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UNMANNED AERIAL VEHICLES (UAV) AS A SUPPORT TO VISUAL INSPECTIONS OF CONCRETE DAMS

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Abstract. *Some signals of deterioration and cracking of dams can only be identified by visual inspections. For this reason, visual inspections are irreplaceable in the control of the safety of dams. Concerning the exterior walls, and sometimes also the crest, as there is no direct access to most of these areas, it is used cameras and/or binoculars to perform the inspection work, which is usually done from the banks of the river.*
In the last few years it has appeared new aerial mini aircrafts – airplanes and helicopters and multirotors, remotely piloted, commonly called drones – that can carry digital cameras and can be flown near to the structures. For this reason they can acquire high quality images, at a very low price, from points of view that were never used before.
This paper presents the results of a photographic survey of a small area on the downstream face and of the central spillway of Bouçã dam, in Portugal. The photographs were taken by a digital camera mounted under a octocopter drone. Besides the interest of the photographs, since one can easily see all the features of the surface of the dam, the images were gathered and it was created an orthomosaic from the area surveyed on downstream face, a cartographic product that can be used as a support to other photographic surveys, and a point cloud of the spillway.

1 INTRODUCTION

Drone or UAV (unmanned aerial vehicle) are the most common names used to refer light aircrafts without human pilots aboard. Being light, not very expensive, and, concerning piloting, not much demanding, the civil use of these vehicles has been exponential, especially in the last few years. This paper presents one application that explores its use as a carrier of digital cameras[1,2], allowing the acquisition of images at distances of a few meters of the object under study. This "object" is a dam.

Dams, and especially large dams, are structures that usually present high risk. For this reason they are subject to surveillance to evaluate its safety. Visual inspections contribute to the knowledge of the structure and are irreplaceable since some problems can only be detected, and their evolution followed, by this method. If to make a photographic reportage inside galleries or in other accessible areas is easy, when one must evaluate the state of the exterior walls or other inaccessible locations on dams, the only method available to inspect the surface was to set the camera/binoculars on the banks of the river.

Drones can easily overcome this problem, since they can be guided near the structure, at distances of a few meters as one can see in Figures 1 and 2 where two photographs of

Bouçã dam taken nearby the downstream face and the spillway on the crest by a digital camera carried by a drone octocopter are showed. This paper presents the results of this experience and it is described the UAV system used, the dam, the flights, the photogrammetric products generated (orthomosaic and point cloud), the problems faced.

Figure 1: Horizontal photograph of the downstream wall of Bouçã dam.

Figure 2: Inclined photograph of the spillway on the crest of Bouçã dam.

2 THE DRONE

The drone used to take the photographs of Bouçã dam is called SKY II (Figure 3), and its owner is the Portuguese enterprise Skyeye. This drone is an octocopter, an eight-rotor mini helicopter**,** improved by Skyeye: it was added a GPS receiver, an IMU, a gimble and a camera. In the photo survey of Bouçã dam it was used a digital camera Sony Nex-7 equipped with lens E 16-50mm f3.5-5.6 OSS. Each photograph is 6000 pixel × 4000 pixel.

Figure 3: Drone octocopter SKY II. The support of the camera is under the drone, between the landing gears. This photograph was taken before the Sony camera was mounted.

The flight was remotely controlled by a pilot on the ground. There was a second technician who controlled the camera (its orientation and when to trigger). Each one had a remote control (Figures 4 and 5) that communicated with the drone. The unit that was used to command the drone received an image of a camera that is on the drone, the other command the image from the Sony camera. Camera operator ensured that images were orthogonal to the dam. In this flight the operator tried to ensure a minimum 60% image overlap.

The autonomy of SKY II was "only" eight minutes. It seems that this is a short period of time but is normal if one takes into account the payload of this UAV and the high number of equipments that consume electricity. The most demanding units are the eight rotors of the octocopter and the three motors of the gimble[1]. But there is also the need of electricity by the communication system (driving commands and operation of the camera), the IMU, the GPS receiver, the camera of the drone, several electronic boards, the landing gears, etc..

