3D SHORELINE MAPPING WITH UNMANNED AERIAL VEHICLE

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Key words: Unmanned Aerial Vehicle (UAV), Drone, Shoreline Mapping, Hydrographic Surveying, Coastal Management

SUMMARY

Recent developments in surveying technology, sensors and processing algorithm provide to develop some new measurement platforms. One of them is Unmanned Aerial Vehicle (UAV) and they are widely used in land, marine and air applications because of their economic and easy applications, as well as their accuracy. In this study, extraction of a dam's coastline by processing images obtained from Unmanned Aerial Vehicle (UAV) is presented. Within this frame, a test measurement was conducted in Obruk Dam Lake of Çorum City in Turkey and about 900 aerial images were taken by using a DJI Phantom 3 Pro UAV. The collected data were processed with Pix4D Mapper Pro software and 3D point cloud, Digital Surface Model (DSM) and true orthophoto maps were produced for a part of dam's shoreline with a certain band. The study concludes that UAVs can be used for many different types of coastal mapping and surveying projects at lower cost, increased operational flexibility within cm to dm level of accuracy and depending of these advantages, they are becoming viable alternative to conventional terrestrial measurement methods.

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1. INTRODUCTION

Hydrographic surveys are carried out for many different type of projects, mainly the determination of underwater features and the water bottom surface of water-covered areas such as seas, lakes, ponds, and dams, besides defining their shoreline. Although the boundary of this kind of study is generally restricted to the shoreline, the topography of a certain bandwitdh (land strip) should be surveyed above the shoreline at the time of measurement. The overall coordination and/or implementation of any kind of study to be carried out in the dams of Turkey conducted by the General Directorate of the State Hydraulic Works (DSI) within the framework of the specifications that are given in their regulations. According to the General Map and Map Information Production Regulation of DSI, the boundary of hydrographic surveying to be made in dams is restricted to dam crest level. The underwater features are determined with different bathymetric surveying techniques where the 3D map of a bandwith around the measured water mass are carried out with various methodologies depending on the survey condition and the size of the area to be surveyed. When the water bottom surface of the existing reservoir is determined with bathymetric surveying, the bandwidth around the water mass should also be mapped in addition to shoreline (Ceylan and Ekizoglu, 2014).

Nowadays, there are various measurement methods in use for mapping projects. Depending on the field conditions and the size of the area to be surveyed, conventional terrestrial, space-based GNSS measurements, photogrammetric and remote-sensing techniques are used. The conventional measurement techniques have been used for a long time but dependability of weather conditions, the requirement of labour field studies, and difficulties such as measuring at certain times of the day restrict usability of this type of technique in practice. More recently, conventional surveys have become less preferred and left their place to GNSS systems. However, it is difficult or even impossible to implement these methods in some fields such as densely wooded area or extreme/harsh environments. Furthermore, there are some difficulties for measuring along the shoreline because of mud, brushwood that prevent walking or even moving.

In recent years, Unmanned Aerial Vehicles (UAVs) have been widely used in many applications such as producing large scale maps, coastal measurements, integrated coastal zone management projects, environmental surveying, forestry, urban planning, agriculture, movie, search and rescue, documentation of cultural heritage, 3D modelling and documentation in archaeological studies, energy, real-estate, public safety, monitoring of natural protected areas, traffic monitoring, water quality estimate and so on. UAVs are preferred since they provide fast, accurate and cost-effective solutions for the creation of higher resolution maps especially in smaller areas with a great flexibility. They can be operated in hazardous or inaccessible areas for obtaining spatial data while allowing the easy repletion of a survey (Papakonstantinou et al., 2016; Hidaka et al., 2017; Madawalagama et al., 2017). Due to their several advantages, the use of UAV systems for acquiring geoscientific data has grown rapidly and traditional geodetic surveying methods are replaced with the UAVs. Different types of products can be obtained from UAVs such as geographically accurate orthorectified two-dimensional maps, elevation models, thermal maps, and 3D maps or models (Greenwood, 2015).

