Benchmarking modern gloss correlators with established ISO 2813 standard and visual judgment of gloss

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Abstract
Interaction between the diffuse colour and the gloss of its surface is common. In this work, the influence of different gloss levels is tested on the diffuse colour. Firstly, we investigated how the albedo colour correlates with the reflected specular part. Furthermore, we provided a visual experiment. The visual experiment is conducted in two parts. The results of the visual experiment show that changing the angle of illumination does not affect the final gloss perception. Furthermore, a fitting of the gloss perception is done to find a parameter that correlates with the visual perception of gloss. The results show that there is a quadratic correlation between the Canon scattering indexes and the perceptual gloss.

Introduction
According to ISO 4618, colour is a sensation from the human eye's perception of a given spectral composition. [1] As a result of the restrictions made when defining the term colour, the gloss appearance cannot be included in the colour term.[2] This current definition of colour ignores the fact that an object's visual appearance can be changed by changing its gloss level. [3]

Most colour measurement systems aim to record what an observer sees and quantify it using CIE colorimetry. CIE defines measurement geometries including 0:45 and 0:d (and the optically equivalent 45:0 and d:0.[4]

In integrating sphere spectrophotometers, the normal/diffuse detector is placed at a slight angular offset to the normal, by 6° to 8°. By placing the specular port at the opposite angle, the specular reflection can be either included or excluded. Specular reflection is detected when the angle of reflection is equal and opposite to the angle of incidence, and it causes surfaces to exhibit highlights and to appear somewhat like a mirror.[5] By excluding the specular reflection from measurements, the results have a better correlation to visual appearance.[6] Using SCE (Specular Component Exclude) mode, a glossy surface will typically measure darker than a matt surface of the same colour. This mode is typically used during quality control evaluations to ensure colour matches the colour standards by visual inspection.[7]

For gloss measurement, there is a variety of established methods. In Hunter's "Measurement of Appearance", it is stated that 20° works best on high-gloss materials, and 75° or 85° is best on matt materials. This approach is adopted in ASTM D 523 "Test Method for Specular Gloss" standard.[8] Later, ISO published the ISO 2813 standard "Determination of specular gloss of non-metallic paint films at 20°, 60° and 85°". [9]

Motivation
Gloss is the second most important appearance attribute, right after the colour,[10] and influences the appearance of the object surface. For commercial printing, the most common way to reproduce colours with the desired gloss level is by printing on substrates that exhibit a similar level of gloss. According to [11], the gloss of solid tone colours should be visually similar to the gloss of the production print to be simulated on the proof print. Therefore, it is essential to be able to predict the visual gloss of the print and vice vera. Due to the gloss differences, the most amount of reflected light and not its spectral composition changes. The obtained measurements show that this mostly affects the CIE L* information and that the changes in the CIE a* b* channels are so small that they are negligible for this work. Therefore, only the influence on the CIE L* of the colour patches will be investigated.

Approach

Equipment and samples
In the first part of the work, firstly, the gloss and the diffuse reflectance were measured. The gloss is measured at the 60° illumination angle, and for that, we used Canon Surface reflectance Analyzer RA-532H. The colour was measured with the Konica Minolta CM2600d spherical spectrophotometer, with both specular component included (SCI) and specular component excluded (SCE). The TORSO palette was used for the reference samples, which is a gloss scale with four colours (white, grey, red and black) manufactured in different gloss levels using the lacquer drawing process. In other words, the colours are not printed but created with varnish. (Fig 1). The second set of samples are the Fogra Media Wedge CMYK v3.0 which contains 72 colour patches, defined with different tine values of the process inks (CMYK). Depending on the printing process and the substrate, each patch has a colorimetric target value allocated according to the ISO 12647-7 standard. [11] From the rich database, 14 samples were chosen with the ISO 2813 gloss level of the substrate varying from 3,5 to 93 Gloss Units (further in text: GU) measured at 60° illumination angle.

