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Heritage site preservation with combined radiometric and geometric analysis of TLS data

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ABSTRACT

Damage mapping is considered a critical stage in the correct diagnosis of the state of conservation of Cultural Heritage manifestations. The common approach generally implies a large user interaction to map the different pathological processes presented on 2D documents such as elevations or sections, among others. In contrast with this practice, the present paper proposes a semiautomatic 3D-methodology, with a minimum user interaction, able to accurately analyse both radiometric and geometric data recovered by a non-contact technology (Terrestrial Laser Scanning), allowing the extraction and quantification of a wide diversity of pathological processes from biological colonization to deformations. This approach is therefore a potential tool for the rapid and accurate diagnosis of Cultural Heritage. To confirm the applicability and potential offered by the proposed methodology, a highly affected historical masonry, the San Francisco Master Gate of the Almeida Fortress (Portugal), was evaluated by using the Faro Focus 3D 120 Laser Scanner.

1. Introduction

Currently, Cultural Heritage (CH) is considered not only a keystone in the economic development of a country but also a living witness of our age-old traditions [1]. For this reason, it is necessary to safeguard the authenticity and integrity of our Cultural Heritage for future generations [2].

Inside the wide variety of constructions that compose our CH assets, from religious buildings [3], to network infrastructures [4] or rock art manifestations [5], masonry is the most commonly used constructive solution. This popularity arises from its resistance to degradation agents compared with other materials such as wood or adobe [6,7]. However, as the other constructive systems, biological colonization, salts, and moisture among others [8] can promote the deterioration of the ornamental pieces presented on the monument as well as a reduction of its service life [9].

Based on these considerations, several international documents such as the Venice or Krakow Charters [2,10] demand the use of rigorous multidisciplinary approaches to study the conservation state of our cultural legacy. The final aim is to preserve its authenticity and values and design suitable restoration strategies to preserve the monument through time according to some modern restoration principles [11].

The non-contact and accurate nature of Terrestrial Laser Scanners (TLSs) as well as the fast and dense data acquisitions place these sensors as one of the best solutions for the 3D digitalization [12] of CH assets. The 3D models obtained with these geomatic sensors are normally used to create complex CAD models for further structural evaluation [4,13,14] or used to extract elevations or section maps [15]. However, the potential of these sensors goes beyond a massive register of spatial coordinates, since they also store very useful radiometric information, the backscattered intensity data [16]. Using the combination of these two capabilities (radiometric and geometric), a laser scanner can be positioned as one of the most versatile tools to remotely study the conservation state of historical construction. In this way, a damage assessment can be performed in three dimensions with the advantage of being able to quantify the damages mapped on the monument in contrast with more traditional practices of manual damage mapping on orthoimages or sections [15,17].

Under this assumption, this paper proposes a methodology to analyse together the radiometric and geometric data captured by TLS systems. The final goal is to develop a method capable of mapping a wide range of the most common damages of historical masonry

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construction promoted by the presence of chemical, biological and physical alteration agents. To validate the proposed strategy, a historical construction inside the Fortress of Almeida, in Portugal, was chosen as a case study: the San Francisco Master Gate.

Within this context, the paper has been organized as follows: Section 2 defines the sensor used to diagnose the state of conservation as well as the processing methodology that was followed; Section 3 describes the Almeida Fortress and the San Francisco Master Gate; Section 4 shows the results after applying the proposed methodology, and finally, Section 5 summarizes the conclusions arising from the use of TLS data to analyse pathologies of historical constructions as well as some future work.

2. Methodology for exploiting radiometric and geometric data from TLS point clouds

2.1. Terrestrial laser scanner

Due to the difficulty in accessing some parts of the case study as well as the unfavourable lighting conditions (shaded and lighted areas) to perform the data acquisition in some parts, the use of a TLS is the best solution given its active nature (independent of solar lighting conditions) and versatility. Specifically, the Faro Focus 3D 120 (FF3D120) (Fig. 1) was the sensor used to evaluate the methodology proposed in this paper. The most relevant features of this TLS are specified in Table 1.

