Camera's Performance in Measuring Small Colour Differences in the Nearly Neutral Region

María S. Millán and Edison Valencia
Universitat Politècnica de Catalunya
Terrassa, Barcelona, Spain

Abstract

A method to evaluate the discrimination capability of camera to measure small colour differences in the nearly neutral region (very pale and dark grayish colours) is proposed. The measurements obtained by the camera are compared with those obtained by a reference instrument (spectrophotometer). Such comparisons indicate the reliability of the camera for this colorimetric purpose. CIELAB and CIEDE2000 formulae have been used for the estimation of colour differences. The method is applied to an acquisition system composed by a 3CCD colour camera capturing under standard D65 illumination. The results for the testing set of selected Munsell matte chip pairs show that the colour differences obtained by the given camera are close to those measured by the spectrophotometer over the circle of hue.

The application to real cases of colour matching in textile inspection demonstrates that the camera system is reliable enough for this task.

Introduction

Colour imaging devices such as cameras and scanners have an increasing relevance in colour data acquisition of spatially variant scenes. A colour camera can be a component integrated in a versatile computer vision system, not necessarily complex nor too expensive, that permits a great variety of tasks in image featuring and inspection with a good trade-off between image quality and precision in colour measurement. A remarkable effort has been devoted to establish methods for the characterization and modelling of cameras.[1-3] They allow one to predict an acceptable acquisition and recording of the colour content of the image with enough covering of luminance, hue and chroma scales.

As far as we know, less effort has been devoted to exploit the discrimination capability of colour cameras in the measurement of colour differences. Although there exist a number of instruments (colorimeters, spectrophotometers, spectroradiometers) capable to measure colour differences with high precision, 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 3CCD cameras that are appearing in the market.

In this paper we explore the possibility of using the 3CCD camera to measure small colour differences with certain reliability. We concern with the precision of the camera and compare it with a reference instrument. We propose a method to carry out the study and particularize it to the nearly neutral region of colour space (unsaturated colours). This region represents a challenge for the instrument since the nearly neutral colours entail a similar stimulation of the three–red, green and blue-sensitive channels of the camera and the differences between these colours involve small variations on a nearly constant background signal. On the other hand, most of the colours contained in real scenes have low chroma and they draw the industrial attention, particularly related to materials for painting, clothing or decorating.

The CIELAB[4,5] and the more recent CIEDE2000[6] formulae are used to estimate colour differences. More especially, CIEDE2000 includes a term to improve performance of low-chroma colours[7] and therefore we have considered it suitable for our study. We analyse the camera's performance for the very pale and the dark greyish colour regions. As example of application, we consider a practical real case of colour matching in textile industry.

Selecting the Working Conditions of the Camera

The method we propose has two stages. In the first stage, we determine the appropriate working conditions of the acquisition system that consists of a 3CCD camera (SONY DX-9100P, 8-bit), a framegrabber, a PC, and a given lighting-viewing configuration. We consider standard daylight illumination (D_{65}) and a spatial configuration for which the scene is captured away from specular reflections (20º for illumination, 0º for capturing). Figure 1 shows the three spectral response curves of the camera sensors. Considering the measure of goodness ν of a set of colour-scanning filters defined in Ref. [8] we obtained ν=0.928 for our camera system. This value of the ν factor indicates a high similarity of the set of the camera spectral sensitivities to human colour-matching functions, and according to Berns and Reiman,[9] this value higher than 0.9 makes the camera suitable for colorimetric purposes in a first approach.

