Colour measurement of natural stones using a calibrated digital camera

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ABSTRACT

Natural stones (marbles, granites, etc.) are used as building materials like ceramic tiles and artificial stones. In this work, we evaluate whether automatic natural-stone classification can be performed based on colorimetric calibration and S-CIELAB model of human colour perception. We found significant differences between the histograms of the ΔE S-CIELAB model from different marble types, which might be taken into account on industrial applications.

1. INTRODUCTION

Natural stones (marbles, granites, etc.) are used as building materials like ceramic tiles and artificial stones. Unlike human-made elements, natural stones are irregular with texture elements (veins, spots, fine grain, etc.) that are hard to colour evaluate using a tele-spectroradiometer. When the texture of the natural stone is spatially variable, then the measured and perceived colour at different distances changes due to spatial dithering. Moreover, the problem of natural stone classification brings additional industrial problems as each stone type changes in texture among horizontal and vertical sections of the same stone block, which forces to visually classify each natural stone into several subjective categories of marble quality. This visual classification is performed at near distances (less that 1 m) even though these building elements might be covering facades of buildings that are at much more viewing distance. As a consequence, there is a visual over-classification in the production plant due to humans being the 'stone classifiers'.

In this work, we evaluate whether natural-stone classification could be performed automatically using colorimetric calibration and the S-CIELAB model of a digital image capture device. We analyze colour differences among different natural stones and we further evaluate whether colour appearance of different samples at several distances might produce the same percept.

2. MATERIALS AND METHODS

Thanks to the company Eurostone S.A., we have got twelve polished samples of size $10*10\text{cm}^2$ of six types of spanish marble (Crema Marfil, Marrón Emperador, Marrón Imperial, Negro Marquina, Rosa Zarci, and Rojo Alicante; two samples per marble type). The samples were captured by a CMOS digital camera Pixelink 662, with zoom lens Navitar 7000, at 0.58 meter distance using the repro stand Kaiser RS 2 XA, with incandescent lighting in geometry configuration double 45/0.

$$\begin{bmatrix} X(i,j) \\ Y(i,j) \\ Z(i,j) \end{bmatrix} \frac{\text{cd}}{\text{m}^2} = \begin{bmatrix} -258.47 \\ -290.63 \\ -23.97 \end{bmatrix} + \begin{bmatrix} 6.749 & 0 & 0 \\ 0 & 4.254 & 0 \\ 0 & 0 & 4.429 \end{bmatrix} \cdot \begin{bmatrix} 0.6357 & 0.5472 & 0.2541 \\ 0.2855 & 1.6156 & 0.092 \\ -0.2654 & -0.4864 & 1.4588 \end{bmatrix} \cdot \begin{bmatrix} -13.99R^2(i,j) + 73.77R(i,j) + 10.95 \\ -3.75G^2(i,j) + 47.95G(i,j) + 37.84 \\ -17.45B^2(i,j) + 71.51B(i,j) + 13.97 \end{bmatrix} \quad (1)$$

$$\text{with} \begin{bmatrix} R(i,j) \\ G(i,j) \\ B(i,j) \end{bmatrix} = \begin{bmatrix} 0.7881\cdot(255-2.10) & 0 & 0 \\ 0 & 0.4630\cdot(255-2.56) & 0 \\ 0 & 0 & 255-15.14 \end{bmatrix}^{-1} \cdot \begin{bmatrix} DOL_R(i,j) \\ DOL_G(i,j) \\ DOL_B(i,j) \end{bmatrix}$$

The digital camera was calibrated spectrally, using a monochromator method[1], and colorimectrically[2]. The colorimetric calibration was developed with a DC ColorChecker chart prior the calculation of a colour model based on the data from the spectral calibration. This colour calibration was valid according to several initially fixed opto-electronic parameters: white balance, gain and saturation applied through the manufacturer control software. If DOL(i,j) are RGB digital output levels with 8bit-depth captured at pixel (i,j), the absolute tristimulus values XYZ(i,j) (in cd/m^2) are obtained from the complete colour transform describe in Equation 1.

Here, we assume that spatial calibration of the camera was not needed. Thus, the colour calibration associated only to the centre of the sensor was applied to all the sensor extent. The camera spatial resolution was 1280*1024 active squared pixels with *p*' = 7.5 μm as pixel size. The image distance *x*' was 36.19 mm to the sensor area. Therefore, the angular resolution of the pixel is

$$u = 2\arctan\left(\frac{active\ pixel}{2x'}\right) = 2\arctan\left(\frac{7.5e-6}{2\cdot 36.19e-3}\right) = 0.0119 \text{ deg}\,, \qquad (2)$$

and the subtended object of size *p* from one pixel at distance *x* (= 0.58 m, our measurement distance) is $p = 2\cdot x\cdot\tan(u/2)$ = 0.12 mm, which produces an image size of 832*832pixels.

