Mapping of Archaeological Sites using UAV Aerial Survey and PPK GNSS Ground Survey Techniques in Central Asia

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Abstract. Geospatial technologies such as Unmanned Aerial Vehicle (UAV) and Global Navigation Satellite Systems (GNSS) are becoming popular in various applications also for archaeological purposes. This is due to the abilities also the usefulness of UAV and GNSS technologies for digitally documenting and recording archaeological sites in great detail. Such information is crucial for the efforts of preserving and protecting historical sites. This paper demonstrates the workflows and results of mapping techniques using consumer-grade UAV for aerial survey and low-cost Post-Processing Kinematics (PPK) GNSS ground survey for documentation of two archaeological sites in Batken State, Kyrgyzstan in Central Asia. Both UAV and PPK GNSS data were acquired simultaneously during the fieldworks in early winter while processing were explicitly done using currently available commercial and open-source software. Results of the UAV and PPK GNSS was combined and qualitatively evaluated. Despite advantages and disadvantages identified in both UAV and PPK GNSS results, it was learned that the combination of both techniques found to be very beneficial for mapping of archaeological sites.

Keywords: Mapping; Archaeology; UAV; PPK GNSS; Central Asia

1. Introduction

The use of geospatial technologies such as UAV and GNSS is gaining popularity for various useful applications across disciplines including in archaeology. Availability of current advanced civilian UAV technology such as the DJI Phantom offers a fast, easy to operate, high-mobility and at a low deployment cost compare to rather expensive high-end ones [1-2]. It is also an efficient working tool enabling researchers to perform a complete high resolution digital site documentation of cultural heritage sites through modern UAV photogrammetry method [3]. Three dimensional UAV aerial photogrammetry uses Structure from Motion (SfM) technique whereby the three dimensional (3D) data are constructed from series of a highly overlap two dimension (2D) aerial photos acquired from multiple viewpoints [4].
Various outputs such as Digital Elevation Model (DEM), Orthomosaic Aerial Photos and point clouds data are useful for precise recordings of the landscapes of archaeological sites. The PPK/RTK GNSS applications for archaeology gain prominence recently with proliferation of technology [5] in low-cost high-quality centimetre precision GNSS receiver such as the Emlid Reach [6]. Recording spatial data are central to archaeological fieldwork and research [6] for the purpose of preservation efforts because archaeological sites as observed in the study area are also subjected to overtime land use land cover changes and erosion risks. Therefore, digital documentation maps will help management of sites provided with spatial information of locations, topographic and geometry aspect records. Similar study [5], found that UAV aerial survey yielded greater details as compare to RTK GNSS which requires more data intensities where a systematic points approach was employed to map the microtopography of archaeological study site. In addition, combination of both aerial and ground survey establish an efficient method of data collection while maintaining hands-on and boots-on-the ground knowledge of the archaeological site. Neither UAV aerial survey nor ground PPK GNSS is easy to implement since it requires training and experience to produce data of acceptable quality [5]. This paper is preliminary efforts for documenting archaeological sites in the Ferghana valley with the initial purpose of performing aerial survey data acquisition using UAV and ground survey PPK GNSS production of outputs.

2. Study Area
The study area is located within the Ferghana valley in the Batken region of Kyrgyzstan, Central Asia. The two sites are: (Site 1) Kara-Bulak, ancient burial tombs site (39°56'3.70"N, 70°55'12.59"E) located on mountain foot (1,560m ASL) on the south facing valley north. The site is tombs dated between the second to the fourth century AD and many tombs were explored. A few mummified bodies associated with many kinds of artefacts were also found. (Site 2) Aktepe is a hill shaped site (39°57'59.76"N, 70°55'29.16"E) located north on the valley (1,400mASL) in which ancient ceramic artefacts were uncovered since the first century B.C. until the pre-Islamic era (Figure 3). The two sites are located 3.6 kilometre apart with Kara-Bulak Village located in between. The Kara-Bulak ancient burial site located on a mountain foot on the south and Aktepe located on the flat area (Figure 1).

![Figure 1. Location of the Study Area (Google Map).](image-url)
3. Materials and Method

3.1 Materials

The study utilises commercially available consumer grade hardware such as DJI Phantom 4 Multirotor UAV equipped with on-board 12 megapixels camera manufactured by DJI for the aerial surveys and 3 sets of low cost Emlid Reach (emlid.com) receivers attached with Tallysman TW4721 (tallysman.com) GNSS antennas and powered by power banks for the ground surveys (one set used as based station and two sets as rovers). In addition, open source applications such as Android based DroneDeploy for flight mission planning of the UAV, Android based applications ReachView for controlling the Emlid Reach GNSS and Android based applications DJI GO 4 for the UAV settings. The data processing were done using Structure from Motion (SfM) software of Agisoft Metashape, Open source RTKLib and Open source CloudCompare software for processing the post-processed GNSS ground survey data.

