LED-based gonio-hyperspectral system for the analysis of automotive paintings

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ABSTRACT

The potential of goniochromatic pigments is being widely exploited in several industries. One clear example is the automotive sector. In order to evaluate specific colorimetric features of these pigments, commercial gonio-spectrometers have been recently developed such as the BYK-mac®, the X-Rite MA98® and the Datacolor FX10®. With the same purpose, gonio-spectral imaging systems can be very useful as they provide spectral information with high spatial resolution from a large area overcoming some of the limitations of the commercial systems currently used. A novel gonio-hyperspectral imaging system based on light-emitting diodes (LEDs) is presented in this work. The proposed device is composed by two motorized rotation stages, two digital cameras and a LED-based light source that includes a linear actuator. The imaging set includes a visible CCD camera with enhanced sensitivity in the ultraviolet region of the spectrum and an InGaAs camera covering the near-infrared range. The light source consists of 29 different kinds of LEDs from 365nm to 1300nm. White LEDs were also incorporated to analyse texture descriptors used in the automotive sector. The geometries shared by the BYK-mac® and the X-Rite MA98® were evaluated (45ºx:-60º, 45ºx:-30º, 45ºx:-20º, 45ºx:0º, 45ºx:30º and 45ºx:65º) to compare their results with those obtained with the proposed system in terms of CIE L*a*b* coordinates. As a first approach, three samples of real automotive paintings were analised: one solid, one metallic and one pearlescent. The results of this study show the usefulness of the developed system in the assessment of colorimetric features of coatings containing goniochromatic pigments with a high spatial resolution.

1. INTRODUCTION

In the last decades, the automotive sector is widely using goniochromatic or effect pigments for any kind of car painting. The result is that, nowadays, 80% of the automotive finishes are effect coatings. These kind of pigments are divided in two categories: metallic pigments, which mainly show variations in lightness; and pearlescent pigments, which exhibit hue and chroma shifts as a function of the illumination and/or observation angle (Maile 2005; Pfaff 2008).

Commercial gonio-spectrophotometers have been recently launched to cover the need of characterising these particular coatings such as the BYK-mac®, the X-Rite MA98® and the Datacolor FX10®. Even though these devices offer very accurate colorimetric information, they only evaluate integrated information from a relatively small area over the sample. This fact can be considered a limitation, especially when dealing with materials that change their appearance all over the sample depending on how they are illuminated and observed. To overcome this, we propose a LED-based gonio-hyperspectral imaging system that guarantees the colorimetric evaluation of the appearance and the spatial distribution of it along an extended area pixel by pixel. As a first step, the goal of this work is to demonstrate that the developed system allows obtaining similar colorimetric results to those provided by commercial gonio-spectrometers when analysing a central area of the acquired image.

2. METHOD

2.1 Setup

The proposed LED-based gonio-hyperspectral imaging system consists of two motorized rotation stages, two digital cameras and a light source based on LEDs (Figure 1). One of the rotation stages (8MR151-30; STANDA, Lithuania) controls the angle of illumination by rotating the sample with respect to the light source while the other stage (8MR191-30-28; STANDA, Lithuania) controls the observation angle by moving the arm that supports the cameras. The system includes two monochromatic cameras, one visible CCD camera (CM-140GE-UV; JAI, Japan) with enhanced sensitivity in the ultraviolet range of the spectrum (200nm – 1000nm) and an InGaAs camera (C10633-13; HAMAMATSU, Japan) that covers the near-infrared range (900nm – 1700nm). The resolution of the visible camera is 1392x1040 pixels while that of the near-infrared camera is of 320x256 pixels. The illumination set includes 29 different groups of LEDs, a linear actuator (ZLW-0630-02-B-60-L-1000; IGUS, Germany) that holds the LED board and allows changing from one spectral channel to the next one and a collimating lens. The light source is constituted by 28 different spectral channels with peak wavelengths from 365nm to 1300nm (370, 395, 410, 448, 470, 490, 505, 530, 568, 590, 617, 627, 655, 670, 690, 700, 720, 735, 750, 770, 810, 850, 870, 940, 970, 1020, 1050 and 1300 nm). Moreover, the light source also incorporates white LEDs which are intended for the evaluation of texture descriptors such as sparkle, graininess and mottling. They are also used in the automotive industry to describe appearance of coatings besides colorimetric features.

