DAMS AUSCULTATION USING DRONES

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ABSTRACT

Joint evolution of aerospace and auscultation technologies allows the development of drones specialized in deformation control of large structures and infrastructures. This work studies the viability of the use of drones for deformational control, analyzing for each case the resolution, precision and validation with other techniques. The Structure From Motion photogrammetric technique is presented in detail, allowing the production of accurate orthophotographs and 3D models without knowing previously positions and angles of incidence. The use of precise control points (Ground Control Points) as well as drones with integrated Real Time Kinetic "RTK" system, are relevant factors for obtaining high precision results. The case study of the monitoring of a large structure is presented, in this case an arch-gravity dam. The initial results show a precision in deformations of ± 2 mm. This paper confirms that drone photogrammetry is applicable to the deformational control of concrete dams, opening the possibilities to the monitoring of other large structures and infrastructures.

Key words: *UAV; RPAs; photogrammetry; SFM; structural control; dam monitoring; slope monitoring*

1. INTRODUCTIÓN

New technologies applied to deformational control, such as differential GPS, laser scanner, ground radar etc., are based on taking of data from a fixed point. This affirmation limits the application in areas where the access is difficult and visibility is low. Likewise, not all observed points are in equal conditions of distance, angle of incidence, luminosity etc. and may affect these conditions to the accuracy of the final result

New image and information capture systems from any location have favored the advancement and improvement of classic measurement systems such as photogrammetry. In this sense, the emergence of equipment capable of carrying different sensors and being piloted by remote control "RPAs or drones" has made possible that the inspection of facades, walls and in generall large structures, can be carried out with a high degree of detail

1.1 General trends

Drones´s development, and therefore their usefulness and diversity of application, has grown exponentially in recent years, which has led to the need to develop specific regulations.

The evolution of this new technology, and therefore the use of drones in a wide range of areas, is reflected directly in the growing number of technical articles published in recent years (Figure 1).

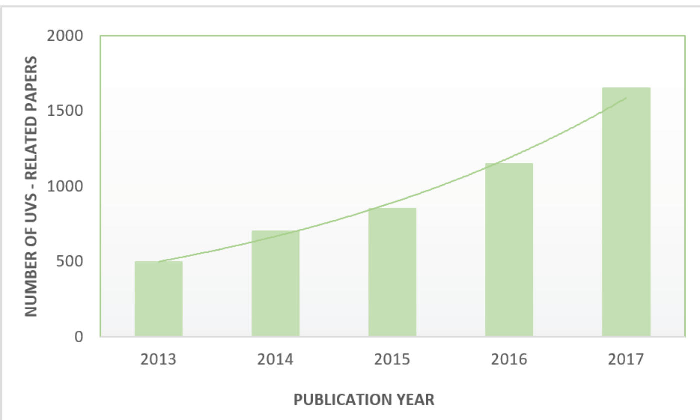

Figure 1 : Number of publications related to UAVs per year. Own elaboration based on source data: NRC Research Press.

The number of publications on UAV and drones has been tripled in the last four years, reaching more than 1500 annual pubblications on Web of Science (Chabot, 2018). The infrastructure sector accounts for more than 35% of the drone market investments (Patterson, 2018), highlighting the maintenance of them both in building and in large infrastructures, where the dams are included.

A second indicator of the development of this new technology is the investment forecast that each country makes and plans to make in this sector. Goldman Sachs, a global leader in investment banking, presented in 2018 an economic forecast of investments by country from 2017 to 2021 (Sachs, 2018), in which the United States reaches 17.5 million dollars, China at 4.5 and the United Kingdom 3.5 million invested in this sector.

New intelligent systems applied to construction, such as the Building Information Modelling "BIM", are considered part of the "digital revolution" within this sector (Patterson, 2018), and are directly related to drones, including, almost instant 3D models, real-time construction process monitoring and images and orthophotographs with high-precision.

New developments in both the drones themselves, as well as the sensors, the data transmission system between the station and the drone, and the real-time positioning improvements (RTK/PPK), allow to achieve precisions less than a centimeter, as presented in this article.

1.2 Drone Photogrammetry "Structure From Motion"

With the Structure From Motion (SFM) technique, photographs taken from different angles and distances can be used, even without their position being known (Nissen, Arrowsmith, & Crosby, 2010) (Furukawa & Ponce, 2010).

In dam safety, the combination of images and videos, the obtaining of georeferenced and scaled models in which measurements can be made (Figure 2), is an important feature of this technique. This fact, but also the economic competitiveness that drones offers, makes it a technology with great possibilities.

