USING UNMANNED AERIAL VEHICLES FOR OPEN MINING AREAS: CURRENT APPLICATIONS AND FUTURE POTENTIALS

Abdullah Harun Incekara[1], Omer Yildirim[1], Tekin Susam[1], Dursun Zafer Seker[2]*
[1]Gaziosmanpasa University, Department of Geomatics Engineering, 60150, Tokat Turkey
e-mail: (abdullah.incekara; omer.yildirim; tekin.susam)@gop.edu.tr
[2]Istanbul Technical University, Department of Geomatics Engineering, 34469, Istanbul Turkey
e-mail: seker@itu.edu.tr

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ABSTRACT: Unmanned Aerial Vehicles (UAVs) are preferred in a variety of applications such as forestry, precise agriculture and disaster management due to the good coverage of study area provided by high-resolution photographs in a short period of time. Due to its richness of natural and geographic features, Turkey has a real potential to use these instruments in many different application, especially in the cut and fill calculations of the open pit mines. The most important advantage of using UAV in open mines is to increase productivity in many aspects like time, cost, accuracy and safety without reducing work force. In this study, potential usage of unmanned aerial vehicles in open mines has been investigated. A marble mine located in the province of Antalya was selected as the study area. Related data was collected by means of a rotorcraft type UAV. The reason of preferring this type of UAV is its maneuverability during the monitoring for smaller areas with complex surfaces and no require large space for rotation at the end of the strips relative to the fixed-wing type. After the photographs were taken, 3D models were created and cut and fill (volume) calculations were done very quickly, to evaluate the daily changes occurred in the mining area. Another main advantage of using UAV for similar studies is to prevent any possible accidents that may cause serious injure or even death of the people who are trying to evaluate these changes by the help of new derivative data sets such as the terrain gradient created on the model and their interpretation. Depending on the location of the mine, it is possible to determine the effect of the studies carried out on the natural environment temporally, such as forestry area. Just the opposite, it is possible to determine the potential for influencing the mine by any flood of natural resource such as the basin, dam or stream bed which is located near the mine and is not adversely affected by the mine.

1. INTRODUCTION

People have become a user of “Unmanned Aerial Vehicles” (UAV) easily in their works, hobbies and commercial purposes. There are many different brands are available on the market. In Turkey, number of registered drone, or UAV, is 8.349 with users of 11.839 according to the last announcement done by Directorate General of Civil Aviation within the Ministry of Transport, Maritime Affairs and Communications. The increase in demand for these devices is accompanied by their use in various fields for different purposes. Forestry (Paneque-Gálvez et al., 2014), precise agriculture (Guo et al., 2012; Ruangwiset, 2014), and disaster management (Restas, 2015) for engineering applications are among the main areas where unmanned aerial vehicles are used due to the good coverage of study area provided by high-resolution photographs in a short period of time. Similarly, the use of these devices in “Open Pit Mines” (OPM), where geomatics engineers work intensively, is increasing day by day.

An OPM is a field in dynamic structure which is altered by human activities and thus modifies its environment. Expansion of the existing area, excavation and production in that area and transportation within and outside the current area constitute the relationship of the OPM to the environments, which must be constantly examined (Filipova, 2016). For this reason, it is the most important issue to gather the data quickly and at the same time without waiving the desired accuracy. Images obtained from a satellite or airborne are automatically disabled because they may be insufficient in terms of temporal resolution of the necessary data even if they meet certain criteria (Eisenbeiss, 2011) which operations in some mines are being carried out with 7/24 system.

In conventional methods, it is necessary to make GPS measurements to collect information about the surface. The number of points that can be taken from the terrain surface is based on the physical boundaries of the human being, even if this process provides sufficient accuracy. So, it is possible to picture the surface of the land only to a certain extent with this method. In this case for open mine operations, it is more logical to evaluate measurements done by means of GPS only for sufficient number of ground control points and photographs to be obtained by UAV in a short period of time together. The advantages of the measurements to be made with the UAV compared to the conventional methods are no need to climb stockpiles for volumetric calculations, no need to be near in slippery high hazard areas and thus reduced accident possibility, the desired product and the accuracy of this product in a shorter time, remotely survey for unreachable areas that would appear as gaps in measurements made using conventional methods, and lower costs.

