https://doi.org/10.2352/issn.2694-118X.2020.LIM-10

Physics-based modeling of a light booth to improve color accuracy of 3D rendering

Khalil Huraibat[1]*, Esther Perales[1], Alejandro Ferrero[2], Joaquín Campos[2], Ivo Van der Lans[3], Eric Kirchner[3].

[1]Department of Optics, University of Alicante, Alicante, Spain.

[2]Instituto de Óptica, Consejo Superior de Investigaciones Científicas, Madrid, Spain.

[3]AkzoNobel Technology Group Color; Sassenheim, the Netherlands.

Email: khalil.huraibat@ua.es

Abstract

Computer Aided Design (CAD) is increasingly used as a tool in industries varying from automotive to interior design. Digital visualization allows users to design their working and living spaces, and to select materials and colors for future products.

The rendering software that is currently available often suggests photorealistic quality. However, visual comparisons of these images with the physical objects they represent reveal that the color accuracy of these methods is not good enough for critical applications such as automotive design.

Therefore, we recently developed a spectral pipeline for rendering gonio-apparent materials such as effect coatings. In order to accurately render objects as they appear in a physical environment, this new approach requires a physics-based representation of the illumination surrounding the objects. In the present article we investigate how to physically represent one, well-defined lighting environment.

Therefore, we investigated the lighting inside a recent, commercially available light booth that is widely used in the paint and graphical industry. We determined the spatial dimensions of the X-Rite SpectraLight QC light booth, and built a digital geometrical model of this light booth in the Open Source software Blender. We then measured the spectral radiance emitted by the various light sources that are integrated in the luminaire of this light booth, as well as the illuminance on a grid of measurement spots on the platform below the luminaire. Using these measurement data, we were able to develop an accurate physical simulation of the light field inside the light booth.

We plan to use the physics-based model of the lighting inside the light booth to set up visual tests in which physical objects inside the physical light booth are visually compared to images showing virtual objects inside the virtual light booth. These visual tests will form the basis for developing improved models for displaying the color and texture of gonio-apparent materials.

Introduction

Nowadays, digital visualization has become an important part of our daily life, especially with the huge breakthrough on virtual reality and 3D visualization technology. These are getting a massive presence in gaming, entertainment, trading and more specific areas such as medicine and many industrial applications. Common rendering software such as Maya, Keyshot, VRED (Autodesk), Revit and Mentalray (Nvidia) produces images that suggest photorealism, and serve the needs for applications such as the movie and games industry [1]. However, upon close examination it becomes clear that the virtual objects shown in these images do not have a good color accuracy when visually compared to the physical objects they represent [2]. For critical applications such as industrial quality control or automotive design, the color accuracy of these images is not good enough [3].

Current rendering software has a number of additional disadvantages: sparkle and other texture effects are either absent or not represented well [2][4][5][6], the rendering of materials with specific levels of gloss requires developers to estimate numerical values of a series of model parameters [7][8][9], the angular color variation of metallic coatings and other gonio-apparent materials is not covered correctly in current rendering algorithms [10], and rendering generally requires expensive processors, graphical cards or other hardware.

We recently developed a new approach to solve these problems [11]. In this approach we optimize color accuracy by taking into account the technical specifications of the display and also the local lighting conditions. This is combined with the open source rendering framework of OpenGL 3.0 ES (Embedded Systems) that we turned into a fully spectral rendering pipeline, unlike most existing rendering software libraries. Our software implementation is fast enough to enable real-time rendering on tablet computers, without requiring expensive additional hardware such as graphics cards.

We plan to use the spectral rendering pipeline for creating physics-based rendered images that represent samples in well-controlled lighting conditions [12][13]. We will set up visual tests in which the virtual samples are visually compared to the corresponding physical objects. In this way, we will develop methods to improve the accuracy of rendering sparkle, gloss and the color of gonio-apparent materials.

