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Analysis of the Accuracy of Earth Movement with Drone Surveys

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***Abstract*—**New technologies for the capture of point clouds have experienced a great advance in recent years. In this way, its use has been extended in geomatics, providing measurement solutions that have been popularized without there being, many times, a detailed study of its accuracy. This research focuses on the study of the viability of topographic works with drones incorporating different sensors sensitive to the visible spectrum. The fundamentals have been applied to a road, located in Cantabria (Spain), where a platform extension and the reform of a riprap were being constructed. A total of six flights were made during two months, all of them with GPS as part of the photogrammetric process, and the results were contrasted with those measured with total station. The obtained results show that the choice of the camera and the planning of the flight have an important impact on the accuracy. In fact, the representations with a level of detail corresponding to 1/1000 scale are admissible, depending on the existing vegetation, and obtaining better results in the area of the riprap. This set of techniques is, therefore, suitable for the control of earthworks in road works but with certain limitations which are exposed in this paper.

***Keywords*—**Drone, earth movement control, global position system, surveying technology.

I. Introduction

DIGITAL models of terrain (DTM) have always been a fundamental element in the execution of works, especially in those in which earth movement supposes an estimable cost of it, with the purpose of quantifying, most of times, the volume which has been excavated or filled so much so that they are generated during the project phase and regularly during the works. Its formation has been based, in great number of occasions, on the measurement of a set of significant points from which a model was generated that was considered with the suitable precision in order to achieve the results that were wished to obtain.

The appearance of new technologies for measuring clouds of points, together with the improvement of the instruments used for these measurements, has meant a great advance for surveying activities in civil works when these land models are made. In this way, the capture of points quickly and massively is achieved by different techniques. Among these techniques, it can be distinguished these based on measurements from lasers, either located on land or airborne and these based on photogrammetric methodologies, among others.

In the field of civil engineering all of them are used to a larger or lesser extent and for different uses. In such a way, lidar technologies are frequently used in studies for large areas, when they are airborne [1], [2], [6] or for local surveys in the case of the terrestrial laser scanner (TLS) [7].

The surveying with drones, or unmanned aerial vehicles (UAV), is usually made within the scope of civil engineering, in areas of smaller extension. In this sense, they are increasingly used for controlling excavations or even in open-pit mining activities. It is essential, therefore, to study the accuracy derived from these measures that will depend on different factors, both material and environmental or even human. Among them we can distinguish the following ones [4], [5]:

1) Errors due to the positioning of the drone.
2) Weather conditions
3) Errors produced in taking pictures [3], including camera calibration.
4) Errors in the georeferencing.
5) Errors derived from interpolation in the digital terrain model.

This paper covers the need to determine the accuracy obtained with surveys made with UAV by photogrammetric techniques in the field of earthworks within civil engineering. To this end, a set of seven flights (the first one developed for calibration purposes) were made on a stretch of road in Cantabria (Spain), specifically the road section La Canal-Soto (CA-627), which included the construction of a breakwater wall.

In order to obtain reliable results, it have been compared them with those obtained by classical topographic techniques in five different zones and for each of the flights, having considered that classical surveying is guaranteed by experience. One of the aspects to consider consisted in the temporary integration of data, for which flights have been made to perform evolutionary analysis of the works, evaluating the earth movement based on its initial state or work executed in a certain period of time.

II. Instrumental

For the contrast of measurements, and as mentioned, both the instruments used for the control data and the one necessary for the U.A.V. survey have been used.

A. Instrumental Control

The reference data to compare with those obtained with the UAV have been obtained with a Leica TS06 total station

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(angular precision 3’’, 30 magnification, leveling sensitivity 0.5’’ and distances accuracy 1.5 mm+2 ppm)

Fig. 1 Total station Leica TS06. (Leyca Geosystems)

B. Instrument for Photogrammetric Flights

The main element is the UAV. In this case, a Yuneec H520 hexacopter was used, since it is considered adequate as it has satellite positioning (GPS, GLONASS, and Galileo), it is robust and has an adequate flight autonomy, around 30min.

Fig. 2 UAV Yuneec H520

An ST16S ground station was used in order to control the U.A.V., as well as other auxiliary elements. Among them it is necessary to highlight the cameras used. In this case, two different cameras were used: a Yuneec E90 metric camera with a 1-inch 20MP sensor and a high-speed H2 processor and a Yuneec E50 12MP camera.

Fig. 3 Photogrammetric point and GPS

Additionally, a set of photogrammetric control points, previously marked by plates, was measured, giving coordinates in the reference system ETRS-89, UTM projection zone 30 and heights with respect to sea level in Alicante. The device, that was used, was a GPS Leica Viva GS10 receiver and the G.N.S.S network of Cantabria.

III. Methodology

The methodology to achieve acceptable results required different well differentiated phases.