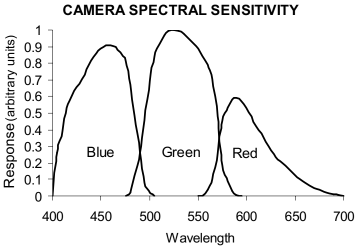


Figure 1. Spectral sensitivity of the three sensors of the SONY DX-9100P camera

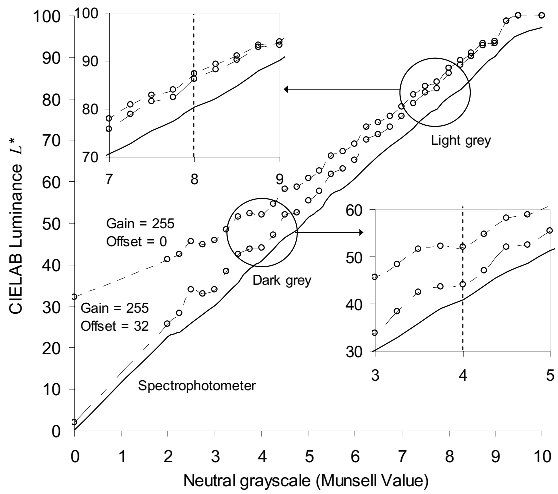
To overcome the device dependent representation of colour based on the R, G, B components provided by the camera, we calculated the coefficients of a linear transformation that defines a mapping between the camera R, G, B signals and a device independent representation, such as the standard CIE 1931 XYZ. The (3x3) coefficients were calculated following the method described in Refs. [10-11] that takes into account the three spectral response curves of the camera sensors (Figure 1), the standard observer responses x_{10}, y_{10}, z_{10} (CIE 1976), and the spectral distribution of the light source (D_{65}). We obtained

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{bmatrix} 2.419 & 0.272 & 0.364 \\ 1.419 & 0.957 & 0.114 \\ 0.085 & -0.034 & 2.070 \end{bmatrix}_{3CCD,D_{65}} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \quad (1)$$

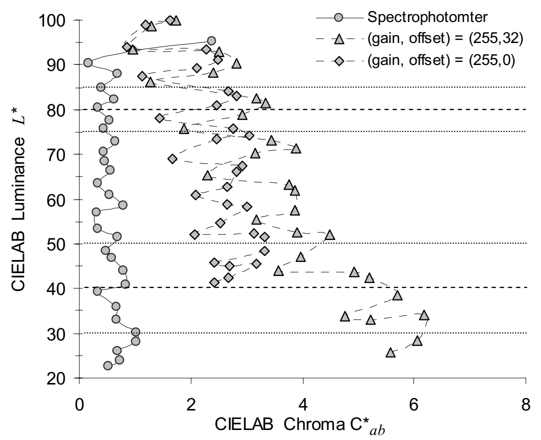
From the XYZ values, the CIELAB coordinates L^* a^* b^* and the values of hue h_{ab} and chroma C_{ab} can be calculated using the CIE 1976 formula.[4,5] As white reference we used the X_n, Y_n and Z_n obtained for the standard reflectance plate Photoresearch RS-3.

Provided the camera is used with gamma function disabled, we analyse their linearity over the operating range, and try to adjust the gain and offset controls to obtain the camera response closest to the reference instrument response for an achromatic grade in the CIELAB system. Particularly, we analyse the L^* and the chroma C_{ab} of the neutral grade measured by the camera and by the reference instrument. The spectrophotometer MINOLTA CM-2600D is taken as the reference instrument in this work. The analysis is carried out by using an achromatic scale of 31 neutral chips from the matte edition of Munsell Book of Colour (within the Value range V=2 up to V=9.5). To complete the range of the grey scale, we occluded totally the instrument aperture (that stands for V=0) and then, we stimulate with the reference white, the standard RS3 plate (that stands for V=10). When using the camera, the field of view is totally occupied by a single Munsell chip.

In the camera initialization, the gain and offset values have to be fixed so that the framegrabber converts the analogical signal of the camera into the R, G, B digital values in the 8-bit range of 0 to 255. Apart from the four possible combinations for which the gain and the offset take the extreme values of the range, i.e. either 0 or 255, we have analysed different capturing conditions by varying the values of gain and offset. Figure 2(a) plots L^* versus the Munsell Value and Figure 2(b) L^* versus C_{ab} for the results obtained by the reference instrument and the most interesting results obtained by the camera. The corresponds to two capturing conditions given by (gain, offset) = {(255,0), (255,32)}. From Figure 2(a) we notice that both capturing conditions of (gain, offset) lead to quite similar results in the light grey region. However, the results in the dark grey are different. In this region, the capturing condition given by (gain, offset)=(255,32) gives the results closest to those obtained by the spectrophotometer. It can be seen in Figure 2(b) that, when using the camera, the capturing condition (gain, offset)=(255,0) gives lower chromacity values -as it corresponds to a neutral scale- but, on the other hand, it also has less covering of luminance than the pair (gain, offset)=(255,32). For these reasons, we still consider both capturing conditions (gain, offset)={(255,0), (255,32)} in the experiment.