![Diagram](image)

Figure 2. Methodology of the Study.

| Data Collections | Processing | Results |
|------------------|------------|---------|
| Ground Survey (PPK-GNSS) | Download Log Files | Raster Digital Terrain Model |
| Download UNAVCO (Local GNSS Station) | RTKCONV: (Convert ublox to RINEX Format) | Topography Contours |
| Aerial Survey (UAV) | RTKPOST: (Post-Processed Kinematic PPK) 1. Emlid Base 2. Emlid Rovers | LAS Point Clouds |
|                 | Edit & Combine Log Files .asc using Text Editor | Data Integration PPK GNSS + UAV Outputs |
|                 | Read .asc in Excel, Edit (height -1m) → save as CSV format | Digital Elevation Model (DEM) |
|                 | Open CSV in ArcMap → export as Shapefile (UTM Zone 44N), → LAS format | Orthomosaic RGB Aerial Photos |
|                 | CloudCompare: Editing point clouds & Rasterize | Point Clouds |
|                 | QGIS: Generate Contours | |

Align Photos
Build Dense Cloud
Build Mesh
Build Texture
Build DEM
Build Orthomosaic
3.2 Data Collections

The aerial and ground surveys were conducted simultaneously during early winter on (Wednesday) 27 November 2019 for Kara-Bulak and (Thursday) 28 November 2019 for Aktepe.

3.2.1. Kara-Bulak Ground and Aerial Surveys

The surveys for Kara-Bulak site were done between 11am to 2pm the site was covered with snow and temperature was around -7° Celsius during the fieldwork. For the ground survey, one set GNSS receiver was used as based station placed approximately at the middle of the survey area while the other two sets GNSS receivers were used as rovers for the topography tracking. Each rover was hand carried by the surveyors at height approximately 1 meter above ground. Topography data tracking was collected in a cross-hatched pattern with one surveyor walking north-south bound with interval approximately 3-4 meters between lines while another surveyor walking pattern was east-west bound this was aimed to completely cover the Kara-Bulak site. The GNSS receivers were controlled using Emlid Reach application installed on smartphones and data logging were set to automatic for continuous recording for the ground survey tracking.

Meanwhile for the aerial survey, the area covered was 74 acres with aerial photos capturing was programme using mobile app of DroneDeploy at 60 meters flight altitude above the ground level. The pictures capturing was set to: 80% front overlap and 70% side overlap, flight directions north-south, flight speed at 5m/s. Two batteries were used for the 30 minutes flights. We encountered various problems operating the electronics under such freezing conditions which were: the UAV sometimes disconnected with the DroneDeploy apps, Lipo batteries drains much faster, the UAV a bit drifted when on manual flight altitude hold and the GNSS receiver somehow very slow in getting satellite signals.

3.2.2. Aktepe Ground and Aerial Surveys

Surveys for Aktepe site were done between 1pm to 3pm taking advantage of good and less freezing sunny day. Temperature during the surveys was around -1° to -2° Celsius and the ground was slightly covered with snow. For the ground survey similar approach with Kara-Bulak was used, which was one GNSS used as base station and two rovers for tracking. Ground tracking patterns used were different where one surveyor tracked circling clock-wise and another anti-clockwise until both covered the
Aktepe hill like shape. However there was a disadvantage to the GNSS ground tracking method where one side of the Aktepe which were excavated earlier could not be tracked due to vertical slope. Simultaneously three known Ground Control Points (GCPs) of various objects (stone, file & DJI casing) were recorded.

Meanwhile, after identifying the specific needs and the required Ground Sample Distance (GSD), two approaches were planned for collecting the aerial photos for Aktepe site [7]. Firstly, to record a good three dimensional hill-shaped of the Aktepe, the UAV was flown manually orbiting the site at various altitude and aerial photos were captured manually. The camera angle was adjusted to acquire low oblique and high oblique point of view over the Aktepe site. It is very important to capture a high overlap where every required surface should be covered at least 3 aerial photos to guarantee completeness [8, 9] when processing using SfM software. Secondly, a normal flight path pattern was planned and executed using DroneDeploy for obtaining the Nadir view aerial photos. Flight altitude planned was at 30 meters above ground with high overlap of 90% front overlap and 80% side overlap. Three batteries were used for both flight patterns.

