Influence of Colour Ranges on Colour Measurements Performed with a Colorimetric and a Multispectral Imaging Systems

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Abstract

The aim of this work is analyzing the colour measurements performed using a colorimetric imaging system, with three acquisition channels, and a multispectral imaging system, with seven acquisition channels, in terms of the colour ranges measured, i.e. sets of colour samples grouped by their hue property, in order to determine if both the colorimetric and the multispectral imaging systems are especially sensitive to some hues and/or some other colour properties.

General tendencies of system's performance in terms of CIELAB coordinates have been analyzed using the GretagMacbeth ColorChecker DC chart (CCDC). System's performance was also analyzed with respect mainly of Munsell hue coordinate using the 1269 colour patches of the Munsell Book of Color – Matte Collection.

Similar results were obtained for both configurations using the GretagMacbeth ColorChecker DC chart as training and test sets, but outstandingly different results between both configurations were obtained using the Munsell colour patches grouped in hues and sub-hues, as training and test sets. The multispectral imaging system resulted to be very sensitive to hue homogeneity and the greater uniformity in hue the better results obtained. Moreover, performance of colour measurements for the multispectral imaging system seemed to depend mainly on the hue property of colour samples composing the training and test sets, but not on other colour properties such those represented by the Munsell value V and chroma C coordinates.

Introduction

The aim of this work is analyzing the colour measurements performed using a colorimetric imaging system, with three acquisition channels, and a multispectral imaging system, with seven acquisition channels, in terms of the colour ranges measured. By colour ranges we mean sets of colour samples grouped by their hue property. This analysis is intended to determine if both the colorimetric and the multispectral imaging systems are especially sensitive to some hues and/or some other colour properties. In order to perform this analysis, apart from the GretagMacbeth ColorChecker DC chart (CCDC), used to analyze general tendencies, the 1269 colour samples of the Munsell Book of Color – Matte Collection were measured and used both as training and test sets.

In previous works [1, 2] the efficiency of these colorimetric and multispectral imaging systems as instruments for colour measurements, was assessed applying several mathematical methods to calculate the XYZ tristimulus values from the corresponding measured digital levels. Acceptable results were obtained, the best being averaged CIELAB colour differences of 3 between the measured and the calculated XYZ tristimulus values, when using the same set of colour samples as training and test sets. Despite the CIELAB colour differences were acceptable for most of the colour samples, some considerably large CIELAB colour differences were also obtained for some concrete colour samples. Besides analyzing the performance of the colorimetric and multispectral imaging systems in terms of colour ranges, this work is also aimed to determine if the worst results obtained in previous works can be overcome by training the imaging system separately for different colour ranges.

Material and Method

The imaging systems used in this work were composed of a 12 bits cooled monochrome CCD camera (QImaging QICAM Fast1394 12 bit cooled), an objective lens (Nikon AF Nikkor 28 – 105 mm) and two sets of filters: an RGB liquid crystal tunable filter for the colorimetric configuration of the imaging system (three acquisition channels), and a set of seven interferential filters with a full width at half maximum (FWHM) of approximately 40nm, covering the whole visible range of the spectrum, and fitted in a motorized filter wheel for the multispectral configuration of the imaging system. For both configurations, XYZ tristimulus values were calculated by applying a direct transformation between digital values and their corresponding XYZ tristimulus values, by means of the Moore-Penrose pseudo-inverse technique.

In order to analyze the colour measurements performed by both configurations of the imaging system, the GretagMacbeth ColorChecker DC chart (CCDC) and the 1269 colour patches of the Munsell Book of Color – Matte Collection were used as training and test sets of the colorimetric and multispectral imaging systems. In order to analyze the imaging system's performance, the same set of samples was used as training and test sets. Classification of the colour patches of the Munsell Book of Color in 10 Munsell hues (R, YR, Y, GY, G, BG, B, PB, P, RP), and each one of these in 4 sub-hues (2.5, 5, 7.5, 10), was used to analyze the influence of colour ranges on colour measurements performed, i.e. the sensitivity of the imaging system to some hue/s, for all of the remaining colour properties.

