A mathematical model for gloss prediction of 2D prints.

Donatela Saric[1,2], Andreas Kraushaar[1], Aditya Suneel Sole[2]
[1]Fogra Research Institute for Media Technology
[2]Norwegian University of Science and Technology, Gjøvik, Norway

Abstract

Predicting the final appearance of a print is crucial in the graphic industry. The aim of this work is to build a mathematical model to predict the visual gloss of 2D printed samples. We conducted a psychophysical experiment where the observers judged the gloss of samples with different colours and different gloss values. For the psychophysical experiment, a new reference scale was built. Using the results from the psychophysical experiment, a mathematical prediction model for the visual assessment of gloss has been developed. By using the Principal Component Analysis to explain and predict the perceived gloss, the dimensions were reduced to three dimensions: specular gloss measured at 60°, Lightness (L) and Distinctness of Image (DOI).*

Introduction

According to ISO 2813, gloss is defined as "the attribute of visual perception by which a surface appears to have a shiny or lustrous quality. [1] In general, gloss refers to the visual appearance of a surface, particularly its shininess or reflectivity. Gloss is considered to have different numbers of dimensions depending on the context. In the industry, one dimension, which is related to the level of reflectivity of a surface is considered enough to describe the gloss output. However, gloss can also be described using additional dimensions, such as clarity or texture. Visual gloss, which is the subjective perception of a surface's shininess or reflectance is a complex phenomenon that involves multiple aspects of vision and cognition. It is difficult to determine the exact number of dimensions needed to describe the psychophysics of gloss, as it is influenced by a range of factors, such as the lighting conditions, texture, and material of the surface. However, researchers have attempted to quantify the perception of gloss using various models and methods. One commonly used model is the multidimensional scaling (MDS) approach, which was done in many studies which reported gloss as a combination of multiple dimensions, such as roughness, shininess, and uniformity.[2]–[7] Since gloss is a second-order appearance attribute, this makes gloss and gloss perception more complicated to study. Existing gloss measurement methods are giving only a one-dimensional description of gloss. While for industry this is enough for gloss output control, for more complex and luxurious products simple gloss measurements are not enough to describe the perception of gloss. For instance, besides the strength of the front surface reflection, the luminance contrast between the reflected virtual image of the illumination scene and the surface background may affect the observed response. [2] [3]

In this work, a psychophysical experiment is conducted. The purpose of the experiment is to investigate how observers perceive gloss and develop a mathematical model that gives a numeric value to reflect the gloss of the samples. In the experiment, we used a new reference scale since available gloss scales from manufacturers did not have consistency in gloss and/or colour reproduction. The observers judged the gloss of samples printed on papers with different gloss. We use results from the psychophysical experiment to build a mathematical model.

Equipment

The psychophysical experiment was carried out in a Just Normlicht prototype viewing booth with a uniform rectangular light source. In the experiment, the D50 illumination was used, without exterior light. The viewing booth has a rotatable light source with the ability to adjust the width of the light source. In the experiment, the light was pointed at 60° at the samples and the width of the light source was set to minimum, which is 4 cm.[1] The distance between the sample and the light source was 90 cm. The viewing booth can be seen on the Figure 5.

Samples

The first set of samples (Set A) consists of 9 different colour patches (see Figure 1) printed on 10 papers, with different gloss levels. The gloss of the papers ranges from 3,4 GU to 60 GU (60°). The gloss of the 10 used papers was measured with a specular glossmeter at 60° incidence angle (see Table 1). For that, Canon Surface Reflectance Analyzer was used.[9] The samples were printed on an Epson SCP7000, InkJet printer. During the print, the colour was controlled ensuring that the colour difference is not greater than 2 ΔE_{00}. The colour was measured with Konica Minolta FD-7 spectrophotometer, with D50 illumination and 2° standard observer.[10] In total, 90 samples were printed in the size 2,5 x 2,5 cm. Since the thickness (and weight) of the papers were not the same, each colour patch was glued to a cardboard so that the observers do not feel the difference when holding samples. The final gloss of each sample was measured (60°). The gloss values of the samples are shown in Figure 2. When measuring the gloss of each sample, the measurement device was rotated in 4 directions, and the final gloss was calculated as the average of these 4 directions. Figure 2 demonstrates that gloss deviations upon rotating the device are minimal, which is crucial for the experiment and how observers will handle the samples.