Published scientific papers about UAV based coastal studies are relatively limited: O'Young and Hubbard (2007) develop a management system in Canada's harsh coastal environment; Mancini et al., (2013) measure the topography of a 200 m section of beach and dune in Italy; Casella et al., (2014) generate temporal Digital Terrain Models (DTMs) of beach for modelling wave run-up; Gonçalves and Henriques (2015) mapped and monitored sand dunes and beaches with UAV based high resolution digital surface model; Drummond et al., (2015) performed a coastal management UAV applications in order to get coastal wetland mapping and management; Papakonstantinou et al., (2016) used UAV to generate an accurate orthophoto and 3D model of two coastal area in Greece. Yoo and Oh (2016) try to detect short term temporal topographic changes in a 1 km beach. More detailed information about the usability of UAVs (or drones) in coastal area for surveying and mapping can be found in Turner et al., (2016); Nikolakopoulos et al., (2017); Templin et al., (2017); Topouzelis et al., (2017). As a result, UAVs expand the ability of observing and data collecting in terms of temporal and spatial resolution. Especially in logistically challenging areas and dynamic landscape such as coasts the UAVs started to take over the manned aircraft.

In this study, the usability of Unmanned Aerial Vehicle (UAV) for extraction of the shoreline was investigated. Within this context, a test study was conducted in the Obruk Dam Lake, of Çorum City in Turkey by using an UAV and 3D map of a part of a dam's shoreline with a certain band was produced. Additionally, the test procedure and obtained results are discussed in detail.

2. CASE STUDY

2.1. Description of the Study Area

The Obruk Dam was constructed in 2009 on the Kızılırmak which is the longest river of Turkey, in Çorum City (Figure 1). Obruk Dam is a the clay core semi-permeable inlay body dam that has a height of 67 meters from the riverbed and 125 meters from the foundation with 12 hm^3 reservoir volume. The installed electricity generation capacity of the Obruk Hydroelectric Power Plant is 202.8 MW and the annual energy generation is 515 million kWh (URL-1). The shoreline of the dam is nearly 90 km and water surface area is 50 km^2, respectively.

Figure 1. The Study Area, Obruk Dam Lake

2.2. Data Collection with an Unmanned Aerial Vehicle (UAV)

UAV measurements were conducted for mapping of the bandwidth above the existing water surface up to the crest level on selected part of Obruk Dam Lake. DJI Phantom 3 Pro quadcopter was used during test measurement. The images were acquired with 12 MP flying camera with 4K video at up to 30 frames per second and capturing 12 megapixel photos with the average Ground Sampling Distance (GSD), i.e. resolution of the images or pixel size, was 4.77 cm (1.88 in). The field measurement for data acquisition was carried out in June 2017 (Figure 2).

Figure 2. UAV Measurement

The UAV flew autonomously at an altitude of 100 m above ground level at a maximum speed of 16 m/s and photos were taken. UAV mission was planned to have a 75% of side-overlap and 70% forward–overlap rates. The taken photographs were carefully screened and totally 933 (out of 973) clear and suitable selected photos were used for processing. The total measurement time during six separate UAV flight was lasted approximately 1.5 hours including take-offs and landings.

In order to geo-referencing the data collected with UAV, i.e. calculate scale, orientation, and absolute position of the photos, 10 Ground Control Points (GCPs) were established in suitable locations through the study area. Before starting the UAV flight, these points were marked as easily to be seen from the taken photographs. In order to achieve the best positional accuracy for whole process, the coordinates of these points were determined by Network-RTK GNSS measurement technique with centimetre-level of accuracy. In order to achieve this, TUSAGA-Aktif (or Turkish RTK CORS Network/CORS-TR) Network RTK which has been serving with 146 reference stations, having an average spacing of 70-100 km interstation distances to civilian users in Turkey since 2009 was utilized (Figure 3).

