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The use of UAS for 3D mapping of Municipal Landfill

ABSTRACT

Unmanned aerial systems (UAS) are a cutting edge technology for spatial data acquisition and are used as a low cost and time saving method for surveying and monitoring landfills. This paper presents the exploitation of UAS for the 3D mapping and the volume estimation of Municipal Landfill of Lesvos Island, Greece. The proposed methodology combines UAS and RTK-GPS measurements in order to produce high resolution Digital Elevation Model (DEM) and an orthophoto map of the area. This case study consists of the field work with fast and precise measurements of the Ground Control Points (GCPs) using an RTK-GPS in order to georeference the data. Subsequently, the UAV mission for the acquisition of the high resolution images and afterwards the data processing phase. Finally, a DEM of 4cm resolution and an orthophoto map of 2cm resolution were created. Further processing applied, with the combination of these products and the municipal's topographic diagram for the estimation of the landfill's volume. The UAS is a flexible and rapid technique for mapping large areas like landfills and the proposed method can be implemented in similar applications.

Keywords: UAS, Landfill, Volume estimation, GCPs

Introduction

The use of unmanned aerial systems (UAS) for the collection of geospatial data has increased in recent years and is particularly popular in various application domains. This is mainly due to the low cost, fast speed, high availability and high security of UAS for image capture. Unlike the traditional aerial photography and LIDAR, the cost of surveying with unmanned aerial vehicle (UAV) is low enough so that in environments that change constantly they can fly as often as necessary, recording the change over time. Such environments are also the landfills, where their surveying is done by traditional geodetic methods, with several techniques, like GPS-RTK, Total stations, etc. These techniques are time-consuming and of low spatial density when covering large areas (Gasperini, Allemand, Delacourt, & Grandjean, 2014). According to Siebert & Teizer (2014), two goals are important in the adoption of UAV to existing surveying approaches: (a) cost-effectiveness and (b) highly accurate measurements. Lucero et al (2015), mention that the UAS might be the best solution for surveying of landfills. Furthermore, according to Draeyer & Strecha (2014), the use of UAS for surveying produces a DSM and a georeferenced, highly detailed orthophoto map that is an important added-value for stockpile site documentation. In this paper, a mapping application of the municipal landfill of Lesvos Island is presented. The method combines the use of UAS for the acquisition of the high-resolution images and GPS-RTK surveying of the GCPs. The basic products are, a high resolution and georeferenced orthophoto map of the area and a DEM with significant horizontal and vertical accuracy. Finally, an estimation of the landfill's volume is presented.

Related work

Landfills in Greece, for the needs of surveying, construction, mapping, monitoring, etc. use terrestrial topographic measurements. Internationally, besides traditional measurements, LIDAR systems are used in very large landfills. However, innovative technologies such as UAS are gradually implemented for mapping landfills. According to Gasperini et al. (2014), using a landfill monitoring technique with UAV, produced orthophotos and DEMs capable of volume measurements. Also, compared to topographical measurements, the UAV system was more productive and fast, with a hundred times denser point cloud. Finally, compared to LIDAR, it was more economical, faster and simpler. The flight was made at 150 meters by placing GCPs and the products were of 2.8 cm resolution. In another study by Cryderman et al. (2015), in order to determine the accuracy of the UAV photogrammetry in conjunction with GNSS RTK employed in waste piles, the RMSE of the measurements was calculated. In total 22 GCPs were placed, the flight height was 118 meters, the GSD was 25 mm, and finally the data were processed at Agisoft PhotoScan for the production of dense point cloud. The altitude error was $RSME_z$ = 0.044 m and the horizontal $RSME_r$ = 0.039 m. Lucero et al. (2015), at their research, used the UAV technology and compared it with a topographic survey, for monitoring one of the largest landfills of South America. According to their results, the cost of the UAV flight was six times lower than the traditional method and the 3D model production was twelve times faster. In addition, the total geodetic points were 1250 while the dense point cloud of UAV was of 2 million. Neitzel and Klonowski (2012), employed UAV photogrammetry for monitoring a landfill of 25,000m^2. The flight altitude was at 50 m, they placed 8 GCPs with the RTK GNSS method and produced 3d point cloud and DTM. They proved that, compared to the time-consuming tachymeter method, the alternative UAV method is faster and of low-cost.

Study Area

The landfill of Lesvos Island is located at a distance of 28 km from the city of Mytilene and has started operating since 2010. The total area of the land is 307 acres, of which 77 acres form the total area of the landfill. The landfill serves the whole island, which has a population of 90,000 permanent residents, while during the summer months it can reach 150,000.