Colour samples were imaged and measured placed into a special light booth (63cm x 64cm x 52cm) with six incandescent lamps (MAZDA 22c 40W 230V Softone), which provided a uniform illumination field. A big window on the opposite side of the booth allowed us to measure the colour samples with both the imaging system, that provided the digital signals, and a tele-spectracolorimeter (PhotoResearch PR-650 with MS-75 objective lens) that provided the measured XYZ tristimulus values and the spectral radiance. Accuracy of colour measurements was assessed in terms of the mean, minimum and maximum CIELAB colour differences (ΔE^*_{ab}) between calculated and measured XYZ tristimulus values. Results obtained were analyzed in terms of colour characteristics of samples measured such as the CIELAB coordinates, the Munsell hue, value and chroma coordinates, and the reflectance spectra of the colour samples.

Results

Colorimetric Configuration

For the colorimetric configuration of the imaging system (three acquisition channels) the performance of colour measurements was firstly analyzed using the GretagMacbeth ColorChecker DC Chart (CCDC). The set of CIELAB colour differences associated to the colour samples of the CCDC chart had an acceptable average value (meanΔE^*_{ab}) but a very high maximum (Table 1.). There was no correlation between CIELAB colour differences and a* and/or b* CIELAB coordinates (Figure 1.), but increasing CIELAB colour differences were associated to lower values of L* coordinate (Figure 2.).

Table 1. Colorimetric configuration: mean, minimum and maximum CIELAB colour differences (ΔE^*_{ab}) between measured and calculated XYZ tristimulus values for the colour samples of the CCDC chart, used as training and test sets.

meanΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}
4.26	0.49	12.38

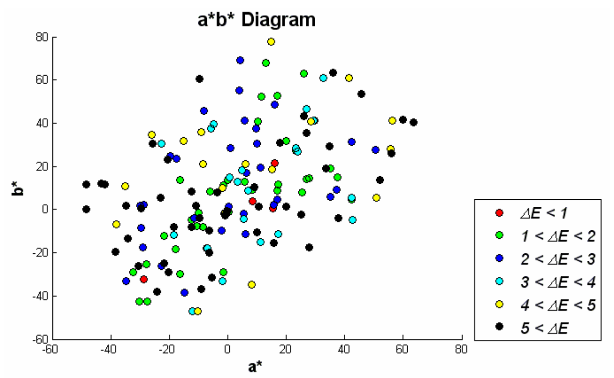

Figure 1. *Colorimetric Configuration: a*b* Diagram for the colour samples of the CCDC chart grouped in six groups in terms of their associated CIELAB colour differences.*

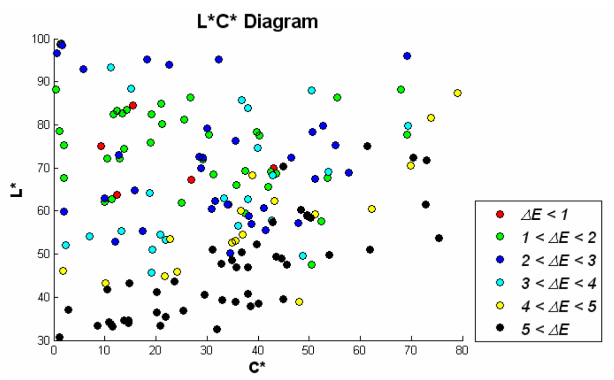

Figure 2. *Colorimetric Configuration: L*C* Diagram for the colour samples of the CCDC chart grouped in six groups in terms of their associated CIELAB colour differences.*

The mean, minimum and maximum CIELAB colour differences obtained using he colour patches of the Munsell Book of Color – Matte Collection were very similar to those obtained using the CCDC chart, and very similar among different hues (Table 2.).