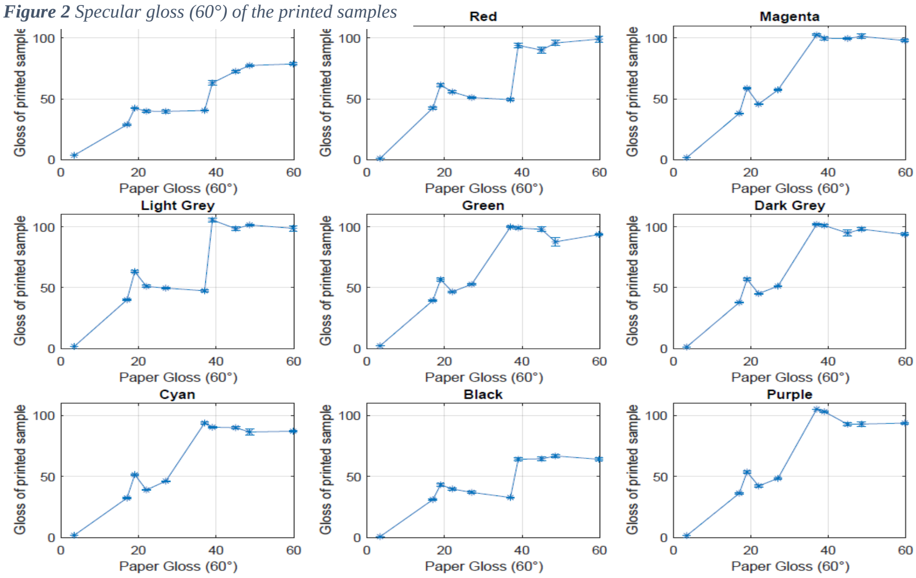
The specular gloss (60°) of the printed samples is not linearly increasing with the paper gloss. Namely, samples printed on paper with the gloss 19,5 GU have slightly higher gloss than the samples printed on paper with 21,6 GU. This is due to the paper structure, by closer observation it is noted that the paper with the 21,6 GU gloss has a rougher surface. Furthermore, the gloss values are varying for different colour patches on the same paper due to different ink combinations with which the samples are printed.

Table 1: Papers used to print the samples.

Paper No	Gloss (60°)
Paper 1	3,4 ± 0,2 GU
Paper 2	17 ± 0,1 GU
Paper 3	19,5 ± 0,2 GU
Paper 4	21,6 ± 4 GU
Paper 5	27,5 ± 3 GU
Paper 6	37 ± 0,5 GU
Paper 7	39 ± 0,5 GU
Paper 8	45 ± 1,5 GU
Paper 9	48,6 ± 0,6 GU
Paper 10	59,6 ± 0,2 GU

Figure 1 *Print form for samples in Set A.*

Figure 2 *Specular gloss (60°) of the printed samples*



Reference scale

In this study, we used ratio scaling to assign numerical values to the glossiness of the printed samples. Since existing gloss scales were not well-defined and lacked a consistent standard unit of glossiness or colour, we developed a new one.

Our reference scale consists of 9 grey samples with different glossiness (Set B). To create these samples, we printed colour patches with 30%K on the Mimaki UJF-3042 printer and then applied varying amounts of varnish on top. The applied tone values of varnish range from 0 to 200%. The variation of varnish tone values was done in the ColorGATE Productionserver 21 RIP software.[11] This way, we were able to create a range of gloss levels. To ensure that the colour variation between samples is no larger than 2 ΔE, each sample was measured with a spherical spectrophotometer with d:8° geometry. Set B was printed on three different papers, matte (6 GU), semi-matte (23,3 GU) and high gloss (50,6 GU). In total, 39 samples were printed (13 varnish tone values x 3 papers). The tone values of varnish and their specular gloss (60°) are shown in Figure 3.

With the 39 samples from Set B, we conducted first psychophysical experiment to build our reference scale. Five observers participated in the scale construction. Firstly, we presented them the 39 samples, and they were asked to identify the sample that they considered to be the glossiest. Each observer selected the sample with 200% varnish on top printed on high gloss paper as the glossiest. This was considered as the first anchor point on the reference scale. Next, we presented the second glossiest sample (180% TV varnish, high gloss paper) next to the 1. anchor point (AP) and asked if they see a difference in gloss between the two samples. If the response was affirmative, the sample would be preserved as the next anchor point on the reference scale, and the process would be repeated for all the samples. The responses from all five observers were mostly unanimous. The final reference scale was then presented to the observers, who were asked if they were satisfied with the "gloss smoothness" of the scale and if they had any suggestions for changes. Once the observers confirmed, we glued the samples to a curved surface to enhance the visibility of the specular reflection of each anchor point. Table 2 lists samples observers selected for the reference scale along with the specular gloss (60°) and varnish tone value. Note that no anchor point is printed on semi-matte paper.