To state successfully the problem of the visual over-classification at near distance in some types of natural stones, we must consider several topics about spatial colour dithering. This is the same visual effect that arises in TV colour reproduction and halftone printing. However, it is modelled like in displays, different from way for halftone printing[3]. In fact, since we have calibrated XYZ images, where the active pixels are squared and non-overlapping, a partition additive mixing[4] with the same weighting in all *k by k* pixels, is transformed onto the XYZ average of *k by k* pixels. That is, the dithered tristimulus values XYZ of a *k by k* cell of calibrated active pixels are

$$X = \frac{1}{k^2}\sum_{i,j=1}^{k} X(i,j) \quad , \quad Y = \frac{1}{k^2}\sum_{i,j=1}^{k} Y(i,j) \quad , \quad Z = \frac{1}{k^2}\sum_{i,j=1}^{k} Z(i,j) \qquad (3)$$

This argument is correct from psychophysical data because the tristimulus values XYZ in cd/m^2 have been estimated with the calibrated digital camera.

For simulating now the spatial colour dithering at intermediate, let us at first place that the dimensions of the spot or vein with minimum size of a natural stone was *cell* millimeters. Therefore, using the fundamentals of sampling theory, the capture distance of the stone where these minimum feature regions are resolved independently would be $x_0 = cell/(2\cdot\tan(u/2))$. To simulate the spatial colour dithering of the natural stone, we should assume two conditions: First, the far distance x was equals to $k\cdot x_0$, with *k* being a natural number. And second, the digital camera is capturing a mosaic (facade) with $size = N\cdot cell$, with *N* also being a natural number. These conditions are essential to this simulation. The first condition links the sampling theory with the partition additive colour mixing (Eq. 3). The second condition forces on focussing on the whole mosaic, but not on their components. Thus, the subtended object of size *p* at distance *x* equals to $2\cdot k\cdot x_0\cdot\tan(u/2)$. Therefore, the dimensions of the captured image are ready for image processing at both distances (x_0 and $k\cdot x_0$) are the same, but not the subtended object-size *p*, though. Then, the second image (at distance $x = k\cdot x_0$) can be considered as an image with minor spatial resolution because the dimensions are now $(1/k^2)*(N\cdot cell)/(2\cdot x_0\cdot\tan(u/2))*(N\cdot cell)/(2\cdot x_0\cdot\tan(u/2))$. And since we have now two images with the same spatial register, the S-CIELAB model would compute the colour difference between the marbles sample seen at x_0 and the simulated texture image seen at $k\cdot x_0$. We assume this argument is correct given the size of the colour features are constant independently of the tile size (*N* free) and that humans always focus optimally at real size $N\cdot cell$, not focus on particular colour features (*cells*).

With calibrated XYZ images the S-CIELAB[4-7] model can be next applied. We modified its original MATLAB implementation to adapt a camera instead of a CRT display[4,5]. The *whitePoint* data was replaced by a reference white measured in the capture setting. We obtained the following values for the white point X = 981 cd/m^2, Y = 914 cd/m^2, and Z = 324 cd/m^2. We also replaced the parameter *sampPerDeg* of the MATLAB implementation as the inverse of angle *u* (Eq. 2).

S-CIELAB models are used to obtain the CIE- L*a*b* prior spatial filtering[4-8] of the XYZ colour channels through a simple opponent colour model. Therefore, it is one of the more easy models that combine spatial and chromatic features of human vision.

4. RESULTS

The third column of Figure 1 shows the histograms of global colour differences between pairs of marble samples (Rosa Zarci -A1- versus Rojo Alicante -A2; Marrón Emperador –B1- versus Marrón Imperial –B2; and two samples of Marrón Emperador –C1 and C2; Figure 1) as seen at different distances. Global colour differences from samples from different marble types produce histograms where the maximum of the differences (ΔE median = 41.97, k = 1; 44.46, k = 20; 43.86, k = 40, for A1 and A2 samples) are far higher the perceptual discrimination threshold, which is assumed to be around 10 jnd (upper right panel, Figure 1) for colour memory. On the other hand, samples with visually similar textures and nuances, but coming from different marble types, produced colour differences that are also above the perceptual discrimination threshold, but closer to it (ΔE median = 26.76, k = 1; 25.20, k = 20, 22.35, k = 40, for B1 and B2 samples). Finally, samples from the same marble type produced the most striking profiles. These samples have shown a roughly linear fall in a semi-logarithmic scale at all distances. Interestingly enough, the peak is closer to the perceptual discrimination threshold (ΔE median = 15.35, k = 1; 13.08, k = 20; 10.99, k = 40, for C1 and C2 samples). For all samples analyzed, we found that distance produced a leftward shift to the distribution towards smaller ΔE values.