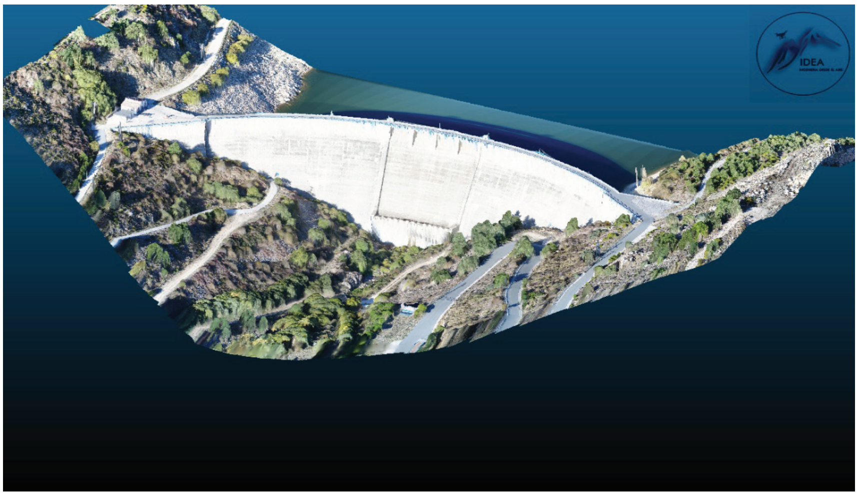

Figure 2 : 3D model with drone in a arc-gravity dam.

The improved calculation speed of new computers and the computational development of photogrammetry (Hartley & Zisserman, 1999b), has resulted in higher quality and better accuracy results, together with the evolution of drones. In this context, development of SFM´s software enables the acquisition of point clouds and 3D models very quickly.

The theoretical basis of the SFM technique (Ullman, 1979) is based on overlapping images to obtain the 3D model, that is, from at least two images that have common pixels (homodes), is obteined the position and orientation of the camera as well as the coordinates of the point corresponding to the pixel.

With the new algorithms, obtaining such point clouds from the SFM process is carried out based on the detected correspondences between the images. These correspondences or pairings are carried out by the characteristic transformation of invariant scale (SIFT) (Lowe, 1999), which allows such pairing even with large variations of scale, position and even illumination. These parameters influence the desired degree of accuracy.

As has been said, one of the advantages that characterizes the SFM technique is that it is not necessary that the images from which the processing is carried out, are referenced, scaled etc. so if so, the resulting 3D model will be referenced in coordinates relatives. This fact, does not imply that a georeferenced model cannot be obtained in absolute coordinates. This is where the concept of Support Points or Ground Control Points (GCPs) is incorporated. Giving these support points a known coordinates (GCPs), the model is obtained from the SFM technique in absolute coordinates.

1.3 Real time Positioning: RTK / PPK

The REAL Time Kinetic (RTK) or real-time automatic geopositioning of each image taken by the drone, makes that the comparison betwen images in two periods of time, have the same perspective, with a position error about 2-4 cm. In this way, even without the need to incorporate GCPs, you can have a quick comparison to analyze the evolution of the area of the infrastructure studied.

1.4 Drone Monitoring

The monitoring and surveillance of a large structure, has as a starting point the visual inspection of it. By definition, drone auscultation starts from that premise, because it is from the images taken on the flight, with which the work and processed begins. Through commercial programs, you get the point cloud and 3D model in true color.

The comparison of two models, in different moments of time, allows to obtain the differences between both models, but if they are also georeferenced in the same coordinate system, their displacement and / or deformation is obtained. In this way, the improvement of the drones themselves, together with the development of the processing software, implies that the inspection, surveillance, analysis and control of movements of large structures with drones, is a reality in cases such as:

1. Structures: Inspection, mapping and control of deformations in buildings, dams and bridges.
2. Slopes:
   (a) Inspection and control of movements in slips, overturns etc. both in soils and in rock massifs.
   (b) Stability analysis by obtaining: diving, diving direction, etc. of cracks and fractures for stereographic analysis and therefore to obtain the slope stability analysis.
3. Emergency situations: Earthquakes, floods, fires etc.

1.5 Objectives

The main objective of this research is to develop its own methodology for the control of movements, in structures and slopes, using photogrammetric techniques based on acquisitions of drone images. The validation of this methodology will be carried out by comparison with classical monitoring techniques. In addition, the main aspects and limitations will be analyzed and a case study will be carried out on an arc-gravity dam.