(a)

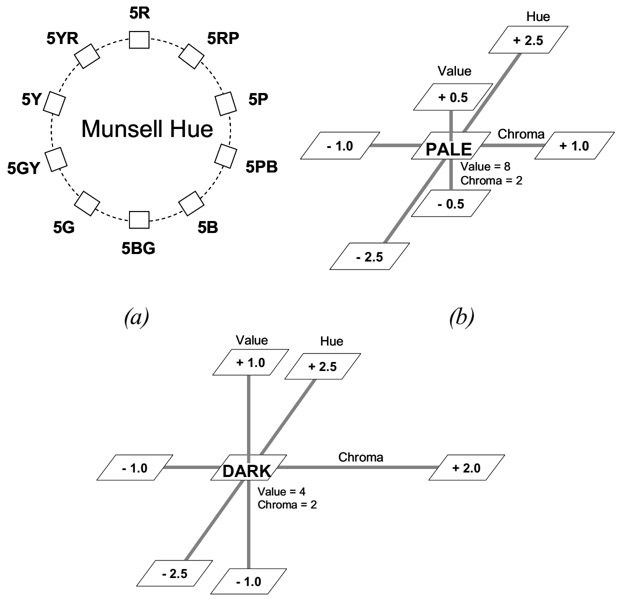


(b)

Figure 2. CIELAB luminance L versus: (a) the Munsell Value and (b) Chroma C_{ab},, of the neutral chips of the grayscale.*

Test

To analyse the camera capability to measure colour differences, we selected two sets of samples from two matte Munsell collections (the Munsell Book of Colour and the Nearly Neutral Munsell Collection). The samples were regularly distributed in the hue circle (Figure 3(a)), they had low value of Chroma =2, and two values of Value: V=8 (Figure 3(b)), and V=4, (Figure 3(c)). The two sets of samples generated in this way are the very pale colour set (with V=8) and the dark greyish colour set (with V=4). In the experiment, each one of the selected chips was compared with its neighbours according to the sketch of Figure 3.



(a) *(b)* *(c)*

Figure 3. Scheme of the Munsell matte chips selected for the test. They are grouped in 10 subsets regularly distributed on the Hue circle (a). Each subset consists of a group centre and its neighbours: (b) very pale, (c) dark grayish

Comparative Measurement of Small Colour Differences

In the second stage of the method, all the colour differences between every group centre and its neighbours were measured in pairs by the camera as well as by the reference instrument (spectrophotometer MINOLTA CM-2600D). The comparison between the results obtained by the camera and the results obtained by the reference instrument is the basis on which we test the reliability of the camera's performance. Two capturing conditions given by (gain, offset)={(255,0),(255,32)} were successively considered for the camera. CIELAB and CIEDE2000 formulae were used to calculate the colour differences ΔE_{ab} and ΔE_{00}, respectively. Figure 4 shows ΔE_{00} measured by the spectrophotometer and by the camera with (gain, offset)=(255,32) the three sorts of variations (in Munsell Value, Chroma, and Hue) with respect to each group centre. The results are separately presented for the very pale (Figure 4(a)) and for the dark greyish (Figure 4(b)) sets.

From the results plotted in Figure 4, we realize that the camera and the reference instrument present a high level of agreement in the estimation of the colour differences. The colour differences corresponding to Value variations in both very pale and dark greyish sets are nearly uniform as measured by both devices around the circle of hue. Munsell Chroma and Hue variations give rise to colour differences not so uniform around the circle and the fluctuations affect the measurements obtained by both the spectrophotometer and the camera.