FIGURE 1 TORSO SAMPLES MANUFACTURED WITH THE LACQUER PROCESS (DULL MATT LEFT AND HIGH GLOSS RIGHT)

In the second part of the work, a visual experiment was conducted. The experiment was performed in two parts. The observers first evaluated the gloss under the 60° illumination angle and then repeated the same process under the 85° illumination angle. The experiment is conducted in a viewing booth prototype, specially designed by JUST Normlicht (see Figure 4). New samples were printed since the colour patches on the Fogra Media Wedge are too small for visual observation of gloss. The samples have similar colour as the Torso set samples (dE <5) and are printed with the same ink on papers with different gloss values. The samples have been printed on inkjet substrates with an ISO 2813 GU from 1,2GU to 65GU. Baar et al. [12] concluded that the final gloss of the printed samples is dependent on the order of the printed CMY colours. They found that the tone value sum correlates with the perceived gloss (the higher the ink load). Our CMYK values differed – as needed by color management.

TABLE 1 MEASURED VALUES OF THE 12 PRINTED SAMPLES ON ALL COLOUR PATCHES THE AVERAGE VISUAL JUDGMENT IS DONE ACCORDING TO THE TORSO REFERENCE SAMPLES (1 - 6)

Sample	DOI	Rspec	C20	C60	Haze	Image clarity	Av. Gloss judgment
1	1,1	1,4	235,6	164,8	16,2	1,55	3,5
2	10,5	7,1	58,8	51,8	27,9	29,02	4,75
3	0,8	1	233,3	162,8	12,5	1,7	2,8
4	1,7	2,1	150,3	123,1	23,1	6,8	3,45
5	0,1	0,1	1000	1000	1,1	0	0,6
6	15,8	7,9	55,6	46,5	16,4	32,4	5
7	0	0,1	1000	1000	1,1	0	0,5
8	11,5	7,6	53,1	32,3	24,2	33,62	4,7
9	0,1	0,4	1000	1000	1,1	00	0,5
10	16,6	9,4	46,0	37,2	21,9	38,9	4,9
11	0,8	1,2	198,9	151,9	18,2	2,6	3,3
12	1,3	1,4	233,6	164,6	15,4	1,7	3,25

Experimental protocol

To investigate how the specular reflection of different colour behaves on surfaces with different colours, the first set of samples, the Torso samples, were measured with the spherical spectrophotometer. The samples contain four colours, namely white, grey, red and black. For each colour, the specular component included (SCI) and specular component excluded (SCE) was measured on each sample. We calculated the specular component as the difference between these two measurements ($L^*_{SCI} - L^*_{SCE}$). The same procedure was repeated on the second set of samples, the 14 Fogra Media Wedges, to compare results. Measurements were obtained using the M1 measurement condition, with an illumination source approximating D50, on a white backing. The gloss of the samples was measured according to ISO 2813 [9]. Besides the gloss values, other parameters were measured, including the scattering index under 20° (C20) and 60° (C60) illumination angle. The C20 and C60 are the scattering indexes, which are unique Canon indexes. They describe the scattering of light on the surface. The higher the values, the greater the scattering. According to [13], these indexes only quantify the image sharpness of the reflection on the surface layer. about a feature of the C20 and C60 values is that they can be used to differentiate high-gloss and very matte surfaces, while the DOI (Distinctness of Image) and IC (Image Clarity) would result in a reading of zero for matte surfaces. The C20 and the C60 take only the shape of the BRDF into account and not the intensity of reflected light.[13] Furthermore, with the same device, the image clarity was measured. It is measured through slits with different sizes of openings. This is the value expressing the degrees of image clarity or distortion reflected from the target surface.[14] In some literature [15] image clarity is synonymous with Distinctness of image (DOI), while in other literature they are not described as same parameter, since the measurement method and the scales are different.[16] Due to the differences in the measurement geometries between the instruments and the scales for the measurements, these two parameters will be considered as different attributes.

