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Structural monitoring of a breakwater using UAVs and photogrammetry

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Abstract

The present project addresses a problem related to the erosion effects on a breakwater barrier due to waves which leads to its degradation and that may eventually lead to lack of functionality of the structure. In the present case, the breakwater acts as a physical barrier between the Atlantic Ocean and the cargo Harbour of Leixões, in Matosinhos, Portugal, justifying the needs of health monitoring of the barrier.

To monitor this structure, with a length of roughly 700 m, the need of a fast data acquisition system led to the choice of imaging techniques which allow for a fast acquisition of a diversified data set. The images were acquired using a high-resolution camera attached to an unmanned aerial vehicle (UAV), enabling a faster and more automated procedure that leads to the systematization of the process, while being compatible with the difficult accessibility of the structure, which is surrounded by sea waves. Point clouds corresponding to the breakwater's geometry were then obtained from the set of the UAV aerial images using photogrammetry.

Two image acquisition and processing operations were performed three months apart in order to compare the point clouds acquired in the different instances and identify possible changes in the geometric configuration of the breakwater. By registering the two point clouds and computing the distance between them, it was possible to show that some movement within the structure occurred between the two points in time.

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1. Introduction

Breakwaters are very common maritime structures, designed to protect areas of interest from the damaging effects of sea waves (D'Angremond et al., 2008). However, they are themselves subjected to the effects of the sea during long periods of time, which results in a continued erosion process, as well as shape changes. The shape of a breakwater is of utmost importance for maintenance purposes, which highlights the need to monitor not only possible shape differences, but also displacement of breakwater elements, which also result in effective shape differences (Capitão et al., 2020; Lemos et al., 2020).

The availability of breakwater shape data at several points in time allows the maintenance crews not only have a better understanding of the current state of the structure, but also to have more detailed information to try to predict necessary interventions in the future (Ueno et al., 2021).

Thus, the main objective of this work is to apply photogrammetry and airborne image acquisition to monitor these large structures. The selected target was the north breakwater of the cargo harbor of Leixões, in Matosinhos, Portugal, whose resistant armour layer is mainly composed of tetrapod elements along a length of approximately 700 m.

The implemented process can be divided into three main phases, one corresponding to the image acquisition and the others to post-processing. The first operation corresponds to the UAV flight for image acquisition itself. In this case, two flights were undertaken three months apart. The second corresponds to image processing using photogrammetry to obtain 3D point clouds, while the final step involved processing these point clouds to detect changes in the breakwater shape that may have occurred in between both flights.

Nomenclature

EXIF	Exchangeable image file format
GNSS	Global Navigation Satellite System
IIQ	Phase One's Intelligent Image Quality file format
TIF	Tag Image File Format
UAV	Unmanned Aerial Vehicle

2. Equipment

For the first phase of the process, the necessary equipment is comprised of the UAV system, complemented by control software.

In this project, a DJI Matrice 600 Pro was used as the main body of the UAV, Fig. 1. It carried a payload that consisted of a DJI Ronin MX gimbal and a Phase One iXM-50 camera. This camera offers a resolution of 50 MP and is specially manufactured for aerial photography.

Regarding the control software, it was necessary to use a set of applications, including: the ground station software, UgCS (SPH Engineering, Latvia) where the route was planned and executed; the DJI Go flight controller app (DJI, China), used for setup purposes; and the iX Capture app (Phase One, Denmark), for camera control. The latter required the use of an iOS device instead of other otherwise compatible Android devices (Phase One A/S, n.d.), while the ground station software was split in two parts, one running on a laptop and another on the iPad connected to the controller.

After the flight, the acquired images were processed using the Pix4DMapper software (Pix4D SA, Switzerland) and the resulting point clouds were processed using CloudCompare (GPL software, cloudcompare.org).

Fig. 1. The UAV system used in this project for image acquisition: DJI Matrice 600 Pro, with DJI Ronin MX gimbal and Phase One iXM-50 camera.

3. Flight and image acquisition

The flights were planned in advance in the ground station software, where it was possible to define the UAV route and orientation, as well as the camera's tilt.

For the first flight, whose path is shown in Fig. 2a, two passes were defined, both of them with the camera facing the direction of motion, tilted at an angle of 90 degrees with the horizontal. Both flights started on the south breakwater, crossing the straight to the north one, before proceeding to perform the predefined passes while acquiring images. Due to the employed camera solution, it was necessary to start image acquisition prior to takeoff.