There are two types of vehicles when the UAV is used in open mine areas: One is rotorcraft or rotary-wing and the other is fixed-wing. The main difference between these two types of UAVs is the equipment that allows them to remain in the air during the flight. There are propellers which starts to rotate during take-off in the mechanism of the rotorcraft vehicle while two wings on the left and right are used for the other vehicle. In OPMs, rotorcraft UAVs are more advantageous in many ways. Firstly, a rotorcraft UAV has a capability of taking off vertically and landing on any surface in the same way but there must be appropriate surface for fixed wing that the body of the device is in contact with the ground in some way or another. Second, it is possible to fly with rotorcraft vehicle at a lower altitude while at least 50 m of flight height is generally required for a fixed-wing vehicle. As the third, maneuverability of rotorcraft UAV during the monitoring for smaller areas with complex surfaces and no require large space for rotation at the end of the strips relative to the fixed-wing type make it more preferable. Fourthly, rotorcraft UAV can be stationary in the desired position in the air. This feature makes it more advantageous in situations such as monitoring an accident event. Fixed-wing type UAVs are better to stay in the air in terms of time and more suitable for larger areas instead of mine fields. Other than these, there are UAVs called as hybrid system which combine the advantages of both rotary-wing and fixed wing, naturally with higher cost. There are several publications in the literature on the use of unmanned aerial vehicles in mine areas such as (Rathore and Kumar, 2015; Lee and Choi, 2016). In this study, it is aimed to show the current applications of UAVs in OPMs, how measurements are performed and to evaluate future potentials.

2. DATA AND METHODOLOGY

A marble mine located in the province of Antalya was selected as the study area. The mine showed in Figure 1 is in the forestry region and area covered by mine is approximately 60 ha (1,2 km x 0.5 km). The mine has height differences of up to 40 meters and maximum slope is around %58.

Figure 1: Study area

Teknomer GEO1 Hexacopter Rotary-Wing UAV shown in Figure 2 was used to create 3D model of OPM by integrating the terrestrial GPS measurements and photographs taken by UAV. Weight of the platform selected is 2.6 kg without payload and 4 kg with the equipments loaded on it. Preferred digital camera is Canon IXUS which is in the weight of 127 g including battery. Maximum resolution and sensor size of the camera are respectively 5152 x 3864 pixel and 6.16 x 4.62 mm which corresponds to a value of 1.19 μm pixel pitch. This configuration is capable of producing enough quality photographs for the open mine area with the existing technical features as well as the weight that does not affect the flight time of the UAV negatively.

Figure 2: Hexacopter UAV and other equipments

General procedure for a task with an UAV is as follows:

-Flight planning
-Setting ground control points
-Performing flight
-Image processing
-Generating output (Orthomosaic, DSM etc.)

The photographs were collected with 2 flights to cover the entire terrain surface as shown in Figure 3. The reason for the 2 flights is due to the inadequacy of the existing battery at the first flight. The actual duration of the UAV used without payload is about 25 minutes. Photographs were taken at 8 minutes to cover the whole mine site and surrounding area.

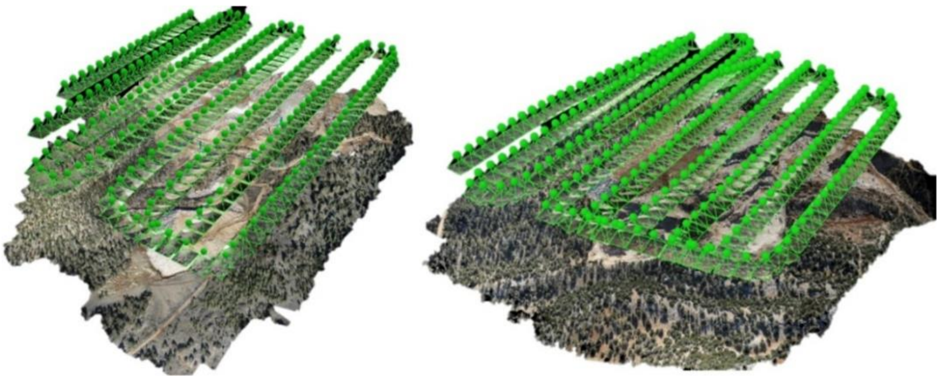

Figure 3: Flight task and taking photographs

Total number of the photographs taken is 494. For 2 flights, 13 ground control points homogeneously distributed on the surface were used. Focal length (f) of the camera used is 5 mm and pixel pitch is around 1.19 µm. Flight height (D) is 150 m which corresponds to 3.6 cm ground sampling distance (GSD) when other numerical values are considered according to the formulas given below:

$$Pixel\ Pitch = \frac{Sensor\ Size}{Maximum\ Resolution} \qquad (1)$$

In formula 1, pixel pitch is actually pixel size image and generally provided on the instrument guide. Directions are important in mathematical process. In other words, the horizontal and vertical sensor dimensions and the maximum horizontal and vertical resolution values correspond to each other.

$$GSD = \frac{D}{f}\ x\ Pixel\ Pitch \qquad (2)$$

where; D is flight height and f is focal length.