In Figure 3 it can be noted that the gloss of the samples printed on semi-matte paper is not changing and the gloss can be achieved by printing on matte and high gloss paper.

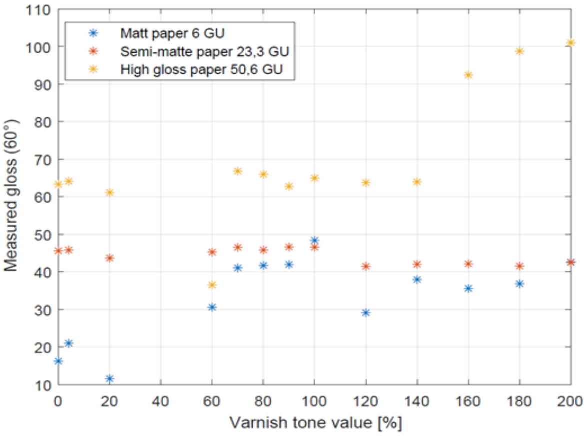


Figure 3 *Gloss (60°) of samples printed for the reference scale (Set B)*

Table 2: Gloss (60°) and varnish tone values of samples selected for the reference scale (*A.P.=Anchor points)

Anchor point No.	Paper type	Varnish [%]	Gloss (60°)
A.P. 9	High gloss	200%	98,75 ± 0,5 GU
A.P. 8	High gloss	180%	92,4 ± 0,9 GU
A.P. 7	High gloss	120%	84,4 ± 0,6 GU
A.P. 6	High gloss	60%	77,2 ± 4,8 GU
A.P. 5	Matte	70%	41 ± 4,3 GU
A.P. 4	Matte	60%	30,6 ± 5,4 GU
A.P. 3	Matte	40%	21 ± 2,2 GU
A.P. 2	Matte	0%	16,2 ± 1,4 GU
A.P. 1	Matte	20%	11,2 ± 0,4 GU

Experimental protocol

To examine how observers perceive gloss, a psychophysical experiment was conducted, wherein observers rated the gloss of the printed samples. The observers rated the gloss according to the reference scale that we developed (Set B). It is noteworthy that the nine anchor points in the reference scale were considered