The second instrument that was used is the Rhopoint IQ-s. The device measures gloss, haze, Distinctness of Image (DOI) and Rspec. RSpec is the peak reflectance measured over a very narrow angular band in the specular direction (+/-) 0.0991º. RSpec is very sensitive to surface texture. When Rspec equals the gloss value, the surface is smooth; the Rspec value decreases as texture increases.[17]

Results

Figure 2 shows the calculated specular component on the colour patches from the Torso samples. As expected, the differences in the lightness between the SCI and SCE (ΔL*) geometry are more significant with the increase of the gloss. This is due to the greater specular reflection that is reflected from the surface. It can be noted that the differences increase on the black colour patch. On the lighter colour patches, the increase is not so intense. In other words, the lower the L* value, the larger are the differences in lightness between the SCI and SCE measurement geometry. This is due to the contrast between the specular reflection and the object colour.[10] The same process was repeated for the Fogra Media Wedge samples. In order to get a clearer view of the results, instead of showing the measurements for all 72 patches, only the white, grey, red and black colour patches from each print are shown in Figure 2 for easier comparison between these two sets of samples.

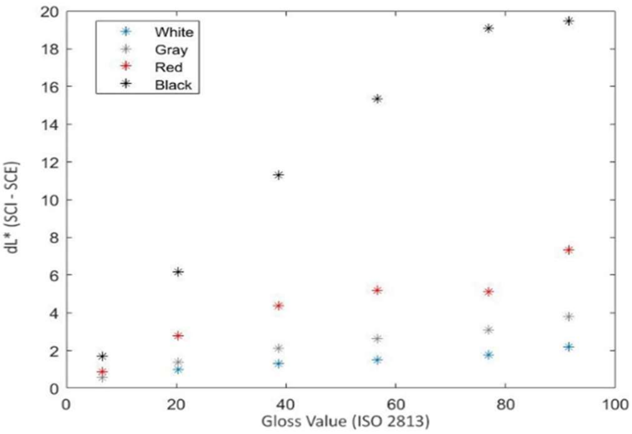

FIGURE 2 DIFFERENCES IN LIGHTNESS BETWEEN SCI AND SCE MEASUREMENT GEOMETRY ON TORSO SAMPLES
*GLOSS IS MEASURED ACCORDING TO ISO 2813 STANDARD

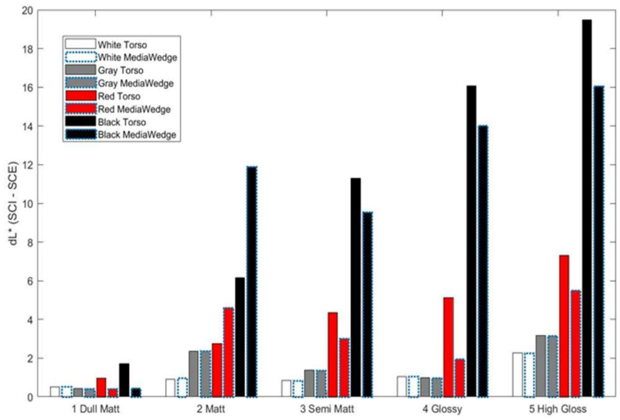

FIGURE 3 COMPARISON OF THE dL* OF TORSO SAMPLES AND FOGRA MEDIA WEDGE SAMPLES.