For accurate rendering of the colors observed on objects it is important to accurately characterize the local lighting conditions, including the spectral radiance of the light sources surrounding the object. In recent publications we focused on describing the well-defined lighting conditions of the Byko-Spectra Effect light booth from manufacturer BYK-Gardner, which is a light booth common for the automotive industry. In the current article we will describe our work on creating a physics-based model of the X-Rite SpectraLight QC (here abbreviated as SPLQC) light booth (Figure 1, left). This light booth is widely used in the paint and graphical industry for visual quality evaluation and color assessment. As illustrated on the right-hand side of fig. 1, the SPLQC integrates seven different standardized lighting sources that are placed on the overhead luminaire, illuminating a medium gloss neutral colored viewing box. For now, we will focus on the simulation of the daylight D65 and the A-illuminant, since these are most relevant for industrial practice. A physically accurate model of the lighting conditions inside this light booth is needed to create accurate rendering images of objects as they would appear inside this light booth, which could help communication on color between paint laboratories or textile manufacturing sites across the globe.

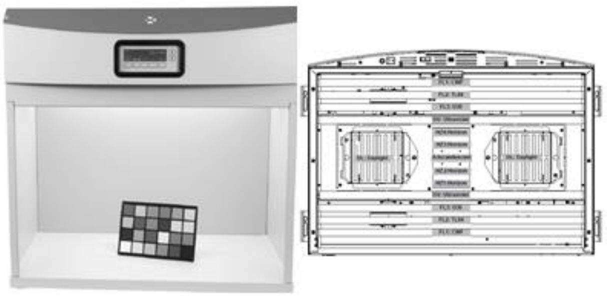

***Figure 1.** Left: The X-Rite SpectraLight QC light booth. Right: The overhead luminaire configuration from an upward view.*

In this article, we start by making a geometrical model of the SPLQC light booth, including the spatial dimensions of all inner components that are relevant for rendering objects inside the light booth. Next, we present measurement data to characterize the spectral radiance of the light sources as well as their global light distribution, and also the reflectance properties of the walls of the lighting booth. All data are integrated in a physical model and combined with the spectral rendering pipeline.

Methods

Geometrical shape and dimensions

To build a physically correct model of the lighting inside the SPLQC light booth, we first created a geometrical model of this light booth. We measured the shape and spatial dimensions of the physical light booth, and we created a geometrical model by using the open source software Blender [11], which features a complete 3D creation pipeline. The geometrical model consists of a 3D mesh for the body of the light booth (shown on the left-hand side of figure 1), as well as for the overhead luminaire cavity. The latter contains a configuration of seven different light sources: two D65 filtered tungsten halogen lamps with a calibrated color temperature of 6500 K, one horizon calibrated tungsten halogen light with a color temperature of 2300 K (denoted as HZ), one incandescent tungsten halogen light (denoted as A), three fluorescent tubes (denoted as FL) and an ultraviolet light source calibrated with adjustable UVA levels (denoted as UV). All these sources are covered by a glass diffuser plate.

In this work we focus on simulating only the two light sources that are most relevant for industrial applications, the daylight D65 and the A-illuminant. Figure 2 shows the Blender 3D model wireframe. The orange colors in this figure highlight the two D65 illumination boxes that are placed on both sides of the overhead luminaire. Both boxes contain a prism-shaped metallic mirror that serves to guide the illumination from the tungsten lamp. D65 filters are placed inside a mask at the bottom side of these boxes.

The A-illuminant is obtained through a single tungsten bare lamp placed at the center of the overhead luminaire (also colored orange in Figure 2).

The 3D model already contains the other lamps and tubes as well, although their illuminations are not intended to be simulated yet. However, they need to be included in the geometrical model since they affect the overall resulting illumination. In future extensions to the present work we may use the same 3D model to simulate these additional light sources as well.

The complete 3D mesh that describes all components of the SPLQC light booth was exported as an .obj file, which allows importing it into common rendering software.

