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COMPARISON OF COLORIMETRIC FEATURES OF SOME CURRENT LIGHTING BOOTHS FOR OBTAINING A RIGHT VISUAL AND INSTRUMENTAL CORRELATION FOR GONIO-APPARENT COATINGS AND PLASTICS

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Abstract

In this work we did a colorimetric and photometric analysis of new two lighting booths, with directional illumination, and comparing them with a conventional lighting booth with diffuse illumination. The colorimetric analysis shows that the first one (byko-spectra effect) uses light sources very different from the D65 illuminant, thus the visual and instrumental correlation cannot be right when at instrumental level the D65 illuminant is continuously used as reference. In contrast, the second one (gonio-vision-box) uses one light source closer to the D65 illuminant, but with a medium level of color rendering. The photometric analysis in both cabinets shows the corresponding illuminance fields are not homogenous, although the average illuminance values are right according to the technical recommendations for visual assessments. Consequently, many improvements could be done in both types of directional illumination cabinets for increasing the high quality control protocols about colour & texture for gonio-apparent materials in the automotive sector.

Keywords: Visual Appearance, Colour, Texture, Special-Effect Pigments, Gonio-Spectrophotometry, Photometry, Colour Rendering, Lighting Booth, Directional Illumination

1 Introduction

Nowadays, in the automotive sector (Streitberger, Dössel, 2008), in order to guarantee a high quality level in colour & texture appearance in car bodies, composed by gonio-apparent coatings and plastics (Brock, Groteklaes, Mischke, 2010; Poth, 2008) based on special-effect pigments (Maile, Pfaff, Reynders, 2005; Pfaff, 2008; Wissling 2006), and after doing spectral and colour measurements with one multi-gonio-spectrophotometer, it is very important to use as second step (for visual assessment) new lighting booths, with directional luminous incidence and viewing positions. This second step, focused on the visual assessment of some exterior components (bumpers, hood, doors, etc) under controlled illumination (based on some D65 illuminant simulators), when it is highly correlated with the corresponding colorimetric data measured at instrumental level at the initial step, is used to state a final colour & texture approval of any complete car. Therefore, spite of this link between both steps are sporadically used in many car manufacturers, it is a key action to get a right correlation between visual and instrumental data, so it reinforces some high quality control protocols for this so strategic worldwide industrial sector.

At instrumental level, due to existence of many kinds of special-effect pigments with some conventional or solid pigments in many colour recipes for automotive coatings (Cramer 2012; Klein 2010), the colour appearance of these special coatings is enough complex due to goniochromism, i.e., the abrupt changes in lightness, hue and chroma in some viewing directions depending on the incidence light direction. For this reason, in the current colour instrumentation market there are some types of multi-gonio-spectrophotometers, based on some directional measurement geometries (Figures 1 and 2, and Table 1), mostly of them highly recommended by worldwide standard normatives (ASTM 2012a; ASTM 2012b; Kirchner, Cramer 2012). Then, the minimum number of measurement geometries currently recommended for gonio-apparent materials is six, all them in the same incidence plane (Figure 2, Table 1). However, some recent multi-gonio-spectrophotometers are including new measurement geometries, sometimes into the same incidence plane (in-plane), but also out-of-plane. In any case, the current reference multi-gonio-spectrophotometer for the automotive sector is the BYK-mac, with six measurement geometries: 45as110, 45as75, 45as45, 45as25, 45as15 and 45as-15, according to DIN/ASTM nomenclature (Table 1).

Figure 1 – Current multi-gonio-spectrophotometers mostly used in the automotive sector. From left to right: Datacolor MultiFX 10, X-Rite MA98 and BYK-mac.

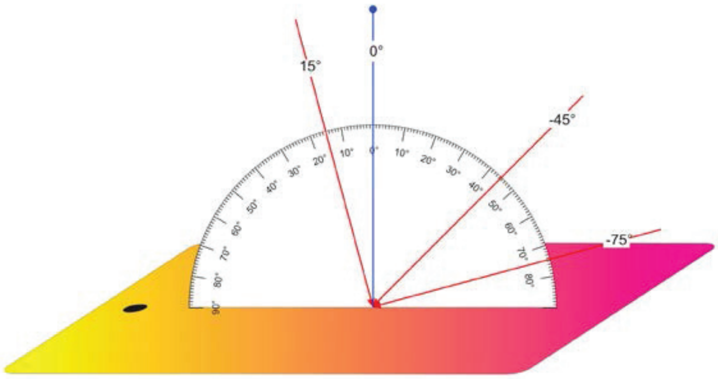

Figure 2 – Schema of the illumination (influx) and observation (detection or efflux) angles used in this study following the CIE nomenclature (See Table 1 for its application)

On the other hand, many of these new gonio-apparent coatings and plastics have new visual effects due to some micro-textures, named sparkle or glitter (viewed under directional illumination), or graininess or coarseness (viewed under diffuse illumination). However, only one instrument, the BYK-mac, also running as multi-gonio-spectrophotometer, currently incorporates a basic optical design (Figure 3) for measuring the sparkle and graininess effects. Therefore, for the final visual approval of gonio-apparent materials in car bodies, it is necessary to match both colour and texture in some visual directions and textures (Huang et al., 2010; Dekker et al., 2011).

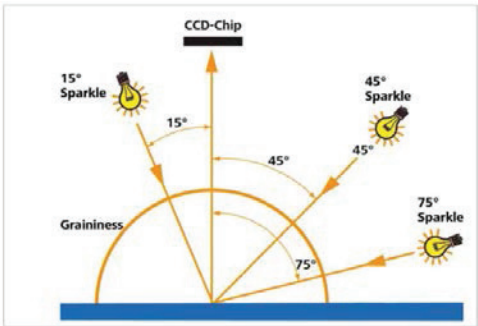

Figure 3 – Basic optical design for measuring the sparkle (or glitter) effect in the BYK-mac multi-gonio-spectrophotometer. With diffuse illumination configuration, this instrument also measures the texture effect named graininess (or coarseness).