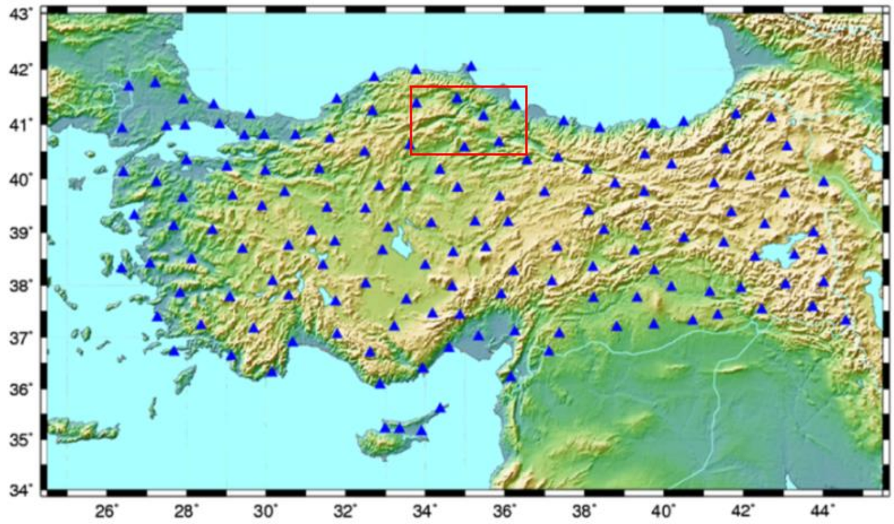

Figure 3. Location of TUSAGA-Aktif Reference Stations

TUSAGA-Aktif system make possible real-time positioning with an accuracy of under 3 cm for 2D position and 5 cm for height components (Bakıcı and Mekik, 2014; Aykut, et al., 2015). More information about TUSAGA-Aktif Network RTK system is given in Bakıcı and Mekik, (2014). During this survey, multi-constellation/multi-frequency Trimble R10 GNSS receivers were used. The attainable Network RTK accuracy for used GNSS receivers are given as 8 mm + 0.5 ppm RMS for horizontal and 15 mm + 0.5 ppm RMS for vertical components (URL-2).

2.3. Generating 3D Point Cloud, Digital Surface Model (DSM) and Orthophoto Map

The main aim of process is to produce a georeferenced 3D dense point cloud by handling with overlapping aerial image data (Siebert and Teizer, 2014). The approach of point cloud generation from images is called as Structure from Motion (SfM). Despite this approach is developed in 1990s by computer vision community in order to get an automatic feature-matching algorithm, it runs under the same basic conditions as stereoscopic photogrammetry (Harris and Stephens, 1988; Spetsakis and Aloimonos, 1991; Boufama et al., 1993; Szeliski and Kang, 1994). It uses overlapping images in order to get 3D structure of interested object. In this study, Pix4D Mapper Pro software was used in order to process the image data collected by UAV flying. Processing of the collected data was started by importing the images into the workstation and dense 3D point cloud was extracted. After 4 hours processing time, 46546956 of 3D densified points (with 17.12 per m^3 average density) were obtained. As a next step, Digital Surface Model (DSM) generation and an orthophoto map covering about 176.67 hectare production was implemented for the study area with Pix4D Mapper Pro software (Figure 4). It should be noted that, Inverse Distance Weighting algorithm was used to interpolate the DSM from the point cloud.