Figure 4: One remote controller.

Figure 5: Remotely commanding the drone and the camera.

2 BOUÇÃ DAM

Bouçã dam was built in the river Zêzere valley, in the central region of Portugal. It is a thin double curvature concrete arch dam (Figure 6). The maximum height above foundation is 70 m, the crest length is 171 m and the thickness at the crest is 0.9 m. The dam is provided with an overflow spillway which develops in two levels, without gates. The hydraulic scheme is mainly intended for power production and the power station is located in the right bank.

In the central blocks of the downstream wall there are cracks in horizontal concreting joints. Due to the colour of the deposits of carbonates under the cracks, one can easily see their location in Figure 6. The evolution of these cracks has been follow by the owner of the dam through regular visual inspections.

3 THE FLIGHT

During the demo, made on the morning of the 28th of October 2014, there were made three flights and taken a total of 208 photos of the dam. In Table 1 is made a resume of each flight. The first flight had to be interrupted due to a short shower, during which the drone was on land, protected from the rain.

[1] The gimble is an accessory that maintains a steady level balance of view and keeps the orientation of the camera even when the flight platform is rolling and pitching by gusts of wind.

Figure 6: Bouçã dam seen from downstream.

Flight	Area	Distance to the dam	Flight length	N.º photos	Nº blurry photos	Focal lenght	Size pixel
A	cracks	4m-9m	4min 45s	99	9	50 mm	1.3 mm
B	cracks	8m-12m	2min 52s	83	7	16 mm	5.0 mm
C	spillway	2m-4m	53s	26	1	16 mm	5.6 mm

Table 1: Some data about the flights.

About the information included in Table 1 is necessary to clarify that: i) distance to the dam: calculated from the point cloud that includes the camera positions (see Figures 17 and 20); ii) flight length: time span between the first and the last picture of the set; iii) size of the pixel: estimated from some lengths of the dam, lengths like the width of the blocks, which is known. The change of the focal length allowed, without changing much the distance drone-wall, to have a group of images more global, better to produce an orthomosaic of the dam. On Figures 7 and 8 one can see the differences between the photographs taken with the focal length of 50 mm (flight A) and a focal length of 16 mm (flight B).

Figure 7: Flight A. Crack n.º2 photographed with a focal length of 50 mm.

Figure 8: Flight B. Crack n.º2 (between cracks n.º1 and n.º3) photographed with a focal length of 16 mm.

4 PHOTOGRAMMETRIC PRODUCTS: ORTHOMOSAIC AND POINT CLOUD

The purpose of the flight was the acquisition of high quality photographs from good points of view. As there is overlapping between photographs it was possible to generate orthomosaics (with photos of flight A and B) and a 3D model (with photos of the flight C). An orthomosaic is an orthogonal projection of the wall, composed by selected portions of the photographs corrected of the distortions of the lenses and of the geometry of acquisition. Orthomosaics are most adapted to present features that are mostly planar like the wall of Bouçã dam. 3D models, presented as a point cloud, are used to represent features that have a strong 3D development, like the spillway does. In point clouds the external surface of the object photographed is represented by points. From each point is known the 3D coordinates (in the referential chosen) and a colour. Nowadays, orthomosaics and point clouds generated from photographs, are created using the "same" software (this is, software that is included in the same package) that uses a technique called stereophotogrammetry, which enables the estimation of coordinates of points in 3D from photographs taken from different positions.

The software included in these packages performs many tasks, which include: i) the identification of common points in all pairs of images; ii) computation of the parameters of calibration (camera distortions) and correction of the photos in a relative (not absolute) referential; iii) geo-reference of the data, to transform the relative orientation in an absolute orientation, defined by the user; iv) final computation of the external orientation (correct position and orientation of a camera with respect to the coordinate system chosen) and internal orientations; v) image matching; vi) generation of the orthomosaic and/or of the point cloud.

Skyeye produced an image of the wall (see Figure 9), using images of flight A and the software VisualSFM. This software generates a low/medium quality images using, in some areas near the borders, only two images. In Figure 10 is presented a detail of this image. An image with more details will be generated (in a near future) using the software PMVS/CMVS.

