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Comparison of colourimetric results obtained by spherical and spectrophotometer with directional geometry on samples with extreme UV varnish application

ABSTRACT

It is known that gloss has a significant impact on colour measurement. The UV varnish used for surface finishing, spot effects, as well as special effects, such as 3D effects and formation of Braille, has a pronounced gloss effect. In this work, a comparison of the spectrophotometer measurement geometry influence on the colour measurement of an unprinted PVC sample covered with UV varnish was done. UV varnish was applied successively in layers, and patches with different number of varnish layers, from 1 to 12, were formed. Two spectrophotometers with different measurement geometries were used for the measurement: Konica Minolta CM-2600d with d/8 measurement geometry, with spectral reflection included and excluded, and different measurement aperture 3 and 8 mm, and X-Rite eXact with 45/0 measurement geometry. By comparing the measurements, it was established that there is a significant difference in the measured values between different measuring device geometries on the given samples, and that the number of UV varnish layers has a significant influence on this difference.

KEY WORDS
Spectrophotometer geometry, UV varnish, plastic, colour difference

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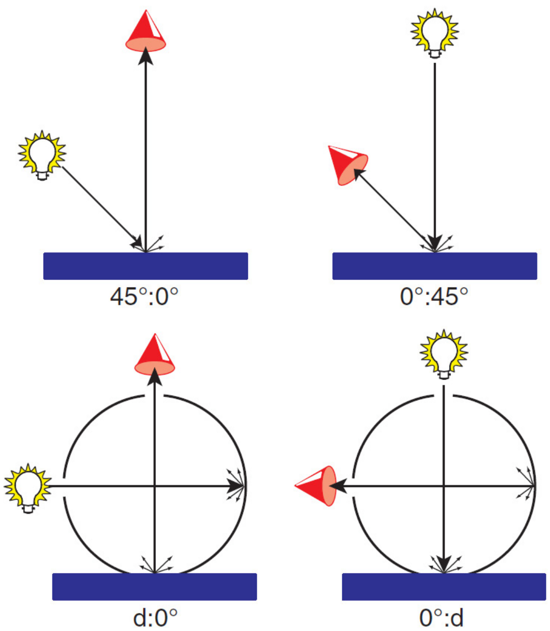
Introduction

Spectrophotometers represent colour measuring instruments which are the most reliable and precise. Different factors influence perceived colour; thus, it can be concluded that also different measuring conditions influence measured colour. The illumination condition and viewing angle are most important of them. Therefore, measuring geometry have a great impact on measurement results (Dalal & Natale–Hoffman, 1999). It has been shown in some previous studies that measured results can significantly differ among different measuring geometries, depending on the characteristics of measured sample (Dalal & Natale–Hoffman, 1999; Kandi, 2011; Milić, Novaković & Kašiković, 2011).

Two most common measuring geometries are directional and diffuse. There are two types of directional geometry: 45/0 and 0/45 (figure 1 a and b). The first number stands for illumination angle, and second for optics. Since the optics are positioned at an angle of 45 degrees related to the illumination, they do not detect specular reflection. In case of diffuse geometry, there are two common types: d/8 and 8/d (figure 1 c and d). The letter d stands for diffuse, which means that illumination or viewing is not directional but diffuse. This is achieved with use of an integrating sphere. Number 8 represents the angle of optics. In first case, d/8, instrument illuminates the sample from scattered directions and reflected light is detected at an 8-degree angle. In second case, 8/d, instrument illuminates the sample at an 8-degree angle and reflected light is detected from scattered directions. In this kind of geometry, specular port can be used, in order to exclude specular component. Therefore, with this kind of instrument two modes of measurement can be done – the specular component included (SCI) and the specular component excluded (SCE). With mode SCE, the idea is to exclude the specular component, and obtain measurement similar to 0/45 geometry. Since the size of the specular port is limited, sometimes it is not able to allow all of the gloss to escape, thus measurements between 0/45 geometry and diffuse geometry with the specular component excluded may vary (Kandi, 2011; Milić, Novaković & Kašiković, 2011; Yuan, Yan & Jin, 2013; Berns, 2019). Size of specular port and integrating sphere is not specified by CIE, which leads to inconsistency between measurement results of two different instruments (Yuan, Yan & Jin, 2013).



» **Figure 1:** *Spectrophotometer measuring geometries (a) 45/0, (b) 0/45, (c) d/0 and (d) 0/d (Berns, 2019: p.117)*

Both geometries have some advantages and are used for different purposes. Since the observed and measured sample is another factor that has great influence on measurement, type of selected geometry depends on it. In case of samples with matte, regular surface, reflected light is almost same at all angles, thus results obtained with diffuse, both SCI and SCE, and directional geometry would be almost equal. But, in case of gloss or surfaces that are not flat and regular, diffuse geometry shows its supremacy (Milić, Novaković & Kašiković, 2011).