Very recently, for only two years, for covering the high demand to do visual assessment of gonio-apparent materials in this industrial sector, there are new types of lighting booths or cabinets, based on directional illumination, not diffuse illumination as in conventional lighting booths for other coloration industries with minor visual and instrumental requirements. Then, there is one lightweight cabinet named gonio-vision-box® (GVB), from Merck, and one heavy cabinet named byko-spectra effect® (BSE), from BYK-Gardner. In both cases (Figure 4), the main purpose in their opto-mechanical design is to cover the most number of measurement geometries available in the current multi-gonio-spectrophotometers (Table 1).

Table 1 – Measurement geometries commonly used in multi-gonio-spectrophotometry for the automotive sector and CIE nomenclature

Influx (incident angle)	Efflux (detection angle)	Aspecular angle	CIE notation	ASTM/DIN notation	Instruments	Lighting booths
45º	25º	+110º	45ºx:65º (as 110º)	45as110	FX10, MA98, mac	BSE, GVB
45º	60º	+75º	45ºx:30º (as 75º)	45as75	FX10, MA98, mac	BSE, GVB
45º	90º	+45º	45ºx:0º (as 45º)	45as45	FX10, MA98, mac	BSE, GVB
45º	110º	+25º	45ºx:-20º (as 25º)	45as25	FX10, MA98, mac	BSE, GVB
45º	120º	+15º	45ºx:-30º (as 15º)	45as15	FX10, MA98, mac	BSE, GVB
45º	150º	-15º	45ºx:-60º (as -15º)	45as-15	FX10, MA98, mac	BSE, GVB
15º	90º	+15º	15ºx:0º (as 15º)	15as15	FX10, MA98	GVB
15º	120º	-15º	15ºx:-30º (as -15º)	15as-15	FX10, MA98	GVB
65º	140º	+15º	65ºx:-50º (as 15º)	65as15	FX10	GVB
65º	170º	-15º	65ºx:-80º (as -15º)	65as-15	FX10	GVB

Since the cabinets BSE and GVB, joint to the multi-gonio-spectrophotometers Datacolor FX10, X-Rite MA98 and BYK-mac, are performing in the laboratory of the Colour & Vision Group of the University of Alicante (Spain), for only six months, we have adequate to make a colorimetric and photometric comparison of both cabinets with regard the same features available in one conventional lighting booth (Verivide CAC-150, with diffuse illumination). The aim of this work is therefore to check if the design and performance of both cabinets fulfill the high demanding requirements for this automotive sector, as well as for colour and texture.

2 Materials

As general colour instrumentation for this work, we used a tele-spectroradiometer Photo Research 650 (PR-650), with its own white reference (based on $BaSO_4$), and a BYK-mac multi-gonio-spectrophotometer, with its corresponding white reference, based on halon material.

Both lighting booths (Figure 4) will be exhaustively described in next subsections, including some technical information about the arrangement of their luminaires, their technologies, etc.

Figure 4 – Lighting booths analysed in this work. From to left to right: byko-spectra effect (exterior and interior view) and gonio-vision-box inside one Verivide CAC-150 cabinet (diffuse illumination), with some gonio-apparent panels and the instruments BYK-mac and X-Rite MA98

For one specific subsection inside the results section, we have adequate to use some gonio-apparent panels, previously measured with a BYK-mac (Figure 5) for testing the visual and instrumental correlation. As it can be seen in Figure 6, typical gonio-apparent material shows different CIELAB values for some measurement geometries, shaping in some cases a well-recognised T-shape (Chorro, et al., 2009; Perales, et al., 2011), where the horizontal side is associated with the interference line (or set of measurement geometries with variable incidence angles whose aspecular angle is fixed), and the vertical side, with minor color travel (basically lightness travel), is associated with the aspecular line (set of measurement geometries with fixed incidence angle and different aspecular angles).

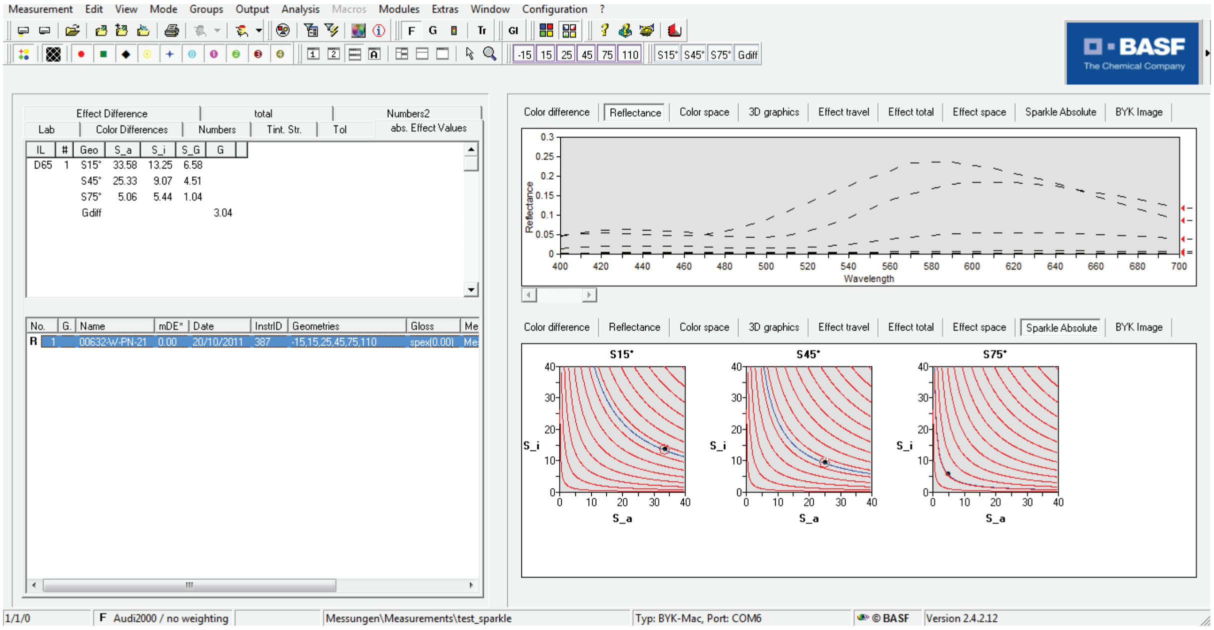

Figure 5 – Spectral reflectances (right-upper side) and sparkle values (left-upper and right-lower sides) of one typical gonio-apparent panel measured with a BYK-mac instrument shown in the ColorCare® user interface (see Figure 12 for discovering the true colour appearance of this panel)