Table 2. Colorimetric configuration: mean, minimum and maximum CIELAB colour differences (ΔE^*_{ab}) between measured and calculated XYZ tristimulus values for the Munsell colour patches grouped in hues, used as training and test sets.

Munsell H	meanΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}
R	3.97	0.25	11.01
YR	3.43	0.39	10.44
Y	4.09	0.85	18.49
GY	3.99	0.31	11.81
G	4.35	0.67	11.06
BG	4.19	0.40	10.54
B	4.05	0.28	11.83
PB	3.83	0.39	12.09
P	4.25	0.65	11.99
RP	3.97	0.34	11.37

These results allowed us to conclude that for the colorimetric configuration, firstly, homogeneity in hue did not improve outstandingly the performance of colour measurements and, secondly, there was no correlation between the CIELAB colour differences and the a*b* coordinates of the corresponding colour samples. On the other hand, performance of colour measurements slightly improved for all hues considering the colour samples sub-grouped in four sub-hues as training and test sets, although a great dispersion (great maxΔE^*_{ab}) in CIELAB colour differences was still shown (Table 3.). Very similar results were obtained between the sub-hues of a same hue.

Table 3. Colorimetric configuration: mean, minimum and maximum CIELAB colour differences (ΔE^*_{ab}) between measured and calculated XYZ tristimulus values for the colour samples of the Munsell Y hue and sub-hues, used as training and test sets.

Munsell H	meanΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}
2'5Y	3.03	0.59	10.45
5Y	3.45	0.19	10.41
7'5Y	3.73	0.54	10.49
10Y	3.73	0.32	10.58
All Y	4.09	0.85	18.49

The performance of colour measurements was also analyzed in terms of the Munsell value *V* coordinate, for all the values of the Munsell chroma *C* coordinate. For all the Munsell hues, the CIELAB colour differences decreased with an increasing value of the *V* coordinate for all the possible Munsell *C* values, and for all the four sub-hues of each Munsell hue. Larger CIELAB colour differences were obtained for samples with $V < 5$ and CIELAB colour differences slightly increased for samples having $V > 8$ (Figure 3.).

Next, in order to determine any kind of correlation between the CIELAB colour differences and any property of the associated reflectance spectra, performance of colour measurements was analyzed considering the reflectance spectra of measured samples. For all the Munsell hues, comparing the reflectance spectra of colour samples having the larger and the minimum CIELAB colour differences, reflectance spectra associated to the colour sample with the minimum CIELAB colour difference had a smooth shape and a certain minimum area under the curve of reflectance spectra. On the other hand, reflectance spectra associated to colour samples having CIELAB colour differences < 3 had very similar shape and area under the curve to those of the colour sample of minimum CIELAB colour difference, for all Munsell hues.

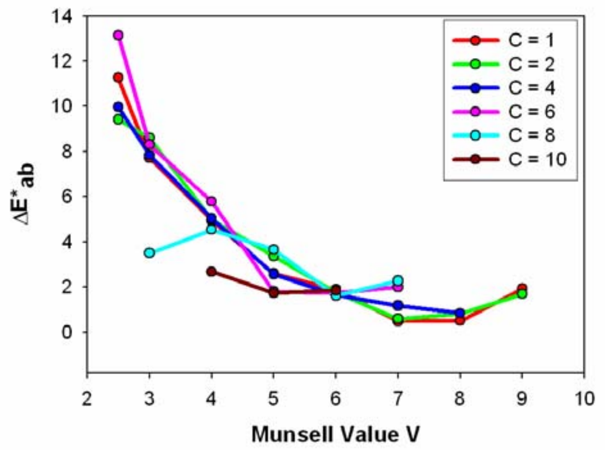

Figure 3. *Colorimetric Configuration: mean CIELAB colour difference (ΔE^*_{ab}) for the colour samples of the Munsell 10PB sub-hue in terms of the Munsell Vaue V, for all the Munsell Chroma C.*

Taking these results into account, performance of colour measurements was analyzed in terms of, on one hand, the smoothness of the reflectance spectra curve, by means of the Discrete Fourier Transform (DFT), which is usually used in spectral analysis to determine the smoothness of curves, and, on the other hand, the total reflectance associated to each reflectance spectra, by means of the area under the curve of spectral reflectance.