Figure 9: Image generated by Skyeye using software VisualSFM and photos of flight A.

Figure 10: A detail of crack n.º 3 (crack on the right side).

LNEC generated an orthomosaic, using Micmac, also a free and open source software, developed at the French Institut Géographique National (IGN). This software produces many outputs, being that one allows the user to see, in each pair of images, the location of the common points (Figure 11 to 13). Figures 11 and 12, of the wall of the dam, one can see that is difficult for the software to identify points in the white areas and in the wet areas. In Figure 13, the spillway, surprisingly (and unusually) the green areas nearer the dam have many points. The fact that it was a quiet morning, with almost no wind, and the variety of tree (the majority of the points are in the areas covered by mimosa trees) might be the reason. On smooth areas, as for example a small area on the top of the spillway and on the downstream wall, the software had difficulty to find points.

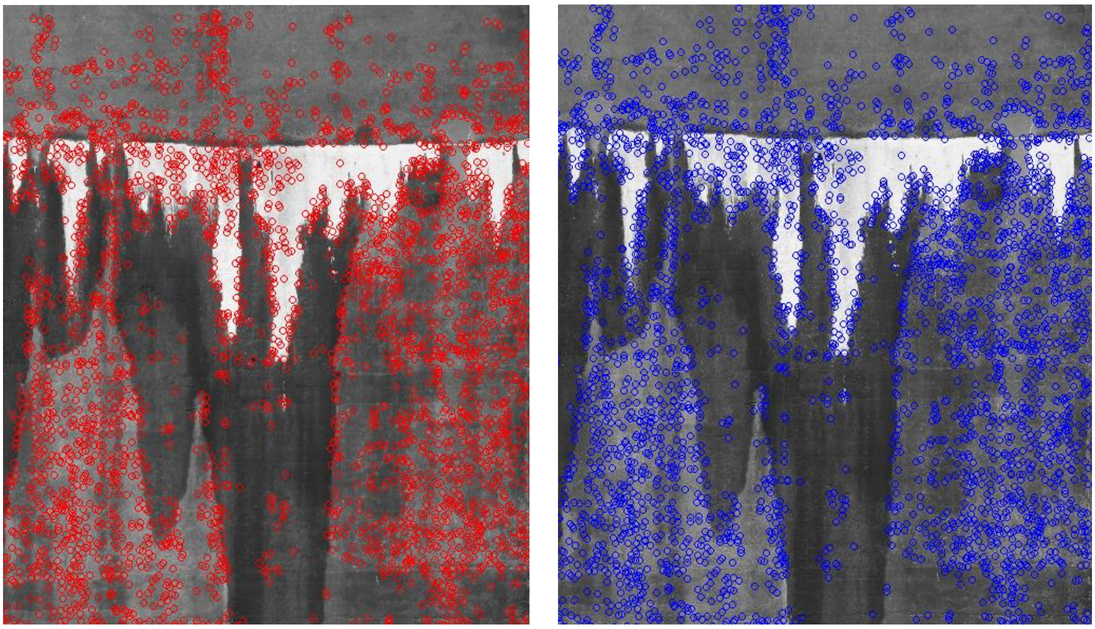

Figure 11: Common points in a pair of photographs

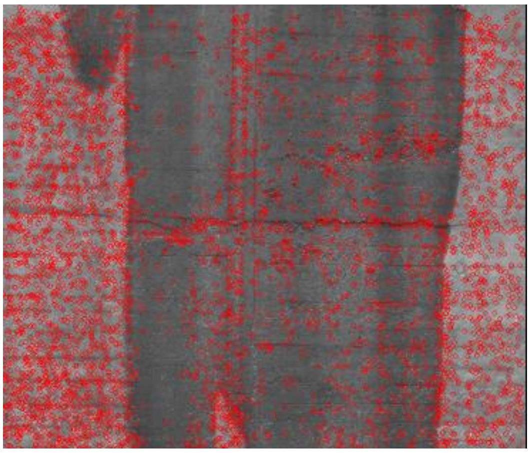

Figure 12: Identification of points on a wet surface.