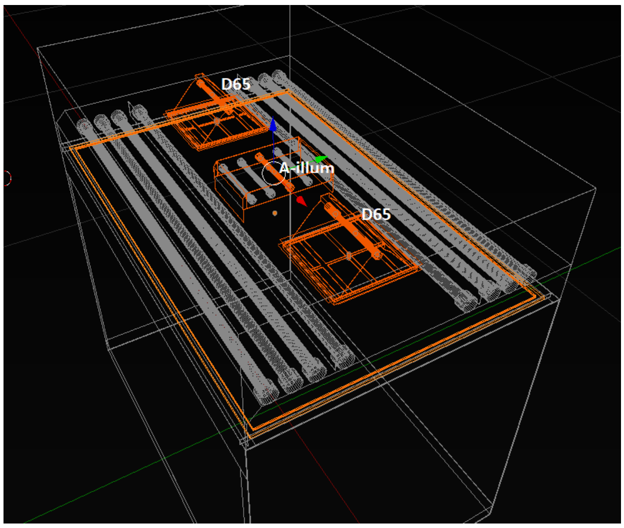

***Figure 2.** Geometrical representation of the SPLQC light booth and all its components as a 3D mesh in Blender.*

Diffusivity of the diffuser plate

Figure 2 also shows a rectangular plate (orange colored), placed underneath all the illumination cavity components. This represents the glass diffuser plate. In the Blender software, we selected the BSDF (bidirectional scattering distribution function) of glass material to simulate the physical effect of the diffuser plate.

The so-called roughness parameter of the BSDF model in Blender specifies the blurring of the glass rendered surface. We found an optimum value for this roughness parameter by visually comparing the amount of blur in real photos of the diffuser surface with blur in images rendered by Blender.

Figure 3 shows that the borders of the D65 filter mask that is visible through the glass plate is suitable for this visual comparison. The comparison was made by considering different photos of the physical diffuser plate as shown in

Figure 3. We found that a value of 0.04 for the roughness parameter resulted in the best visual match of the blurring.

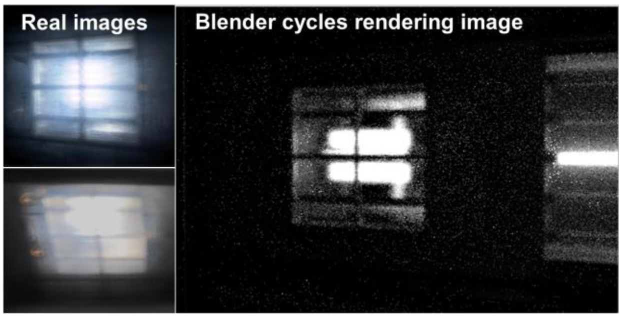

Figure 3. *Left: Photographs ("Real images") used to adjust the roughness of the glass diffuser in the rendering, Right: Rendered image using Blender cycles.*

Lighting

We characterized the light inside the D65 and A illumination configurations as follows.

We measured the spectral radiance on the platform below the luminaire by using a tele-spectroradiometer Konica Minolta CS2000® and a perfect white diffuser simulator (calibrated white tile) placed at the center of the lightbooth. We took separate measurements for the case that the diffuser plate was removed and also for the case the diffuser plate was in place. In this way, we assessed the influence of the diffuser plate on the resulting spectral power distribution of the light.

We also characterized the emission profile for both the D65 and the A illumination configurations. For this we used the methodology as described in detail in our previous publications [12][13][14][15]. In short, we used a CL500A illuminance spectroradiometer to measure the illuminance at 55 different grid points as indicated on an A3 paper sheet. This sheet was placed at the center of the floor part of the light booth. This is illustrated at the right-hand side of figure 4. However, and unlike the model used on our previous publications [12][13][14], direct light is not present in our rendering for the SPLQC light booth. Since there is a diffuser blocking the direct light anyway and specular reflected light via the mirror-like cavity would not be analytically feasible. In fact, we are using the indirect-light (diffuse) assumption via the cube-map projection method that was pre-calculated in Blender. There is no need to approximate the angular radiance distribution from the light source tubes because Cycles rendering in Blender does that for us and stores the result in a per-pixel map. This pre-computed map contains the light distribution of the entire light booth environment.

Finally, we measured the spectral reflectance factor of the inner walls and floor surface of the light booth. Since these surfaces reflect part of the light inside the light booth, indirect light reflections affect the light falling on objects inside the light booth.