For all the Munsell hues, no correlation was observed between the shape of the DFT of the reflectance spectra of a colour sample (characteristic harmonics) and the corresponding CIELAB colour difference (Figure 4.).

Finally, it was also observed for all the Munsell hues that increasing CIELAB colour differences were associated to decreasing areas under the spectral reflectance curve (Figure 5.).

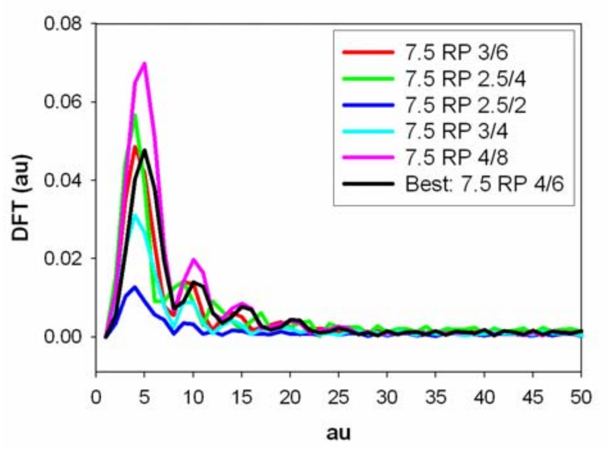

Figure 4. *Colorimetric Configuration: DFT for the Munsell 7.5RP colour samples with the larger (5 worst) and the minimum (Best) CIELAB colour differences.*

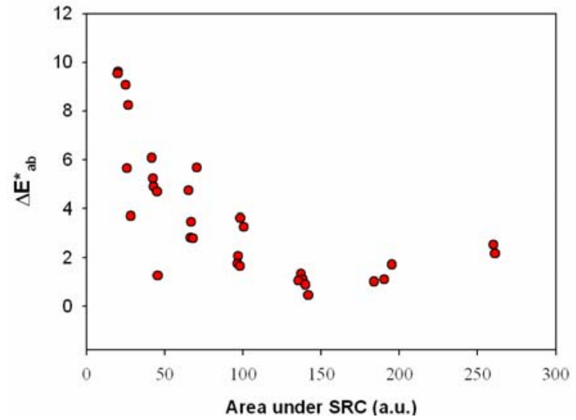

Figure 5. *Colorimetric Configuration: Area under the Spectral Reflectance Curve (SRC) for the Munsell 5B colour samples.*

Multispectral Configuration

For the multispectral configuration of the imaging system (seven acquisition channels) the performance of colour measurements was also firstly analyzed using the GretagMacbeth ColorChecker DC Chart (CCDC). The set of CIELAB colour differences associated to the colour samples of the CCDC chart was slightly better (Table 4.) than those for the colorimetric configuration (Table 1.), having an acceptable meanΔE^*_{ab} but still a very high maximum.

Table 4. Multispectral Configuration: mean, minimum and maximum CIELAB colour differences (ΔE^*_{ab}) between measured and calculated XYZ tristimulus values for the colour samples of the CCDC chart, used as training and test set.

meanΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}
3.44	0.12	11.34

No correlation between CIELAB colour differences and a* and/or b* CIELAB coordinates was observed either for the multispectral configuration (Figure 6.).

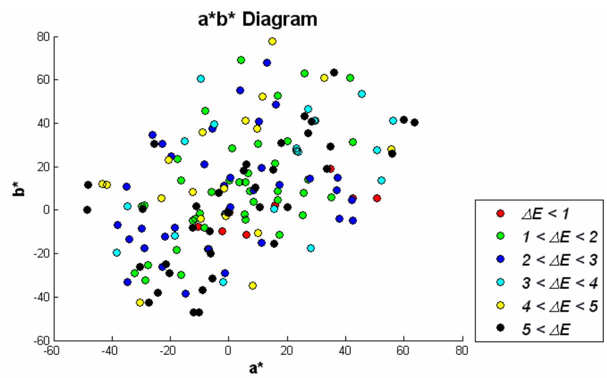

Figure 6. *Multispectral Configuration: a*b* Diagram for the colour samples of the CCDC chart grouped in six groups in terms of their associated CIELAB colour differences.*

Similarly to the colorimetric configuration, increasing CIELAB colour differences could also be associated to lower values of L* coordinate (Figure 7.).