2. CURRENT PURPOSE OF DAM MONITORING WITH DRONES

An in-depth search has been carried out, in the academic and professional portals, publishers and publishing media, to be able to start from the most advanced point. The result of this search shows that at least 34 published articles used drones in inspection, deformation control and related activities

2.1 Application to dams, slopes and rocky massifs

The found articles have been summarized and ordered according to the country where the technique is applied (Figure 3), year of publication (Figure 14) and typology (Figure 5). As a new technology, publications in related articles are recent. In this way it can be concluded that the use of Drones in aspects related to the dams and slopes safety has taken in the last 5 years (Figure 4).

2.2 Development by countries

In the first place are Italy and Austria with 6 articles each one, although it is true that in the case of Italy several of them are referring to the same Dam "Ridracoli". Then are China and the United States, with the Americans having an oficial document called "Monitoring Levees" (USSD Committee on Monitoring of Dams and Their Foundations; USSD Committee on Levees, 2016) in wich are made a explicitly referencing at use of drones in dam safety.

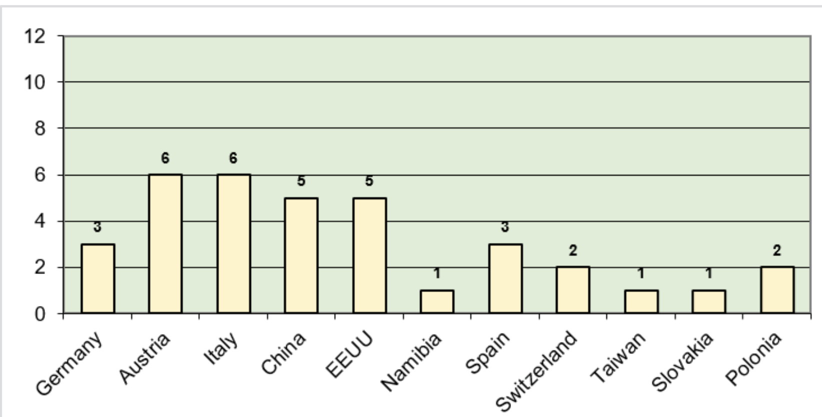

Figure 3 : Classification of articles from country

As can be seen, and despite being a relatively recent technique, it has already been used in several countries, probably because of its low cost.

2.3 Temporary evolution and by application fields.

An indicative analysis of the trend of a technique is the evolution of its publications. In this sense, and within the sector of the inspection and monitoring of structures, and in particular in dams, it can be observed that their greatest development has occurred in the last five years. The current and future technological development and investment of drones, sensors and processing software, together with the need for improvement in the safety of structures, makes it anticipate that the application of this technique will be triggered in the short period of time, as can be shown in Figure 4.

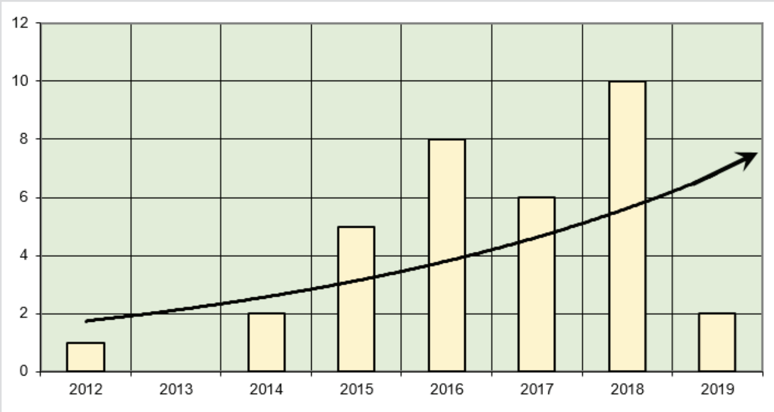

Figure 4 : Classification of articles by year of publication

In the case of application to dams and slopes, the studies found have been classified into three large groups as can be seen in Figure 5. These are: the main structure "Dam", the management and quality of the reservoir "Water Management" and the one that refers to slopes "slopes".

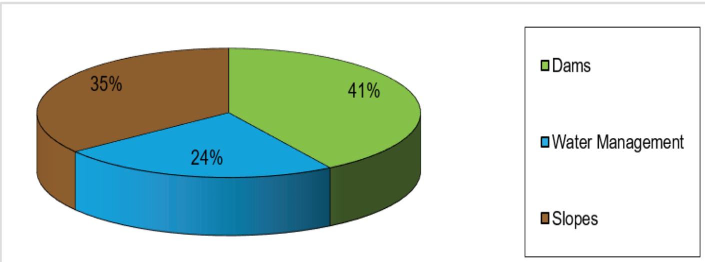

Figure 5 : Classification of articles by application tipology

3. CASE STUDY. APPLICATION TO THE CONTROL OF LARGE INFRAESTRUCTURES. CONCRETE DAMS

3.1 Fieldwork

In the case of study, flights were performed on an Arc-Gravity dam, using RGB type sensors. The altitude of the flights were between 20 m and 80m., all of them performed at constant flight speed of 4m/s and a equidistant distance between imaging. In addition, camera parameters, lens, and distribution of GCPs have been taken into account.