Figure 4. *Left: Set-up to measure spectral radiance with a tele-spectroradiometer and a perfect white diffuser simulator (white tile). Right: Set-up for measuring illuminance at 55 positions on a grid.*

Real-time accurate rendering

In the rendering software, we combine all data collected in the previous steps. The geometrical shape and dimensions of the light booth and its components, the spectral power distribution of the light, the global illuminance of light booth environment through the pre-computed cube-maps, and the spectral reflectance values of inner walls and floor area.

For interactive real-time rendering it is important that the total calculation for a given scene is finished within approximately 50 milliseconds, since that would lead to a framerate of 20 frames per second. We note that this requirement is very demanding, since we also need the software to run real-time on a common tablet computer (iPad Air 2 or later model) rather than on expensive hardware or graphical card. For this reason, we decided to let those parts of the calculation that are identical for each frame be calculated in a pre-computation phase that also avoids too large consumption of battery power. The pre-computation step is executed by the physics-based path tracer that is called Cycles, and that is part of the Blender software. We adapted it to process the spectral rendering and to calculate the resulting global illumination as a high-fidelity representation of the luminance scene. We store its details in files that are used as input for the OpenGL based real-time rendering pipeline on the tablet computer.

Results

Light characterization

Figure 5 shows the spectral radiance curves of the D65 and the A light sources inside the SPLQC light booth. As mentioned before, both were measured not only with the diffuser in place but also without the diffuser. Our results show that the A-illuminant is represented by a very smooth curve in this light booth and closely follows the CIE standard [16]. Clearly, the diffuser plate has only very little effect on the radiance or on the shape of the spectrum.

Our data show that the D65 light source does show some deviations from the CIE standard illuminant D65 [16], for example around 560 nm. These deviations are common in commercial light booths, and result from the limited possibilities to fine-tune the light spectrum of the halogen lights even in combination with a transmission filter. Figure 5 also shows that the radiance of the D65 illuminant is reduced by the diffuser plate. This seems to be caused by the shape of the mirrors surrounding the D65 lamps, which result in two focused beams of light if no diffuser plate is mounted. When the diffuser plate is put in place, this light is scattered towards multiple directions, less light falls on the white tile (Figure 4, left) and a lower signal is measured by the spectroradiometer.

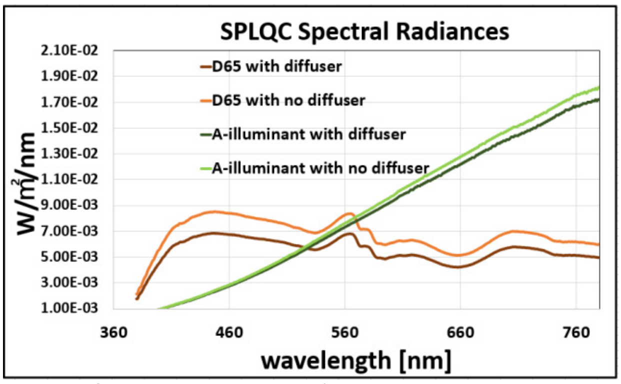

Figure 5. *Spectral radiance curves of the D65 and the A-illuminant light sources measured with and without the diffuser plate.*

Figure 6 shows the measured values for the illuminance at the grid points on the floor surface of the light booth, separately for the case of D65 lighting and for A lighting. In an ideal light booth, illuminance would be uniform across the floor area of the light booth, but Figure 6 shows a clear variation.

For D65 lighting, our results show the highest values are measured on two lines indicated as horizontal levels of approximately +2 and -2 in Figure 6a. This is as expected, since these two lines correspond to the positions on the floor surface of the light booth that lie directly under the two D65 luminaires as indicated in Figure 2. The direction denoted as vertical in Figure 6a corresponds to the direction from the place where the observer is placed towards the rear wall of the light booth. Figure 6a shows that the highest illuminance values are measured at that rear end of the light booth, which is due to internal reflection from the rear wall.

The illuminance profile for the A illuminant is shown in Figure 6b. It shows a large difference with the profile for D65. When varying along the horizontal direction (i.e., from the left wall towards the right wall inside the light booth), the illuminance of the A illuminant shows a peak at the center. This agrees with the central position of the A lamp inside the overhead luminaire (Figure 2). When varying positions along the vertical direction (i.e., from the position of the observer towards the rear wall of the light booth), the illuminance values show a variation that is very similar to what we measured for the D65 illuminant (Figure 6a): due to internal reflections from the rear wall, the highest illuminance values are measured at the back end of the light booth.