Finally, other important instrument used in this work is a photometer, Gossen Mavolux 5032, necessary for obtaining the photometric data of both cabinets.

Moreover, as reference lighting booth, we have a Verivide CAC-150 cabinet, with some D65 and D50 fluorescent simulators, which, as we will see below, they will be important as spectral, colorimetric and photometric references for next sections.

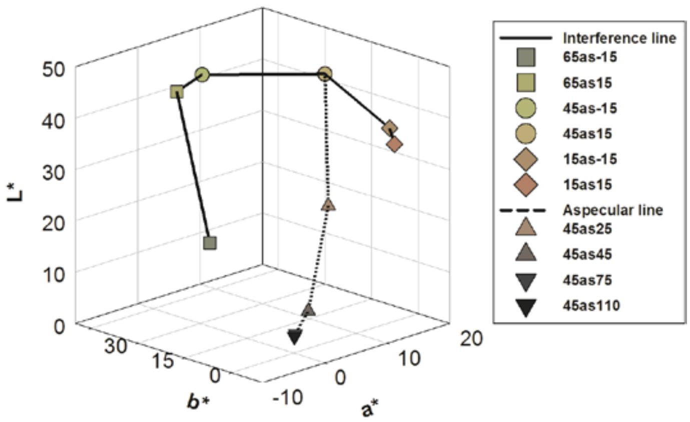

Figure 6 – Colorimetric data plotted in CIELAB diagram of one typical gonio-apparent panel measured with one Datacolor MultiFX 10 instrument (see Figure for discovering the true colour appearance of this panel)

As it is usual, all luminaires or light sources installed into the three cabinets used for this work were switched on 10 minutes before doing the corresponding spectral, colorimetric and photometric measurements.

2.1 Byko-spectra effect cabinet

This lighting booth has two different luminaires for visually assessing colour and texture (only sparkle). In first case, the luminaire is composed by two fluorescent tubes at 45 deg with regard to the illumination plane or scene (Figure 7, left), without an identical luminaire arrangement in the opposite side to the scene. One lateral toggle, in the right side (Figure 4, left), permits to change the incidence angle, and consequently, with the fixed slit or long narrow window for the visual assessment of one human observer, to select six measurement geometries: 45as110, 45as75, 45as45, 45as25, 45as15 and 45as-15, just those six highly recommended and designed in the most of current multi-gonio-spectrophotometers (Table 1). For visual assessment of the three sparkle grades, S15, S45 and S75, this cabinet has arranged three wLED luminaires, slightly color-filtered with yellowish nuance, in some specific positions (Figure 3) with regard to the scene. The observer position is always fixed, so the orientation of the panel for the colour or texture evaluations changes at mechanical level, at 50 cm approx. Moreover, these wLED luminaires have a corresponding DC voltage controller (Figure 4, centre) for varying the illuminance level on the scene (Figure 8).As it can be seen in this figure, it is not easy to fix a constant illuminance level for the three sparkle grades, when it would be interesting to have the same illuminance vs. voltage curves, and with very high levels, in order to replicate the true daylight conditions in most of situations (looking at cars in parkings, on beach, etc).

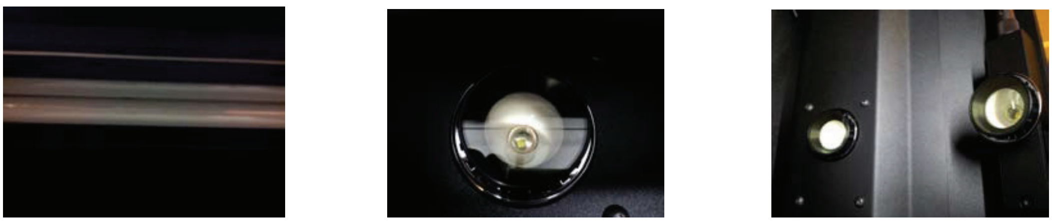

Figure 7 – Interior view of the byko-spectra effect cabinet. From to left to right: luminaire for colour assessments composed by two fluorescent tubes, wLED luminaire for sparkle assessments, and, the two wLED luminaires for visually assessing S45 and S75 sparkle values (see Figure 3)

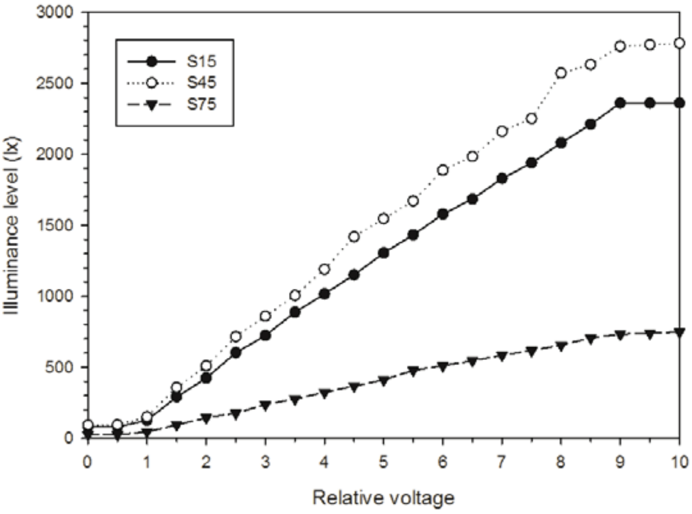

Figure 8 – Illuminance level vs. relative voltage curves of the three wLED luminaires used for the sparkle assessments.

