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MAPPING MONUMENTS' STONE WEATHERING USING LOW-COST MULTISPECTRAL TECHNOLOGIES AND IMAGE PROCESSING

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Abstract:

Mapping and analyzing stone monuments' surface condition and time-induced deterioration are necessary for the decision making on conservation measures. Since the assessment of architectural facades and elements is often conducted manually, there is significant value in investigating automatic weathering mapping procedures. This short paper aims to discuss how the combination of multispectral imaging, computational visualistics, and geomatics techniques can cost-effectively assist in evaluating the state of preservation of monumental heritage through the use of low-cost sensors. The conducted experiments employ a medium-format camera modified for spectral imaging, mobile sensors, free and low-cost software. The Presented results concern three important archaeological sites in ancient Elis and Arcadia (Greece).

Keywords: multispectral imaging, photogrammetry, decay mapping, image processing, low-cost sensors, stone heritage

1. Introduction

Monuments made of stone represent a substantial part of the word's heritage. They possess essential values tied to culture, religion, construction techniques, and aesthetics of the period during which they were built. The importance of conserving them stems from the need to preserve these values and from the sense of continuity and identity historic buildings provide for future generations (Baer, & Snethlage, 1997). However, building stones are subjected to continuous weathering, which imposes significant challenges to ensuring the stone monuments' preservation. Weathering results from physicochemical interactions between the stones and the environment (climate, biosphere, pollution) and leads to gradual deterioration (Siegesmund, Weiss, & Vollbrecht, 2002).

The diagnosis of deterioration constitutes the basis for successful decision-making and effective implementation of conservation measures; therefore, documentation and monitoring of weathering forms is essential for safeguarding stone monuments' sustainability (Fitzner, 2016). Weathering documentation through mapping methods has been established as a non-destructive technique for recording and evaluating lithotypes and deterioration patterns (Fitzner, 2004). Maps of weathering are obtained through photographic documentation, on-site observations, graphic mapping—often conducted manually—and facilitate the identification of mechanisms of the genesis and progress of decay (D' Agostino, 2010; Adamopoulos et al., 2017).

In the last years, digital image processing has been widely used in the field of stone heritage conservation for studying decay indicators, such as black crusts and salt efflorescences (Moropoulou, Labropoulos, Delegou, Karoglou, & Bakolas, 2013; Vázquez, Galán, Guerrero, & Ortiz, 2011). Furthermore, the employment of multi-band imaging has proven the ability to contribute to more accurate mapping results due to different radiometric signatures that historical materials, decay forms, and moisture content levels show, especially at the near-infrared (NIR) and thermal infrared (TIR) spectra (Lerma, Cabrelles, Akasheh, & Haddad, 2012; Rahrig, Drewello, & Lazzeri, 2018). The combination with photogrammetric techniques (Del Pozo et al., 2015; Themistocleous, Evagorou, Mettas, Prodromou, & Hadjimitsis, 2020) and low-cost sensors (Adamopoulos, Rinaudo, & Bovero, 2019; Russo, Giugliano, & Asciutti, 2019) provides an additional potential towards increasing the automatization and cost-effectiveness of weathering mapping procedures.

Based on the above rationale, the presented work aims to investigate the application of low-cost multispectral sensing techniques and simple digital image processing procedures to record stone weathering on the remains of monumental structures. This combination serves to facilitate the rapid preliminary evaluation of heritage assets, by identifying regions of interest for more in-depth diagnostic investigations (invasive and non-invasive).

2. Materials and Methods

The techniques implemented in this work involved three sensors for capturing imagery at different spectra. A Canon Rebel-SL1 digital camera (with resolution of 5184

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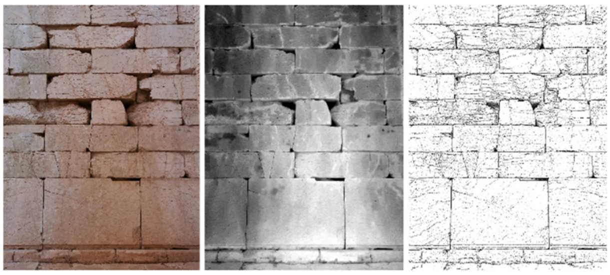
x 3456 pixels) was used to acquire the NIR images. A Huawei P30 smartphone (Sony IMX650 sensor) was used to acquire the visible spectrum images, and a FLIR ONE Pro TIR camera (with resolution of 160 x 120 pixels) was used to acquire long-wavelength infrared images.