Workflow

The first step of the methodology is the establishment of a GCPs network. This step includes the RTK measurements in the field, the appropriate distribution of the GCPs and the investigation of the pattern used as a target. Afterwards, the UAS mission includes the UAV and camera selection, the determination of the flight parameters and finally the aerial survey. After the acquisition of the aerial images, the data are processed with the SFM algorithm. Subsequently, the results are the DEM and an orthophoto of the study case. Finally, with further processing, the estimation of the landfill's volume occurs. The Figure 1 shows the workflow that was followed.

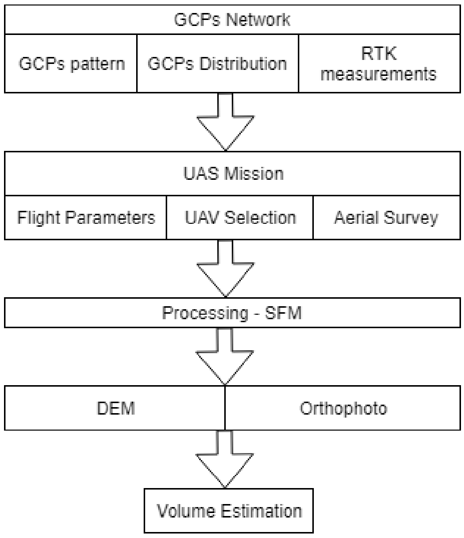

Figure 1: Workflow

Ground Control Points Network

The GCPs network is needed in order to allow the necessary georeference of the aerial images acquired from the UAS in a common coordinate system. Regarding the accuracy of the final products, the distribution of the GCPs is a major issue, thus the GCPs must be distributed over the whole zone and their visibility in images must be maximized (Shahbazi, Sohn, Théau, & Menard, 2015). Also in order to achieve the highest accuracy, it is recommended to establish a large number of GCPs. The technique employed for the establishment of the GCPs is the Real Time Kinematic (RTK). Firstly, the base GPS receiver placed on the pedestal of the National Trigonometric Network (NTN) located 800m from the area of the landfill, with known coordinates x:705000.00, y:4345000.00, z:254.81. Afterwards, two new base stations were established in the area of the landfill in a static mode in order to achieve the best accuracy of the positions. Subsequently, the GCPs measured and distributed in RTK mode. In total, 49 GCPs distributed uniformly within and peripherally of the landfill site. The marking of the targets was done with spray but also with specific targets designed and printed in dimensions 30 x 42 cm and in black and white colour after a process of investigating the most suitable patterns. The size and colour of the targets are essential in order to be visible in the acquired aerial images. The process of the distribution of the GCPs and measuring their coordinates with GPS was made during a day in July 2017 and the timeframe was 4-5 hours. For the GCPs measurements, the Magellan ProMark3 RTK used. The GPS consists of two receivers (Base and Rover) and is suitable for real-time measurements. Regarding the accuracy of real-time kinematic mode is Horizontal: 0.012 m + 2.50 ppm Vertical: 0.015 m + 2.50 ppm.

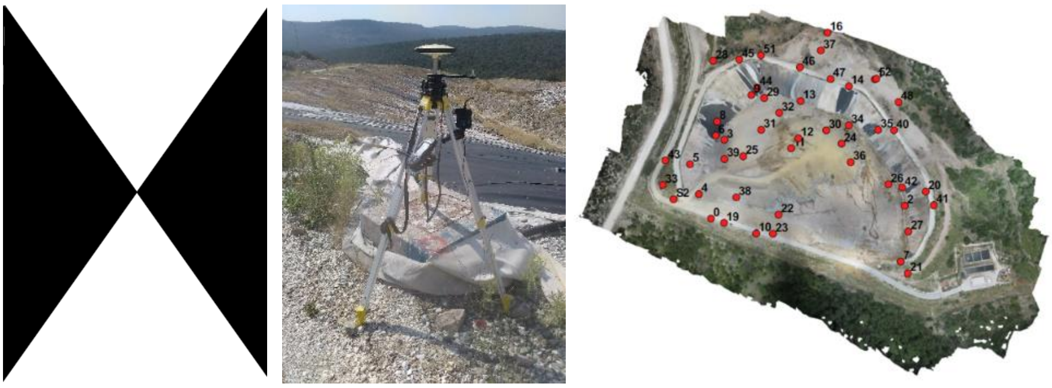

Figure 2: The target applied (left), RTK measurements (center), GCPs distribution (right)