Between the two flights, it was decided to include a third pass in a different perspective to remove voids that were later found when post-processing the first flight, i.e. areas that were not possible to capture from the two acquired perspectives alone. Thus, for the second flight path, shown in Fig. 2b, an additional pass was included, and the UAV had to return home by crossing a larger body of water.

a)

b)

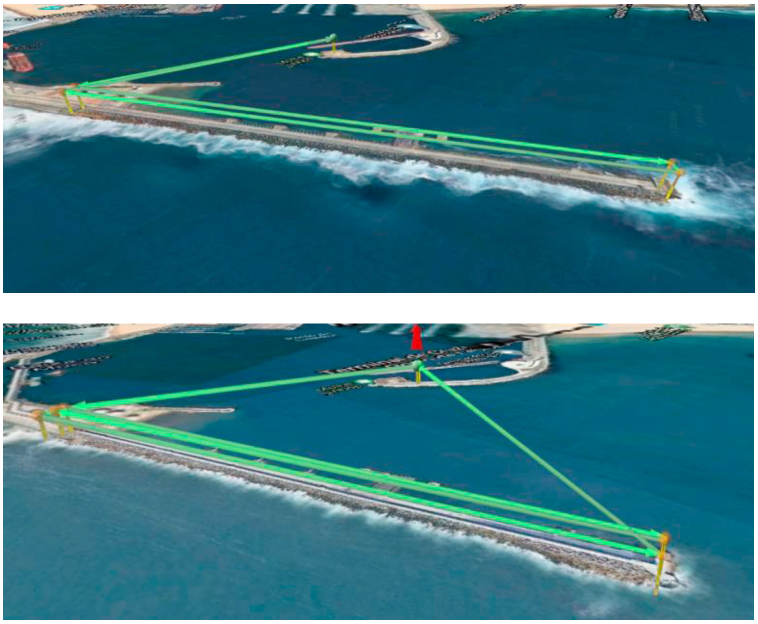


Fig. 2. Flight path for the (a) first and the (b) second flights, separated by three months' time.

After each image acquisition, the data was transferred from the XQD card to the computer and the transit images were deleted. In post-processing, the obtained images in IIQ format were converted to TIF, while transferring the EXIF tags to maintain the necessary GNSS information, and used as input for processing in Pix4DMapper.

4. Outputs

From the photogrammetry process, it was possible to obtain two different point clouds, separated by three months. A global view of the resulting point cloud for the second acquisition can be seen in Fig. 3, which is very similar to the one of the first acquisition, as is to be expected.

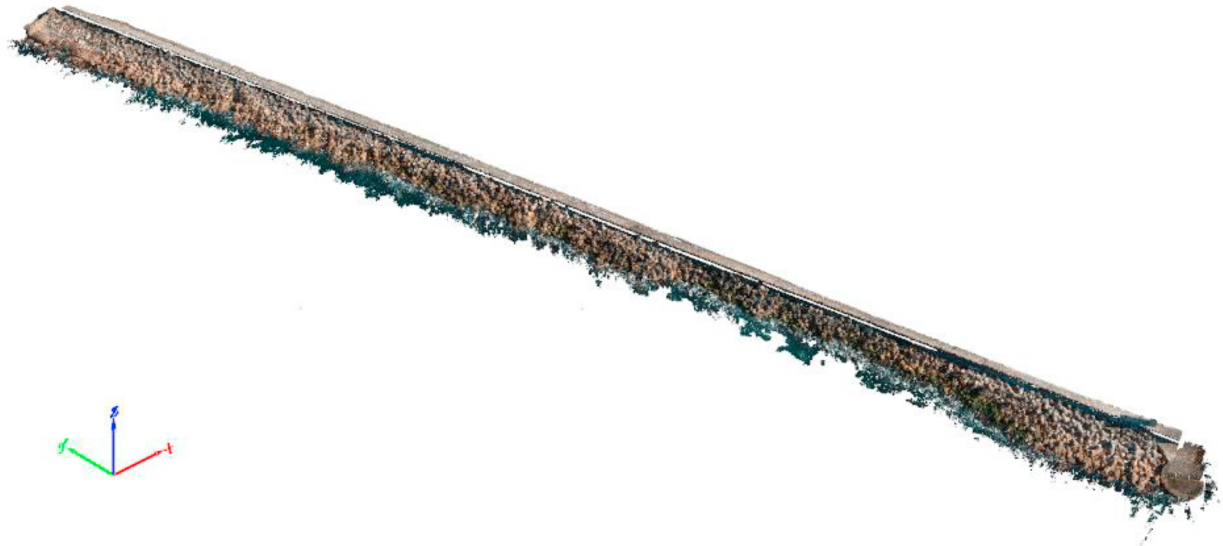


Fig. 3. Point cloud obtained after processing the images acquired in the second flight

Besides the point clouds, it is also possible to obtain other outputs from this processing procedure, such as triangular meshes or orthomosaics and profile monitoring, which, while interesting, were not used in this work.

