure 10). It is important to conduct a flight risk assessment and initiate the flight information log before operations begin. After the aircraft has flown the mission and landed, all equipment is

disassembled and properly stored. The conducting step is usually the simplest part of any sUAS operation, but still requires a high level of focus and professionalism.

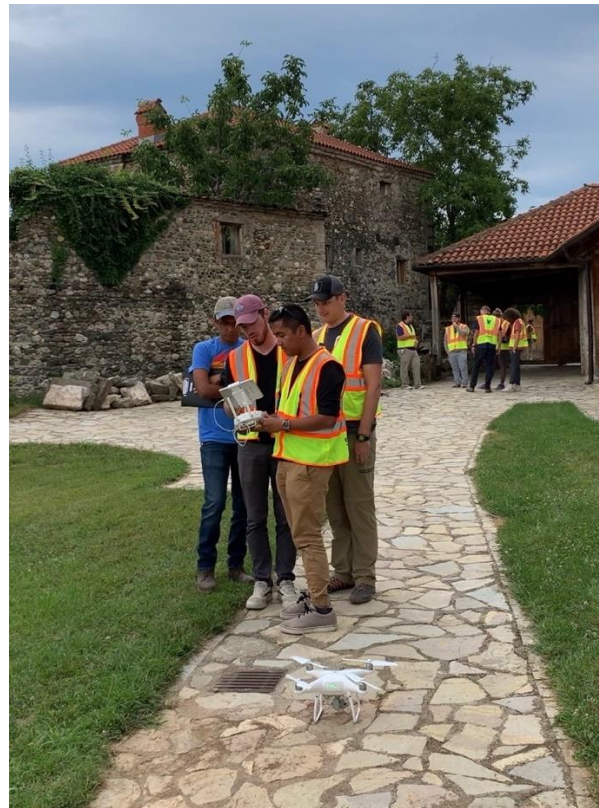


Figure 10. Student researchers conducting the operation in Dranoc with a Phantom 4 Pro V2.

The fourth step is analyzing, which generally takes the longest. All imagery from the flight must be properly taken from the aircraft's micro SD card, labeled and stored. It is then transferred to a new project in Pix4Dmapper Pro from which 3D virtual objects and orthomosaics are created. Because of the amount of processing power required to complete these projects, the processing time can take upwards of 6 to 7 hours. Even then, adjusting parameters and perfecting the project can require reprocessing and several more hours.

The final step of interpreting the imagery requires the use of subject matter experts. Cultural Heritage without Borders (CHwB) served as subject matter experts for cultural and

historical information regarding kullas. Aerial imagery acquired by sUAS readily enables subject matter experts to analyze and draw inferences from the projects.

Dranoc

Student researchers flew two aircraft over the Dranoc kullas capturing 497 images in four flights. These images had a natural resolution of 5472 x 3648 pixels per photograph. The images were stored internally on a micro SD card. A quality report was generated by Pix4Dmapper Pro detailing the specifics of the project. Due to variability there is a small amount of variation between the two cameras' optimized focal lengths. Both cameras were the same model, however, they had different optimized focal lengths reported as 8.551mm and 8.611mm respectively; the physical focal length for both cameras was 8.604mm (see Tables 1 & 2). It is normal that the optimized focal lengths are slightly different for each project (Pix4D, 2018). Optimized focal length values represent the calculated focal length based on keypoint matching. The image properties are f/3.5, a 1/60 shutter speed and an ISO of 100. Pix4Dmapper Pro created orthomosaics and 3D virtual objects that are dynamic visual effects. Each individual picture was geotagged with WGS84 Zone 34N datum.

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	3668.759[pixel]	2736.001[pixel]	1823.999 [pixel]	0.003	-0.008	0.008	-0.000	0.000
	8.604 [mm]	6.417 [mm]	4.278 [mm]					
Optimized Values	3646.202[pixel]	2714.893 [pixel]	1838.042 [pixel]	-0.003	-0.005	0.006	0.001	-0.001
	8.551 [mm]	6.367 [mm]	4.311 [mm]					
Uncertainties (Sigma)	0.116 [pixel]	0.055 [pixel]	0.074 [pixel]	0.000	0.000	0.000	0.000	0.000
	0.000 [mm]	0.000 [mm]	0.000 [mm]					

Table 1. The camera parameters for the first Phantom 4 Pro V2.