2.2 Gonio-vision-box cabinet

This lightweight cabinet (Figure 9) is half-helmet in which it is possible to select in some directions the position of the light source and observer. Putting, for instance, the light source (based on wLED lantern) at 45as geometry (Figure 9, right), it is very easy to see the colour appearance (or sub-gamut) of one gonio-apparent panel (on the centre of the helmet) in some viewing directions, as well as in and out-of-planes (Figure 9, left). Therefore, it seems indispensable when you use a multi-gonio-spectrophotometer and you cannot know the colorimetric data associated with those measurement geometries different to your own instrument. Consequently, as the byko-spectra effect cabinet, this small device is also very useful to correlate the visual perception of gonio-apparent panels with colorimetric data provided by different multi-gonio-spectrophotometers (Table 1).

Figure 9 – Exterior view of the gonio-vision-box cabinet. Left: back side, showing some viewing directions in order to see some colour subgamuts of gonio-apparent panles in out-plane geometries. Right: front view, showing the wLED lamp at 45º incidence angle, and marking some viewing directions in order to simulate the measurement geometries of some multi-gonio-spectrophotometers (see Figure 2 and Table 1).

3 Results and discussion

This section will be distributed in two subsections, colorimetric and photometric analysis. However, the first subsection will include an additional subsection, very focused on one preliminary test in order to check the right correlation between visual and colorimetric data with a typical gonio-apparent panel (Figures 5 and 6). In parallel way, for each analysis, some specific discussions, marking the main strengths and drawbacks with regard to the original aim or applicability will be included.

3.1 Colorimetric analysis

For this technical assay, we used one tele-spectroradiometer (PR-650) arranged in the same position when a human observer look into byko-spectra effect (BSE) cabinet, or into the gonio-vision-box (GVB). Placing the white reference ($BaSO_4$) in the centre of the scene, it is very important or crucial to keep the same visual direction or angle for the PR-650 instrument such as any human observer would do in both cabinets.

Figure 10 – Position of the tele-spectroradiometer PR-650 implemented in this work. Left: imposing the same visual angle as any human observer viewing across the slit or narrow long window. Right: keeping the same visual angle for measuring the white reference in the center of the illuminated scene for colour assessments (only illuminated by one side at 45º).

Using, therefore, the white reference it is very easy to measure the spectral power distribution (SPD) of any light source or luminaire of each lighting booth, and transforming the spectral data into colorimetric data (Table 2) and other typical colorimetric parameters in order to evaluate the colour quality of any light sources and illuminants (CIE 2004).

Table 2 – CIE-1931 colorimetric data, correlated colour temperature and general colour rendering indexes of the light sources/luminaires installed in the lighting booths analysed in this work, and comparing with those similar belonging to the Verivide CAC-150 cabinet.

CIE-1931		x	y	T_c (K)	R_a	R_b
BSE	45as110	0,3495	0,3772	4931	85,69	78,39
	45as75	0,3498	0,3770	4921	85,83	78,57
	45as45	0,3506	0,3769	4896	86,24	79,07
	45as25	0,3504	0,3771	4901	86,02	78,78
	45as15	0,3503	0,3773	4906	85,86	78,60
	45as-15	0,3496	0,3771	4929	85,90	78,67
	S15	0,3478	0,3899	5022	70,32	58,24
	S45	0,3415	0,3821	5208	71,51	59,74
	S75	0,3415	0,3823	5208	71,55	59,79
GVB	lantern	0,3185	0,3141	6278	69,07	60,27
Verivide	D65 sim,	0,3127	0,3383	6439	95,29	94,11
	D50 sim,	0,3550	0,3760	4751	96,53	95,09

According to the Table 2, we can see that the supposed daylight flourecent of the BSE cabinet is not a good D65 simulator, else a D50 simulator, although with class 1B, not 1A (maximum category). In contrast, the wLED lantern for the GVB cabinet is a good D65 simulator, though the color rendering indexes mark a class 2 (medium category). This affirmation is supported with the comparison of the SPDs of the light sources of both cabinets, moreover including the corresponding D65 and D50 fluorescent simulators of the Verivide cabinet (Figure 11). As we can see here, only the One point for the BSE cabinet is to initially select the similar Tc for colour and sparkle assessments, though the color rendering level of the wLED luminaires is clearly lower (class 2) than the D50 simulator (class 1B). Consequently, spite of the fact that the new solid-state lighting technologies, as LED or OLED technologies, have very interesting advantages for many industrial sectors and other human activities with regard to conventional (incandencent and fluorescent) lighting technologies, the large amount of demanding requirements from the colour reproduction industries, as the automotive sector, imposes new challenges for discovering or color filtering new lighting technologies able to replicate at spectral level the D65 or D50 illuminants.

