A comparison of a multi-layer silicon sensor camera and a 3CCD camera for measuring small colour differences

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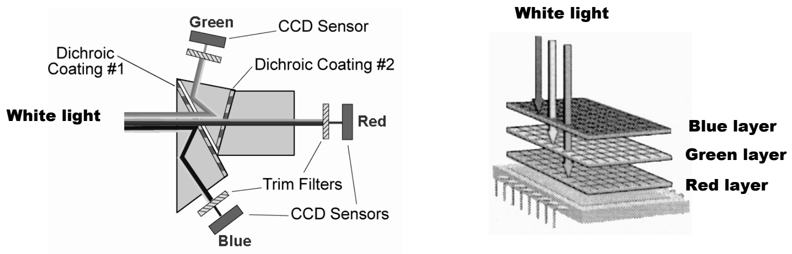
ABSTRACT

We explore the possibility of using cameras to measure small colour differences with certain reliability. Attention is paid to the camera's performance in the nearly neutral region of colour space. We investigate two cameras: a 3CCD video camera (SONY DX-9100P) and a digital still camera (Sigma SD-9) with a multi-layer silicon sensor (Foveon sensor). The cost of this camera is much lesser than the Sony camera and has better resolution. Its potential application to colorimetric purposes is assessed and compared with a 3CCD. We evaluate the discrepancy in the small colour differences measured by the two cameras in comparison to the same colour differences measured by a reference instrument (Photo Research PR-715 spectroradiometer). The colour differences are calculated using the CIELAB and CIEDE2000 colour-differences formulas.

1. INTRODUCTION

The methods for the characterization and modelling of cameras[1] allow one to predict whether the acquisition and recording of the colour content of the image has enough covering of luminance, hue and chroma scales. As far as we know, few efforts has been devoted to exploit the discrimination capability of colour cameras in the measurement of small colour differences.[2,3] Marszalec et al.[2] and Hong et al.[4] have analysed the metamerism in cameras comparing it with that of the human visual system. Although there exist a number of instruments (colourimeters, spectro-photometers, spectroradiometers) capable to measure colour differences with high precision and accuracy, these instruments measure colour in an integration area of the sample with limited flexibility in configuration and dimensions. These constraints cannot be easily modified in general, even for some expensive and sophisticated instruments. On the other hand, it is interesting to measure reliable colour differences limited to pixel resolution with relative reduced cost. This is a promising property of the smart and improved cameras that are appearing in the market.

We investigate two cameras (Figure 1): a 3CCD video camera (Sony DX-9100P) and a digital still camera (Sigma SD-9) with a multi-layer silicon sensor (Foveon sensor) with a new technology. The cost of camera with the Foveon sensor is much lesser than the camera with the 3CCD sensor and has better resolution. In this work we explore the possibility of using these cameras to measure small colour differences in a perceptually uniform system with certain reliability. We compare each camera performance with a reference instrument (spectroradiometer PR-715) and then, we compare the two cameras. We focus on the nearly neutral region of colour space. In this region we have a set of Munsell patches of very next colours. The nearly neutral colours entail a similar stimulation of the three –red, green and blue- sensitive channels and the differences between these colours involve small variations on a nearly constant background signal. This sort of colours is very used by the industry (of the



a) b)

Figure 1: Scheme of: a) 3CCD sensor, b) multilayer silicon sensor.

paper, textile, painting and decorating) and they have commercial interest.

2. METHOD

The method has two stages. In the first stage, we determine the appropriate working conditions of the two cameras with a given lighting-viewing configuration. This geometry is also used to measure with the reference instrument. The characterization of a camera requires the spectral sensitivity curves of the sensors. A conceptually simple method to estimate them is based on sequentially stimulating the camera with very narrow-band illuminations in the range of the visible spectrum. To overcome the device dependent representation of colour, we follow the method described in Refs. 5, 6 to calculate the coefficients of a linear transformation that defines a mapping between the camera R, G, B signals and a device independent representation, such as the standard CIE 1931 XYZ. Once the linear transformation is defined for a given camera and a given light source (D65 simulator), the CIELAB coordinates can be calculated using the standard formulas. CIELAB and CIEDE2000[7] formulae (ΔE^*_{ab} and ΔE_{00}) are used to calculate the colour differences. We have considered CIEDE2000 suitable for our study because includes a term to improve performance of low-chroma colours.[8] Concerning the amount of uncertainty associated with the measurement process we consider an specific metric called the mean colour difference from the mean (MCDM).[9] For a set of CIELAB measurements, the average ($\overline{L}^*, \overline{a}^*, \overline{b}^*$) is calculated. Then, a colour-difference equation (in our case, either ΔE^*_{ab} and ΔE_{00}) is calculated between each individual measurement and ($\overline{L}^*, \overline{a}^*, \overline{b}^*$). The average of all the colour differences defines the MCDM. We calculated the MCDM of the three instruments.