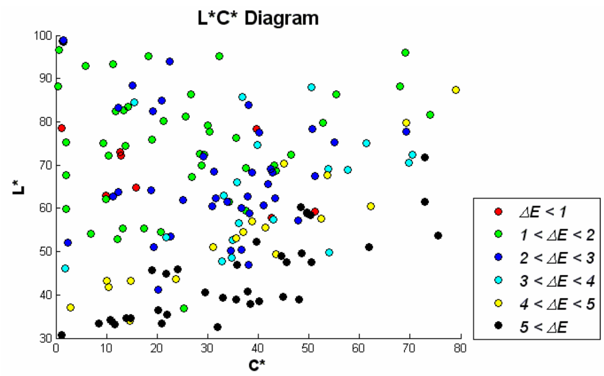

Figure 7. *Multispectral Configuration: L*C* Diagram for the colour samples of the CCDC chart grouped in six groups in terms of their associated CIELAB colour differences.*

For the multispectral configuration, the mean, minimum and maximum CIELAB colour differences obtained using the Munsell colour patches (Table 5.) were outstandingly better than those obtained using the CCDC chart (Table 4.) as training and test sets. Using the Munsell colour patches some noticeable differences appear among different hues (Table 5.), and dispersion in CIELAB colour differences (Table 5.) was considerably lower than that for the colorimetric configuration (Table 2.). The best performance of the imaging system is obtained for the colour patches of the Munsell YR hue, followed by the BG, G, RP, R, B, Y, PB, GY, and P hues.

Table 5. Multispectral configuration: mean, minimum and maximum CIELAB colour differences (ΔE^*_{ab}) between measured and calculated XYZ tristimulus values for the Munsell colour patches grouped in hues, used as training and test set.

Munsell H	meanΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}
R	0.58	0.03	2.39
YR	0.36	0.05	2.23
Y	0.82	0.05	2.67
GY	0.92	0.02	3.17
G	0.51	0.04	2.05
BG	0.44	0.02	2.14
B	0.70	0.04	3.08
PB	0.85	0.02	4.64
P	0.99	0.05	2.94
RP	0.54	0.06	3.92

Performance of colour measurements was also slightly improved in average for the multispectral configuration using the colour samples grouped in sub-hues as training and test sets (Table 6.).

According to these results, the multispectral system seemed to be sensitive to colour hues, and performance of colour measurements depended on homogeneity in hue of the training and test sets.

Unlike the performance for the colorimetric configuration, average CIELAB colour differences associated to Munsell hues did not follow any general tendency with respect of the Munsell value *V* coordinate, for all the possible Munsell *C* values and for all the four sub-hues of each Munsell hue (Figure 8).

Table 6. Multispectral configuration: mean, minimum and maximum CIELAB colour differences (ΔE^*_{ab}) between measured and calculated XYZ tristimulus values for the colour patche of the Munsell Y hue and sub-hues, used as training and test set.

Munsell H	meanΔE^*_{ab}	min ΔE^*_{ab}	max ΔE^*_{ab}
2'5Y	0.27	0.04	0.76
5Y	0.59	0.07	2.84
7'5Y	0.63	0.05	2.27
10Y	0.54	0.08	1.89
All Y	0.82	0.05	2.67

Consequently, for the multispectral configuration, performance of colour measures seemed to depend mainly on the hue property of the colour samples composing the training and test sets. In this case, system's performance did not depend on other colour properties such those represented by the Munsell value *V* and chroma *C* coordinates.

