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PATHOLOGY MAPPING IN CONCRETE DAMS THROUGH DIGITAL PHOTOGRAMMETRY AND IMAGE PROCESSING


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ABSTRACT

Visual inspection is a crucial task for the assessment of a dam conservation state. However, these tasks are time consuming and operator dependent, which leads to the aim of developing more objective procedures. Photographs are a way to register the conservation state of a structure at a certain epoch, providing a record that can be later reanalysed and compared to new data. Although they are already used for support of inspection activities, their capture is often limited to accessible areas of the structure, leading to large lacunae in the analysed surface. Photographs obtained from long distances can reach a larger surface area, but the achievable resolution and detail of the identifiable elements is compromised. Furthermore, the manual analysis of the photographs for pathology identification and characterization is also a tedious task.

In this study, a map of pathologies on all visible surfaces of Santa Luzia dam, in Portugal, was performed through photogrammetry and digital image processing. The dam crest, downstream wall and the emerged part of the upstream wall were thoroughly photographed through drone and terrestrial surveys, in order to achieve a digital representation of the dam. The photographs were subjected to photogrammetric procedures, in order to create orthophotographs (distortion-free images of the surfaces). Those images were used to map a set of occurrences observed on the dam surface, such as cracks, calcium carbonate deposits, biologic colonization, leakage and irregularities. The location and extension of these elements were detected in the images using digital image processing algorithms. Both the orthophotographs and the pathology outlines were imported into a spatial database, which can be explored in open-source software. As the orthophotographs and pathology outlines are geometrically corrected, it is possible to measure the dimensions of the affected regions, such as areas, lengths and widths. Furthermore, alphanumeric information can be added to the spatial database, complementing the image-based data with field observations. The initial condition assessment can be updated through new surveys, enabling the analysis of the evolution of the pathologies.

Keywords: Conservation state assessment, photogrammetry, digital image processing, spatial database.

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1. INTRODUCTION

Many concrete dams in Portugal have been operating for several decades, demanding a thorough surveillance to ensure their safety requirements are met. Studies in distinct areas of knowledge must be performed for a complete assessment of the structure condition, such as analysing concrete properties, following the dam structural behaviour and detecting signs of damage.

Visual inspections of the dam surface are crucial for damage detection. This task is usually performed by trained experts, who characterize the visible pathologies. Registered information includes approximate location and manual crack width measurements, among others. Despite being effective, the described method is subjective, as it is operator dependent. Furthermore, when manual measurements are required, the method is limited to the accessible areas of the dam.

Visual inspections are currently supported by photographs; however, the manual image analysis for pathology delimitation is a time consuming and tedious task rarely performed. Therefore, digital image processing and machine learning methods for identifying pathologies frequently found in concrete dams have been developed. Most studies are focused on crack detection [1-5], but leakage, calcification, spalling and collapse are also considered by some authors [2][4]. Images are captured through different techniques, such as terrestrial photography [1], unmanned aerial vehicles (UAV) [2][3], closed-circuit television (CCTV) [6] or underwater remotely operated vehicles (ROV) [7]. For pathology identification, most of these studies provide a label or caption indicating the presence of a certain pathology in the image [3][4], but a few of them are capable to determine their location [1][5]. Although most studies are focused on dam emerged walls and crest, there are also some approaches for inspecting dam pathologies underwater [7] and in structure sub-surface through boreholes [6].

The Portuguese National Laboratory for Civil Engineering started studying digital image processing methods for pathology mapping in concrete dams a decade ago [8][9], but the rapid development of reality capture technology in the last years brought several improvements, by enabling high resolution image capture even in inaccessible areas of the structure. In this study, a method for pathology mapping based on photogrammetry, digital image processing and geographic information systems (GIS) is proposed. The method was applied to Santa Luzia dam, in Portugal, which was subjected to a thorough photographic survey of its visible surfaces. The achieved digital representation of the dam was used for pathology detection and delimitation. The collected information, both images and pathology limits, were integrated in a spatial database, accessible through an open-source GIS system, which forms a graphic registration of the dam conservation state.