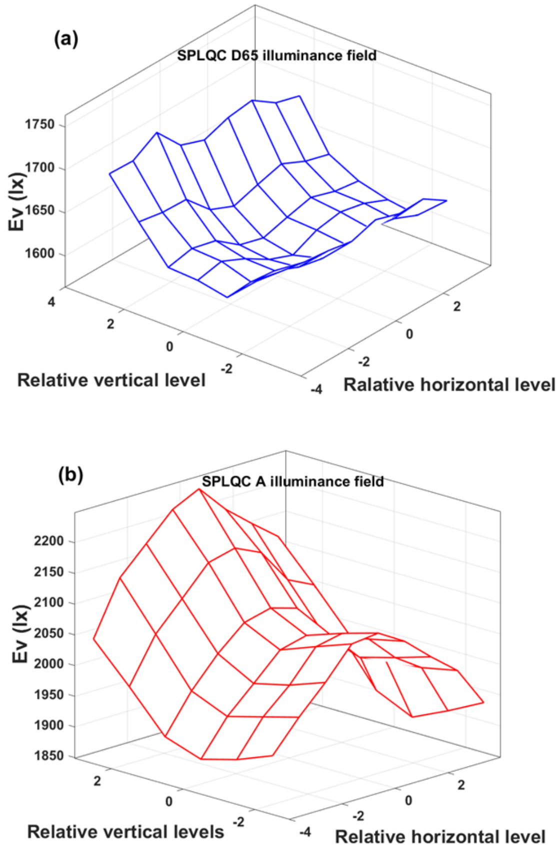

Figure 6. *(a): Illuminance profile of the D65 illumination configuration as measured at the grid points located at the floor surface of the SPLQC light booth. (b): Illuminance profile of the A-illuminant configuration as measured at the same points.*

3D Rendering of sample and light booth

In Figure 7a we show a photograph of the physical SPLQC light booth, with its D65 lamps switched on. This may be compared to the image shown in Figure 7c, which is the image calculated by the 3D rendering pipeline on an iPad Air 2, using the measurement data collected as described in the previous sections. The rendered image can be seen to capture the variations in illuminance that can be recognized in the photograph as well. Actually, we note that the photograph shows fewer details in illuminance profile than the rendered image, which may be due to the optical quality of the camera, or to a relatively narrow focus plane of the camera.

Figures 7b and 7d show the corresponding photograph and rendered image when switching on the A illuminant. We conclude that also in this case the rendered images correctly capture the lighting patterns and the global illumination.

This conclusion is mainly based on a visual comparison of the rendered images with the photographs. In the future, we plan to conduct a quantitative analysis to confirm the accuracy of the rendered images. We plan to organize visual tests in which observers compare physical objects inside the physical SPLQC light booth with images that render the same object as viewed inside the virtual SPLQC light booth, using the described spectral rendering pipeline and the SPLQC lighting model as developed in the current article. Figure 7b and 7d already show a flat sample as rendered inside the light booth, based also on spectral reflectance data for the sample. The planned visual tests will enable us to draw more quantitative conclusions on the accuracy of the current renderings, and on the most important points to further improve their accuracy.