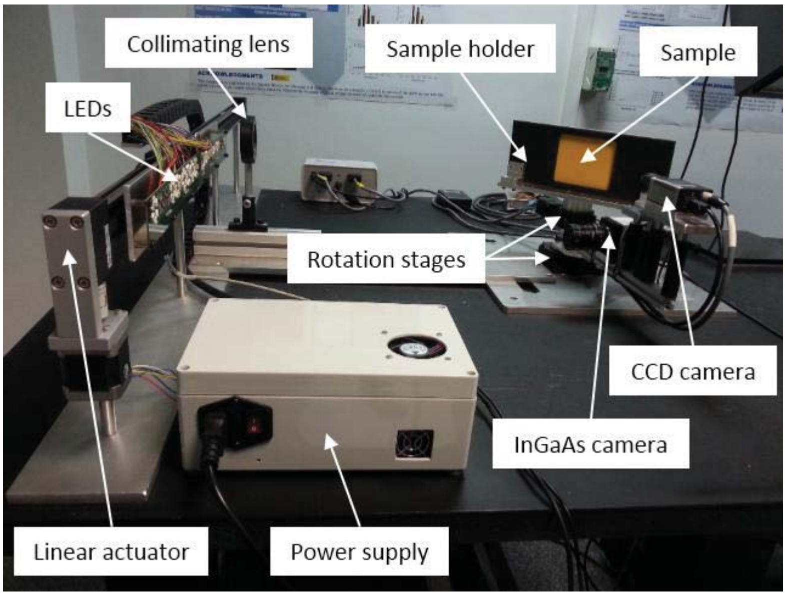


Figure 1: Setup.

2.2 Experimental Procedure

Three different samples were analyzed: one solid, one metallic and one pearlescent plates. Each one was measured at six different geometries: 45ºx:-60º, 45ºx:-30º, 45ºx:-20º, 45ºx:0º, 45ºx:30º and 45ºx:65º (Figure 2). The illumination direction was fixed at 45º from the normal direction of the sample while the observation arm was situated at six different positions with respect to the normal (-60º, -30º, -20º, 0º, 30º, 65º). These geometries were chosen because they are the angular positions that the BYK-mac® and the X-Rite MA98® share, thus allowing for a more accurate comparison of the results.

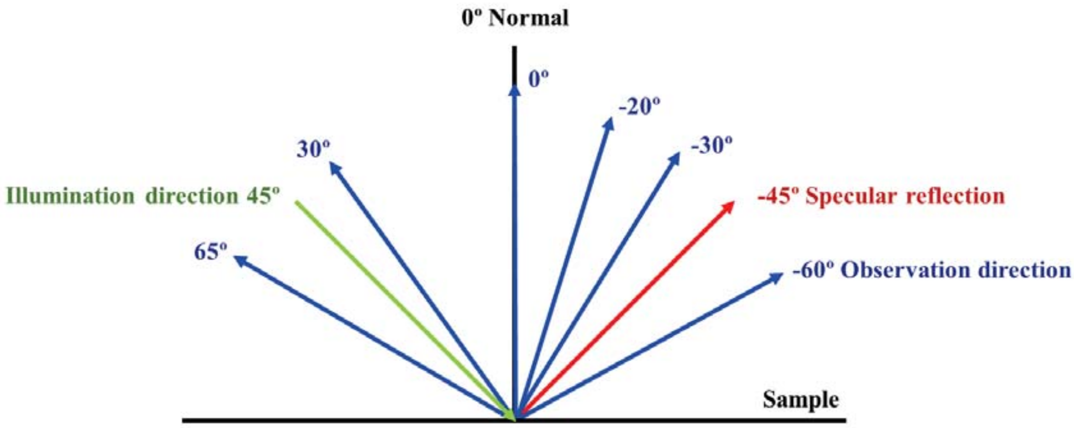


Figure 2: Measurement geometries (45ºx:-60º, 45ºx:-30º, 45ºx:-20º, 45ºx:0º, 45ºx:30º and 45ºx:65º).