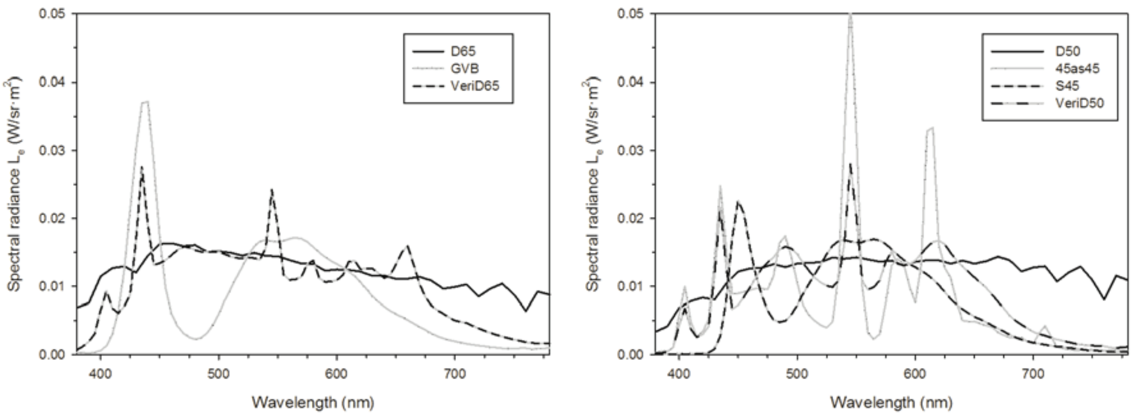

Figure 11 – Absolute SPD (spectral radiance), normalised to 1000 lx of illuminance level, of the light sources installed in the lighting booths analysed in this work. Left: D65 illuminant (as reference), gonio-vision-box (GVB) light source and Verivide D65 simulator. Right: D50 illuminant (as reference), byko-spectra effect (45as45 and S45 luminaires) and Verivide D50 simulator.

3.1.1 Visual and instrumental correlation

Inside this section, it seems adequate to test the grade of coincidence of the colorimetric data measured into the BSE cabinet with the PR-650 instrument for a gonio-apparent panel (Figure 5, 6 and 12) with regard the colorimetric data from a multi-gonio-spectrophotometer for the same gonio-apparent panel, and for the same measurement geometries. This test is basically consists of checking the visual and instrumental correlation, although perhaps it is worth to study for other works this crucial issue for the automotive sector with much more gonio-apparent panels.

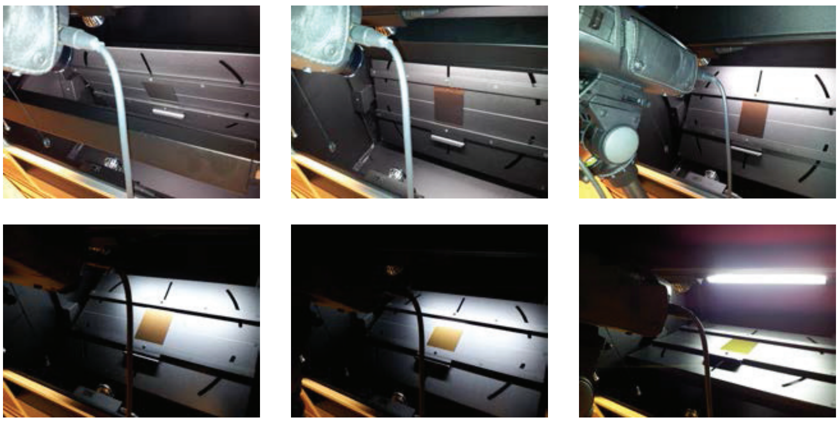

Figure 12 – Pictures of a typical gonio-apparent panel inside the byko-spectra cabinet such as it is measured by a PR-650 tele-spectroradiometer. Top, left to right: measurement geometries 45as110, 45as75 and 45as45. Bottom, left to right: 45as25, 45as15 and 45as-15.

In any case, here we used our BYK-mac multi-gonio-spectrophotometer as reference, and using its white reference in the scene centre of the BSE cabinet for obtaining the absolute tristimulus values CIE-1964 XYZ (in cd·m^{-2}) with the PR-650 instrument. Next, placing the panel in the same position we obtained the corresponding absolute tristimulus values XYZ, so applying the conventional equations for the CIELAB colour space, it is very direct to obtain the corresponding CIE-L*a*b* values for the gonio-apparent panel for each measurement geometry. Taking the similar CIE-L*a*b* values from a multi-gonio-spectrophotometer, and considering these ones as reference data, the next step was to calculate and plot the colour differences Δa^* vs. Δb^*, and, ΔC_{ab}^* and ΔL^*, for the six measurement geometries (Figure 13).

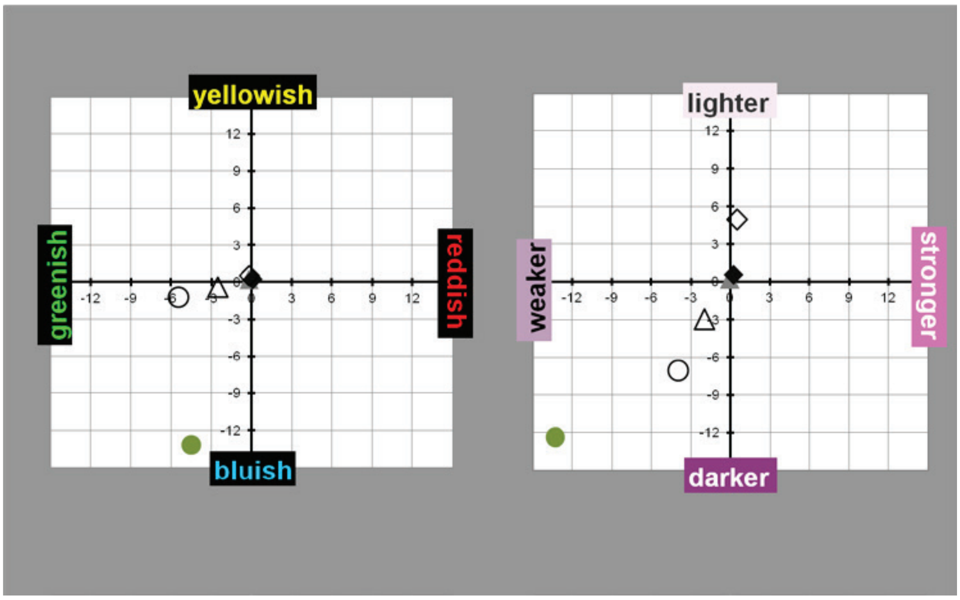

Figure 13 – CIELAB colour differences for one gonio-apparent panel, inside the byko-spectra effect cabinet, measured with the tele-spectroradiometer PR-650, using the same white reference used with one BYK-mac, and previously measured with the BYK-mac instrument (CIELAB data under D65 illuminant and CIE-1964 standard observer as reference). Symbols for the measurement geometries: 45as45 (solid triangle), 45as25 (triangle), 45as15 (circle), 45as-15 (solid circle), 45as75 (solid diamond) and 45as110 (diamond).