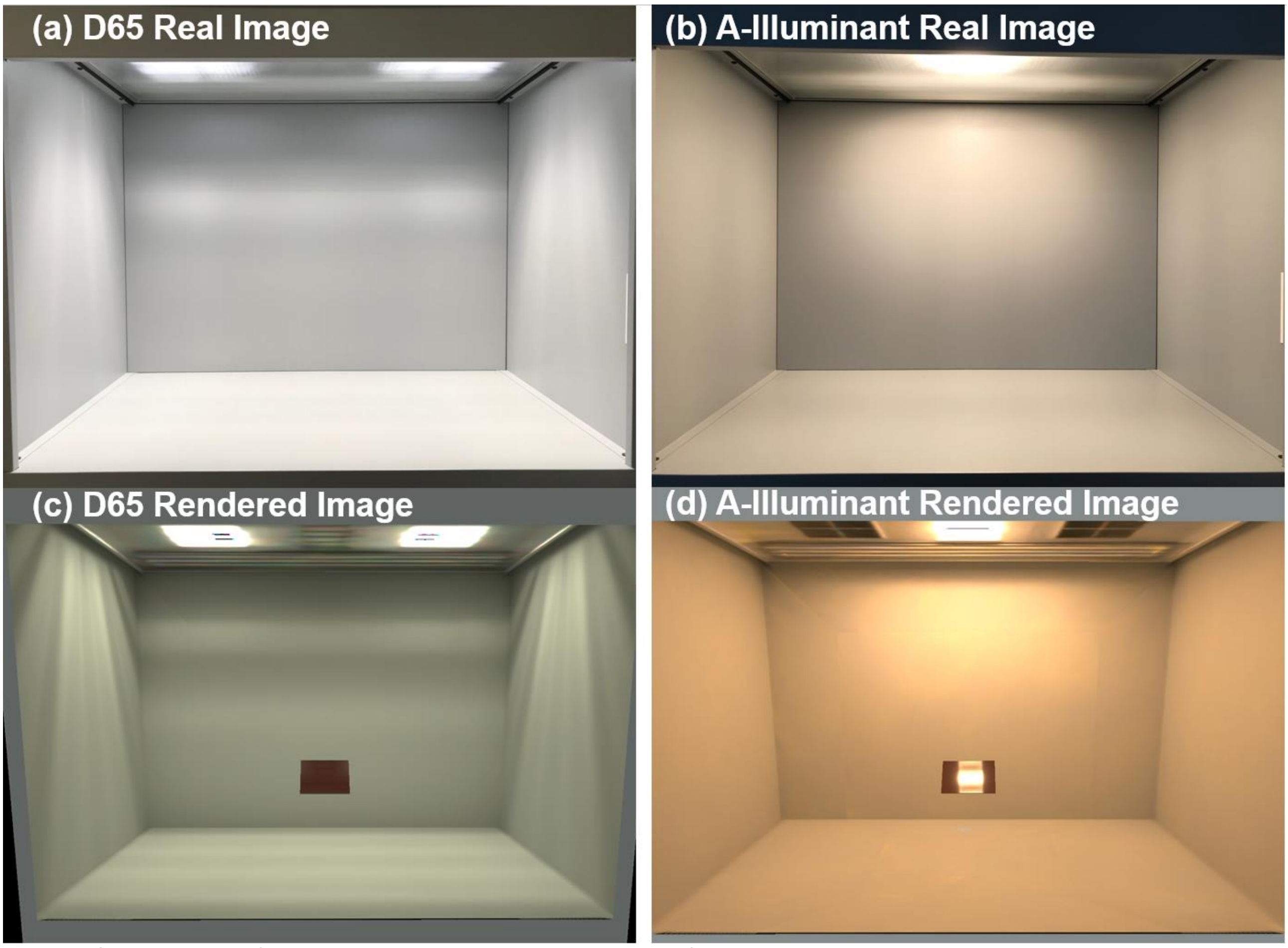

Figure 7. *Comparing results for D65 daylight illuminant (both images on the left) and A-illumination (both images on the right). Both top images are photographs taken from the physical light booth. Both bottom images are rendered on an iPad Air 2 using the spectral pipeline discussed in the current article and applied to the physical-mathematical model of the SPLQC light booth.*

Conclusion

We developed a model to represent the X-Rite SpectraLight QC light booth. The model describes the geometrical and dimensional properties of this light booth. The spatial dimensions and shape of the light booth as well as its inner components were represented by a 3D model of the light booth and built by using the open source software Blender. It also includes an indirect-light assumption of the global illuminance surrounding an object placed inside the light booth. We included two different lighting configurations for the SPLQC light booth: both the daylight D65 light source and the A-illuminant lighting were included in this work. Our measurements show that the illuminance profiles of both lighting configurations are less uniform across the floor area of the light booth than expected.

Our indirect-light assumption is well able to capture the non-uniformity in illuminance across the light booth. A visual comparison of the light booth under both illumination conditions as captured by photographs of the physical light booth and by rendered images of the virtual light booth indicate that the models derived in this article provide a physically accurate representation of global illumination. We plan further work to quantitatively confirm this conclusion and to further improve the color accuracy of the rendering.