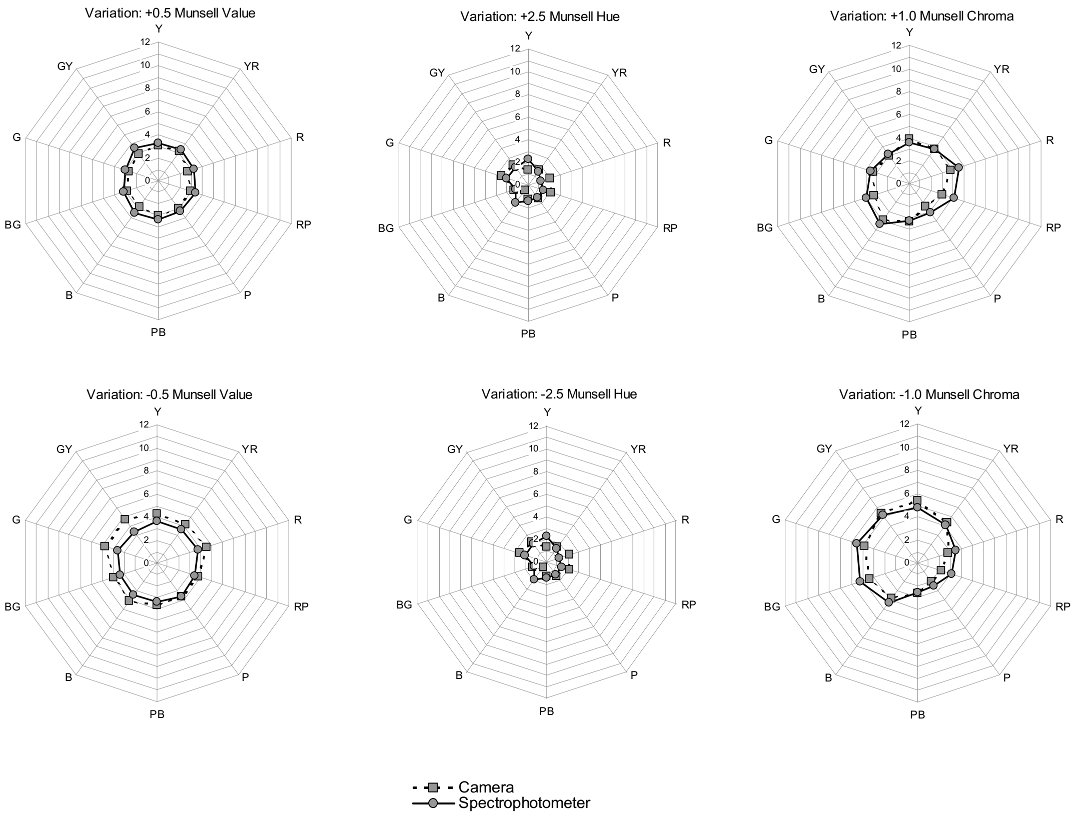
We have estimated the absolute discrepancy D between the colour differences measured by the reference instrument and the camera under a given (gain, offset) capturing condition by simply subtracting them and taking the absolute value. The relative discrepancy D^r is the absolute discrepancy divided by the mean value <,> of the colour differences measured by the spectrophotometer and the camera,

$$D_i^r = \frac{D_i}{\left\langle \Delta E_i(ref), \Delta E_i\left(cam_{gain,offset}\right)\right\rangle} = \frac{2\left|\Delta E_i(ref) - \Delta E_i\left(cam_{gain,offset}\right)\right|}{\Delta E_i(ref) + \Delta E_i\left(cam_{gain,offset}\right)}. \quad (2)$$