Discussion

Many studies [10], [18]–[20] of gloss perception have noted that apparent gloss is affected by the diffuse surface reflectance, with light coloured surfaces appearing less glossy than dark ones with the same finish. The differences in lightness shown in Figure 2 show that on patches with lower L* values (darker patches), the differences in lightness are greater than on the lighter-coloured patches. That is due to the difference in diffuse reflectance. Gloss/no gloss differences result in larger differences on lower reflectance than on objects with higher reflectance. Ferwerda et al. [21] Hunter & Harold [10], and Pellacini et al. [22] noted that observers were evaluating the darker objects as glossier and glossier surfaces as darker, due to the contrast that the observers perceive between the specular reflection and the colour of an object. Around 1930, Pfund pointed out that specular shininess is the primary (objective) evidence of gloss, but that actual surface glossy appearance (subjective) relates to the contrast between specular shininess and the diffuse lightness of the surrounding surface area (now called “contrast gloss” and “lustre”). If black and white surfaces of the same gloss are compared visually, the black will appear to be glossier because there is greater contrast of a specular highlight with black surroundings than with white surroundings. [23] unfortunately, it is out of scope of a glossmeter to access the albedo color. Hence, additional measurements need to be taken into consideration.

Visual approach

In the second part of this paper, a psychophysical experiment was performed with six colour normal observers (2 female, four male). The experiment was conducted in a dark room, inside a viewing booth with D50-simulating illumination. In ISO 2813, it is recommended to measure gloss under 60° illumination angle, and very matt samples to measure with 85° illumination. These two angles are (together with the 20° angle) proposed in the ISO 2813 standard for the gloss measurement.[9] Therefore, in the experiment, these two angles are also used. Twelve samples were printed on papers with different gloss values (from 1GU to 60GU). First, the observers were asked to assign a grade from 0.5 to 6 for the gloss of every patch. The torso samples were used as reference samples for the grades, where 1 is dull matt, and 6 is high gloss. When each colour was evaluated, the other colour patches were covered with a grey mask (see Figure 4). Next to the sample, a mirror was placed, and the observers were asked to stand so that they see the lamp in the mirror. In that way, the observers were observing the samples at a specular angle, and they were allowed to tilt their head a little when observing the gloss of the samples. The samples were placed on a curved aluminium plate so that the observers had a better observation at the specular reflection without tilting the samples. (Figure 4). After observers had assigned a grade to every patch on the sample, the process was repeated, but with the light source at 85° to the samples. At this point, the observers were allowed to tilt their head more to avoid looking directly at the lamp.

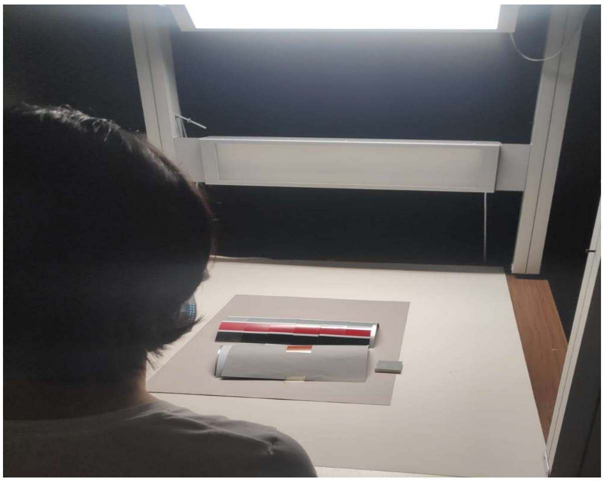

FIGURE 4 SETUP OF THE VISUAL EXPERIMENT

Results

The results of the rating of the samples show that, when changing the angle of illumination, the differences in visual gloss evaluation are negligible and that there is no significance in changing the angle of illumination. This was also investigated in the past by Obein[24] et al. If we look at the judgments for all the samples, we can note that the observers judged the white colour consistently.

The standard deviation (std) of the gloss judgment of the white colour is only 0,2. For the other three printed colours, the biggest std is for gloss judgement of black and red colour patches, and it is 1,5. The std of the gloss judgment of the grey colour patch is slightly lower, 1,3. If we compare the visual gloss judgment (Figure 5) with the measured specular part, ΔL* (SCI – SCE) (Figure 3), it can be noted that the red and black colour patch on the reference and printed samples also have larger deviations than other two colour patches. The red and black patches have a lower L* value (are darker), and therefore they are subject for larger gloss perception and can therefore be considered to explain the larger dispersion among observers.