Captured visible-spectrum and NIR photos were exported in raw image format, then undistorted, denoised, and devignetted (Del Pozo et al., 2015). RGB images were additionally color-balanced. The band-specific images of all sources (visible-spectrum, NIR, and TIR) were co-registered—using feature based-matching, and affine transform and cubic interpolation for the resampling—and fused to create multispectral images and pseudo-color composites in the HyperCube free software. For some of the investigated surfaces, partial three-dimensional (3D) models were constructed in a standard photogrammetric procedure, while the processing and the classification of multispectral images and mesh textures were also conducted in HyperCube. Visualization and exploitation of the 3D meshes were executed in CloudCompare.

3. Results and Discussion

The first case study used to showcase the considerable value of the implemented technologies was the temple of Apollo Epikourios at Bassae (Greece), a World Heritage List inscribed monument degraded from acid rain and extreme weather conditions, sheltered since 1987.

Multispectral images of the naos (Fig. 1a) were analyzed utilizing principal component analysis (PCA) to construct maps of the preservation state (Fig. 1b), revealing not only the level of weathering (grayscale) but also the locations of past restoration interventions (white-colored). The NIR images' histogram was adjusted appropriately to derive a map of the extensive cracks (Fig. 1c).

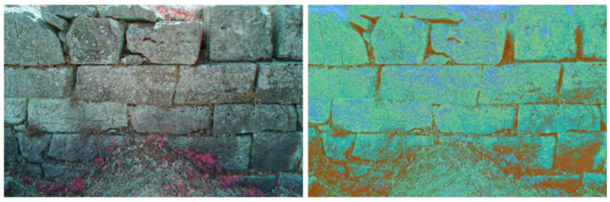


(a) (b) (c)

Figure 1: Weathering mapping for the temple of Epicourios Apollo at Bassae: a) visible image; b) map of weathering stages; c) map of cracks.

The second case study was the temple of Athena and Zeus Sotiros at ancient Phigalia (Greece). Unsupervised k-means segmentation-based classification of NIR-Red-Green composites (based on the number of observable types of deterioration) gave a representative mapping of the crusts (Fig. 2b; brown) and lichens (blue-colored).

The cubic stone pedestal surfaces of the worshiping statue from the cella (Fig. 3a) were digitally 3D modeled using a NIR photogrammetric dataset. The model was segmented in 3D (Fig. 3b) according to the near-infrared intensities. As evident, the white segmented areas represent surface parts covered with lichens, while the gray areas represent the scales of weathering, and specifically the development of black crusts.



(a) (b)

Figure 2: The temple of Athena and Zeus Sotiros: a) NIR-Red-Green composite; b) weathering mapping.

(a) (b)

Figure 3: Ancient pedestal of the worshiping statue from the cella: a) visible-spectrum image; b) 3D classification of the surface weathering by texture segmentation.

The last case study was the remains of the ancient walls at the archaeological site of Lepreum (Greece). Part of the walls was modeled using visible-spectrum imagery and image-based modeling (Fig. 4a). A workflow including orientation of optical images from the ONE Pro camera at the same photogrammetric dataset as the RGB images from the P30 camera, and subsequent replacement of RGB images with the thermal images (after necessary geometric transformations were applied) was implemented to additionally map the model with thermal information (Adamopoulos, Volinia, Girotto, & Rinaudo, 2020) (Fig. 4b). Both models were segmented, revealing the covering of historical surfaces by different alteration and damage types (Fig. 4c) and the approximate distribution of moisture content (Fig.4d).

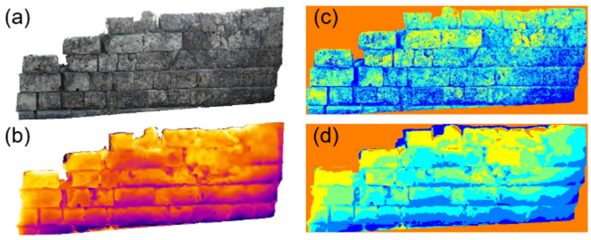


Figure 4: Weathering mapping for the ancient walls at Lepreum: a) 3D model textured with visible-spectrum imagery; b) 3D model textured with thermal imagery; c) classification of surface decay; d) classification of moisture content levels.

4. Conclusions

This short paper presented the authors' progress in involving low-cost sensors for rapid, cost-effective, and automatized generation of maps of the weathering of heritage remains, which can serve as the basis for detailed and accurate non-destructive diagnosis. The results showcase how inexpensive techniques can provide crucial results for the state of preservation assessment that is required for every decision making process regarding essential heritage assets. In particular, near-infrared and thermal-infrared sensors' employment contributed significantly to the results, while weathering indices and different deterioration typologies were successfully identified.

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