To build the test, we select an assortment of ten samples from the matte Munsell collection. The samples, named group centres, were regularly distributed in the Munsell hue circle, with low value of Munsell Chroma (2), and high value of Munsell Value (8) (Figure 2). Taking into account the Munsell specification of hue, Value and Chroma, we consider variations of ±2.5 hue, ±0.5 Value, ±0.5 Chroma around each group center. According to this, our test consists of 70 Munsell matte colour chips. In the second stage of the method, all the colour differences between every group centre and its neighbours are measured in pairs by the two cameras as well as by the reference instrument.

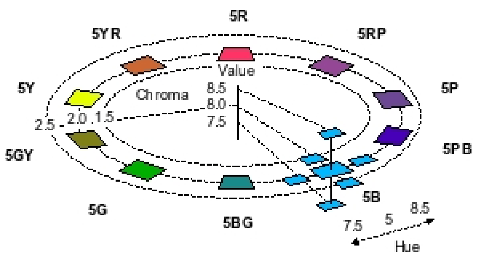


Figure 2: Colour test of Munsell chips.

Once the colour differences are obtained with the three instruments, we estimate the absolute discrepancies (D_{ii}) between the colour differences measured by the reference instrument and by each camera by simply subtracting them and taking the absolute value. This is the way to test the reliability of the camera's performance in comparison with that of the reference instrument. The best camera performance would correspond to the smallest discrepancy.

3. RESULTS

Figure 3 shows the three spectral response curves of the cameras: a) Sony DXC-9100P with (gain, offset) = (255, 32), b) Sigma SD-9 with shutter speed 1/30s and aperture size f8. Other conditions were analysed and we reached the conclusion that the most appropriate sets of curves for our work were those indicated in Figure 3. Considering the measure of goodness ν defined in Ref. 10, the set of spectral sensitivity curves of our camera's sensors reaches the value ν =0.916 for the Sony camera and ν =0.827 for the Sigma camera. This

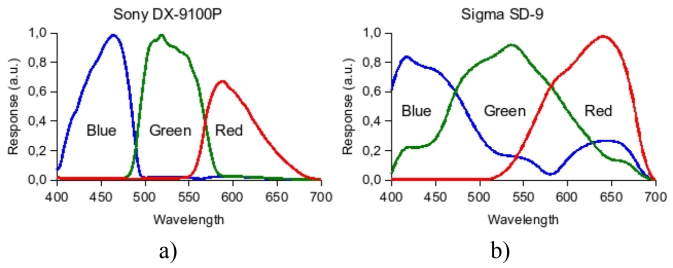


Figure 3: Spectral response of the cameras: a) Sony DX-9100P and b) Sigma SD-9.

value indicates that the Sony camera spectral sensitivities are closer to the human colour-matching functions than the Sigma camera.

Using a D65 simulator and the spectral response curves of the two cameras and following the method described in Ref. 6 we compute the coefficients of the linear transformation that define a mapping between the camera R, G, B signals and the device independent CIE 1931 XYZ triestimulus values. Thus, we obtain for the Sony camera:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 2.080 & 0.246 & 0.359 \\ 1.239 & 1.059 & 0.094 \\ 0.065 & -0.119 & 2.130 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}, \quad (1)$$

and for the Sigma camera:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 1.054 & 0.161 & 0.315 \\ 0.353 & 0.956 & -0.251 \\ -0.185 & -0.393 & 2.256 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}. \quad (2)$$

We calculate the MCDM of the measurements obtained from a set of ten samples, taken at the central area of a Munsell chip, and each one is measured ten times. In the case of the Sony camera measurements, each individual measurement (L_i^*, a_i^*, b_i^*) is, in turn, the average CIELAB coordinates of the central field window of 300x300 pixels. In the case of the Sigma camera the window is of 120x120 pixels. We have repeated the procedure for the ten colour patches and have observed stability in the final result. Following the notation given in Ref. 9, the value $n\Delta E^*_{ab}$ is the MCDM in the CIELAB metrics. Similarly, the value $n\Delta E_{00}$ is the MCDM in the CIEDE2000 metrics. We have obtained that the spectroradiometer has a precision of $0.025\Delta E^*_{ab}$ and $0.020\Delta E_{00}$. The Sony camera has a precision of $0.050\Delta E^*_{ab}$ and $0.060\Delta E_{00}$ working with (gain,offset)=(255,32). The Sigma camera has a precision of $0.103\Delta E^*_{ab}$ and $0.080\Delta E_{00}$ working with shutter speed 1/30s and aperture size f8. According to a statistical rule of thumb, the instrumental colour tolerance should be no less than ten times the measurement precision. This rule gives us a magnitude order of our instrumental tolerances: $0.25\Delta E^*_{ab}$ or $0.20\Delta E_{00}$ for the spectroradiometer, $0.50\Delta E^*_{ab}$ or $0.60\Delta E_{00}$ for the Sony camera, $1.03\Delta E^*_{ab}$ or $0.80\Delta E_{00}$ for the Sigma camera.