2.3 Image and Colour Analysis

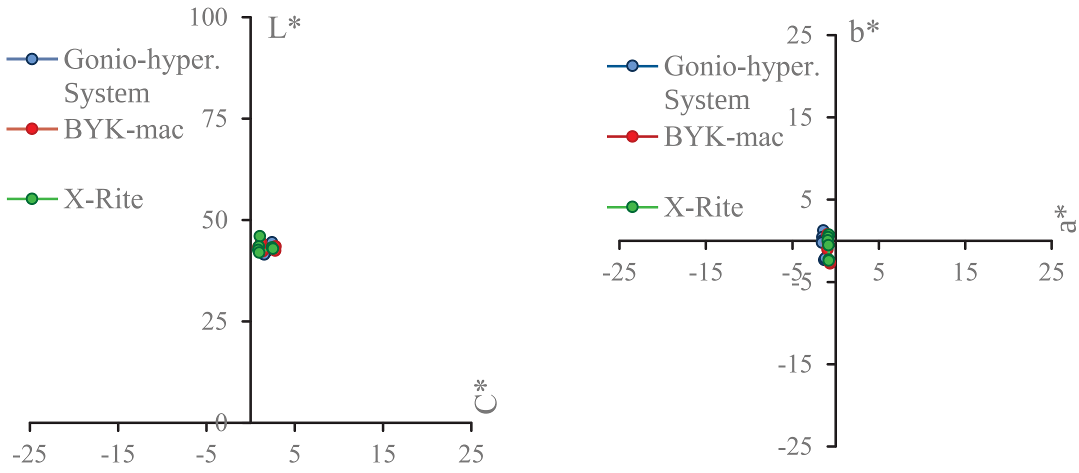
At each geometry and for each spectral channel, 10 images were captured and lately averaged to reduce noise. In addition, the following formula was applied to obtain the reflectance of each pixel of the image at a certain wavelength:

$$r(i,j) = c \cdot \frac{DL_I(i.j) - DL_{DC}(i.j)}{DL_W(i.j) - DL_{DC}(i.j)}, \qquad (1)$$

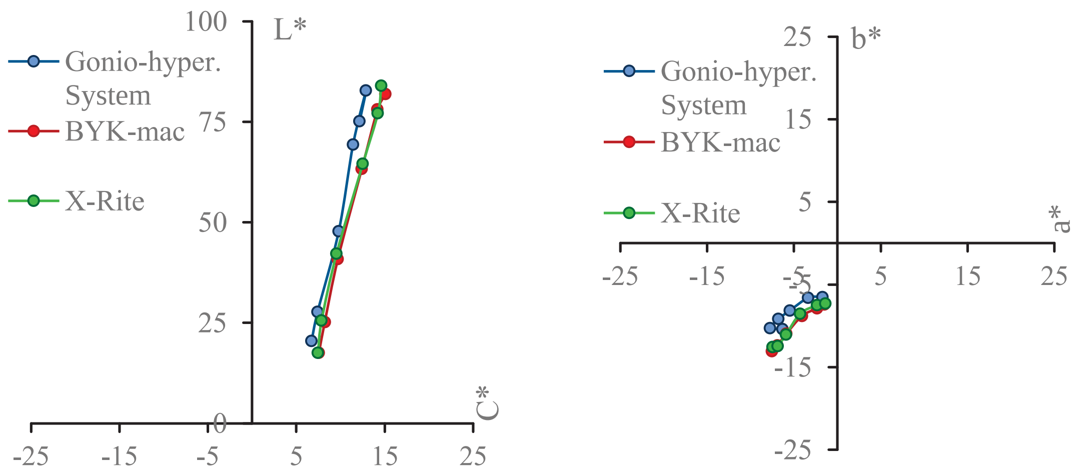
where $r(i,j)$ is the reflectance corresponding to a pixel, $DL_I(i,j)$, $DL_W(i,j)$ and $DL_{DC}(i,j)$ are the digital levels of the raw image, the reference white and the dark current, respectively, and c is the reflectance value of the calibrated reference white (BN-R98-SQ10C; GIGAHERTZ OPTIK, Germany).

Secondly, the tristimulus values XYZ CIE-1964 were computed based on the reflectance spectra from 400nm to 700nm (Nassau 1997). Posteriorly, the CIE L*a*b* coordinates were calculated for the illuminant D65 (Nassau 1997) and compared with those provided by the commercial gonio-spectrometers BYK-mac® and X-Rite MA98® in terms of colour differences (ΔE, CIELAB1976).