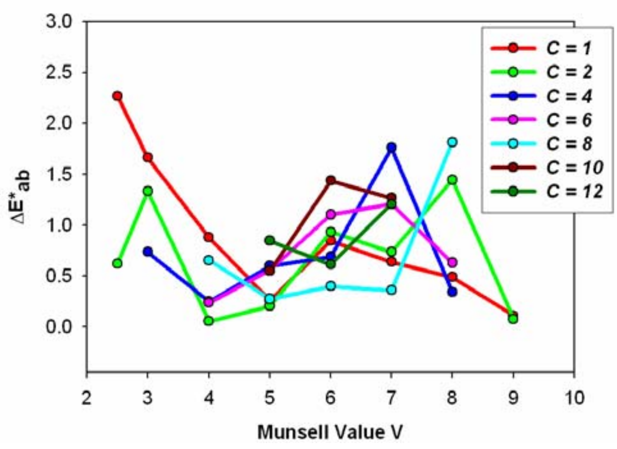

Figure 8. *Multispectral Configuration: mean CIELAB colour difference (ΔE^*_{ab}) for colour samples of the Munsell 10R sub-hue in terms of the Munsell Vaue V, for all values of Munsell Chroma C.*

For the multispectral configuration, the performance of colour measurements was also analyzed in terms of, on one hand, the Discrete Fourier Transform (DFT), and, on the other hand, the area under the curve of spectral reflectance.

Just like for the colorimetric configuration, no correlation between the shape of the DFTs of reflectance spectra (characteristic harmonics) and the CIELAB colour differences associated to colour samples (Figure 9.) was observed, for all the Munsell hues.

Finally, the CIELAB colour differences for all Munsell hues and/or sub-hues did not show any general tendency with respect to the areas under the spectral reflectance curve (Figure 10.), as it occurred for the colorimetric configuration (Figure 5.). In this case, in terms of system's performance, spectral characteristics of measured colour samples seemed to be much more outstanding than global or integrated characteristics.

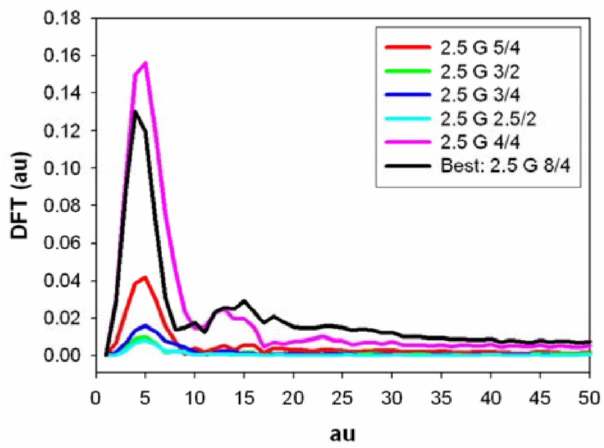

Figure 9. *Multispectral Configuration: DFT for the Munsell 2.5G colour samples with the greater CIELAB colour difference and for the colour sample with the minimum CIELAB colour difference (Best).*

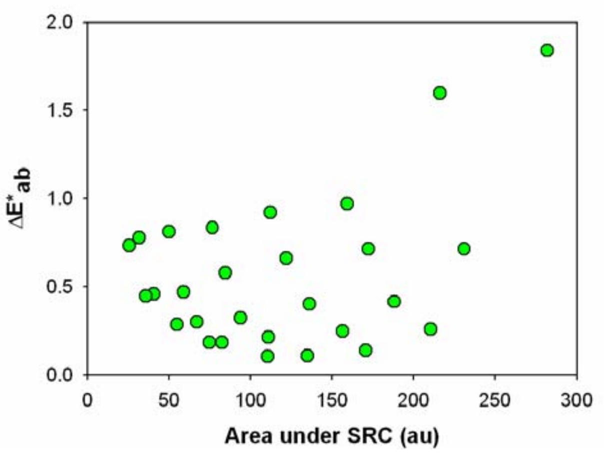

Figure 10. *Multispectral Configuration: Area under the Spectral Reflectance Curve (SRC) for the Munsell 2.5P colour samples.*

Conclusions

In this work colour measurements performed using a colorimetric imaging system, with three acquisition channels, and a multispectral imaging system, with seven acquisition channels, has been analyzed in terms of the colour ranges measured, in order to determine if both configurations are especially sensitive to some hues and/or some other colour properties.