A. Zoning

In order to check and compare the results obtained by classical topography and those obtained with the UAV in the study area a zoning was designed in such a way that, although the flight was executed along the whole stretch of road, only calculations were made in five zones. These covered a wide spectrum of situations that could be found on this study road:

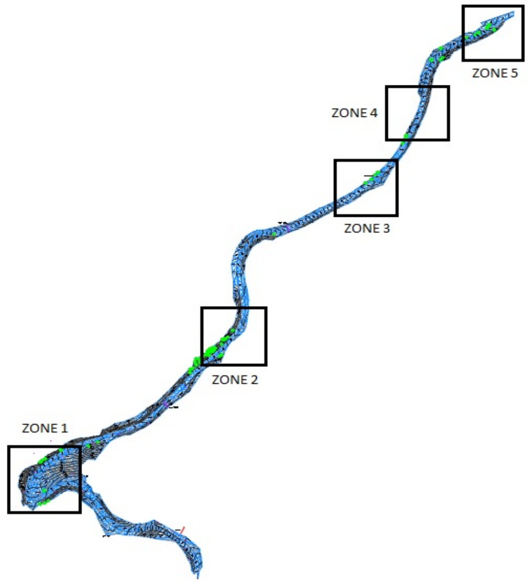

Fig. 4 Zones of study

1) Zone 1: Existence of a breakwater wall.
2) Zone 2: Presents a retaining wall.
3) Zone 3 and 4: It was only going to act on the edges of the platform.
4) Zone 5: Part of it with trees, which necessitated a flight with photographs with the axis not vertical.

In all of them, and on the edges of the road, there were meadows with variable grass height.

B. Planning

Once the instrumentation to be used and the study areas were chosen, it was necessary to plan the control work, by classical topography, and the photogrammetric flights.

Given the climatology of the area, they could not be totally coincident. However, between measures there was no action in any area so the data is related to identical situations of the road land, with the exception of vegetation.

The organization of the planning and execution of the works is the one shown in Table I. It is important to note that flights 4 and 5 were made with the Yuneec E50 camera, with lower performance, the rest having been done with the Yuneec E90 camera.

The different flights were made planning a height of flight around 10 m, when possible, with coatings between photographs of 80%. It is noteworthy that in the forested areas the flight was carried out manually guaranteeing sufficient coverage.