5. Point cloud analysis

Using the obtained point clouds, a comparison was performed to identify particular changes that have occurred in the three months between the two image acquisition flights.

First, it was necessary to extract the same small section from each point cloud, with 50 m in length, to reduce the amount of data to work with to an acceptable range for the used computer.

Afterwards, the remainder of the procedure was performed in CloudCompare, where the two sections were aligned and the distance between point clouds was calculated. This resulted in a visual representation, shown in Fig. 4 for an example section after removal of outliers, which were located mainly along the water edge.

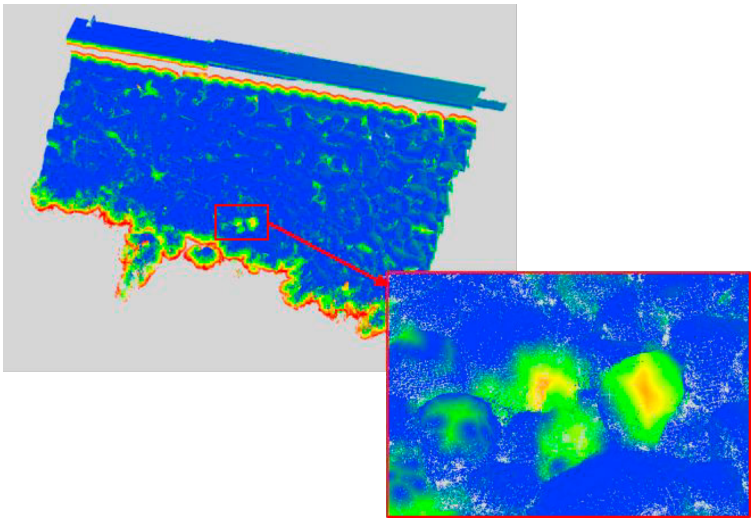
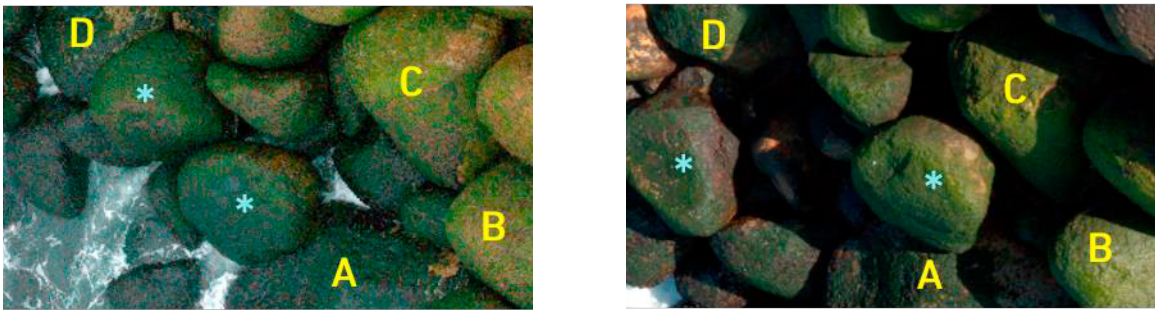


Fig. 4. Result of the difference calculation between the two acquired point clouds, after removing outliers.

Among the visual representation, it was possible to detect regions where the distance between point clouds was higher than expected, such as the highlighted region in Fig. 4, where it was possible to notice that a small rock had moved from its original position. For this particular case, a pair of images, one from each acquisition, was found where the motion of the rocks can be seen, Fig. 5. The elements marked with letters stayed in the same location for three months, while the ones marked with asterisks moved out of their original location in the meantime. It should be noted that the images of Fig. 5 are not exactly from the same perspective.



a) b)

Fig. 5. Images from (a) the first and; (b) the second flights, where changes were detected. The blue * indicates rocks that moved between acquisitions, while the yellow letters indicate rocks that stayed at the same location.

The obtained data can also be used for other purposes, such as to extract profiles in the transverse direction and check if they meet the required shapes.

6. Conclusions

The present work reported successful automated UAV flights for image acquisition of a breakwater, which resulted in high quality point clouds, using photogrammetry software.

While the decision of increasing the number of perspectives for the second acquisition resulted in a point cloud with fewer voids, the comparability of the data remained, as it was possible to not only see changes in breakwater geometry over time, but also to identify which particular rocks moved away from their original positions.

Additionally, the obtained data can also be used for further analysis, such as breakwater profile monitoring, and for high-quality orthomosaic generation.

The employed 3D shape acquisition system has proven its capability, insofar as it was possible to obtain relevant quantitative information for the structure's analysis and to detect geometric differences at different points in time.

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