Acknowledgements

The authors would like to thank the Ministry of Economy and Competitiveness for the project DPI2015-65814-R. The Author would also like to thank the Ministry of Economy and Competitiveness for pre-doctoral fellowship grant (FPI BES-2016-077325).

References

[1] R. Martín, M. Weinmann, M.B. Hullin, "Digital transmission of subjective material appearance", Jour. WSCG 25, no. 2, pp. 123-132, 2017.

[2] J. Günther, T. Chen, M. Goesele, I. Wald and H.P. Seidel, "Efficient acquisition and realistic rendering of car paint" in G. Greiner, J. Hornegger, H. Niemann and M. Stamminger, eds., Proceedings of Vision, Modeling and Visualization (Erlangen, Germany), pp. 487-494, 2005.

[3] J.A. Ferwerda, S.H. Westin, R.C. Smith and R. Pawlicki, "Effects of rendering on shape perception in automobile design". Proceedings ACM Symposium on applied perception in Graphics and Visualization (Los Angeles, US), pp. 107- 114, 2004.

[4] M. Rump, G. Müller, R. Sarlette, D. Koch, R. Klein, "Photo-realistic Rendering of Metallic Car Paint from Image-Based Measurements", Eurographics/Computer Graphics Forum 27 (Crete, Greece), pp. 527-536, 2008.

[5] C. Shimizu, G.W. Meyer, "A computer aided color appearance design system for metallic car paint", J. Imaging Sci. and Technol. 59, 0303403-1-030403-10, 2015.

[6] E. Kirchner, Texture Measurement, Modeling, and Computer Graphics. In: M.R. Luo (Editor), Encyclopedia of Color Science and Technology, edition 2015 (Springer Publications).

[7] M. Pharr, W. Jakob and G. Humphreys, "Physically Based Rendering: From theory to Implementation", Morgan Kaufmann Publishers, third edition, 2016.

[8] M. Haindl and J. Filip, "Visual texture", Springer, 2013.

[9] J. Dorsey, H. Rushmeier ad F. Silion, "Digital Modeling of Material Appearance", Morgan Kaufmann Publishers, 2008.

[10] E. Kirchner, I. van der Lans, A. Ferrero, J. Campos, F.M. Martínez-Verdú, E. Perales, “Fast And Accurate 3D Rendering Of Automotive Coatings”, Proceedings of the Twentythird Color and Imaging Conference (Society for Imaging Science and Technology, 2015), p.154-160.

[11] Blender Foundation (2002)– www.blender.org.

[12] E. Kirchner, I. van der Lans, P. Koeckhoven, K. Huraibat, F.M. Verdú, E. Perales, A. Ferrero and J. Campos, “Real-time accurate rendering of color and texture of car coatings”, Proceedings of IS&T International Symposium on Electronic Imaging 2019, 076.1-5, https://doi.org/10.2352/ISSN.2470-1173.2019.14.COLOR-076.

[13] K. Huraibat, E. Perales, V. Viqueira, E. Kirchner, I. van der Lans, A. Ferrero and J. Campos, "Byko-Spectra effect light booth simulation for digital rendering tool", Proceedings of the XII Congreso Nacional del Color (Linares, September 2019).

[14] K. Huraibat, E. Perales, F.M. Verdú, E. Kirchner, I. van der Lans, A. Ferrero and J. Campos, "Characterization of Byko-spectra light booth for digital simulation in a rendering tool", CIE 2019, 29th session (Washington, 17-19 June 2019), PO070.

[15] Martínez-Verdú, F., Perales, E., Viqueira, V., Chorro, E., Burgos, F. J., & Pujol, J. “Comparison of colorimetric features of some current lighting booths for obtaining a right visual and instrumental correlation for gonio-apparent coatings and plastics”. Proceedings of CIE conference on Lighting Quality and Energy Efficiency, (2012) 692-705.

[16] CIE 15:2004, Colorimetry, 3rd ed., (Commision Internationale de L’Eclaraige, Vienna, 2004).