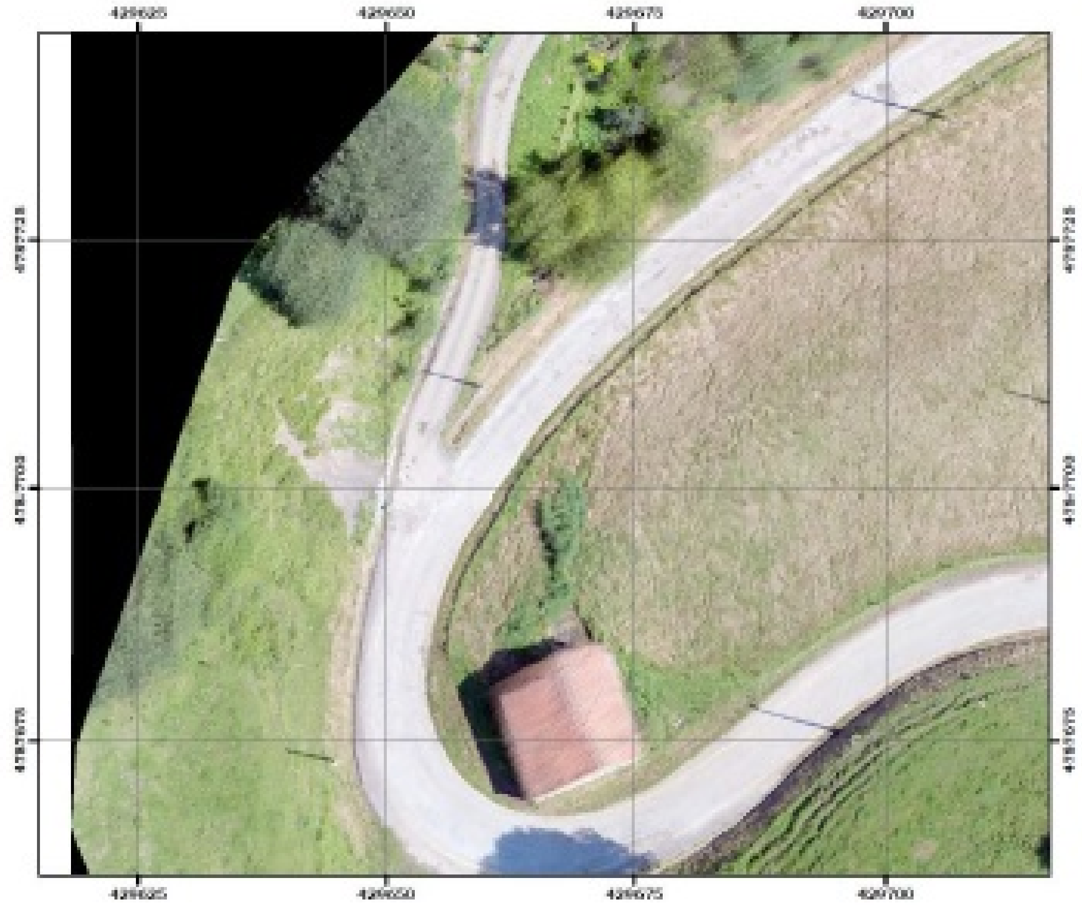

Fig. 5 Detail of Study zone 1

TABLE I
SCHEDULE OF ACTIVITIES

Month	Week	Comments [a]
July	fourth	Camera calibration
August	first	Initial and first flights
August	second	Bad weather
August	third	Second flight
August	fourth	Third flight
September	first	Fourth and fifth flights
September	second	Sixth flight
September	third	Seventh flight

C. Calculation

So as to process the images and generate the digital terrain model from the data obtained by the U.A.V., the software Pix4Dmapper Pro, version 4.2.27, was used. For the rest activities, the layout of roads software Civil 3D and Clip programs were used.

The calculation methodology used consisted of comparing the models obtained with the different flights using various tools. On the one hand, once the digital terrain models have been formed, the existing volume has been calculated: first calculating the volume between a certain flight and the previous one. This should give the volume of earth movement between the times when the flights were made. For an estimate of the total volume of earthworks, it has been made the same calculations with the first and the last flight. In addition, transversal profiles have been drawn in each of the zones to visually check the differences obtained and verify that these are adjusted to the work areas of the works.

Finally, it has been calculated, for the last flight, the existing differences in elevation between the DTM and the points obtained by classical topography to clarify the final results.

IV. RESULTS AND DISCUSSION

A. Results of the Control Points

From the control points observed with GPS and whose coordinates are shown in Table II, all flights made with the U.A.V. were georeferenced.

The calculation of them was obtained with a residue smaller than 2 cm, having been observed by RTK techniques with 4 measurements for each point.

TABLE II
PHOTOGRAMMETRIIC CONTROL POINTS

Name	X	Y	Z
IN01	429924.529	4787547.865	251.735
IN02	429931.606	4787560.570	251.380
IN03	429801.288	4787616.395	238.661
IN04	429676.895	4787674.517	233.917
IN05	429652.960	4787647.602	233.888
IN06	429631.086	4787713.053	247.557
IN07	429720.737	4787745.680	227.289
IN08	429965.054	4787916.263	223.970
IN09	430026.851	4788139.821	223.495
IN10	430280.000	4788285.711	207.089
IN11	430474.724	4788551.957	191.318
IN12	430409.860	4788529.823	188.029

Reference system ETS-89, UTM projection zone 30, and height above sea level in Alicante. Coordinates expressed in meters.

B. Comparison of Volumes

As previously stated, one of the calculations fulfilled consisted in calculating the volume by comparing the model obtained with each of the flights with the previous one and thus being able to estimate the volume of land between both moments.

From the preliminary calculations it was verified that flights 4 and 5, made with the Yuneec E50 camera, showed strong deviations in height from the ground, greater than 50cm in areas where it had not been excavated. For that reason, they were eliminated of all the later calculations, including those of volumes. Table III shows the values obtained in zone1, with the presence of a breakwater wall that was rebuilt.

TABLE III
COMPARISON OF VOLUMES FOR ZONE 1

Flight	Area	D.T.M		TRUE		Difference	
		Cut	Fill	Cut	Fill	Cut	Fill
1-2	1889.35	343.49	113.11	335	0	8.49	113.11
2-3	1886.54	281.15	430.00	150	389	131.15	41.00
3-6	1909.71	868.55	224.36	785	252	83.55	-27.64
1-6	1914.12	956.42	195.52	1025	237	-68.58	-41.48

Area is expressed in m^2, Cut and Fill ar expressed in m^3

In an analogous way, the volumes for the other five zones were calculated, with Table IV showing the overall results of the volume differences expressed as a percentage.