3.3 Data Processing

3.3.1. Processing of Post-Processed Kinematics (PPK) GNSS data

Both GNSS ground survey and base station data of Kara-Bulak and Aktepe were downloaded from the Emlid Reach GNSS modules using the ReachView browser to laptop via the WiFi network at Batken State University campus. By default the log files data were recorded in Ublox format and were converted to RINEX format using RTKCONV software of RTKLib. At this stage it was found that the ground survey data from rover 2 of the Kara-Bulak recorded only half of the tracks. It was due to the problems encountered during data collection whereas rover 2 ran out of battery. Post-Processed Kinematic (PPK) for the corrections of the Kara-Bulak and Aktepe GNSS logs data were done using RTKPOST of the RTKLib software. Local GNSS station data was downloaded from the UNAVCO website for the PPK corrections for the Emlid Reach Base Station corrections prior to corrections of the rover data. Logs data of both rovers of Aktepe ground survey logs were exported in “.asc” format was edited and combined using text editor. The combined logs in .asc format together with the post-processed were inspected spatially using RTKPLOT of RTKLib software.

The combined “.asc” format PPK GNSS ground track logs were read in microsoft excel. Altitude was edited by minus 1m to compensate antenna height during data collections and subsequently converted to “CSV (Comma delimited)” format. The CSV format data were loaded in ArcMap to inspect its quality then exported into shapefile format of UTM Zone 44N coordinate for 3D editing using CloudCompare software. Editing was required to filter fixed points, remove overlapping points and eliminate error points. According to Malek et al (2018), GNSS positional errors are caused by the signal delay between satellite antenna and layers of atmosphere medium which imposes some undesirable effects [10]. In figure 4 (a & b) can be observed many errors tracked points needed editing. Edited and clean track points were rasterised using CloudCompare software was subsequently contours were generated in QGIS software.
Figure 4. Kara-Bulak in 3D (a) and Aktepe in 3D (b). Notice error points clusters in circle and pointed by arrows. Height represented in gradient colours.

3.3.2. Processing of UAV data
There were 648 aerial photos processed for Kara-Bulak site and 403 aerial photos processed for Aktepe site. Processing were done (without GCP) using Structure from Motion (SfM) Agisoft Metashape Photogrammetry Software to produce Orthomosaic outputs such as: RGB Orthomosaic aerial photos, Digital Elevation Model (DEM) and point clouds. The processing steps were rather straight-forward sequences of aligning photos, building dense cloud, meshing, texturizing, building DEM and building orthomosaic. Aktepe aerial photos were combinations of Nadir and 360 photos.

4. Results and Discussions
4.1. Ground Survey
Three types of outputs produced from the PPK GNSS processing are: Raster Digital Terrain Model (DTM), generated topography contours and point clouds in LAS format. It was observed that details of the DTM produced from GNSS were not comparably good quality as the one produced from UAV results. The low quality in microtopographic visible in the GNSS results are primarily caused by the data density corresponds to a very small Ground Sample Distance (GSD) [5]. This is obviously visible for the case of GNSS result produced for small Area of Interest (AOI) of Aktepe site. However for Kara-Bulak, the recorded topographic details are fairly good due to its much larger Area of Interest (AOI). Figure 5 showing the generated DTM of the two sites.
Figure 5. Kara-Bulak (a) and Aktepe (b) 3D PPK GNSS generated Digital Terrain Model (DTM) with cross section profile.

4.2. Aerial Surveys

Three types of outputs produced from the aerial photos processing are: Orthomosaic aerial photos (in RGB), Digital Elevation Model (DEM) and Point Clouds (as in Figure 6). The GSD resolution of Kara-Bulak aerial survey data is 2.7cm/pixels and for Aktepe is 1.3cm/pixels. From the orthomosaic aerial photos can be observe that Kara-Bulak has more snow cover than in Aktepe site. However the landscape forms and slopes of both sites only can be visible from Digital Elevation Models (DEM) of both sites. In additions, the topographic gradients are well represented in the point clouds colour gradient views and high to low land levels are easily identified. The DEM could potentially useful for further analysis such as erosion risk assessment or identifications numbers of tombs in the Kara-Bulak site. Meanwhile further analysis such as volumetric calculation could be performed for the Aktepe site. Until then a much proper planning for detail ground sampling, measurements and establishment of Ground Control Points GCPs will be useful considerations of further studies over the two sites. At the moment initial results from this study would be a good guidance for improvements in UAV and GNSS field data acquisitions.
4.3. Combining GNSS and UAV outputs