UAS Mission

Flight planning was made using the mission planner software that defined the necessary parameters. The polygon covering the area of interest has a total of 78 acres, the flight height was defined at 85 meters, with 75% lateral and 80% longitudinal and finally, the ground sample distance (GSD) was 2.12 cm. In the field, after the detection and positioning of the GCPs, a smooth surface was selected for the take-off and landing of the UAV, and then a standalone flight with the S900 was performed. The flight took place at midday, with high temperatures and relatively low winds. The process of capturing the photographs was spiral. The flight lasted 12 minutes and the area was covered by 252 aerial photographs.

UAV platform

The DJI Spreading Wings S900 (Figure 3) has been chosen for the particular case study. Its lightweight, compact design makes it easy to take anywhere and to survey in windy conditions. The chosen camera is Canon IXUS 140, with sensor size at 6.16 x 4.62 mm and 16MP resolution.

Figure 3: UAV platform

Data processing

In computer vision through the structure from motion (SfM) process, three-dimensional representations of overlapped image sequences are reproduced. SFM is a photogrammetric method, which creates 3D visualizations from two-dimensional image sequences (Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012). The common features are detected in every image and they are matched. Then a sparse point cloud is generated and afterwards, a dense point cloud is created. Finally, the 3d model construction of the area is created. Aerial photos were processed in Agisoft Photoscan software. At first stadium, the images acquired from the UAV are imported. In a second step, the alignment of the images is performed, whereby the SfM algorithm detects the characteristic points of the images (edges or other geometric features).

Results

The first result in the alignment process is a sparse point cloud. Subsequently, the georeferencing was made using the 49 GCPs in Greek reference system EGSA 87. Afterwards, the dense point cloud was created and finally the extraction of DEM and orthophoto. Regarding the accuracy, the root mean square error (RMSE) was used. The GCPs provided accurate georeferencing for the final products. The values of the total RMS error for the 49 GCPs are shown in Figure *4*. The RMSE(x) is 3cm, the RMSE(y) is 3cm and RMSE(z) is 5cm. The quality of DEM and digital orthophotos depends on the accuracy of GCPs. Therefore, if the quality of the GCPs is good, the result of DEM and digital orthophoto map (Figure 5) should also be accurate. Finally, the DEM quality is 4.23 cm/pix. The orthophoto map was produced in the ArcMap environment and has a spatial resolution (GSD) of 2.12 cm/pix.

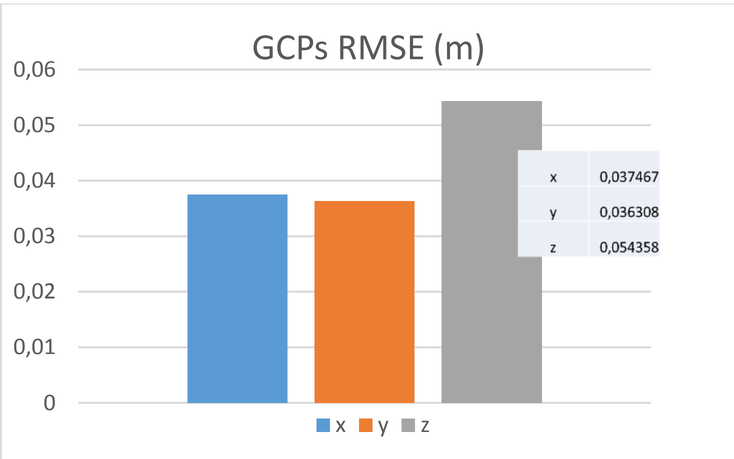

Figure 4: Graph shows the RMSE for the GCPs

Figure 5: Orthophoto map of the landfill

Volume Estimation

Initially, in order to calculate the volume of the landfill, the municipal's topographic diagram was employed, combined with the DEM produced by the UAS survey. These products were imported into ArcGIS software for further processing. The topographic diagram is needed in order to be used as a base surface. Firstly from the contours of the topographic diagram created a DEM of the landfill's area as it was initially. Both DEMs are used to illustrate the cut and fill status of the area. The clip tool is employed in the two DEMs in order to have the same frame. Afterwards, the cut and fill tool is performed for the two DEM in order to estimate the volume. The Cut Fill tool enables the creation of a map based on two input surfaces—before and after—displaying the areas and volumes of surface materials that have been modified by the removal or addition of surface material. Finally, the estimation of the total volume of the landfill is approximately 270000 m3 and 71000 m3 remain to be filled. (Table 1).