However, some observers are subject for deeper scrutiny. For instance, observer 1 judging the gloss of the black patch with scale 0,5 where the mean opinion score (MOS) is about 3. This indicates a misunderstanding of the viewing task or refers to different understanding of the underlying perception. For instance, it was found in a recent study [25] that metallic gloss perception results in a bimodal distribution of gloss ratings. This relates back to different understanding or focus of the particular viewing task.

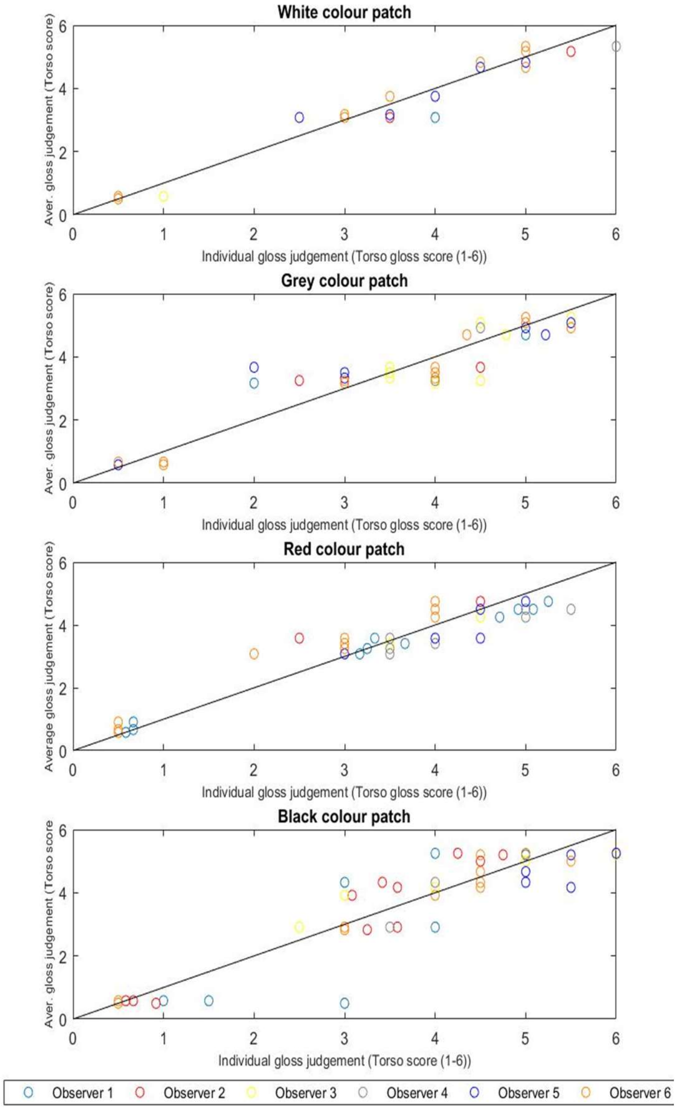

FIGURE 5 INDIVIDUAL GLOSS JUDGMENT FROM THE OBSERVERS FOR THE FOUR PRINTED COLOUR PATCHES OVER THE AVERAGE GLOSS JUDGMENT.
***ALL SCORES ARE ACCORDING TO THE TORSO GLOSS SCALE (1-6)**

On the samples that we used for the visual experiment, various parameters were measured, like haze, image clarity, C20 and C60 indexes, Rspec, and DOI (Table 1). We compared the measured parameters with the average visual ratings of the samples (Mean Opinion Gloss Scores) from the visual experiment. We tested multiple fittings like linear, Gaussian, polynomial (2nd degree) and cubic. The testing showed the best correlations between visual results and scattering indexes (C20 and C60) with the 2nd degree polynomial and the cubic fitting (Figure 6).
The 2nd degree polynomial fitting and cubic fitting look very similar for the C20 index, but for the C60 index, it correlates slightly better in the High gloss part of the sample set. In the work from Samadzadegan et al. [26] the correlation of "Semi-Matt" and "High Gloss" samples with the perceptual gloss was investigated. They found that the relationship between a perceptually uniform gloss scale and measured gloss can be explained with cubic and polynomial (2nd degree) function, with almost equal performance. Our results show that there is indeed a correlation between the perceptual gloss and the scattering indexes at 20° and 60° illumination angles. (Figure 6).