2. CASE STUDY

Santa Luzia is a concrete dam in Pampilhosa da Serra municipality, Portugal. The dam is located in Unhais stream, a tributary of Zêzere river, and it is operating since 1943 [10]. Santa Luzia is a cylindrical arch dam, connected by an arch-gravity structure to the left bank [11] (Fig.1). It has a maximum height of 76 m and the crest length is 115 m [12].

Fig. 1 – Santa Luzia dam and its surroundings

The dam started showing signs of being affected by concrete swelling reactions of internal origin in the 1960s, but it has been decelerating since 2000. The swelling effects are more visible in the arch-gravity than in the dam main body [11].

The dam presents several pathologies in its surfaces, such as cracks, calcium carbonate deposits, leakage and biologic colonization. Other occurrences are also visible, for example temporary wet areas and irregularities corresponding to prior interventions in the dam. Furthermore, part of the downstream wall of the dam main body is covered by a mortar mixture, avoiding the visualization of the pathologies underneath.

This study is focused on the downstream wall, from both the main body and the arch-gravity (the abutment was not included), the crest and the emerged part of the entire upstream wall.

3. DAM PHOTOGRAPHIC SURVEY

The photographic survey of Santa Luzia dam was performed through terrestrial photogrammetry for the downstream walls of the main body and of the arch-gravity, while the dam crest and the upstream wall were photographed from an UAV (drone). Fig.2 presents examples of photographs from each survey.

Fig. 2 – Examples of photographs from the terrestrial (left) and aerial (right) surveys

The terrestrial survey was executed from different locations in the downstream slopes, with partial areas of the dam surface being considered individually. This strategy was performed in order to achieve the best spatial resolution and the less oblique photographs possible for each location. The photographs were captured by a Nikon D200. Most of the surface was photographed using a Nikkor objective with a focal length of 180 mm, with focal lengths 50 mm and 85 mm being used sporadically. The survey took eight days to be completed and it was performed mostly in October 2022. Almost 8000 photographs were required to cover the entire surface of the downstream walls. An orthophotograph was built for each partial area, with spatial resolutions varying from 0.6 mm to 5.5 mm.

The UAV survey for the dam crest and emerged upstream wall will be described in detail in Henriques *et al*. [13]. A unique orthophotograph was built for the crest, as it is a flat surface, with a spatial resolution of 15.1 mm. As the upstream wall presents curved surfaces, several orthophotographs were built in order to minimize the distortion. Spatial resolutions varied from 13.9 mm to 16.8 mm.

Coordinates of ground control points (GCP) were determined for selected details on the dam surface, with respect to the local reference frame of the geodetic observation system. GCP were used to provide a scale and orientation to the images. All the orthophotographs, for the four considered surfaces, were flattened by corregistering them to the CAD files from the dam project. These images were geometrically corrected and free of distortions. The achieved image products were the basis for the pathology mapping.

4. PATHOLOGY MAPPING

The pathology mapping for Santa Luzia dam followed an object-based image analysis (OBIA) strategy. OBIA evaluates the similarities between neighbour pixels and aggregates them whenever they fulfil user defined criteria, forming objects. Those criteria impose a limit to the radiometric heterogeneity acceptable for each object and set the relative weights attributed to object colour and shape. Regarding shape, compactness and smoothness object properties can be set. Hierarchical relationships between objects with different properties may also be defined.

In this study, two different approaches were followed: one for the dam walls and another one for the crest. For the walls, multiresolution segmentation algorithm from eCognition® software was used to build three object hierarchical levels. In the first level, large and compact objects were created, intending to segment the large spots on the walls, such as calcium carbonate deposits or leakage. A second level of objects, resulting from the division between those from the previous level, was used to refine the objects from the first level. Finally, a third level was set to build small non-compact objects with the goal of delimiting cracks (Fig. 3).