In formula 2, GSD means the pixel size in the ground. Pixel pitch and focal length of the camera is fixed values and GSD can be changed depending on the flight height according to desired and expected accuracy. The lower the GSD value, the higher the accuracy, so more accurate results can be obtained with low flight height but at the same time it means to take higher resolution photographs, which increases the processing time of the data. When the Figure 4 is considered, it can be said that GSD is actually depends on the scale.

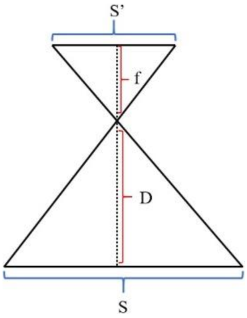

Figure 4: Theory of aerial photogrammetry

S’ is distance on the photograph while S is the distance on the ground. According to basic principle of the photogrammetry, the ratio between S’ and S is equal the ratio between the f and D. Both of them express the map scale. Namely, GSD is basically the multiplication of the inverse of the map scale value and the pixel pitch.

3. RESULTS AND CONCLUSIONS

During the creation of the surface model with the obtained photographs, the weak point cloud was firstly obtained by combining the photographs. After densification, dense point cloud and mesh model were produced. The output products are orthomosaics and digital surface models (DSM) as shown in Figure 5. Two orthomosaic data set can be integrated with each other so that analysis can be done on one mosaic.

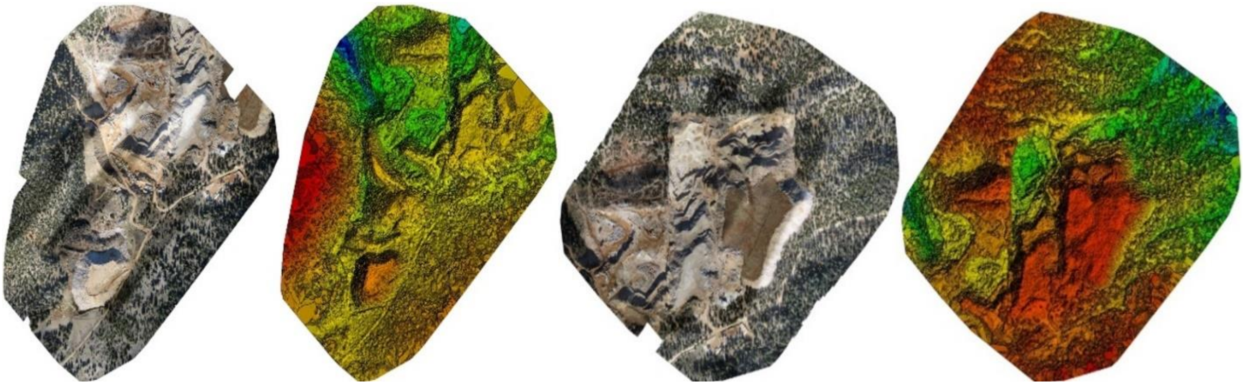

Figure 5: Orthomosaics belonging to two flights and the corresponding sparse Digital Surface Models (DSM) before densification

In OPMs, the most commonly done process is the volume calculation of the mine that was extracted daily. Volume calculated structure is generally called as stockpile which is the mass made up of parts belonging to the mine. How much material is extracted from day to day and temporal follow-up of this are important for better management of the region and decision-making. Climbing to be made for stockpile volume measurements is a dangerous action that requires physical durability. In this method, 3D coordinates of a limited number of points are measured by GPS due to the hard field conditions. These points constitute the lines and these lines form the 3D surface. This is not an effective method for an enterprise's inventory management and follow-up. On the contrary, intense point cloud obtained with the help of photographs taken by UAV can picture the surface as a whole. So, data can be obtained for the place where GPS cannot obtain. This theoretical difference is clearly depicted below in Figure 6.

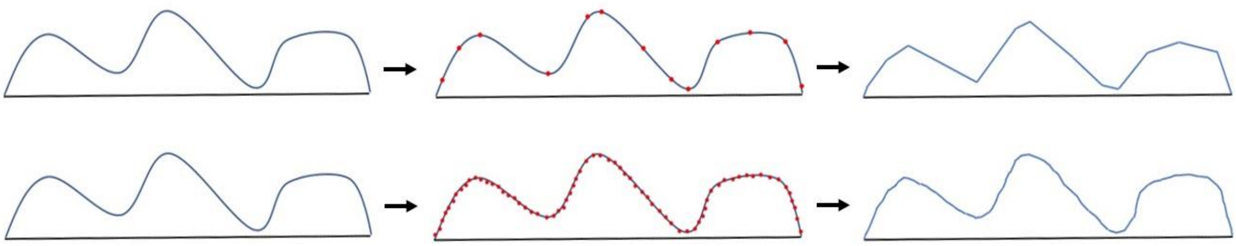

Figure 6: Volume calculation of stockpile with conventional method (upper) and UAV (lower)

For both methods in Figure 6, stockpile on the left is original surface. Those in the middle are points on the surface representing it and formed surfaces are on the right. The surface obtained by using aerial photographs is similar to the original surface than by the conventional method because the number of points per square meter is much higher.