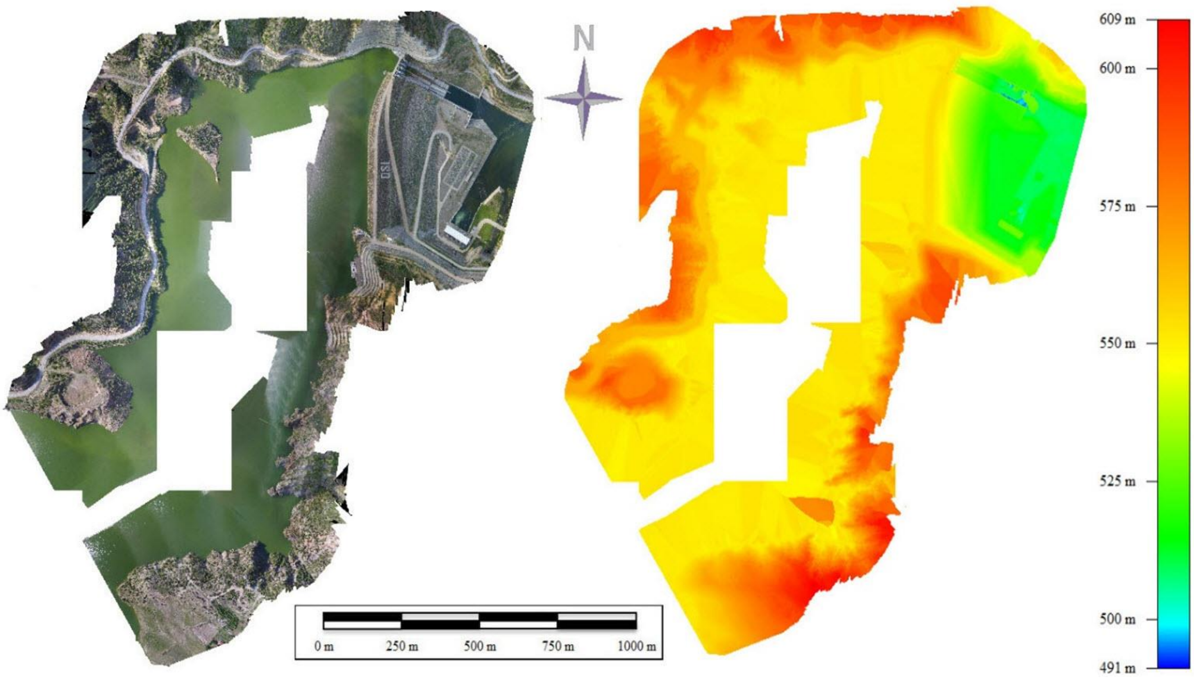

Figure 4. Produced Orthomosaic and Corresponding DSM for Obruk Dam

The water surface topography which was obtained from this study area by bathymetric surveying in the same day and UAV-based land measurement data were merged and 3D model of the study area have been obtained. From there, a high-resolution 3D model of the study area was produced (Figure 5). A detailed information of the abovementioned bathymetric surveying is accessible at İlçi et al., (2017).

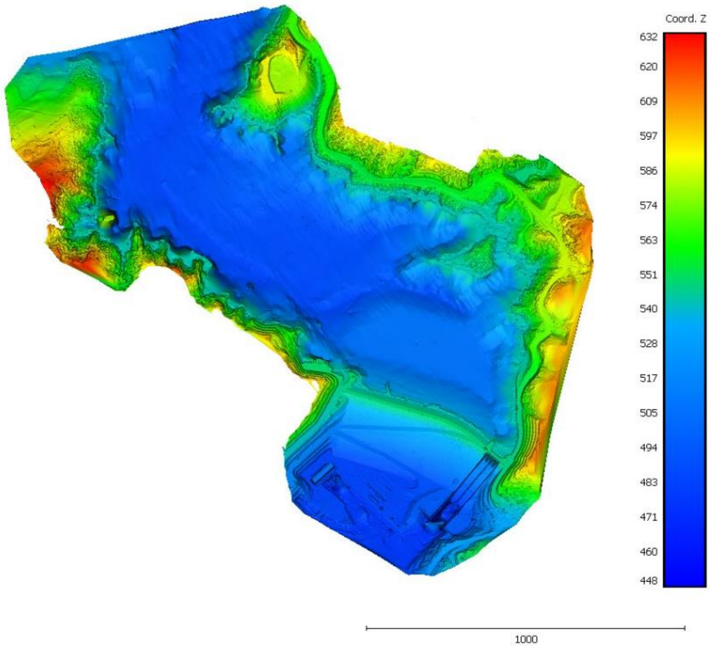

Figure 5. 3D Model of the Study Area

It should be noted that, the whole of the measurement and post-processing stages including identification, marking and measuring of the GCPs, mission planning, image acquisition, post-processing (i.e. orientation, 3D point cloud generation, DSM and orthophoto map production) of 176.67 hectare area took about 3 days, which must be accepted a quite short time if compared with such engineering projects.