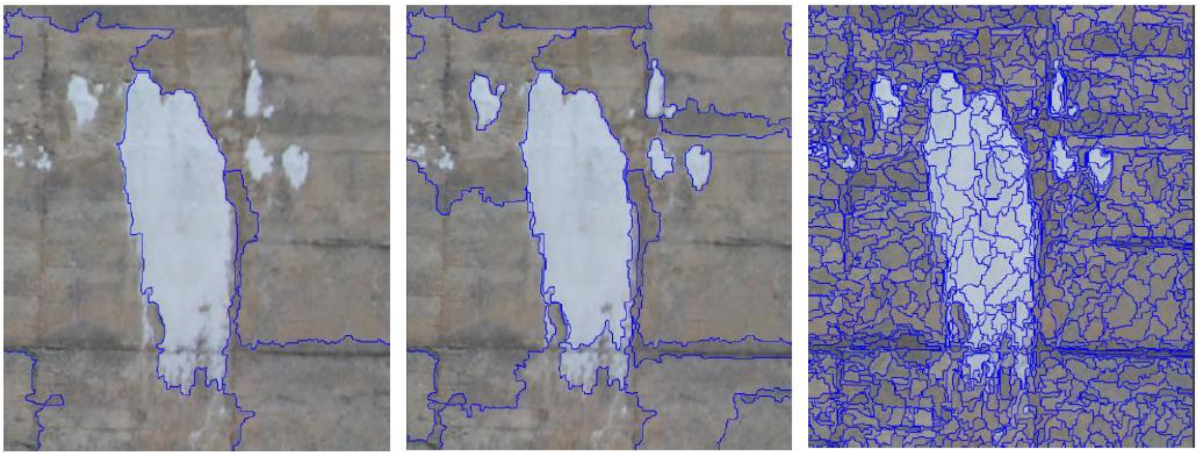


Fig. 3 – Hierarchical segmentations with increasing levels of detail

The association of a pathology class to a certain object was performed by photointerpretation, except for biological colonization in the downstream walls. In this case, the greenish colour presented by the affected areas enabled the automatic detection of the corresponding objects, through a new image built from the original one to enhance the green areas.

Regarding the dam crest, cracks were the only pathologies considered. As these elements showed high contrast to the surrounding background, the algorithm contrast-split segmentation from eCognition® was used. This strategy required a coarse crack delimitation at an initial phase, which was refined through the separation between bright and dark areas inside the initial delimitation (Fig. 4).

Pathology delimitations were exported into shapefile format, which enabled the attribution of alphanumeric information to the files. In this case, intervals of area and of crack width were associated to pathology objects.