As it can be seen in last figure, the partial colour differences related to some measurement geometries (i.e., 45as45 and 45as75) are enough small in order to be within industrial tolerance. However, the rest of measurement geometries, and in particular the measurement geometries 45as15 and 45as-15 have high colour differences at reproducibility level using one multi-gonio-spectrophotometer and one directional lighting booth, specifically well designed to fulfil the requeriments of the colour instrument. Therefore, the visual and instrumental correlation is not good for this first example with a gonio-apparent panel, so it is pending to understand better these colour discrepancies, and to find out, for instance, whether the use of D50 simulator instead of D65 simulator (applied in CIELAB data from the BYK-mac instrument) in the BSE cabinet is the most important reason, or there are other ones more focused on photometric and/or opto-mechanical designs, or due to the use of one not ideal white reference (Cramer 2012), or different instruments (Perales, et al. 2012).

3.2 Photometric analysis

For this technical assay, we used a photometer (Gossen Mavolux 5032) arranged in the many positions across a white paper template placed in the scene of each lighting booth. Then, the collection of illuminance values was used in order to obtain the illuminance field smoothing the original photometric data with some conventional math algorithms found in the Sigmaplot® software.

Next, we show the pictures and illuminance fields corresponding to all photometric configurations applied and analysed in the three lighting booths (BSE, GVB and Verivide). Firstly, in Figure 14 we show the results related to the byko-spectra effect cabinet, finding as most relevant result that the illuminance field for colour assessments is not completely uniform, as just it is for the Verivide cabinet (Figure 15). Therefore, this new result is other drawback for using this directional illumination cabinet, provided the size of colour panel was not enough big.

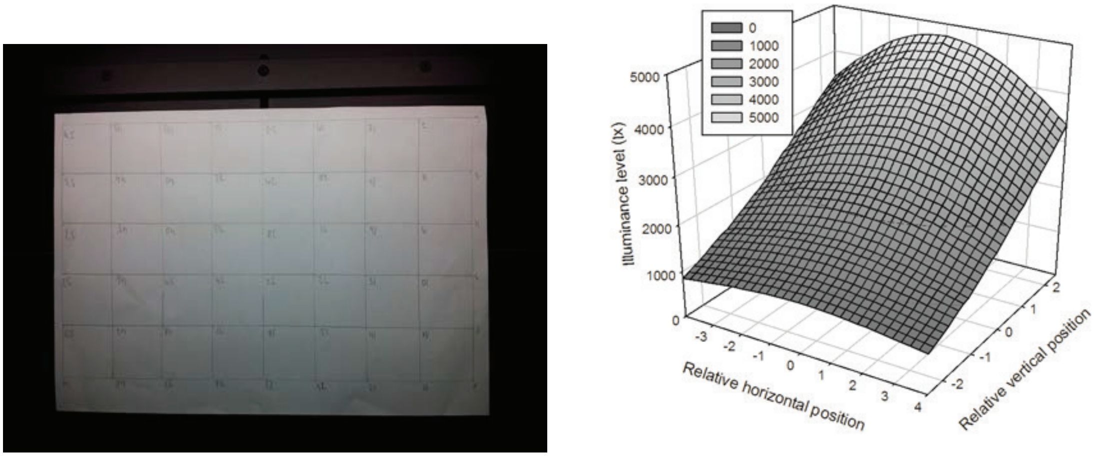

Figure 14 – Illuminance field (left: picture; right: 3D mesh) of the byko-spectra effect cabinet for the measurement geometry 45as45. Absolute scale: Δx = Δy = 5 cm.

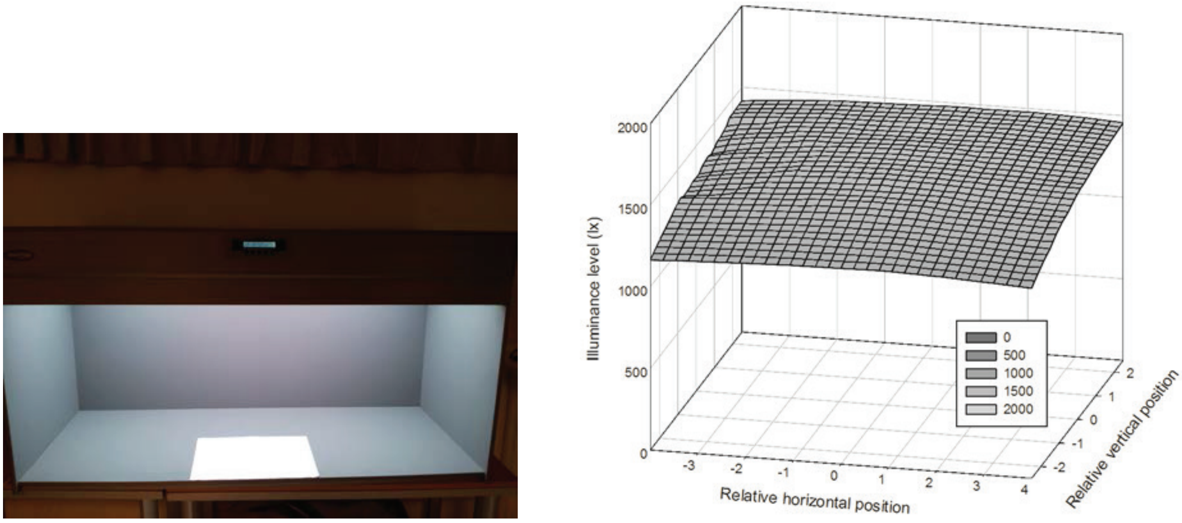

Figure 15 – Illuminance field (left: picture; right: 3D mesh) of the Verivide CAC-150 with the D65 simulator. Absolute scale: Δx = Δy = 5 cm.