2.4. Assessment of the Positioning Accuracy

In order to make a precise assessment of the attainable accuracy of the models obtained from UAV measurement, some sharp, well defined, and clearly identified points on images were determined. The coordinates of these points were coordinated from the produced 3D Model and in the field. The points were coordinated with Network-RTK GNSS measurement technique in the study area. The coordinates of the points having different characteristics were then compared with those obtained from the model. According to the obtained results from the comparison, we conclude that, the final orthophoto map has about 2 dm-level or better for 2D positional accuracy while having about twice vertical accuracy.

Possible reasons for these relatively low accuracy values obtained are given below:

- Due to the topography and shape of the study area, data acquisition with a single flight plan has not been achieved. Therefore, the measurements were carried out with 6 separate flights and then they were processed together. This fact may decrease the accuracy.

- On the other hand, establishing an insufficient number of GCPs in that area due the inability to reach the sharp slopes that are perpendicular to the shoreline in a part of the area caused the accuracy of the obtained model to decrease.

- Photogrammetric process was negatively affected due to the study area was mostly water surface. Because of the water surface images cannot be matched sufficiently, there has been column disconnections in the process.

- The remain parts of the study area are woodlands and have sudden elevation changes which facts affect the especially vertical positional accuracy. In addition, challenging terrain topography and high-voltage lines required higher flights to be made. Depending on the flight altitude, the GSD value has been adversely affected.

- On the other hand, attempts have been made to make revision surveys in order to improve some of the issues listed above, but a new flight permission could not been obtained. For this reason, the measurements could not be done again.

In general, it could be said that, a number of factors like number, spatial distribution and accuracy of GCPs, the quality of GNSS receiver type, i.e. having on-board geodetic-grade RTK-capable GNSS receiver or consumer-grade navigational receiver, image quality, flight altitude and camera orientation, the stability of the flight, flight speed, overlap between images, ground sample distance, algorithm (and software) used to interpolate the DSM from the point cloud to make the orthophoto, the precision of the surveying equipment used, topography of surveyed terrain, i.e. flat or undulated influence the accuracy of UAV-based map. These factors will have an impact on the accuracy of the final product.

Despite all this, the obtained 2D positional accuracy can meet the requirements for several coastal mapping studies. In general, this study demonstrate that UAV gives low-cost and fast solution to the surveyors for creating orthophoto maps.

3. CONCLUSION

In this study, extraction of a coastal line and a certain bandwidth of land within the frame of bathymetric study in a dam lake by using UAVs were introduced. As a result of the study, it was seen that 3D maps can be prepared very quickly and easily by using UAVs for dam basins, which usually have harsh environmental topography, inaccessible, dangerous and forbidden areas (zones). The achieved results of this study indicate that, it is possible to obtain 3D map of the shoreline and surrounding area with sufficient accuracy for many studies with less labour and inexpensive field measurements. The overall results imply that, UAVs provide an efficient and cost-effective survey tool for coastal surveying mainly including 3D mapping and measurement in the coastal zone with dm level accuracy.

From the results of the gained experience in the study, the use of UAVs with the RTK-capabled is suggested instead of the use of GCPs for difficult and rough terrain. Unfortunately, this is a cost increasing factor. As far as possibilities are concerned, for the inaccessible and harsh terrains, it is considered that factors such as redesigning flight plans, increasing GCPs to a sufficient number, reassessing overlapping rates, choosing a high resolution camera will increase the accuracy of the final products.

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