Colour that is measured or perceived is influenced by amount of detected light that is reflected from surface (Dalal & Natale–Hoffman, 1999). It is known that an object's gloss greatly influences perceived colour (Dalal & Natale–Hoffman, 1999; Luo & Cui, 2009). Assessment of samples with different gloss levels is challenging, since agreement between visual and instrumental assessment is not clearly defined. Unlike a measuring instrument, a person can very simply change the observation conditions, as well as the viewing angle, to give a visual assessment of the sample. In this way, a person can simultaneously consider both the gloss and the colour itself. With measuring instruments, the lighting and observation conditions are fixed, which leads to the fact that the instrument does not observe the sample in the way we see it (Datacolour, n.d.). This is summarized in Table 1.

Table 1
Comparing readings with different types of measuring geometries or assessments on matte, regular surface, and gloss and/or irregular surface

Type of measuring geometry or assessment	Matte and regular surface	Gloss and/or irregular surface
Directional geometry	Consistent readings	Great variations in readings
Diffuse geometry	Consistent readings	Consistent readings
Directional vs. diffuse geometry	Nearly identical readings	Great variations in readings
Visual vs. instrumental assessment	Good agreement	Agreement not clearly defined

When observing samples, person usually rotates the sample to avoid specular reflection. If we take that into account, the measuring geometry of 45/0 and 0/45 is closer to human colour vision. It is generally accepted that these measurement geometries have a better agreement with the visual assessment of glossy samples. Still, these geometries are not always best solution. They showed poor performances for computer formulation and correction applications. Also, there is a problem for making corrections of batch. These instruments include gloss differences in measurement results. In case of gloss variations from batch to batch, gloss differences will be taken as colour differences (Datacolour, n.d.).

When comparing objects that have same colour, but different gloss characteristic, matte object seems to have less intense colour, and its lightness is higher, while chroma is lower, compared to corresponding gloss object (Dalal & Natale–Hoffman, 1999; Luo & Cui, 2009). Gloss also has major effect on colour measurement. Small differences in viewing geometry can lead to significant variations in colourfulness, particularly lightness, while change in hue is not so noticeable (Luo & Cui, 2009; Yuan, Yan & Jin, 2013). When measured using 45/0 geometry, colours seem more saturated. This is not so obvious in case of colours that have low chroma and for saturated colours (yellows) of high reflectance. Differences in saturation are largest in case of dark colours (Knowles Middleton, 1953). For material with same colour but different gloss, diffuse measuring geometry, mode SCI, obtains the uniform results. SCI geometry covers up gloss differences, and shows real colour difference (Datacolour, n.d.; Randall, 1998; Yuan, Yan & Jin, 2013). But results obtained with 45/0 measuring geometry will show pretty large colour differences (Randall, 1998). Diffuse instruments detect all of the reflected light; thus, the measured colour is independent of sample gloss. Instruments with 0/45 geometry, quite the opposite, do not detect nearly all specular reflected light, thus the measured colour is quite dependent on the sample gloss (Dalal & Natale–Hoffman, 1999).

UV varnish can be applied directly to substrate, even nonabsorbent, in order to achieve different gloss levels, tactile finishes or drip-off effects. It is used more and more for achieving additional value, especially as spot UV varnish on packaging. The goal is to improve brilliance and glossiness of the printed media underneath. This can be achieved with just a few µm of UV varnish. When the goal is to achieve tactile effects, like embossed texture, layer of applied varnish needs to be thicker, in the range from 20 to 200 µm. This can be reached by applying number of UV varnish layers, one on top of the other. Since UV varnish can be instantly cured after printing, these layers can be printed on the same spot. In this way, UV varnish is also used for printing braille letters, and also illustrations in braille books, signage and labeling in galleries and museums, etc. (Vujčić et al., 2021).

There are some researches that investigated influence of UV varnish on optical characteristic of substrate. They showed that applied UV varnish has impact on colour difference (Majnarić, Bolanča Mirković & Golubović, 2012; Galić, Ljevak & Zjakić, 2015).

This paper investigates influence of different measuring geometries on the results of colour measurement for samples with different number of applied varnish layers. Also, influence of number of applied varnish layers on measurement difference between geometries was investigated.