Mine structures with irregular structure are extracted, accumulated somewhere in the mine and loaded later on. Therefore, it is not possible to achieve 100% accuracy. Main target is to reach necessary results with the least cost as soon as possible within the desired accuracy limit. There is a tolerance of error of up to 10% for this type of volume calculations (Yakar et al., 2010). When the pixel pitch of the used camera is evaluated, it can be said that the desired accuracy can be obtained with the above-mentioned existing equipment. An example for stockpile volume calculation is given in Figure 7.

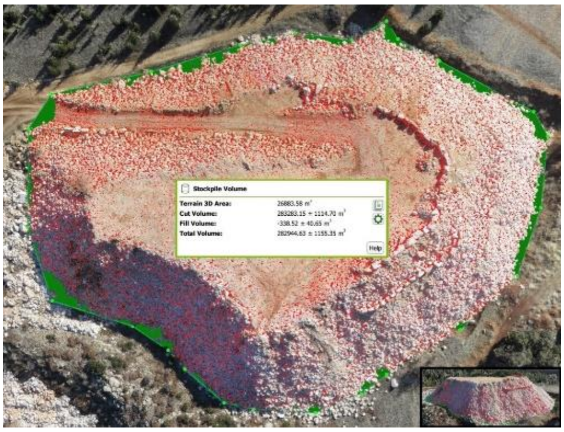

Figure 7: Volumetric calculation for stockpile

More efficient production and management can be achieved with less effort in less time with the help of unmanned aerial vehicle but the most sensitive point in such an application is that the safety of workers significantly increases when all this is done. The dangerous place where the worker must stand with the GPS for the volume measurement of a stockpile as shown in Figure 8a can be observed from the air by means of UAV. There is a cliff with approximately 60% inclination just next to the mine area. Similarly, there is no need for the worker to make dangerous climbs on the soft ground like in Figure 8b. In this mine, there is a height increase of about 450 m from the bottom of the mine to the top. This value corresponds to an average of 55% of the gradient depending on the distance. In this case, there is a fine nuance whether the UAV takes the place of the mine worker or not. The UAV is an auxiliary tool that does not do all the work from beginning to end on its own. The ground control points are marked for the task to be performed and it is made ready for flight before flight, controlled and monitored during flight, and data obtained after flight is processed. The role of the worker does not change, only the methods and techniques used in applying it are changing. Therefore, the use of UAVs in open mines is beneficial to both the manufacturer and the workers actively working during production in land or office.

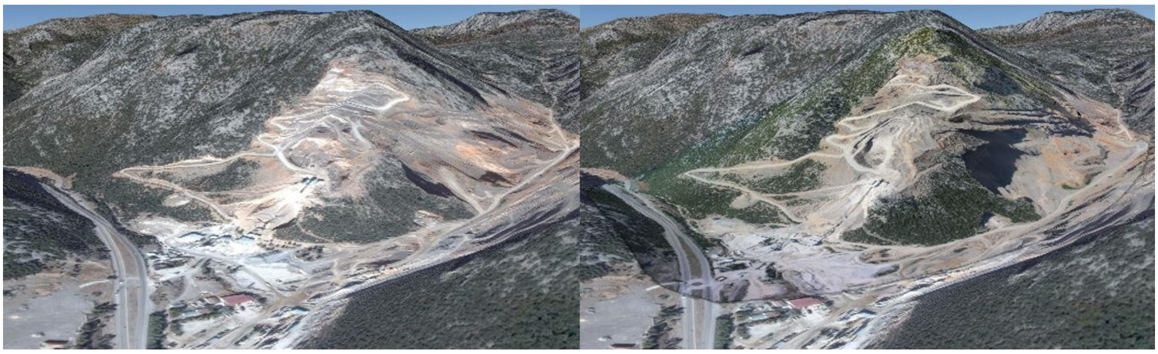

Figure 8a: Mine area and cliff

Figure 8b: Mine area with soft ground and high gradient

4. FUTURE POTENTIALS OF UAVs

Nowadays the LIDAR sensors can successfully be used with UAVs. The UAV embedded with a LIDAR sensor requires to have more carrying capacity. The information that can be obtained with the aid of the laser beam may be more useful, especially for regions having low texture. In addition to all these, an UAV operating in conjunction with the hyperspectral sensor also allows geological mapping for the mine environment. Very detailed information provided by hyperspectral information can play an important role in detecting undiscovered existing sites but these future potentials stand at a high cost for now. Because of this reason, it seems to be a more sensible option to use multispectral cameras which are less costly than hyperspectral cameras and integrated into UAV in mine areas.

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