Following with the photometric analysis of the BSE cabinet, the illuminance fields related to the sparkle luminaires (Figure 16) also show not uniform contour maps, so these kinds of luminaires for visual assessing texture will be valid using small panels. Perhaps, and remembering the Figure 8, the most interesting illuminance fields were S15 and S45, where moreover it is possible to select the same illuminance level for many sparkle assessments and know the true influence of the absolute illuminance level of the visual detection and discrimination of sparkle.

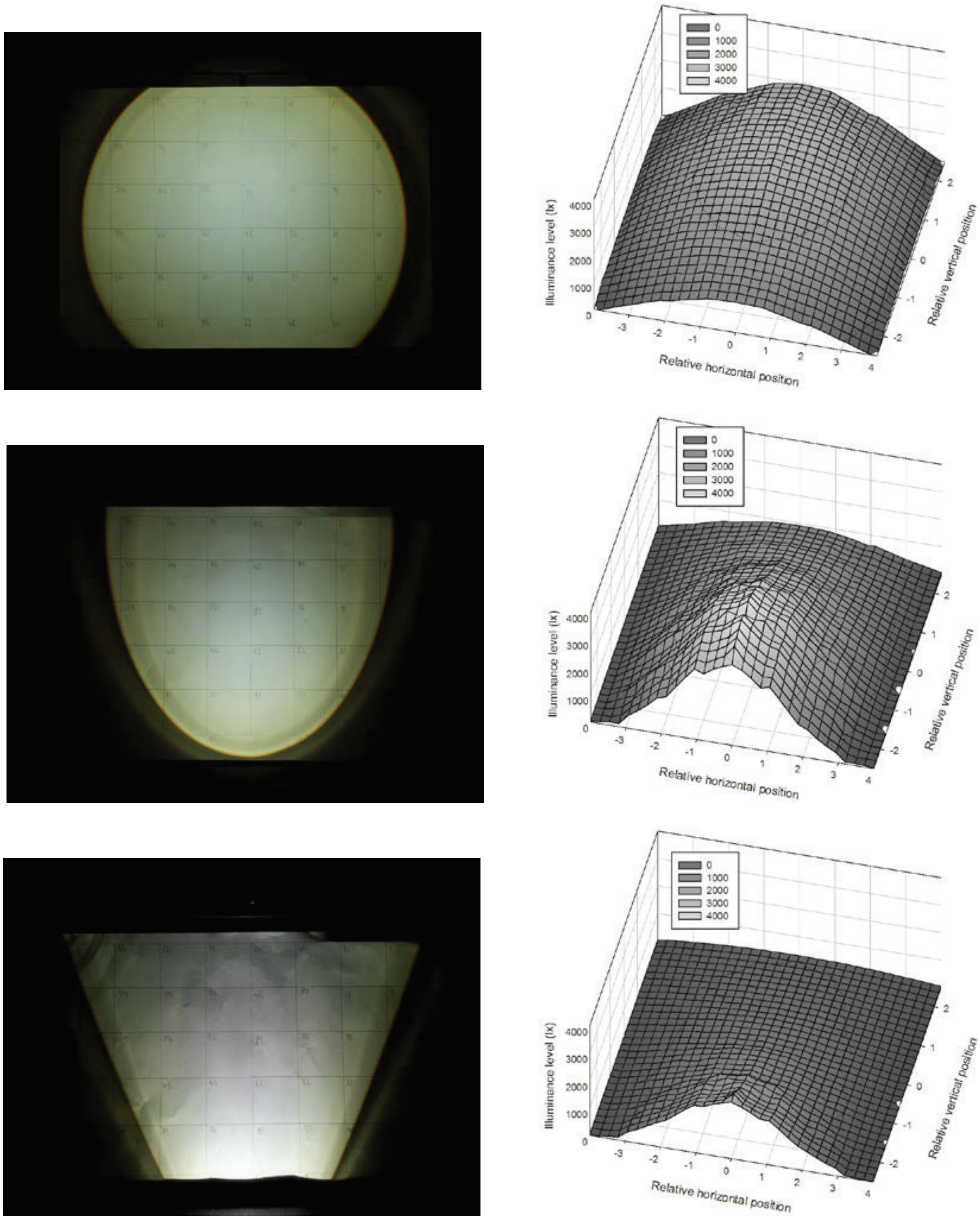

Figure 16 – Illuminance fields (left: picture; right: 3D mesh) of the byko-spectra effect cabinet for the measurement geometries for sparkle assessment. From top to bottom: S15, S45 and S75. Absolute scale: Δx = Δy = 5 cm.

For the GVB cabinet (Figure 17), in three incidence angles (45as, 15as and 65as), it can be seen the non-uniformity of the illuminance fields, so, again, this kind of lighting booth, with directional illumination, is only valid for very small areas. Therefore, for this type of cabinet, having very small uniform areas in their illuminance fields means that the use of this cabinet is only for qualitative purposes (seeing and comparing colour sub-gamuts associated with different gonio-apparent panels with different colour recipes, but not for color matching, testing colour difference formulae, etc), not at quantitative level, as it is possible using the BSE cabinet.