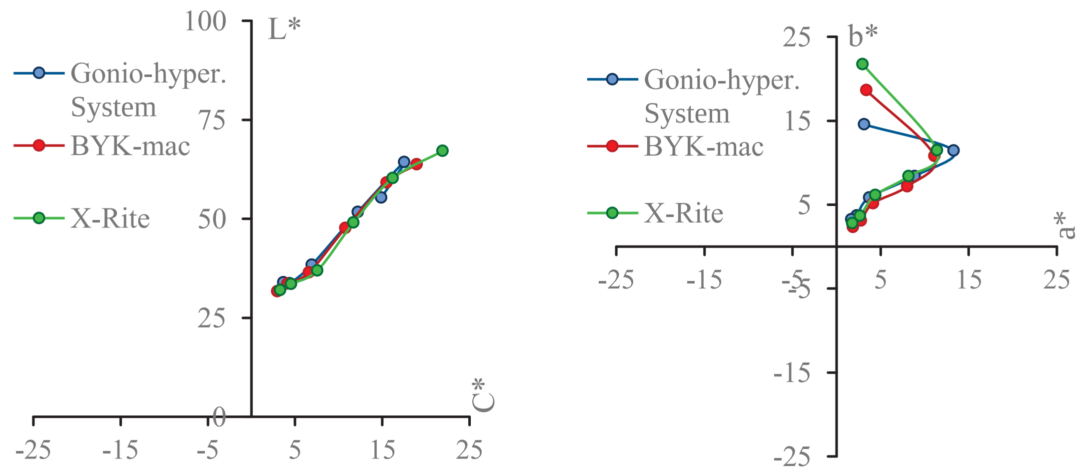
3. RESULTS AND DISCUSSION



(a)



(b)



(c)

Figure 3: CIELAB diagrams of the solid (a), metallic (b) and pearlescent sample (c) for the three devices tested.

Figure 3 shows the colorimetric behavior of three samples (solid, metallic and pearlescent) measured with the BYK-mac®, the X-Rite MA98® and the proposed system. As expected, the solid sample (Figure 3 (a)) exhibited very small variations in *L**, *a**, *b** and *C** ($C^* = \sqrt{(a^*)^2 + (b^*)^2}$) since solid pigments have similar appearance at any direction. Nevertheless, metallic (Figure 3(b)) and pearlescent (Figure 3(c)) samples did behave different as a function of the observation angle. On one hand, the metallic sample experienced the largest changes in *L** parameter, while for *C**, *a** and *b** the variation was very small. The pearlescent sample was characterised by greater shifts in *C**, *a** and *b** parameters rather than in *L**. The three samples showed similar colorimetric performance for the three devices tested.

Table 1 contains the color differences between the CIE L*a*b* parameters obtained with the system and those measured with the BYK-mac® and the X-Rite MA98® gonio-spectrophotometers. The lowest color differences were found for the solid sample with differences of less than four units and rather constant along the different geometries. In the case of the metallic and pearlescent samples, the colour difference values varied depending on the measurement geometry. The highest values were found in those positions closer to the specular reflection (45ºx:-60º, 45ºx:-30º and 45ºx:-20º), reaching values up to 13 ΔE units. In spite of this, at the geometries further to the specular reflection (45ºx:0º, 45ºx:30º and 45ºx:65º) colour differences notably decreased becoming in some cases very small.

Table 1. CIELAB color differences (ΔE, CIE1976) when comparing the gonio-hyperspectral imaging system and the commercial devices for the solid (S), metallic (M) and pearlescent (P) samples.

Sample	ΔE	45ºx:-60º	45ºx:-30º	45ºx:-20º	45ºx:0º	45ºx:30º	45ºx:65º
S	BYK-mac	2.36	0.98	1.28	1.28	0.89	2.14
	X-Rite	3.85	0.98	1.18	0.92	0.58	1.64
M	BYK-mac	7.45	5.18	6.41	7.07	2.97	3.09
	X-Rite	9.24	6.08	5.24	5.65	2.54	3.09
P	BYK-mac	9.34	5.61	4.32	2.11	0.79	2.44
	X-Rite	13.82	4.44	2.78	1.66	0.40	2.00

4. CONCLUSIONS

A LED-based gonio-hyperspectral imaging system for the analysis of automotive paintings has been presented. This system showed a good colorimetric performance similar to that of the BYK-mac® and the X-Rite MA98® commercial gonio-spectrophotometers, in particular for solid pigments. Future work will be focused on diminishing the differences that the system exhibited in comparison with the commercial devices when dealing with goniochromatic pigments. However, preliminary results are already promising. In addition, texture descriptors will be also developed.

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REFERENCES

Maile, F. J., G. Pfaff, and P. Reynders. 2005. Effect Pigments—Past, Present and Future. *Progress in Organic Coatings* 54 (3): 150–163.

Nassau, K. 1997. *Color for Science, Art and Technology*. Amsterdam: Elsevier Science.

Pfaff, G. 2008. *Special Effect Pigments*. Norwich: William Andrew Publishers.

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