TABLE IV
DIFFERENCE IN EARTHMOVING

Zone	Vol. 1-2		Vol. 2-3		Vol. 3-6		Vol 1-6	
	Cut	Fill	Cut	Fill	Cut	Fill	Cut	Fill
1	2.5	100	46.6	9.5	9.6	12.3	7.2	21.2
2	9.6	5.2	23.2	10.1	7.6	8.5	6.2	15
3	7.2	25.2	24.4	6.8	17.6	22.2	7.8	12.1
4	12.3	13.2	8.5	15.3	6.2	18.3	7.2	8.9
5	1.2	19.6	3.6	21.5	33.1	5.4	8.6	8.3

Expressed in percentage

As it can be seen, the differences do not follow a clear pattern and present very large discrepancy values. As it will be explained later, this is due to the fact that in this calculation the entire extension of each zone has been included, taking into account, therefore, land with vegetation, especially prairie. This fact led to the conclusion that a particular analysis was necessary in the areas in which the works were developed, in a first step through transversal profiles and later by controlling the points that had been measured with classical topographic techniques.

C. Cross Sections

As mentioned above, given that the volume calculations presented differences that were not acceptable, we proceeded to draw the cross sections in the study areas. As an example, a transverse profile of zone 1 is presented in Fig. 6.

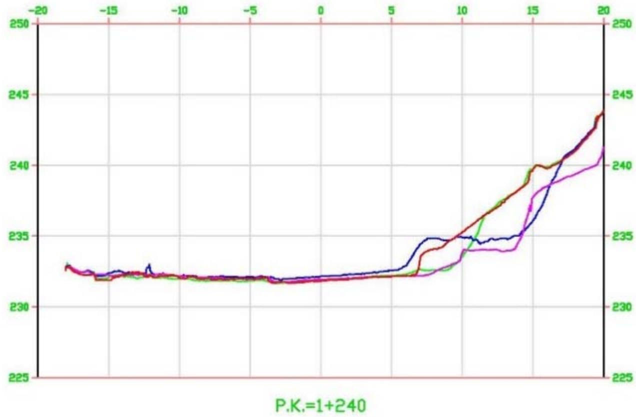

Fig. 6 Cross-section. Zone 1

It is possible to clearly appreciate the variation of the digital terrain models that reflect the development of the works, in this case in a breakwater wall. The same happens in general in the other profiles, so it is confirmed that the previously calculated volumes were affected by the existence of vegetation.

D. Control of Measured Points

In order to quantify the volume of land movement and contrast it with that obtained with classical methodologies, the measured point with total station was compared with those obtained with the digital terrain models, considering exclusively the areas in which it had actually been excavated or filled. A summary of the calculations than have been made can be observed in Table V.

TABLE V
CONTROL POINTS DIFFERENCES

Zone	Flight 1			Flight 2			Flight 3			Flight 6		
	N	M	S.D.	N.	M	S.D.	N	M	S.D.	N	M	S.D.
1	35	3.5	0.5	27	3.1	0.6	32	5.1	0.8	41	5.3	0.8
2	42	2.7	0.4	48	4	0.7	25	4.2	0.8	22	4.9	0.7
3	38	3.8	0.6	32	3.6	0.3	28	4.7	0.7	26	4.3	0.5
4	25	4.2	0.7	30	3.8	0.6	26	3.7	0.6	24	3.6	0.7
5	45	3.1	0.2	36	3.3	0.5	31	3.6	0.6	15	2.1	0.4

N= number of points, M=mean expressed in cm, S.D.= standard deviation expressed in cm

In view of these results, they present on this occasion differences of the order of centimeters whose variability may be due to the system's uncertainties as to the different roughness and irregularity of the measured surface. At this point, it is important to note that an adequate spatial resolution is a fundamental factor. In the case of this investigation, a Ground Sampling Distance (G.S.D.) of 2 cm was used, suitable for this type of controls.

V. Conclusions

From the results obtained, the following conclusions can be highlighted.

First off all, the technology of surveying and control of work with UAV is a viable and powerful methodology as long as a series of aspects are taken into account: Regarding the UAV, it must be sufficiently robust and the camera must be metric, with its parameters perfectly defined; with respect to the flight parameters, the height of the flight as well as spatial resolution (GSD) must be appropriate to the job that is wanted to perform. Although the object of this work was not to establish the appropriate flight height, the results obtained with low flight heights, around 10 meters, show that these are valid for the control of earthworks in civil engineering.

Secondly, the differences obtained between the elevation of the points measured by classical topography and the models indicate that the existence of vegetation can be a factor that limits the use of drones, although in works that are being executed this fact does not usually be a limiting factor. In any case, those areas where they have worked should be differentiated from those that have not been modified. In the first ones, the height differences obtained show that this type of surveys are compatible with accuracies corresponding to a cartography scale of 1/500, or even smaller.

Finally, it is important to indicate that this kind of techniques are highly dependent on meteorological conditions. In this way, a control of a work is not recommended to be made with UAV, only given that in rainy or excessively windy days the use of classical topographic techniques becomes necessary.

As future lines of research, the definition of the optimum flight height can be distinguished to obtain the desired precision and the possibility of using other types of sensors, especially multispectral ones could be studied.

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