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	3668.759[pixel]	2736.001[pixel]	1823.999 [pixel]	0.003	-0.008	0.008	-0.000	0.000
	8.604 [mm]	6.417 [mm]	4.278 [mm]					
Optimized Values	3671.711[pixel]	2736.734 [pixel]	1818.395 [pixel]	0.002	-0.006	0.006	-0.001	-0.000
	8.611 [mm]	6.367 [mm]	4.265 [mm]					
Uncertainties (Sigma)	0.198 [pixel]	0.176 [pixel]	0.241 [pixel]	0.000	0.001	0.001	0.000	0.000
	0.000 [mm]	0.000 [mm]	0.001 [mm]					

Table 2. The camera parameters for the second Phantom 4 Pro V2

Photogrammetric processing intensively uses a graphical processing unit (GPU) and central processing unit (CPU). The computer used to process all 497 images was a Dell Alienware 15 R4 containing an Intel core I9-8950 12 core @ 2.90 Ghz, 32GB of RAM and an 8GB GTX1080 GPU. The computers operating system was Windows 10 Enterprise. The relatively low flight altitude over Dranoc allowed Pix4Dcapture to yield a GSD of 1.43 cm per pixel resulting in a very high resolution orthomosaic. On average 67323 keypoints were

calculated per image following the initial post-processing phase with all the images selected. As a measure of calibration, the internal parameters of the camera had a difference of 0.34%. Pix4D allows for up to a recommended 5% deviation between these initial and optimized parameters, but the lower the percentage difference the higher the quality of the final processed product (see Tables 1 & 2). Pix4D calculated a median of 23517 matches per image and a relative overlap of five or more images over the areas of interest which allowed for high number of matches and keypoints per image (see Figure 11). Overall the root mean square error (RMS) for Dranoc was 0.26m on the X axis, 0.41m on the Y axis and 2.31m on the Z axis. This project yielded high positional accuracy that is more than adequate for cultural heritage preservation purposes. Increased accuracy would be possible by incorporation of surveyed ground control points (GCP) (see Table 3). In conjunction with the high level of accuracy and overlap Pix4Dmapper Pro successfully computed corrected camera locations and was able to generate links between the photographs (see Figure 12).

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.80
-6.00	-3.00	0.00	0.00	16.70
-3.00	0.00	51.51	46.88	11.27
0.00	3.00	48.49	53.12	70.42
3.00	6.00	0.00	0.00	0.80
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.000000	0.000000	-0.000000
Sigma [m]		0.260614	0.410940	2.318502
RMS Error [m]		0.260614	0.410940	2.318502

Table 3. Absolute Geolocation Error.

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Table 4. Relative Geolocation Error.

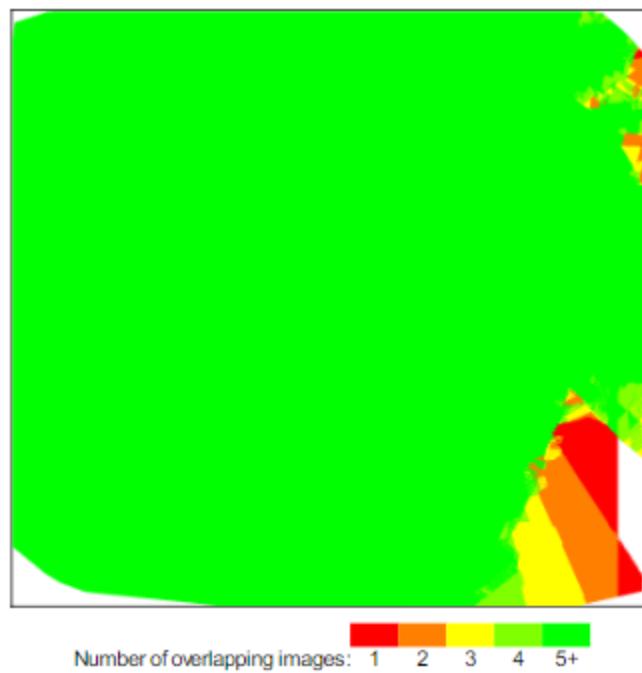


Figure 11. Visual depiction of the number of overlapping images of the Dranoc kulla processing area and picture key (Pix4D, 2018).