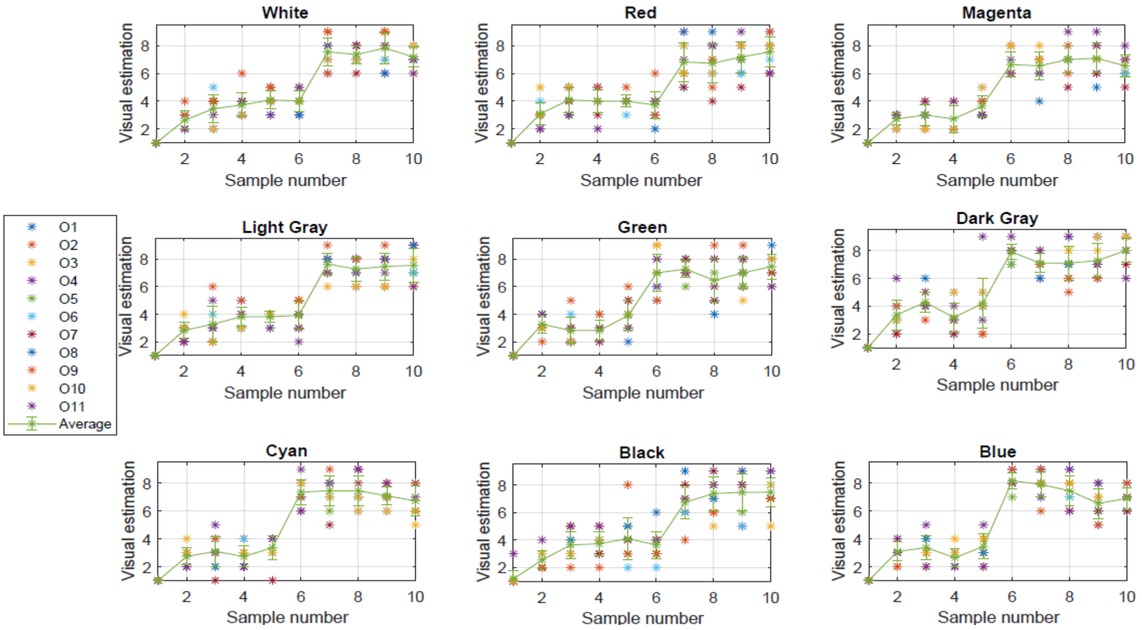


Figure 4 Visual estimation of gloss obtained from the psychophysical experiment for each observer together with the average visual estimation.

equidistant for the experiment. In total, 11 colour-normal or corrected to normal observers (5 females, 6 males) participated in the experiment. Their colour vision was tested prior to the experiment using the Ishihara Color Vision test. [12] The instructions of the experiment were placed in front of them. After reading the instructions, they did a short training experiment with random samples. After that, we gave them the printed samples in random order. The observers were asked to "place each sample where they think it will match on the reference scale. You can put several samples in one place on the scale". The experiment had a duration between 20 and 30 minutes for each observer. During the whole experiment, the observers were wearing gloves and were able to tilt the samples. The results for each observer and mean visual estimation obtained from the psychophysical experiment can be seen in the Figure 4.

Figure 5 Setup of the psychophysical experiment

Prediction model

The motivation for the model is to find optimal measurement parameters that highly correlate with general gloss perception. To find the best parameters that will predict as close as possible the visual response from observers, samples were measured with four different measurement devices. We used the Konica Minolta FD-7 spectrophotometer to measure the L* values of the colour patches. The second device, sphere spectrophotometer CM-2600d from Konica Minolta, was used to measure the L* values with the specular component included (SCI) and excluded (SCE). For both instruments, the M1 measurement condition was used and the D50 illumination, with the 2° standard observer. All measurements were performed on a white backing.[13] Third measurement device was the Canon Surface Reflectance Analyzer to collect the gloss values at 20°, 60° and 85°, Image Clarity, Haze, C20, and C60. The C20 and C60 are unique Canon scattering. The higher the values, the greater the scattering.[9] With the Rhopoint IQ-s, the Distinctness of Image (DOI) and the Rspec were measured. RSpec is the peak reflectance in the specular direction (+/-) measured over a very narrow angular band 0.0991° and is very sensitive to surface texture.[14] Lastly, the Schnetter Technologies STGL 1000 measurement device was used to measure the TAPPI T480 Gloss (incidence angle 75°) and the DIN 54502 Gloss (incidence angle 45°).[15], [16]

Since we measured gloss with different measurement devices and different incidence angles, we tested how the measurement techniques correlate with the visual estimations of gloss. Figure 6 shows different gloss values and their correlation with visual estimation.

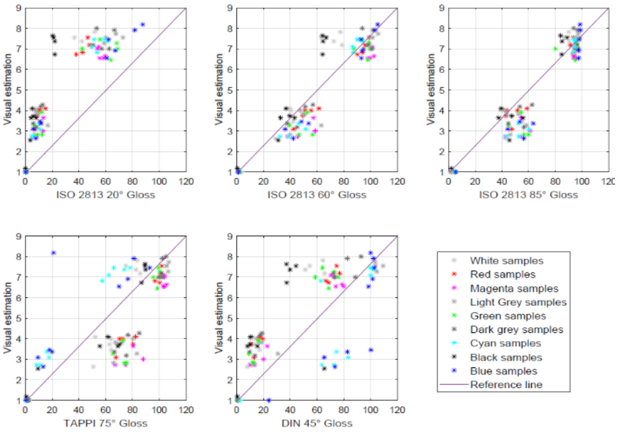


Figure 6 Correlation between different glosses and av. visual estimation of gloss

It can be noted that the best correlation is between the ISO 2813 specular gloss measured at 60° and 85° incidence angles. The 85° specular gloss has a slightly better correlation with the high gloss values, and the 60° specular gloss has a better correlation with the lower gloss values. Since the 60° gloss is mostly used in most industries these gloss measurements will be used for the model. Furthermore, in Figure 6, each colour patch is plotted with its colour, and no difference between the colour samples in terms of gloss measurements is noted. In other words, none of these measurement techniques considers the diffuse reflection, only the specular reflection.