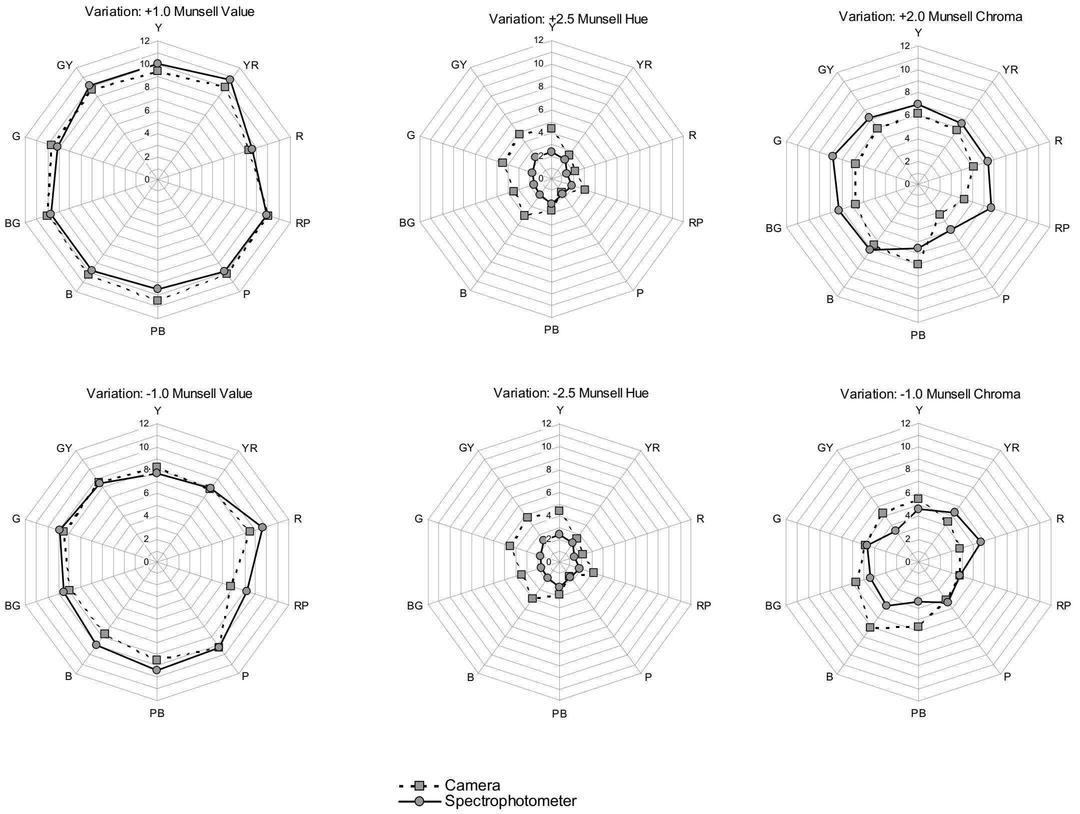
Subindex $i = \{ab, 00\}$ indicates either the CIELAB or the CIEDE2000 metric in Eq. 2. Figure 5 shows the relative discrepancies (in CIEDE2000 D^r_{00} and CIELAB D^r_{ab}) for the two capturing conditions of the camera and for the two sets of very pale and dark greyish samples. This figure shows that the camera is generally more precise when it measures Chroma and Value variations than Hue variations. When evaluating colour differences in the very pale region, both capturing conditions (gain, offset)={(255,0),(255,32)} lead to similar results. The capturing condition (gain, offset)=(255,32) is better than (gain, offset)=(255,0) to evaluate colour differences in the dark greyish region, except for the hue variations.

Application to Colour Matching of Textile Fabrics

Taking into account the results just obtained, we consider that the camera based acquisition system has promising characteristics for objective and automatic inspection of colour matching. For this reason, we have applied this system to the evaluation of colour uniformity in textile dying. A common task in textile inspection of colour is the comparison between the left and right extremes of the usable width of the fabric and the centre (extreme-centre colour matching). If the colour difference of the pair extreme-centre samples is perceived then the fabric is rejected. In our example of application, several extreme-centre pairs of dark greyish samples have been analysed and the CIELAB and CIEDE2000 colour differences measured by the spectrophotometer and by the camera with the two capturing conditions (gain, offset)={(255,0),(255,32)}.



(a)



(b)

Figure 4. ΔE_{00} between each group centre and its neighbours, calculated for the spectrophotometer and for the camera with (gain, offset)=(255,32). (a) Very pale colours, (b) Dark greyish colours.