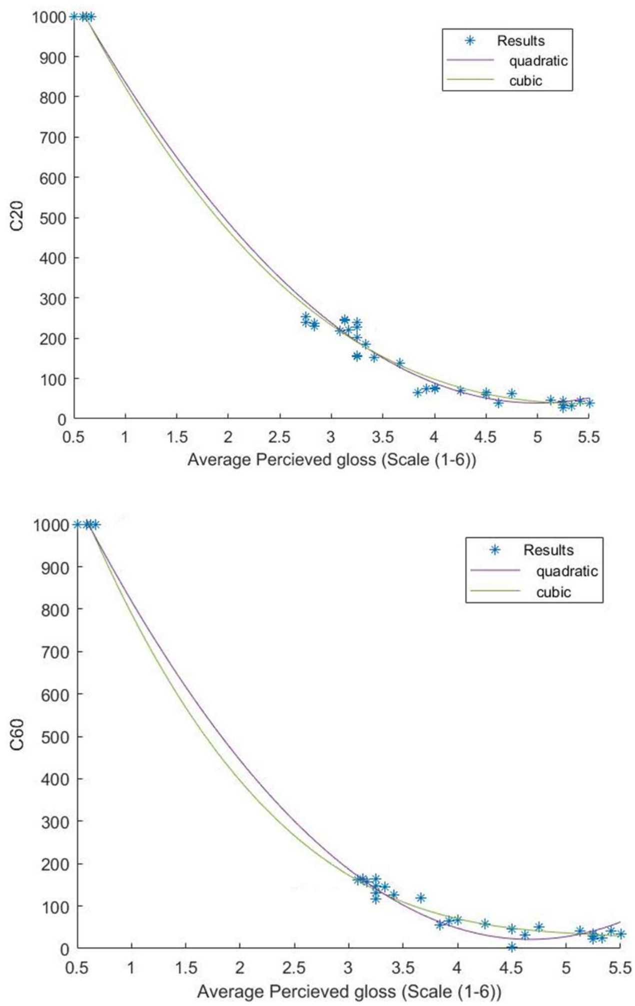

FIGURE 6 CORRELATION BETWEEN THE CANON SCATTERING INDEXES (C20 AND C60) AND THE PERCEPTUAL GLOSS

Conclusion

From the first part of the work, it can be noted that the contrast gloss influences the measured specular part, which also influences the colour when measured with the specular component included. Nevertheless, the specular part does not influence the measured but also the visual judgment of the perceived surface. that the results are consistent with previous work which indicates that darker surfaces tend to be perceived to be glossier, and glossier surfaces tend to be perceived as darker.

The illumination of an object plays a significant role when observing, but the angle of illumination does not affect the final gloss judgment. This claim is already supported in other work [27] and also by our results.

Darker surfaces also have a more significant variation in the gloss judgement. Since the specular reflection is more noticeable on the darker surfaces, inter-observer variability was greater, since observers were not sure whether they should assign the grade according to only the specular reflection or to the whole appearance of the colour patch (specular reflection plus the surrounding). This issue is a subject for upcoming research topic.

Also, in this paper, an example of the disagreement in terminology between two parameters is shown. Unfortunately, there are other examples of terms with one or more meanings. This disagreement, if not explained in the beginning, can lead to misunderstanding, especially when there are new technologies for gloss measurement introduced on the market. Therefore, there is a strong need for a harmonization, both in appearance methodology and terminology.

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