Figure 13: Identification of points on the spillway.

The orthomosaic results from the gathering of selected areas of the corrected images. In Figure 14 is presented a section of the orthomosaic generated by Micmac with the photos of flight B and, in Figure 15, information that helps to understand how the orthomosaic is build: an area with the same colour means that in that area of the orthomosaic it was used the same image (see Figure 16). In Figure 14 one can notice the frontiers between some areas; changing the value of a parameter of Micmac the final image can become more homogeneous.

Figure 14: A section of orthomosaic generated by LNEC using software Micmac and photos of flight B.

Figure 15: Information generated by Micmac: areas covered with the same photo.

Figure 16: Relating the areas with the photos.

As other softwares, Micmac also gives information on the positions of the camera during the flight. This information is displayed graphically on a sparse point cloud. In Figure 17 is presented the position as seen from the “front” position of the camera during flights A and B; in Figure 18 the position seen from the top. The positions of the camera are represented in green (flight A) and yellow (flight B). There weren’t represented all the positions because many were similar. This point cloud is generated only from the photos. The curved shape shown in the Figure 18, was determined solely from the photographs and the first two phases of the processing (the identification of common points and the correction of the distortions of the camera), a phase that is completely automatic.

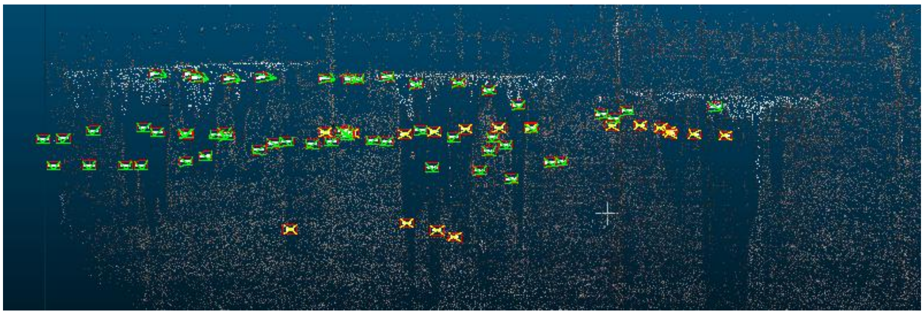

Figure 16: Locations of the camera during flight B (front view).

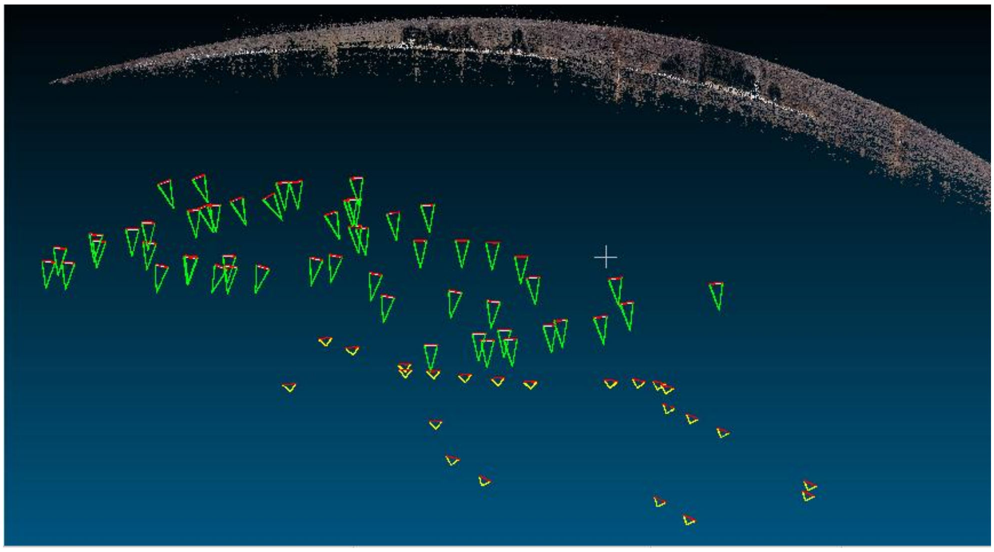

Figure 17: Locations of the camera during flight B (top view).