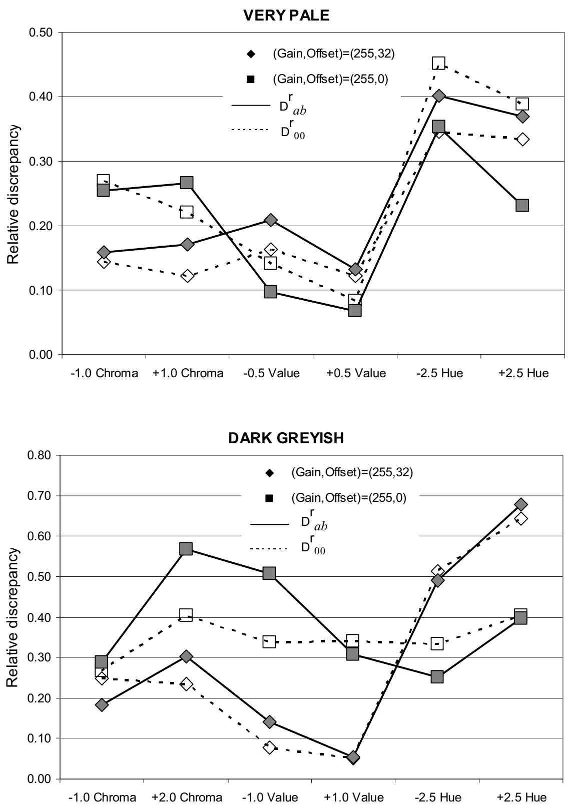
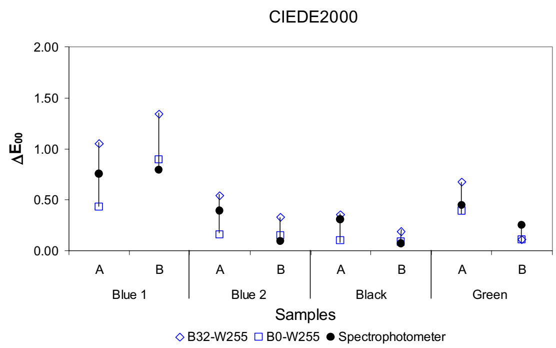


Figure 5. Relative discrepancies between the camera and the reference instrument in the measurement of colour differences.

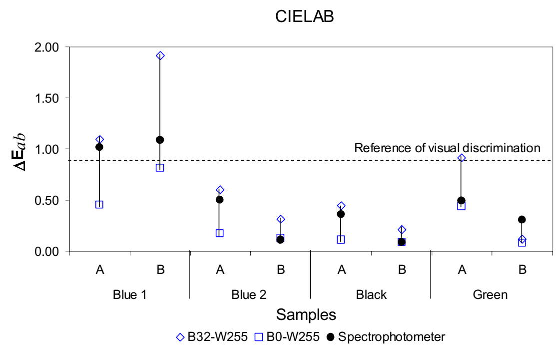
Figure 6 shows the results and the absolute discrepancies between them for each case. We obtain that the concordance is high and the precision obtained by the camera is enough. The absolute discrepancy between the camera and the reference instrument in less than 0.5 CIELAB units in general (see Figure 6(b)). The capturing condition of the camera given by (gain, offset)=(255,32) leads to a relatively higher discrimination capability. Taking into account the suprathreshold of visual discrimination (0.887 CIELAB units, see threshold in Figure 6(b)),[12] we could say that the fabric Blue1 should be rejected because both extreme-centre pairs A and B show a colour difference over the threshold. Fabrics Blue2 and Black are correct and fabric Green could be of intermediate quality (because of the colour difference obtained for the pair A.

Conclusions

The method presented has demonstrated to be useful to analyze the discrimination capability of a colour camera for colorimetric purposes. The comparison between the camera response and the reference instrument in the measure of CIELAB Luminance and Chroma (L^*, C_{ab}) of a greyscale led us to select the gain and the offset range of values in a more appropriate way than by considering the camera response in the separate R, G, B channels exclusively. In the difficult situation of measuring small colour differences in the nearly neutral colour region (very pale and dark greyish), we have obtained reasonably precise measurements for the camera analysed in comparison with the reference instrument (spectrophotometer). The practical application in a real case of colour matching in textile industry has given satisfactory results.



(a)



(b)

Figure 6. Extreme-centre colour differences of textile sample pairs. Each fabric has two pairs (A and B). (a) ΔE_{00}, (b) ΔE_{ab}.

Acknowledgements

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Biographies

María S. Millán recived the PhD degree in physics from the Universidad Autònoma de Barcelona (spain) in 1990. Since 1984, she has been a professor in the Department of Optics and Optometry of the Universitat Politècnica de Catalunya. Her fields of research involve pattern recognition, colour, texture analysis, optical processing and image processing.

Edison Valencia received the system engineering degrees from Universidad EAFIT (Colombia) in 1997 and MS degree in system engineering and computer science from Universidad de Los Andes (Colombia) in 2000. He has been a professor in EAFIT University, and at the moment, He is achieving the degree PhD in optic engineering in the Universitat Politècnica de Catalunya. Him fields of research involve colour metrology, image processing and pattern recognition.