General tendencies of system's performance in terms of CIELAB coordinates have been analyzed using the GretagMacbeth ColorChecker DC chart (CCDC). System's performance was also analyzed with respect mainly of the Munsell hue coordinate using the 1269 colour patches of the Munsell Book of Color – Matte Collection.

For the colorimetric configuration, using the CCDC as training and test set, no correlation between CIELAB colour differences and a* and/or b* CIELAB coordinates was observed, while increasing CIELAB colour differences were associated to lower values of L* coordinate.

Results obtained using the Munsell colour patches allowed us to conclude that for the colorimetric configuration, firstly, homogeneity in hue did not improve outstandingly the performance of colour measurements; and secondly, there was no correlation between CIELAB colour differences and a*b* coordinates associated to colour samples. On the other hand, performance of colour measurements slightly improved using colour samples grouped in sub-hues as training and test sets, for all the Munsell hues, obtaining very similar results for all the sub-hues associated to a same hue. It was also obtained that for all the Munsell hues, CIELAB colour differences decreased with an increasing value of the Munsell V coordinate for all the possible Munsell C values, and for all the four sub-hues associated to each hue. Larger CIELAB colour differences were obtained for samples with $V < 5$ and CIELAB colour differences slightly increased for samples having $V > 8$.

Considering the reflectance spectra of measured samples, no correlation was found between the shape of the Discrete Fourier Transform (DFT) of the reflectance spectra and the CIELAB colour difference associated to a colour sample. On the other hand, increasing CIELAB colour differences were associated to decreasing areas under the spectral reflectance curve.

Results obtained for the multispectral configuration were slightly different to those for the colorimetric configuration. Slightly better results were obtained using the CCDC chart, but no correlation between CIELAB colour differences and a* and/or b* CIELAB coordinates was either observed. Similarly to the colorimetric configuration, increasing CIELAB colour differences could be also associated to lower values of L* coordinate.

Using the Munsell colour patches grouped in Munsell hues, outstandingly better results were obtained than those obtained for both the colorimetric configuration, and the multispectral configuration using the CCDC chart. In this case some noticeable differences appeared among different hues. These results seemed to point that system was sensitive to colour hues, and system's performance considerably depended on homogeneity in hue of the training and test sets. System's performance was also slightly improved in average for the multispectral configuration when using the Munsell colour patches grouped in sub-hues, for each hue, as training and test sets.

For the multispectral configuration, performance of colour measurements seemed to depend mainly on the hue property of the colour samples composing the training and test sets. In this case, system's performance did not depend on other colour properties such those represented by the Munsell value V and chroma C coordinates.

Finally, considering the reflectance spectra of measured samples, on one hand, no correlation between the shape of the DFTs of reflectance spectra (characteristic harmonics) and the CIELAB colour differences associated to colour samples was observed; and, on the other hand, CIELAB colour differences did not show any general tendency for all Munsell hues and/or sub-hues with respect to the areas under the spectral reflectance curve, as it occurred for the colorimetric configuration.

References

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Author Biography

Marta de Lasarte completed her BSc Degree in Physics at the Autonomous University of Barcelona (Spain) in 2004 and received the 2004 year Extraordinary Award of Degree End from the Autonomous University of Barcelona. She is currently enrolled in the PhD program in Optical Engineering at the Technical University of Catalonia, having received a PhD grant from the Ministerio de Educación y Ciencia of Spain. Her work focuses on color imaging (device calibration and characterization, color management) and industrial colorimetry.

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