The photos of the spillway (the set is presented in Figure 18) were used to generate a 3D model (a point cloud). The locations of the camera during the flight are presented in Figures 19 and 20. As one can see, there is a lack of vertical overlapping so it's impossible to generate good quality photogrammetric products as one can notice in the point cloud (Figure 21) as there are areas with no points.

Figure 18: Photos used to generate the 3D model (point cloud) of the spillway.

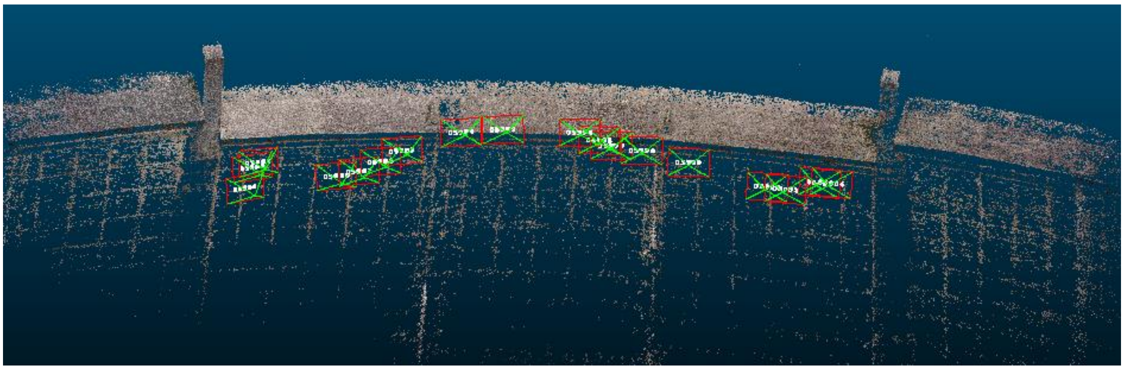

Figure 19: Locations of the camera during flight C (front view).

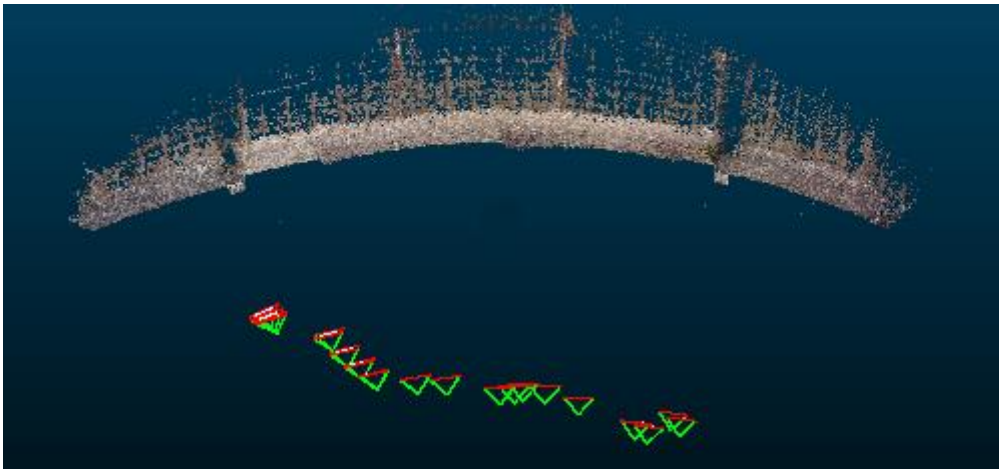

Figure 20: Locations of the camera during flight C (top view).

Figure 21: 3D model (point cloud) of a section of the spillway.

