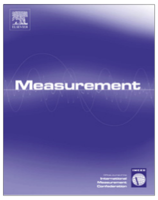
Measurement 56 (2014) 194–202

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement



Conversion of a digital camera into a non-contact colorimeter for use in stone cultural heritage: The application case to Spanish granites

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ARTICLE INFO

Article history:
Received 26 March 2014
Received in revised form 28 May 2014
Accepted 23 June 2014
Available online 16 July 2014

Keywords:
CIELAB system
CMOS camera
Color calibration
Cultural heritage
Granite
Ornamental stone
RGB values

ABSTRACT

In this study, a digital CMOS camera was calibrated for use as a non-contact colorimeter for measuring the color of granite artworks. The low chroma values of the granite, which yield similar stimulation of the three color channels of the camera, proved to be the most challenging aspect of the task. The appropriate parameters for converting the device-dependent RGB color space into a device-independent color space were established. For this purpose, the color of a large number of Munsell samples (corresponding to the previously defined color gamut of granite) was measured with a digital camera and with a spectrophotometer (reference instrument). The color data were then compared using the CIELAB color formulae. The best correlations between measurements were obtained when the camera works to 10-bits and the spectrophotometric measures in SCI mode. Finally, the calibrated instrument was used successfully to measure the color of six commercial varieties of Spanish granite.

1. Introduction

Color is one of the most important visual properties of ornamental and monumental stone. Color changes caused by weathering and decay greatly influence the aesthetic value of stone. Extent of such change can be quantified by contact-type color measuring devices (colorimeters and spectrophotometers [1–6]) and analyzed in a device-independent color space, such as CIE-*XYZ* or CIE-$L^*a^*b^*$. But these devices present some limitations: (1) sometimes is not possible to reach the target object with the instrument, (2) they are more expensive and complex than other non-dedicated color measuring devices (digital cameras, scanners and even mobile-phone cameras) and (3) as the field of view of contact-type color devices is limited, measurement of heterogeneous surfaces produces unrealistic color values. To overcome these limitations, digital cameras can be used because (1) the field of view is only limited by the size of the appropriately illuminated area, (2) contact with the target object is not required, and (3) they encode each point of the entire surface simultaneously, thus quantifying surface characteristics and defects.

Digital cameras only detect changes in light intensity, not color. To encode color, they require three different filters in addition to the sensors. These filters usually have spectral bands in the red (R), green (G) and blue (B)

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http://dx.doi.org/10.1016/j.measurement.2014.06.023
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regions, and therefore the encoded values are RGB digital values. RGB is a device-dependent color space as the filters and other parameters are specific to individual cameras and can be changed with camera settings such as the spectral exposure level, white balance and the dynamic range. As RGB values cannot be transformed to *XYZ* or $L^*a^*b^*$ values directly by using a standard formula, a transformation that defines the mapping between RGB digital values and a device independent color space is necessary. This process is known as camera characterization [7]. Several camera characterization techniques have been used with the aim of developing a model (and estimating its parameters) for obtaining $L^*a^*b^*$ color measurements from RGB digital values (e.g. [7–15]). In general, these techniques can be divided into two categories: (1) *spectral characterization*, which measures the three spectral-sensitivity functions for the red–green–blue (RGB) channels and requires a monochromator and a radiance meter [16]; and (2) *colorimetric characterization*, which involves mathematical transformations that yield the tristimulus values from the digital values and which require use of a reference target that contains a certain number of color samples. In the present study, we used the latter color target-based approach, which only requires a certain number of color samples and is, therefore, a more practical method [7]. We chose target-based characterization procedure described by Hong et al. [7], which is based on polynomial modeling. This calibration model has been used successfully in nearly two hundred scientific papers with different objectives, e.g., to determine how facial skin coloration affects perceived health of human faces [17,18] and for use in dental color matching [19].

In the field of lithology, the image captured by the camera is usually processed by different segmentation strategies. For example, one innovative application focuses on the segmentation of decay zones from images of stone materials [20,21]. Another strategy enables improvement and semi-automatization of the study of chemical decay causing visible changes in color of some regions [22]. A portable stereo active vision system (AVS) has also been specifically designed to perform on-site processing of the data acquired in the field of cultural heritage conservation [23]. Moreover, the digital decorrelation of RGB images by Principal Components Analysis (PCA) enables contrast enhancement of minority elements apparently absent from the initial RGB digital image [24–27]. Camera characterization has been used in very few studies, including that of Chorro et al. [28], who used the sRGB model to predict the CIE-*XYZ* tristimulus values depending on the RGB digital data, with the final aim of quantifying color changes in the appearance of a paving stone (marble) in relation to the viewing distance. More recently, Concha-Lozano et al. [29] used spectroradiometric measurements to calibrate a camera in order to establish the color ranges within which replacement of biodetritic limestone in medieval walls will be imperceptible. Nevertheless, to our knowledge, camera characterization has not previously been reported for granite. Measurement of the color of granite is complicated by the low chroma and spatially heterogeneous color, which is formed by the different colors of the constituent minerals. There is great interest in measuring the color of granite because, amongst other reasons, granite is one of the most commonly used types of igneous rock owing to its abundance and great variety of color and textures, and because it is a major construction material in European historical buildings and monuments [30].

The present study focused on developing a method of RGB digital camera colorimetric characterization for studying stone, specifically granite. The nearly neutral colors of granite yield similar stimulation of the three color channels of the camera (red, green and blue), which makes the task in hand particularly challenging. For the first time, the settings of a digital camera have been adjusted to obtain the camera response closest to that of the reference instrument (spectrophotometer) for granite color measurement using the CIELAB system. The developed method was successfully used to measure the color of granite samples. This is of particular interest in the field of stone conservation, in which innovative non-invasive tools for monitoring the aesthetic changes in stone surfaces are required.

2. Experimental

2.1. Fine-tuning of the camera calibration method

The methodology developed for estimating the RGB → $L^*a^*b^*$ transformation consisted of two parts. In the first part, we determined the appropriate settings and working conditions of the acquisition system (camera) and reference instrument (spectrophotometer). In the second part, we selected a large set of Munsell matte and glossy samples corresponding to the previously defined color gamut of granite [31]. The colors of these samples were measured using both devices under the conditions indicated in the first part. The digital images were obtained with the following image acquisition system (Fig. 1):

- PixeLINK PL-A782 color digital camera, 2008 (suitable for industrial use), with CMOS sensor architecture, 6.6 Mega Pixels of resolution and a user-selectable 8 or 10-bit output. The camera was placed vertically at a distance of 112 cm from the sample. The angle between

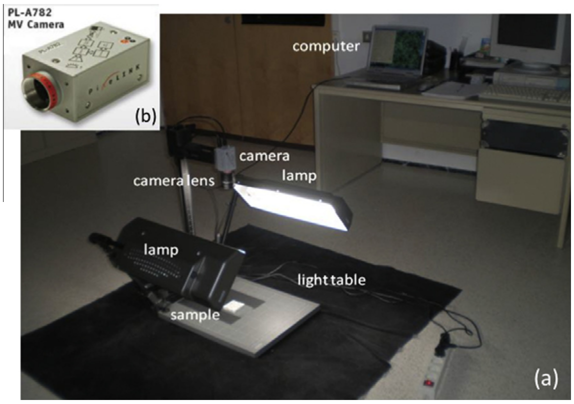

Fig. 1. Image acquisition system setup. (a) Laboratory computer vision and capture system and (b) PL-A782 CMOS digital camera.