From the 90 samples (Set A), random 13 samples from the set were selected to test the model later, and therefore, these 13 samples were not used to train the model. Firstly, we wanted to find optimal parameters for our model. For that, we used Principal Component Analysis (PCA) to eliminate measurement variables which are not relevant for the prediction of the perceptual gloss. Principal Component Analysis is a technique that is widely used for applications such as dimensionality reduction, lossy data compression, feature extraction, clustering and classification and noise reduction.[17] The score plot of the PCA shows that 95% of the variance can be explained with 3 components.

For easier interpretation of the three components, scores and loadings were calculated. Scores are linear combinations of the data that are determined by the coefficients for each principal component. Loading plot graphs the coefficients of each variable versus the principal components. (Figure 7)

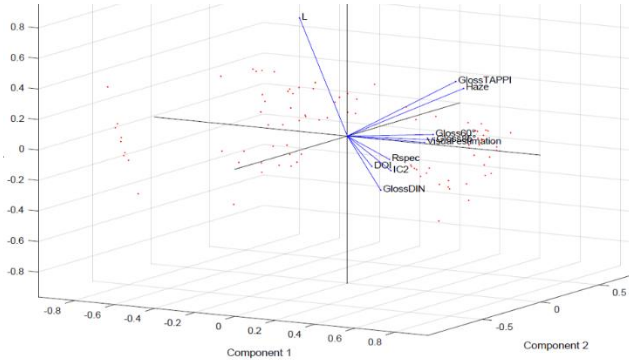


Figure 7 Biplot with scores and loadings for the principal components obtained from the PCA of the measurements. The red dots represent scores for each observation, while the arrows represent the loadings for each variable.

Figure 7 shows that the PCA reduces all measurements to 4 dimensions. One component is indeed the L* value, which stands alone and has a positive loading on component 3. DOI, specular gloss measured at 45° (DIN), Image clarity and Rspec have positive loadings on component 1. Specular glosses measured at 60° and 85° are on the same axis as the average visual estimation from the psychophysical experiment. Fourth component would be Haze and specular gloss measured at 75°.

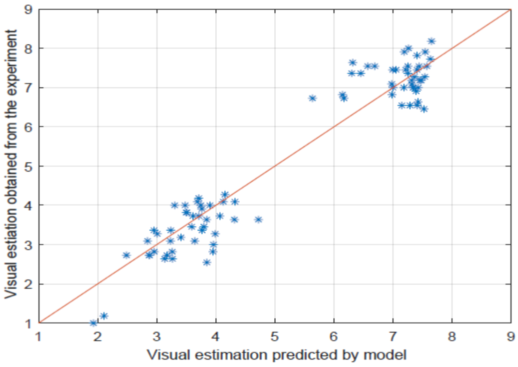


Figure 8 Average visual estimation obtained from the experiment vs. visual estimation predicted by the model.

The scores for the last 2 parameters are so low that they can be ignored. In conclusion, one parameter is the L* measured with the 0°:45° geometry, the second one is the DOI (since it has the largest loading on PC 2) and the third is the specular gloss measured at 60°.

These three components, specular gloss (60°), DOI and L* were used to build the mathematical model. For the regression, Matlab Regression Learner was used.[18] As input, the specular gloss, L* and DOI were used, and the response was the average visual estimation from the experiment. The model was trained with 9 cross-validation folds. Several models have been tested, but the best results, lowest RMSE, had the linear regression model. The performance of the model can be seen in Figure 8. It can be noted that there are samples in the semi-matte part that have slightly lower accuracy, but overall, the model has an RMSE of 0,58 and uncertainty of 0,55 (on a scale from 1 to 9).

After the training of the model, we tested the performance of the model on the 13 samples on which the model was not trained (Figure 9). The final model is provided in the supplementary material, but the mathematical equation for calculating the level of the visual estimation of gloss (on a scale from 1 to 9), where 1 is dull matt and 9 is high gloss, is:

$$\mathrm{VE} = 3{,}976 + 0{,}066\mathrm{G} - 0{,}119L^{*} + 0{,}202\mathrm{DOI} - 0{,}005\mathrm{DOI}^{2} \qquad (1)$$

Where*:*

- VE is the visual gloss estimation,
- G is the specular gloss (measured at 60°),
- L* is the Lightness (0°:45°)
- DOI is Distinctness-of-Image gloss.