4 CLASSIFICATION OF FEATURES ON THE ORTHOMOSAICS

To evidence anomalies on the surface, one can use digital image classification techniques to show the areas that share the same characteristics[3]. It was applied the technique known as “object-based image classification” to classify the anomalies represented in the orthomosaics. The software used was *eCognition* from Trimble. The steps of classification were: i) segmentation: neighbour pixels were aggregated forming objects based on colour and shape (parameters defined by the user); ii) selection of variables and respective thresholds that provide an efficient identification of the features that are going to be classified; iii) automatic classification of the image.
The result of the classification is presented in Figure 22. One can see that three themes were chosen: i) white areas: deposits of calcium carbonate below the cracks where the water has leaked/is leaking; ii) red areas: areas where the calcium carbonates present a reddish colour; iii) wet concrete.

A:
B:
C:

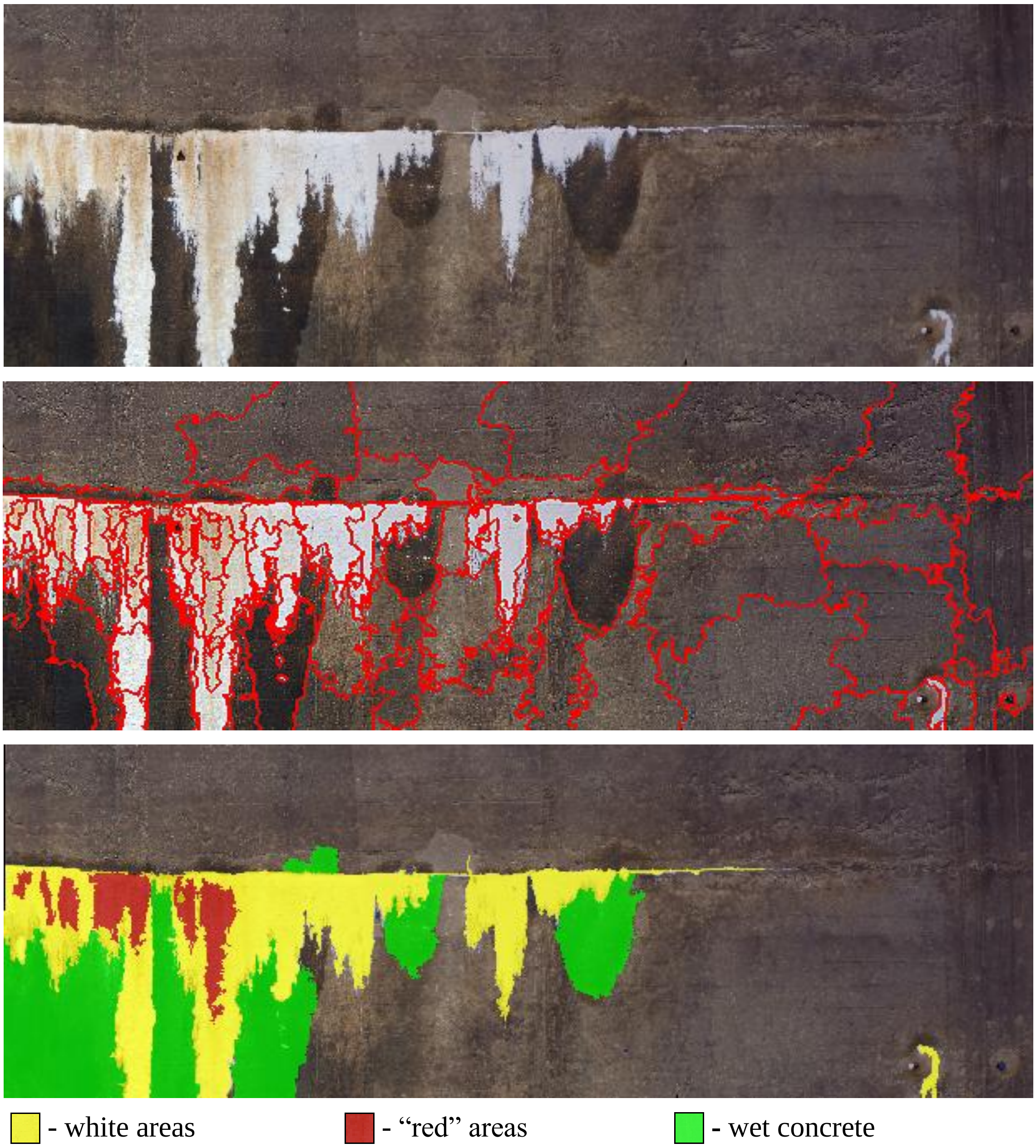

Figure 22: Object-based image classification. A: Original image; B: Segmentation; C: classification of the areas.