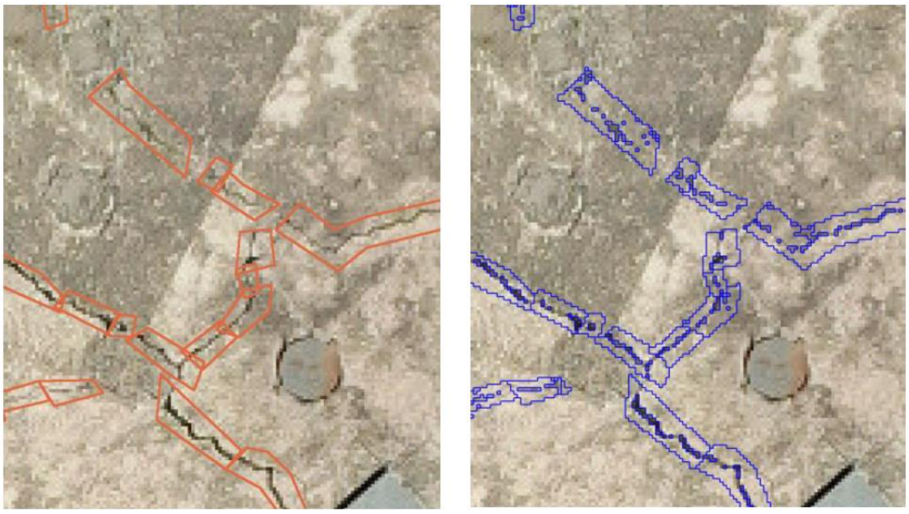


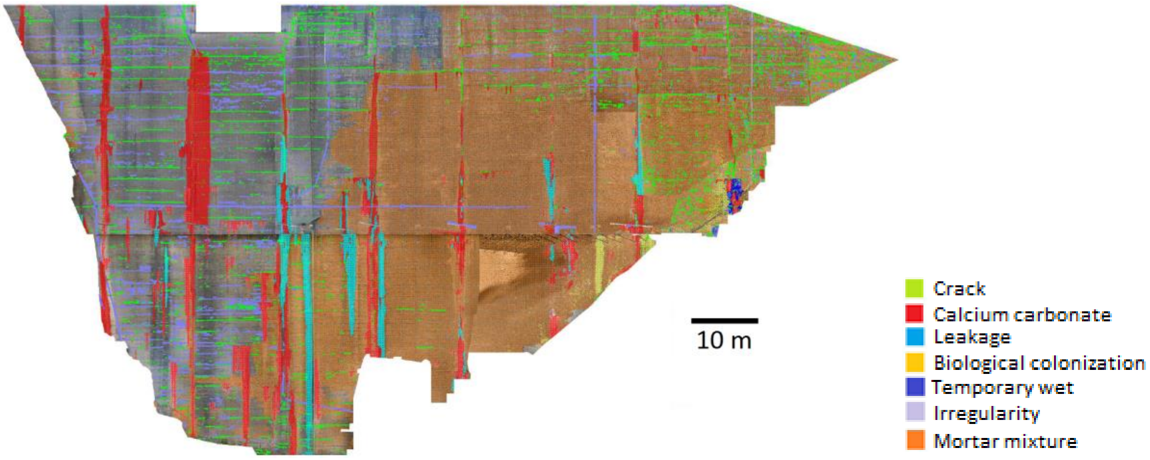
Fig. 4 – Initial crack delimitation (left) and contrast-based crack segmentation (right)

5. RESULTS

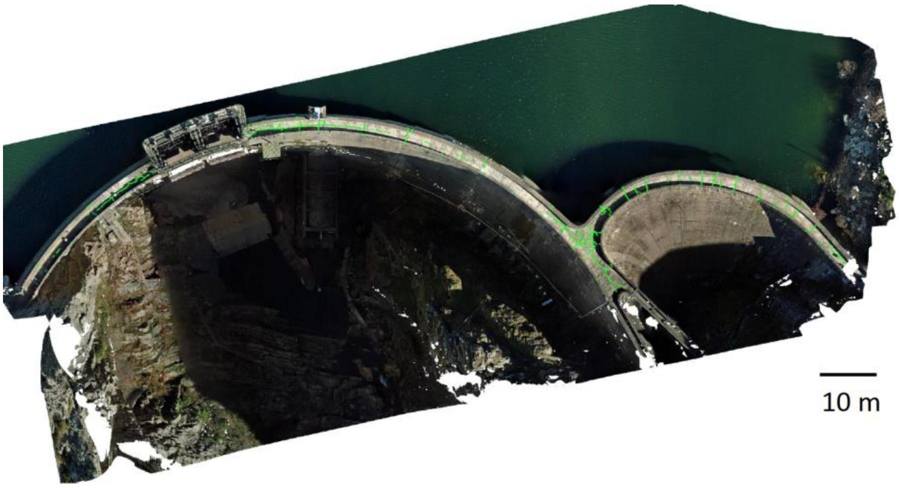
The orthophotographs, the mapped pathologies and the corresponding alphanumeric information were integrated into a spatial database that can be accessed through open-source GIS software, such as QGIS. The pathology map can be superimposed on the orthophotographs and the two datasets can be analysed together. Alphanumeric data can be easily accessed in table format or by clicking on the pathology object of interest. Fig. 5 presents the pathology maps for some of the considered dam surfaces.