Cut Volume	199458 m3
Fill Volume	71436 m3
Total Volume	270894 m3

Table 1: Volume estimations

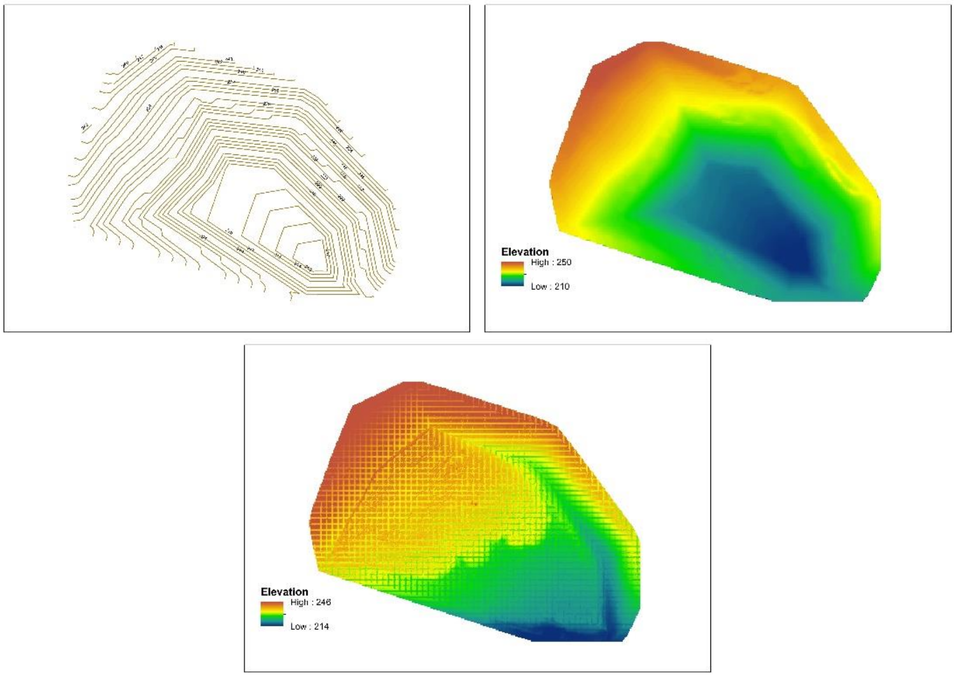

Figure 6: Contours of landfill (left), DEM from topographic diagram (right) and DEM generated from UAV (down)

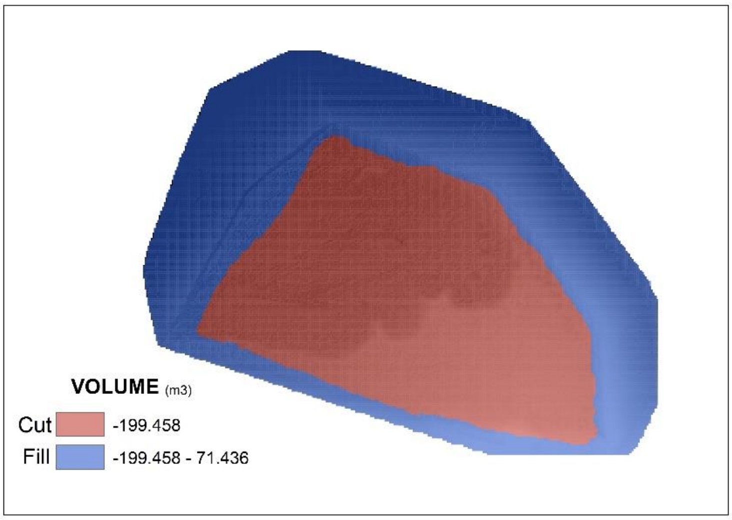

Figure 7: Cut and fill volumes of the landfill

Conclusions

This study case aims to point out the use of the UAS application in landfills. The final products were of high accuracy. The DEM generated with a quality of 4.23 cm/pix and an orthophoto map with a spatial resolution of 2.12 cm/pix. These products can be the reference base for the further monitoring and control of the landfill. The time required for both fieldwork and data processing was less than the time correspondingly requires the topographic survey. The methodology developed, the selection of the appropriate targets, the distribution of the GCPs as well as the flight plan can be applied to further study in the landfill. The generated products are efficient to measure volumes already used or volumes that remain to be filled.

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