During the segmentation process, large and compact objects were formed respecting the radiometric borders visible in the image. Instead of performing the analysis of each individual pixel, the classification was applied over the objects. The objects representing areas with calcium carbonates were identified through radiometric variables. The classification of the wet areas, besides the radiometry, also considered the proximity between the objects to be classified and those previously classified as calcium carbonates. One can notice that some of the areas of the concrete that are darker were not classified as wet because its colour is not dark enough.

The variables and their thresholds for each class were “learnt” with the image presented in Figure 22 (of crack n.º 2) and the classification rules were applied (with no change) to a new orthomosaic, one that has the three cracks. The result of the classification is presented in Figure 23. As in this there was a light change in the colours (maybe resulting from different exposure times during the acquisition of the photographs), some of the wet areas near crack n.º 2, identified in Figure 22, are “not wet” in the image of Figure 23. Also to notice the fact that some wet areas end with straight lines. The reason is also their colour, a result of the mosaicing of images (see Figure 16).

Figure 23: Object-based image classification of the area surrounding the three cracks.

5 IMPROVEMENTS

A flight in front of the wall of the dam can have two purposes: i) to acquire photos so one can generate a full survey of the surface; ii) to acquire photos of a feature, to analyse it.

The first type of flight would be better accomplished if it is established, in advance, the trajectory of the flight (a flight plan or a mission plan) to ensure a good coverage of the surface: good overlapping of the images and a distance wall – drone more constant. To execute this is necessary to have a digital surface model that includes the dam and to have a GNSS guided drone. As there is the need of a high precision flight one needs to use a drone with GNSS RTK to have a, few, centimetre-level accuracy flight.

Unlike the usual GNSS systems installed in drones, which calculate the position with information included in the signal emitted by the GNSS satellites, position that can have some meters of error, GNSS RTK (where RTK stands for Real Time Kinematic) uses measurements of the phase of the signal′s carrier wave and relies on a single reference station to provide real-time corrections. This station, that must be local, is set by the user near the dam, during the flight. The computer (laptop on Figure 24), that receives data from the reference station, sends real-time corrections to the drone so the positions calculated by it can be corrected on the flight.

At the present there is no technology that allows this implementation since the accessories GNSS RTK (antenna + processor) are too heavy to be included in light drones like the one used in the visual inspection of Bouçã dam.

Figure 24: Scheme of communications with a drone with GNSS RTK (adapted from Sensefly).

6 CONCLUSIONS

Visual inspection of the walls of dam can be accomplished with a high precision if one uses photographs taken by cameras mounted on small size and light unmanned helicopters and multirotors. These platforms can be flown near the structure and one can get very good images from the wall and other inaccessible areas. The images, corrected and gathered can produce cartographic products (orthomosaics) or 3D models, which have metric proprieties: this means that one can measure lengths or can calculate areas.

The use of drones has, nevertheless, some limitations. Some models can't fly with rain; there are limits concerning the wind velocity during the flight. The wind, and specially the gusts, can lead to a lack of control that can be dangerous when the drone is near a wall. It should also be avoided when the dam is wet by the rain since it is more difficult to postprocess the photos. Finally, the magnetic field that exists in the vicinity of some dams, can affect the communications between the controller and the drone. And an uncontrolled drone will necessarily crash. This magnetic field might have its origin in the power station, in high-voltage power lines, in high power radio transmissions of the owner's dam communication channel. A good flight planning and careful control of the drone during the flight, for instance to avoid the communication beam, and, if necessary, the use of drones with electromagnetic shields can eliminate this risk.

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