The cracks with the largest widths were observed in the crest, where one of the cracks presented a width close to 100 mm. Most of the identified cracks, for the four surfaces, presented width values above 2.5 mm. However, this result was influenced by the image spatial resolution, as will be discussed in section 6. Around 60% of the main body downstream wall was covered by the mortar mixture, which did not allow the observation of the dam surface, hiding eventual pathologies. Most calcium carbonate deposits on the downstream wall covered areas below 1 dm^2. However, there were several deposits with areas larger than 1 m^2. Most leakage signs in this surface covered areas between 1 cm^2 and 1 dm^2. Areas affected by biological colonization tended to be larger in the arch-gravity (areas from 1 cm^2 to 1 dm^2) than in the main body (areas from 1 mm^2 to 1 cm^2). The upstream wall was mostly affected by calcium carbonate deposits and biological colonization. Calcium carbonate deposits had areas between 1 cm^2 and 1 m^2. Due to the water proximity, the upstream wall was wet and presented large spots of biological colonization, which, in some cases, reached more than 1 m^2.

The quality of the pathology maps was evaluated through the comparison between the map information and the ground truth achieved from photointerpretation of a set of random points. Overall accuracies are presented in Table 1. This index informs the percentage of points that were correctly mapped.



(a)



(b)

Fig. 5 – Pathology maps for the main body downstream wall (a) and the crest (b)

Table 1 – Overall accuracies for the pathology maps

Downstream wall		Upstream wall	Crest
Main body	Arch-gravity		
94.6%	85.6%	90.3%	94.7%

6. DISCUSSION

Image spatial resolution is a critical factor for the mapping quality. The usage of terrestrial photogrammetry enabled the access to higher spatial resolution images for the downstream walls than for the upstream wall and the crest, where the UAV was used. Most mapped cracks presented widths above 2.5 mm, because the image spatial resolution was not large enough to enable the detection of smaller elements. Nevertheless, when the cracks had high contrast with respect to the background, it was still possible to identify them on the orthophotographs, even when their widths were lower than the pixel size. This was verified through comparison of the pathology map with field measurements [14]. In this situation, the crack could be mapped, but its width could not be correctly determined from the image.

The organization of the downstream wall into partial orthophotographs allowed the usage of higher spatial resolution images. However, as each block of images was captured in different light conditions, it also led to light heterogeneities across the surface, which prevented the automatization of the classification procedure. As stated in the introduction, machine learning and digital image processing methods have been used to automatically map pathologies on dams. However, these studies were mostly focused on a single pathology (usually cracks) and the analysed images often presented little area of the surface besides the wanted pathology. In the present study, an area around 10000 m^2 of concrete surface was analysed, with varying spatial resolutions and light conditions, where seven types of pathologies and other occurrences were considered. Although most features were classified through photointerpretation, the usage of different object levels aided the classification task, as the largest pathologies were identified in the first object level and their delimitations only had to be refined in the other levels.

7. CONCLUSIONS

In this study, a method for pathology mapping through photogrammetry and digital image processing was proposed, with the goal of assisting in the evaluation of concrete dams' conservation state. The proposed method enabled the production of a digital representation of Santa Luzia dam, through flattened orthophotographs, which were used as the basis for the pathology mapping. The data were integrated into a spatial database that could be accessed by the dam owner through an open-source GIS software and completed with other available information. The achieved product provided a detailed testimony of the dam conservation state at the epoch of image capture, including for areas difficult to reach. Therefore, the achieved pathology maps were useful to complement the visual inspections performed by the experts, providing accurate information on pathology type, location and extension.

For future work, research on digital image processing methods to turn light uniform inside an image and between images will be performed and the capabilities of machine learning techniques to map different types of pathologies will be evaluated.

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