In the planning, a longitudinal overlap of 90% and the 70% cross-section between each frame was considered. For the realization of the model, a total of 788 images were selected from those obtained, discarding all those not useful. As a result, the average accuracy obtained was 2-3 mm, with the resolution or Ground Sampling Distance (GSD) being 1.2 mm.

Figure 6 : Ortophotography of the second data collection with 1,2 mm/pixel

The photogrammetric campaigns were carried out in two different periods of the year, determining the movement of the dam in that period of time and being able to compare it with the data of the classical auscultation of the dam. The dates on which they were made were:

1. Data collection and Drone Flight between October 24 and October 25, 2017.Campaign 1.
2. Data collection and Drone Flight between February 18 and 26, 2018. Campaign 2.
3. Data collection and drone flight on October 19, 2018. Campaign 3.

3.2 Processing and results

The work to be carried out was:

1. General model: Creation of general model of the dam in 3D by means of a high altitude flight (Figure 7).
2. Plan crest model: Determination of the plan model of the dam crest by means of a low level flight (Figure 6).
3. Elevation crest model: Definition of the downstream parament model. It is made from coronation to dimension -3 m (Figure 9).
4. 3D model integrating elevation and plan: Complete model integrating plan and up to level -3 of the downstream wall of the dam.

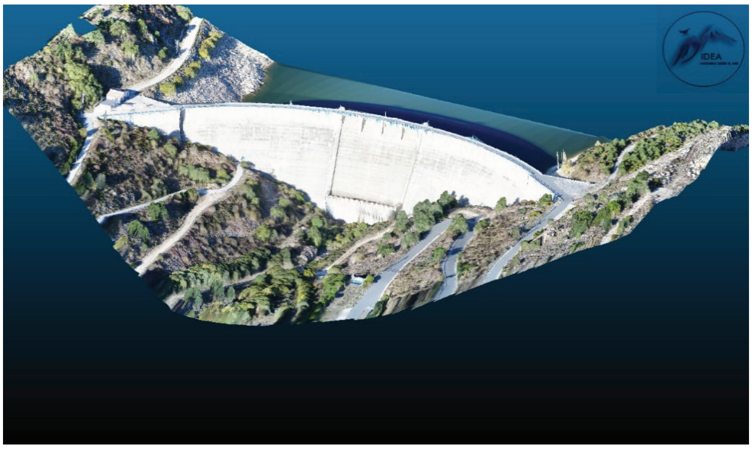

Figure 7 : General Ortophotography.

Once the models have been processed in both campaigns, and orthophotographs, 3D models and point clouds are obtained, both the comparison between the two and the analysis of the results obtained is carried out. The number of points earned on the models with more than 100 million points each is noteworthy.

In order to verify the differences between topographic and photogrammetric values, quality control is carried out (Figure 8) based on the comparison of the coordinates obtained for the leveling nails by both methodologies. Clearly, this topographic data was not introduced in photogrammetric processing. This quality control produces a result whose average value is 1 mm.

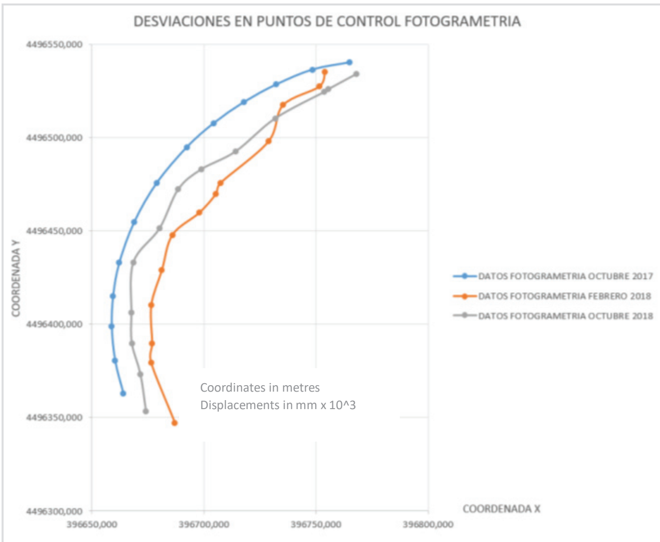

Figure 8 : Quality control of the campaign 2. Coordinates of levelling nails by means of topographic readings versus coordinates of the nails obtained by photogrammetry.