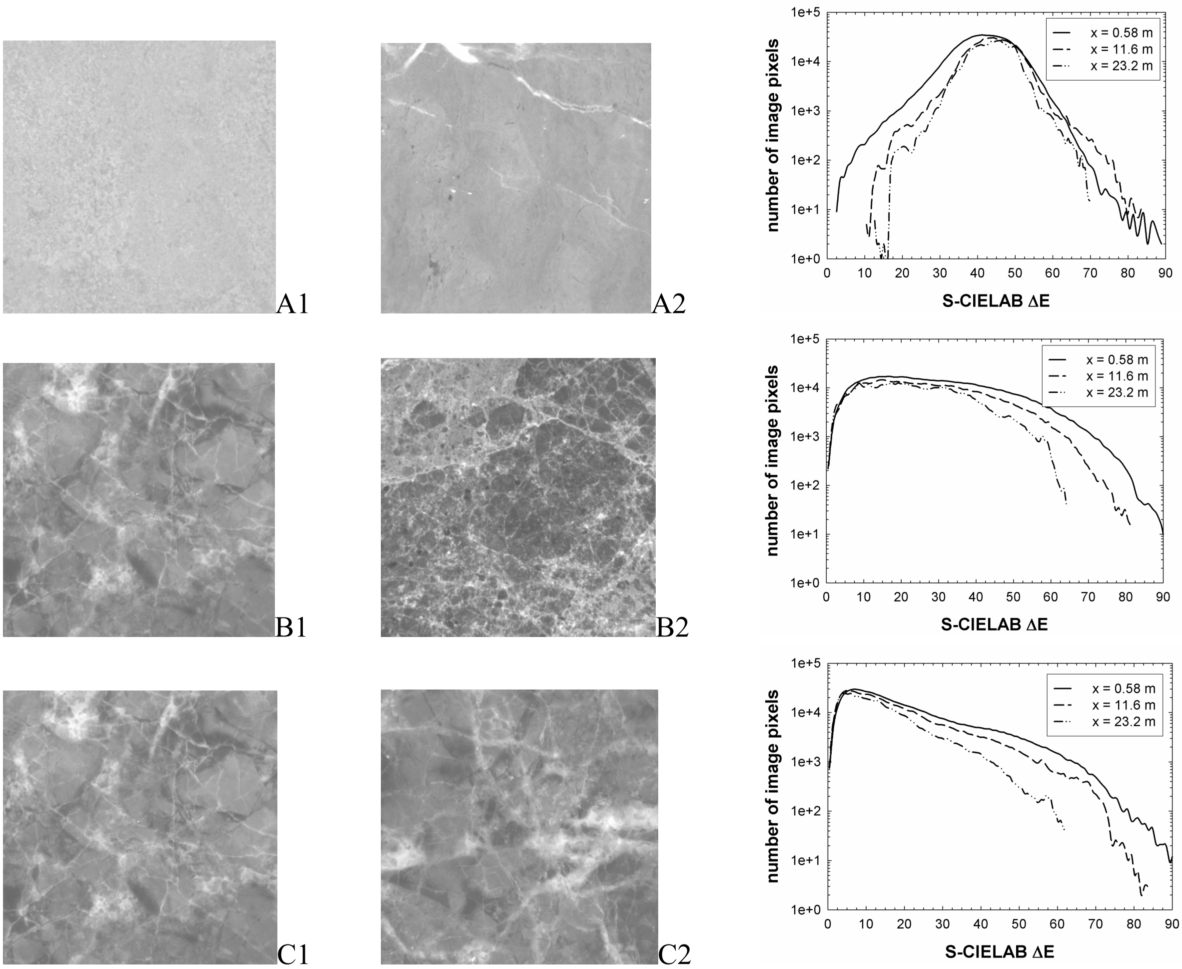

Figure 1: Histograms (the rightmost column) of S-CIELAB colour differences for three pairs of marble samples at different viewing distances (see legend inside graph).

4. DISCUSSION AND CONCLUSIONS

We found differences between the histograms of the colour differences of pairs of samples from several marble types. The strongest differences were found when the samples came from different marble types with very different textures (for instance samples A1 and A2; Figure 1). In this case, the histogram presented a central peak at intermediate ΔE values on a semi-logarithmic scale, which means that the vast majority of pixels in the samples were way above the colour discrimination threshold. This strong difference was also observed when two samples from similar marble types were compared (samples B1 and B2; Figure 1). However, the overall profile of these histograms was less peaked as the result of the increase of small ΔE. Finally, the linear fall of the profiles of the colour differences when analyzing samples from the same marble type provides a reasonable justification to use this methodology on future automatic natural stone classifiers.

Finally, we would like to mention that S-CIELAB model of human colour perception does not fulfil our expectations by providing great differences between visually different marble types as humans are capable. This implies that this model is a good, but partial, approximation to spatial and colour human vision, which would lead us to analyse alternate models[8,9] of human spatial-chromatic perception for industrial purposes.

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