2.2. Processing of laser scanner data for damage detection

To make full use of the TLS data acquisition for damage detection, we have decided to exploit the dual applicability of this sensor, radiometry and geometry laser data. For that reason, the laser point cloud takes two different paths in the processing step, the red- and blue-shaded areas of Fig. 2. This figure summarizes the processing workflow followed to finally obtain a complete diagnosis of the state of degradation of construction.

The radiometric approach encompasses four processes: the radiometric calibration of the laser scanner, an automatic classification of the point cloud to map different pathologies, the validation of the classification by a visual inspection and the final quantification of damages. For its part, the geometric approach encompasses two parallel processes: on one hand, a planar extraction by means of the RANSAC shape detector, a z segmentation of the planes extracted to create the comparison plane and the analysis of the discrepancies between the planar clusters extracted and the comparison planes; and on the other hand, the CANUPO algorithm was trained and applied on the point cloud to evaluate those areas with strong material losses. Finally, with the results of both approaches, a multilayer point cloud was created to make a comprehensive and rigorous diagnosis of the chosen construction considering both radiometric and geometric criteria.

Table 1
FF3D120 technical specifications.

Physical principle	Phase shift
Wavelength (nm)	905 - near infrared
Measurement range (m)	0.6–120
Field of view (degrees)	360 H × 320 V
Accuracy nominal value at 25 m (mm)	2
Beam divergence (mrad)	0.19
Capture rate (points/s)	122,000/976,000
Spatial resolution at 10 m (mm)	6
Radiometric resolution (bits)	11

2.3. Pre-processing

Historical constructions are geometrically characterized by their complexity and size, making necessary the use of several scanning positions to record the whole construction. Considering the complexity and size of the construction, the present methodology applied a coarse to fine strategy to register the different scans taken [14]. First, a pairwise alignment, by means of the Iterative Closest Point (ICP) algorithm [18], was used. Later, and with the aim of minimizing the error accumulation, a global registration based on the Generalized Procrustes Analysis (GPA) approach [19] was carried out. In this way, a dense and accurate 3D representation of the monument was obtained.

With the 3D representation of the monument, the next step required to diagnose the construction involves the extraction of the damage by the radiometric and geometric approaches proposed. In accordance with the visual indicators proposed by ICOMOS [8], the following pathological processes were evaluated: (i) deformations, (ii) disaggregation, (iii) biological activity, (iv) salt crust and (v) moisture.

2.4. Radiometric approach

Backscattered laser intensity generates very useful radiometric information to evaluate the object not only quantitatively but also qualitatively [16,20]. In this way, by using a single sensor, it is possible to perform very comprehensive and rigorous studies of the construction

a) b)

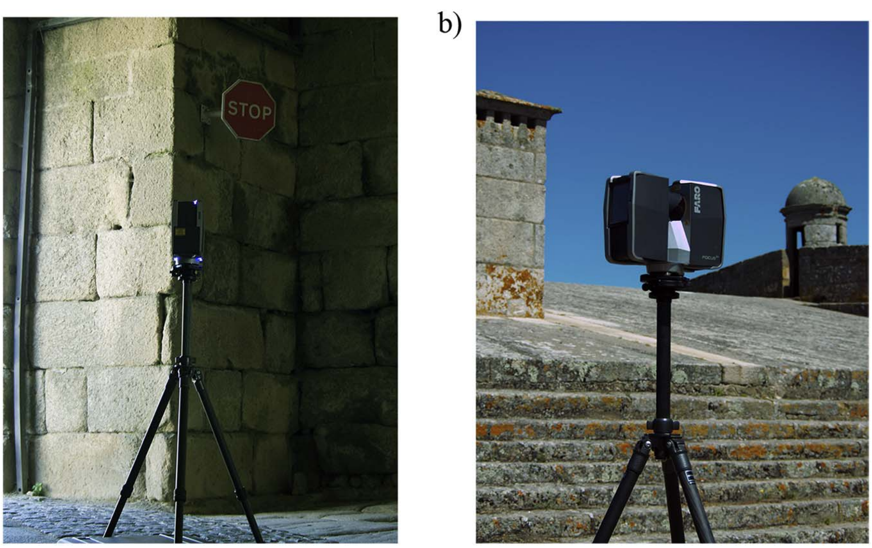

Fig. 1. TLS system during the data acquisition: (a) inside the barrel vault and (b) on the roof.