Figure 4 shows ΔE_{00} measured for the three variations in Munsell hue (±2.5), Chroma (±0.5), and Value (±0.5) with respect to each group centre under D65 illumination as they are measured by the spectroradiometer (black line), the Sony camera (triangle) and the Sigma camera (square). From the results plotted in Figure 4, we realize that the Sony camera and the reference instrument present a high level of agreement in the estimation of the colour differences. The value is the magnitude with smallest absolute discrepancy between the Sony camera and the reference instrument. The colour differences obtained with the 3CCD camera are smaller than with the Foveon camera.

The absolute discrepancy between the Sony camera and the reference instrument is less than 0.5 (D_{ab}) or 0.23 (D_{00}) on average, and we consider this is a great achievement for the Sony camera system because they fall within the camera tolerance. The subindex denotes what colour difference formulas has been used, CIELAB (D_{ab}) or CIEDE2000 (D_{00}). The absolute discrepancy between the Sigma camera and the reference instrument is D_{ab}=0.77 and D_{00}=0.26 on average, and these values are also inside the camera tolerance.

4. CONCLUSIONS

We have explored the possibility of using digital cameras to measure small colour differences in the nearly neutral region with certain reliability. We have investigated two cameras: a 3CCD video camera (SONY DX-9100P) and a digital still camera (Sigma SD-9) with a multi-layer silicon sensor (Foveon sensor) and have compared their performance with a spectroradiometer as reference instrument. According to our experimental results, both cameras are in good agreement with the spectroradiometer in measuring small colour differences. The Sony camera has a better performance than the Sigma camera because the average of the absolute discrepancies with the spectroradiometer has the lowest value. This result is consistent with the fact that the Sony camera has a ν value higher than the Sigma camera. Smallest absolute discrepancy is obtained when the colour differences are calculated using CIEDE2000 formulae. Nevertheless, we consider that the Sigma camera constitutes a good trade-off between its costs and quality.

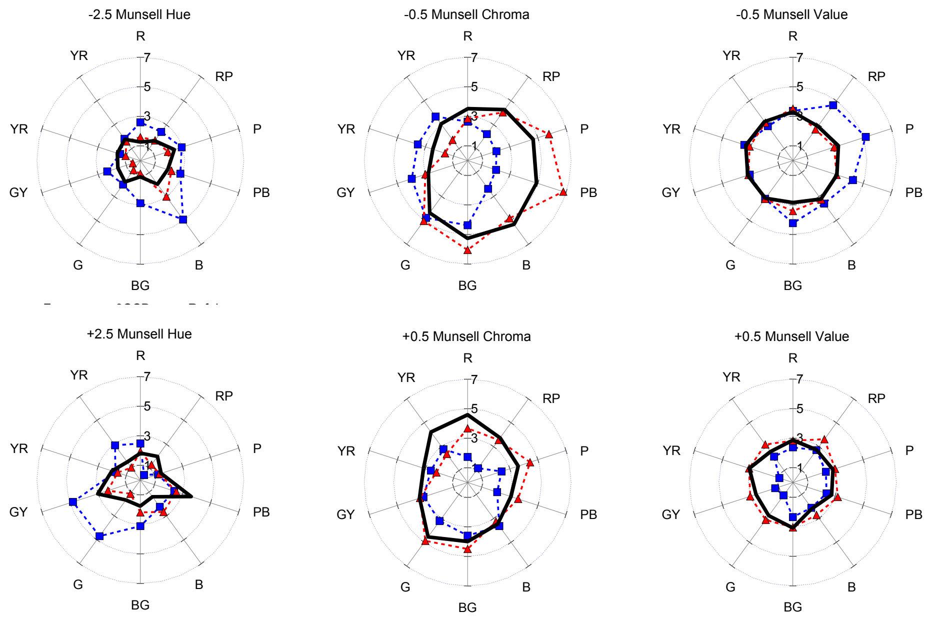


Figure 4: Colour differences ΔE_{00} measured under D65 illumination by the spectroradiometer (black line), the Sony camera (triangle) and the Sigma camera (square).

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