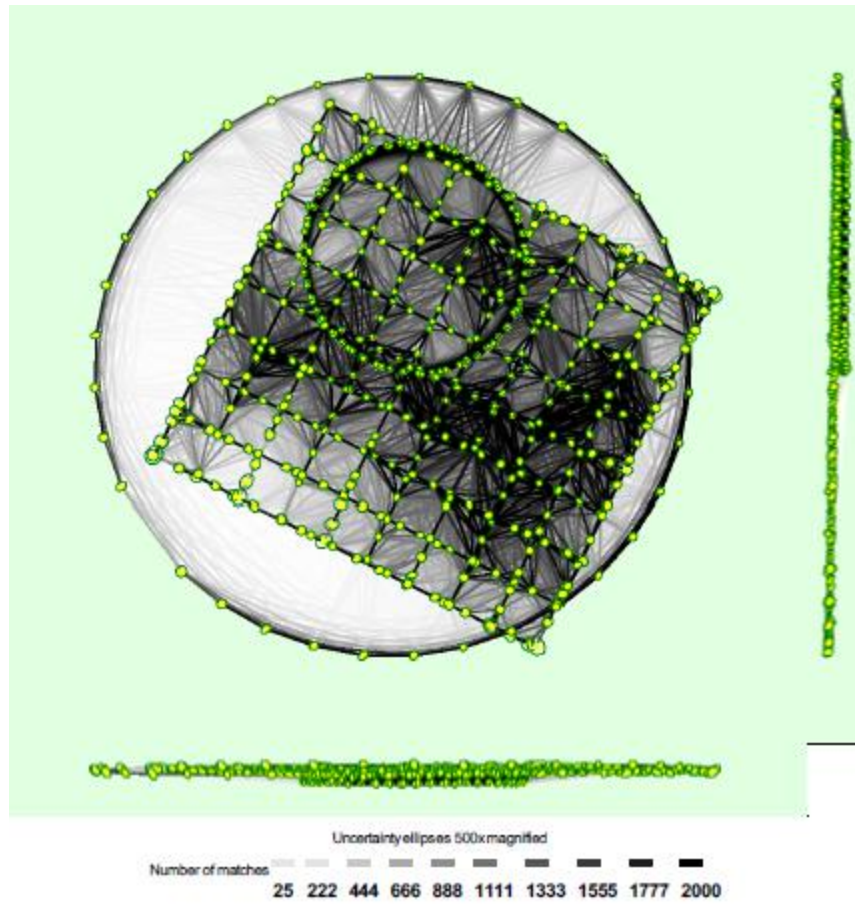


Figure 12. Computed camera locations with links between images (Pix4D, 2018).

Discussion

The history of kullas in Kosovo is interesting and reflects the unique characteristics of the region. Kullas are an evolution of culture and necessity. These structures are truly world treasures. Documenting their presence and characteristics helps all to appreciate the distinct and special place kullas hold in the history of the Kosovar people and humanity.

Small UAS are uniquely capable of positioning cameras to gain aerial perspectives for remote sensing and photogrammetric purposes. When the imagery is processed and turned into high resolution orthomosaics and 3D objects, governmental and nongovernmental organizations can utilize them to analyze the cultural sites from a variety of perspectives and purposes. Subject-matter experts who analyze the imagery can use it for documentation and preservation purposes. Additionally, imagery is used to create an archival record in order to establish a baseline for change detection. Detailed examination of sUAS captured imagery, including the kullas documented, can facilitate historical restorations. Furthermore, sUAS captured imagery can help facilitate raising awareness and help support organizations preserve unique and important historical sites.

Small UAS enable organizations to collect data at sites when financial, political and physical obstacles hinder other means of documentation. Using sUAS, such as Phantom 4 Pros, to capture images for photogrammetric processing is a viable means of documenting culturally important locations. In order to obtain the imagery and desired results, a structured and well documented process must be followed. This process can be seen in the five steps of planning, preparing, conducting, analyzing and interpreting. Without these steps and their components, it is difficult to reach the desired final products that are necessary to properly document culturally important locations. These processes can be readily replicated at sites around the world.

Conclusion

The work performed by these student researchers is a culmination of collective efforts to assist Cultural Heritage without Borders and the Republic of Kosovo in the preservation and documentation of historical and culturally significant sites. Student researchers applied advanced sUAS technology and photogrammetric principles in order to provide high resolution imagery and virtual models for cultural heritage preservation purposes. Cultural Heritage without Borders provided knowledge of the history and significance of selected locations. Applying the five steps practiced by the student researchers demonstrated a means for effective photogrammetry that results in valuable outcomes.

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