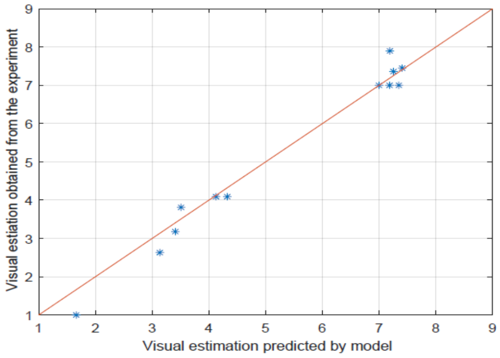


Figure 9 Visual estimation from the experiment and visual estimation predicted by using the model of samples on which the model was not trained.

Results and discussion

Each observer's internal consistency was examined by calculating the Cronbach'S Alpha reliability. Cronbach's Alpha is a measure of the internal consistency of a scale. It expresses how well a group of variables or items measures a single, one-dimensional latent construct.[19] It is computed by correlating the score for each item with the total score for each observation, and then comparing that to the variance for all individual item scores:

$$\alpha = \left(\frac{k}{k-1}\right)\left(1 - \frac{\Sigma_{i=1}^{k}\sigma_{yi}}{\sigma_x^2}\right) \qquad (2)$$

The results show a reliability of 79,3%, which is classified between acceptable and good alpha value. From the results of the PCA, it can be concluded that the measured specular gloss can be expanded with Distinctness of Image, and Lightness (L*) to get a better correlation with the visual estimation.

In the mathematical model (1), it can be noted that the coefficient for the L* value is negative, which means that if the colour is brighter (higher L* values) the perception of gloss will be lower in comparison with darker object. A lot of research has been done in the field of gloss perception and all of them conclude that darker objects are perceived as glossier. According to Hunter, it is identified by contrast between specularly reflecting areas of surfaces and surrounding areas. [3], [20]–[23] Toscani et al. extract lightness as one of the gloss dimensions in their work. [4]

Further, the model uses DOI as an important parameter for gloss perception. During the psychophysical experiment, with some samples, observers doubted between two anchor points. Two observers decided the final gloss score with the following words: "Here is the reflection of the image sharper, therefore I will put it on the higher level." Some work done earlier also use the DOI as one of crucial gloss dimensions. Ferwerda et al. [3] extract DOI and contrast gloss as two crucial dimensions for gloss perception. Leloup et al. did in 2012 evaluate the overall gloss evaluation with pared comparison. The results from his psychophysical experiment show that the observers do indeed use DOI and luminance as cues for gloss perception.[6] This has also been proven in some other work, where the DOI and/or luminance were crucial dimensions for gloss estimation.[8], [24], [25]

Conclusion

We built a gloss reference scale for gloss estimation. Then we conducted a psychophysical experiment where the observers judged the gloss of coloured samples. Results from the psychophysical experiment were used for building a mathematical model for gloss prediction. The PCA shows that the variation of data can be described with 3 dimensions, namely the specular gloss (measured at 60°), DOI and L*. The results correlate with other findings where the Distinctness of Image and Lightness were defined as crucial dimensions in gloss perception. Our model is limited to dielectric printed samples.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 814158

References

[1] ISO, *ISO 2813:2014(en) Paint and varnishes - Determination of gloss at 20 deegress, 60 degress and 85 degrees*. 2014.

[2] G. Ged, G. Obein, Z. Silvestri, J. Le Rohellec, and F. Viénot, "Recognizing real materials from their glossy appearance," *J. Vis.*, vol. 10, no. 9, pp. 1–17, 2010, doi: 10.1167/10.9.18.

[3] J. A. Ferwerda, F. Pellacini, and D. P. Greenberg, "Psychophysically based model of surface gloss perception," *Hum. Vis. Electron. Imaging VI*, vol. 4299, no. June, pp. 291–301, 2001.

[4] M. Toscani, D. Guarnera, G. C. Guarnera, J. Y. Hardeberg, and K. R. Gegenfurtner, "Three Perceptual Dimensions for Specular and Diffuse Reflection," *ACM Trans. Appl. Percept.*, vol. 17, no. 2, 2020, doi: 10.1145/3380741.