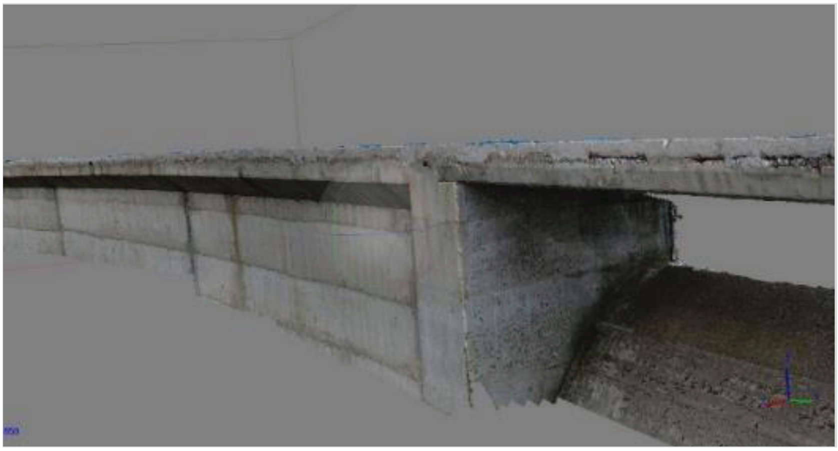

Figure 9 : Cloud of points (230 million) of the spillway generated in campaign 3.

A first result obtained is presented below, in which the movement of the crest of the dam can be seen (Figures 10 and 11) both in 2D made by comparing the orthophotographs and in 3D made by comparing the point clouds.

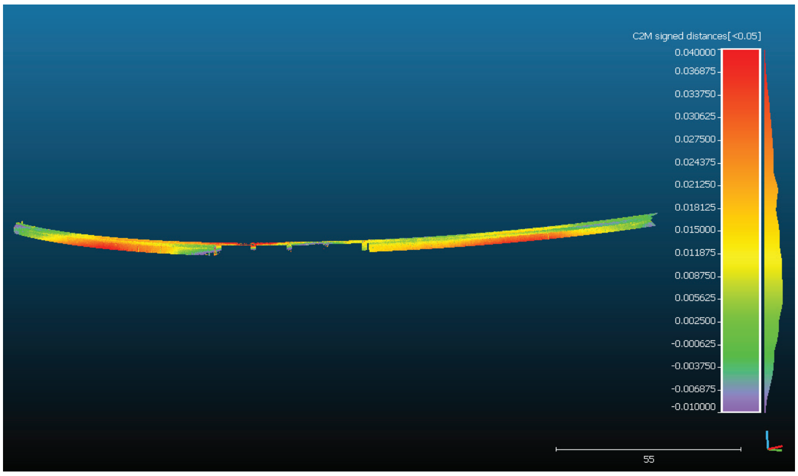

Figure 10 : 3D deformation of the crest between campaigns 1 and 2.

Figure 11 : Radial deformation at the dam plant. Absolute coordinates. Campaigns Oct-17, Feb-18, Oct-18.

4. CONCLUSIONS

The application of photogrammetry by drones is causing a leap not only quantitatively in the massive capture of data, but also qualitative. The product obtained formed by a cloud of dense points and true color of any facade, element or structure, allows together with the creation of a georeferenced mesh, the global and continuous inspection of the element as well as the control of deformations and modelling of it.

The automation, simplicity and amount of data obtained by this technique, make your application more and more.

The determining factors that have been tested for resolution and accuracy are: the layout, shape and typology of GCPs, the distance and angle of incidence of imaging, sensor resolution and stabilization, solar incidence and type of geopositioning used by the drone. In the latter respect, it is noteworthy the use of drones with RTK system, which allow the reduction of the number of GCPs.

Minimizing the costs and times used in the field and office, make this technique very advantageous compared to others existing today. In addition, the photo gallery obtained allows visual inspection in detail.

To date, according to the bibliographic review carried out, the control of movements with drone technology, has only been carried out applying it to the monitoring of a glacier and a hillside obtaining results with a deformation control accuracy of 9 cm.

In this research, the work carried out so far and applied to the case of a hillside and an Arc-Gravity dam, are adequate and follow a good line, obtaining precisions in the control of deformations of 2-3 mm.

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