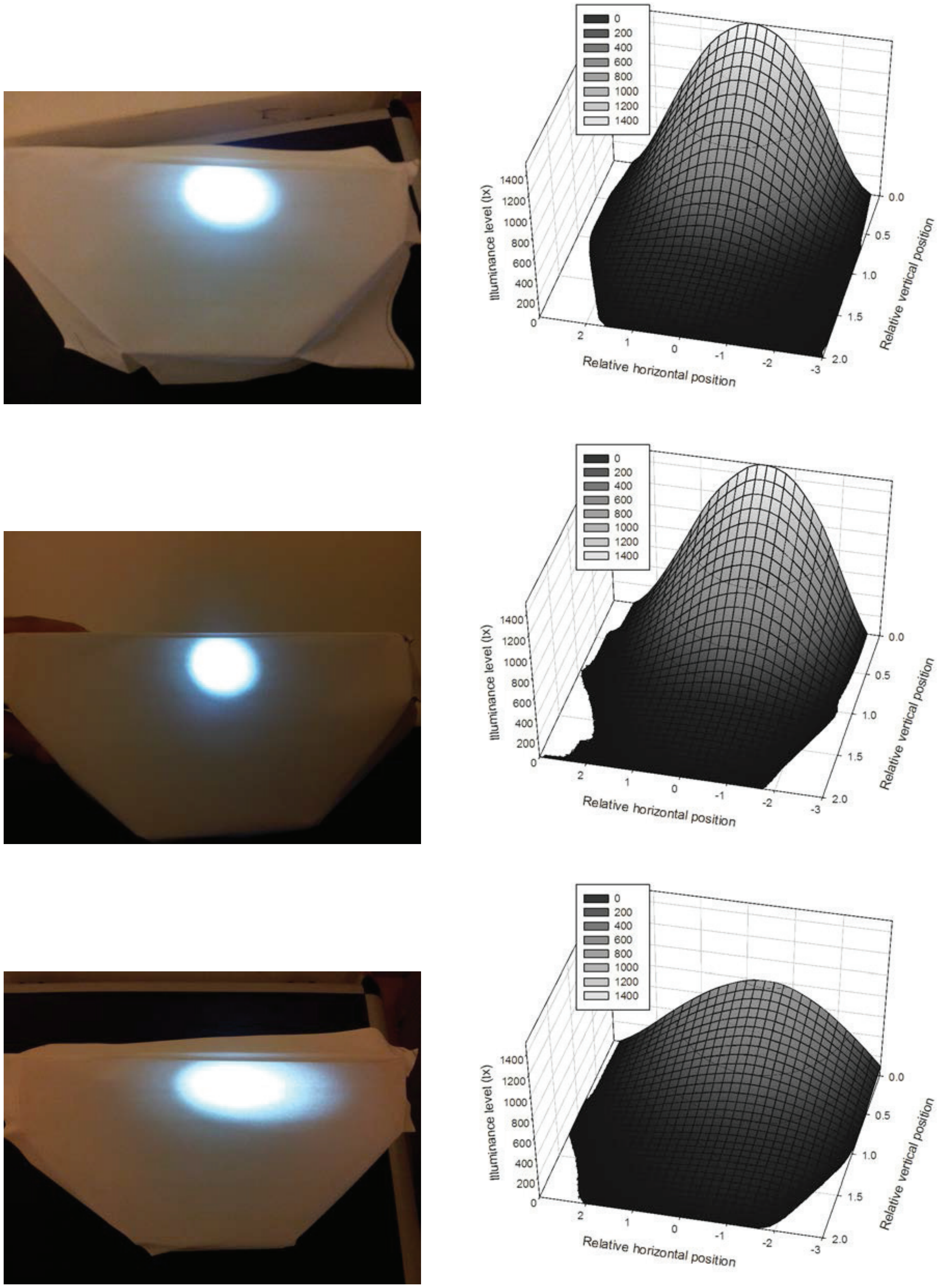

Figure 17 – Illuminance fields (left: picture; right: 3D mesh) of the gonio-vision-box cabinet for the incidence geometries: 45as (top), 15as (center) and 65as (bottom). Absolute scale: ∆x = 2,25 cm, ∆y = 2 cm.

4 Conclusions

The directional lighting booths for the automotive sector analyzed in this work, used nowadays for analyzing the visual and instrumental correlation of gonio-apparent coatings and plastics, based on special-effect pigments, have some strengths and drawbacks at colorimetric and photometric levels. In particular, the new BSE cabinet uses light sources, with different color rendering indexes, enough different to the D65 illuminant, theoretically and continuous used at instrumental level in all multi-gonio-spectrophotometers. This main drawback, due to the very demanding requeriments from the colour reproduction industries, as the automotive sector, imposes new future challenges for discovering or color filtering new lighting technologies able to replicate at spectral level the D65 or D50 illuminants.

On the other hand, for evaluating the visual appearance of sparkle effect of gonio-apparent panels to different geometric configurations, it is not possible to select the same illuminance level, and with high values (> 2000 lx), in these three geometries (15º, 45º and 75º). On other hand, the gonio-vision box is one useful small lighting booth for evaluating the color gamut of gonio-apparent panels for in and out-of-planes directional geometries, but not for evaluating the sparkle due to its limited visual field. Only selecting small areas into the illuminance fields related to the photometric configurations of these new cabinets, it would be possible to apply new psychophysical experiments whose objectives would be to evaluate the detection distance of sparkle in some geometries keeping the same visual angle, or evaluating the performance of new color difference formulae for gonio-apparent samples, or other experiments related to the understanding of the visual appearance (colour & texture) of new materials.

In any case, such as it has been shown above, the visual and instrumental correlation is not satisfactory, spite of rightly applying absolute colorimetry using the BSE cabinet and comparing the extracted CIELAB data in front of the corresponding ones to a BYK-mac multi-gonio-spectrophotometer. Therefore, this specific test is worth to be enlarged with a lot of gonio-apparent panels in future works, trying to find out the main reason of the colour discrepancies in some measurement geometries, in particular in those closer the specular direction, i.e., the 45as15 and 45as-15, but very important to understand better the colour appearance of gonio-apparent materials, and its industrial control for keeping high quality protocols, as it daily happens in the automotive sector, in all car factories, inclusive in coatings and plastics providers.

5 Acknowledgements

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