[5] F. B. Leloup, M. R. Pointer, P. Dutré, and P. Hanselaer, "Geometry of illumination, luminance contrast, and gloss perception," *J. Opt. Soc. Am. A*, vol. 27, no. 9, p. 2046, 2010, doi: 10.1364/josaa.27.002046.

[6] F. B. Leloup, M. R. Pointer, P. Dutré, and P. Hanselaer, "Overall gloss evaluation in the presence of multiple cues to surface glossiness," *J. Opt. Soc. Am. A*, vol. 29, no. 6, p. 1105, 2012, doi: 10.1364/josaa.29.001105.

[7] G. Ged, A. M. Rabal-Almazor, M. E. Himbert, and G. Obein, "Assessing gloss under diffuse and specular lighting," *Color Res. Appl.*, vol. 45, no. 4, pp. 591–602, 2020, doi: 10.1002/col.22510.

[8] G. Obein, K. Knoblauch, and F. Viénot, "Difference scaling of gloss: Nonlinearity, binocularity, and constancy," *J. Vis.*, vol. 4, no. 9, pp. 711–720, 2004, doi: 10.1167/4.9.4.

[9] C. Inoshita, J. Hirabayashi, S. Kato, and J. Kimura, "Application of Material Appearance Technology in CANON INC.," *Imaging Soc. Japan*, vol. 57, no. 2, pp. 225–230, 2018.

[10] K. Minolta, "FD-7 and FD-5 State of the Art instruments for measuring Colour, Density and Light," in *Spectrodensitometer FD-7 and FD-5*, 2013.

[11] ColorGATE Digital Output Solutions, "ColorGATE Innovative Solutions," Hannover, 2021.

[12] S. Ishihara, *Test for colour-blindness*. Tokyo: Han-daya, 1917.

[13] ISO, "ISO 13655:2017 Graphic technology - Spectral measurement and colorimetric computation for graphic arts images," vol. 2017, pp. 1–6, 2017.

[14] Rhopoint Instruments, "The Rhopoint IQ-S," .

[15] TAPPI/ANSI, *Specular gloss of paper and paperboard at 75 degrees, Test Method TAPPI/ANSI T 480 om-15*. .

[16] DIN, *DIN 67530:01 Reflectometer as a means for gloss assessment of plane surfaces of paint coatings and plastics*. 2001.

[17] I. T. Jolliffe, *Principal Component Analysis*, 2nd ed. New York: Springer Science+Business, 2002.

[18] The MathWorks Inc., "MATLAB and Regression Learner 2017a." Natick, Massachusetts, United States, 2017.

[19] L. J. Cronbach, "Coefficient alpha and the internal structure of tests," *Psychometrika*, vol. 16, no. 3, pp. 297–334, 1951, doi: 10.1007/BF02310555.

[20] Y. X. Ho, M. S. Landy, and L. T. Maloney, "Conjoint measurement of gloss and surface texture: Research article," *Psychol. Sci.*, vol. 19, no. 2, pp. 196–204, 2008, doi: 10.1111/j.1467-9280.2008.02067.x.

[21] D. Šarić, A. Kraushaar, M. Mattuschka, and P. Green, "Benchmarking modern gloss correlators with established ISO 2813 standard and visual judgment of gloss," *Color Imaging Conf.*, vol. 2021, no. 29, pp. 306–310, 2021, doi: 10.2352/issn.2169-2629.2021.29.306.

[22] E. N. Dalal and K. M. Natale-Hoffman, "The Effect of Gloss on Color.," *Color Res. Appl.*, vol. 24, no. 5, pp. 369–376, 1999, doi: 10.2307/1419271.

[23] M. Murayama, H. Ishizuka, Y. Shibahara, and S. Soejima, "Evaluation of Glossines for Photographic Prints," in *International Conference on Advanced Imaging 2*, 2020, pp. 14–18.

[24] F. W. Billmeyer and F. X. D. O'Donnell, "Visual gloss scaling and multidimensional scaling analysis of painted specimens," *Color Res. Appl.*, vol. 12, no. 6, pp. 315–326, 1987.

[25] W. Ji, M. R. Pointer, R. M. Luo, and J. Dakin, "Gloss as an aspect of the measurement of appearance," *J. Opt. Soc. Am. A*, vol. 23, no. 1, p. 22, 2006, doi: 10.1364/josaa.23.000022.