Results of UAV and GNSS for both Kara-Bulak and Aktepe site were qualitatively inspected by overlaying in GIS. All results of UAV and PPK GNSS are easily integrated using Projected Coordinate of Universal Transverse Mercator (UTM) Zone 44N for Kyrgyzstan zone. The contours were generated at 2 meters interval form the GNSS raster DTM. The results are nicely depicting the topography of both Kara-Bulak and Aktepe archaeological sites (Figure 7).
5. Conclusions
This paper presented the mapping workflows of archaeological sites in Batken, Kyrgyzstan using UAV aerial survey and PPK GNSS ground survey techniques. Good results such as demonstrated in this paper could be reproduced as well for other archaeological sites by following similar workflows. Because digital recordings by mapping using UAV and PPK GNSS are very important to the archaeological works and research in the area. The mapping effort itself is important for documentation as well the preservation and protection of archaeological sites in the Fergana valley especially in Batken region Kyrgyzstan. At current stage, this study only aimed to produce the mapping results from both UAV and PPK GNSS based on the workshop recently conducted under the ongoing heritage protection project involving Central Asian countries. It is also an early exposure to the participants to gain experiences for implementations of UAV and PPK GNSS techniques to produce good quality data as well as building basic GIS and Geospatial skills. Future steps might possibly look into the analysis of the compiled aerial and ground survey data depending on the objectives of archaeological investigations of the study area.

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References
[1] Hayat, S., E. Yanmaz, and R. Muzaffar 2016 “Survey on Unmanned Aerial Vehicle Networks for Civil Applications: A Communications View-point,” IEEE Communications Surveys & Tutorials, vol. 18, no. 4, pp. 2624–2661.
[2] Thamm, H. P., Brieger, N., Neitzke, K. P., Meyer, M., Jansen, R., & Mönninghof, M. 2015. SONGBIRD-an innovative UAS combining the advantages of fixed wing and multi rotor UAS. International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 40, pp. 345-249
[3] Federman A., M. Santana Quintero S., Kretz, J. Gregg, M. Lengies, C. Ouimet, J. Laliberte 2017 UAV Photogrammetric Workflows: A Best Practice Guideline. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W5, 2017 26th International CIPA Symposium 2017, 28 August–01 September 2017, Ottawa, Canada
[4] Micheletti, N., Chandler, J.H. and LANE, S.N. 2015 Structure from motion (SFM) photogrammetry. IN: Clarke, L.E. and Nield, J.M. (Eds.) Geomorphological Techniques (Online Edition). London: British Society for Geomorphology. ISSN: 2047-0371, Chap. 2, Sec. 2.2.
[5] Rooseveldt, Chris. 2014 Mapping site-level microtopography with Real-Time Kinematic Global Navigation Satellite Systems (RTK GNSS) and Unmanned Aerial Vehicle Photogrammetry (UAVP). Open Archaeology. 1. 10.2478/opar-2014-0003.
[6] Cobb, P., Earley-Spadoni, T., & Dames, P. (2019). Centimeter-Level Recording for All: Field Experimentation with New, Affordable Geolocation Technology. *Advances in Archaeological Practice*, 7(4), 353-365. doi:10.1017/aap.2019.21

[7] Nex, Francesco, and Fabio Remondino 2014 “UAV for 3D Mapping Applications: A Review.” *Applied Geomatics* 6 (1): 1–15.

[8] Zheng Sun and Yingying Zhang 2018 Using Drones and 3D Modeling to Survey Tibetan Architectural Heritage: A Case Study with the Multi-Door Stupa. *Sustainability*, 10, 2259; doi:10.3390/su10072259

[9] Waldhäusl, P.; Ogleby, C. 1994 3 × 3 Rules for simple photogrammetric documentation of architecture. In Proceedings of the International Society for Photogrammetry and Remote Sensing, Comission V, *Australian Photogrammetric and Remote Sensing Society Symposium, Melbourne, Australia*, 1–4 March 1994; Volume5, pp. 426–429.

[10] Malek Karaim, Mohamed Elsheikh and Aboelmagd Noureldin 2018 GNSS Error Sources, Multifunctional Operation and Application of GPS, Rustam B. Rustamov and Arif M. Hashimov, *IntechOpen*, DOI: 10.5772/intechopen.75493