Methods and Materials

Measurements were done on DuraGo PVC plastic (Tekra, LLC., USA) samples 0,5 mm thick. Samples were unprinted and covered with UV varnish on printing machine VersaUV LEC300 (Roland DG Corporation, Japan, 2011), in different number of layers, from 1 to 12 (Figure 2). Liquid UV varnish was transferred directly to the printing substrate, in this case a PVC plastic, and then cured with UV light. ECO-UV varnish, EUV-GL v.4, the following compositions were used (Roland, 2019): 1,6-Hexamethylene diacrylate 20-30%, 2-Methoxyethyl acrylate 20-24%, Benzyl acrylate 10-25%, N-Vinyl caprolactam 10- 20% and Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide 5-10%. The printing was done from 1 to 12 layers, so colour difference could be monitored with every additional layer of varnish. Final 12 layers of varnish were applied, since previous research showed that with this number of layers of UV varnish legible Braille is obtained (Miloš, Vujčić & Majnarić, 2021). Gloss mode (drying with one UV lamp) was used for printing. The print resolution was 740 x 1440 dpi. The direction of printing was set to unidirectional, and rasterization was done according to the dither method. Printing was done in high quality mode- higher amount of varnish and resolution, and lower speed. It is printed using a DX4 Epson piezo Inkjet head with dot size of 3,5 pL (Format Media Ltd., 2010). After 5 layers, the height of the head was changed to a higher level.

During exposition to UV light and polymerization process printed UV varnish turns yellow. It is due to photoinitiators, which become yellow during the curing process and exposition to UV light, and with more varnish layers the yellowness is more pronounced. It can be noticed in Figure 2. UV varnish was printed with the printing machine VersaUV LEC300, which uses LED UV lamps for curing. The deficiency of exposition to the UV light spectrum emitted by these lamps is more pronounced yellowness of UV varnish.

» **Figure 2:** *Scanned sample*

After that, the Lab values of the given samples, before and after applying different number of layers of UV varnish, were measured. Colour characterization was done with two types of spectrophotometers:

- Konica Minolta CM-2600d (Konica Minolta Sensing, Inc., Japan)- d/8 diffuse geometry with the measurement aperture 3 mm and 8 mm and two measurement modes:

SCI- the spectral component included and
SCE- the spectral component excluded and

- X-Rite eXact (X-Rite, Inc., USA)- 45/0 geometry with the measurement aperture 2 mm.

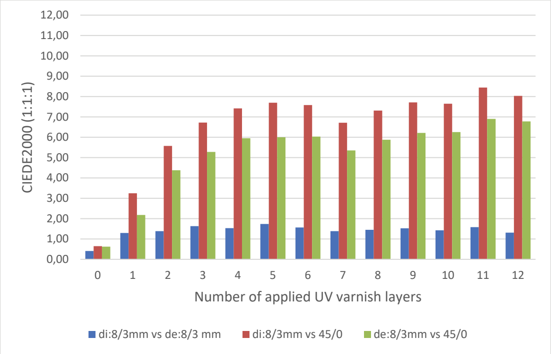
The colour coordinates of the samples were obtained using standard illumination D50 and standard observer angle 2°, according to ISO 3664:2009 (International Organization for Standardization, 2009). Measurements were repeated 10 times for every sample.

Results obtained with two kinds of geometry were compared. The colour difference between measurements done with d/8, SCI and SCE, measurement aperture 3 and 8 mm, and 45/0 spectrophotometer was calculated for each sample, using the CIEDE2000 (1:1:1) colour difference formula (Luo, Cui & Rigg, 2001). For easier distinction of different apertures and modes, in case of diffuse measuring geometry, following marks were used: di:8/3mm, where d stands for diffuse, i for SCI, 8 for angle and 3mm for measurement aperture; de:8/3mm, where e stands for SCE.

Results and Discussion

In Figure 3. are presented colour difference values of measured sample before and after printing different number of UV varnish layers, from 1 to 12, measured with di:8/3mm, de:8/3mm and 45/0 measuring geometry. From the presented results, it can be noticed that spectrophotometer measurement geometry influences the colour coordinates of UV varnished samples. Differences between measured Lab values of unprinted plastic, before applying UV varnish, are in range from 0.41 to 0.65. After applying UV varnish, differences between measurements are higher, especially between di:8/3mm and 45/0 geometries. When comparing di:8/3mm or de:8/3mm with 45/0, these differences are significantly higher with every additional layer of varnish, while they are not changing significantly between di:8/3mm and de:8/3mm. Differences between measured Lab values with di:8/3mm and de:8/3mm are changing in range from 1.29 to 1.74 after applying different number of UV varnish layers, from 1 to 12, and these changes are not regular, but they are also not significant.

Differences between di:8/3mm or de:8/3mm with 45/0 are much higher. They are a little bit higher between di:8/3mm and 45/0. After first and second layer of UV varnish, difference between measurements is extremely higher, and after applying third layer of UV varnish difference is not changing drastically. With every additional layer of UV varnish, there are some changes in calculated colour difference values, but they are not significant. This is case for both di:8/3mm and de:8/3mm measurements compared to 45/0.

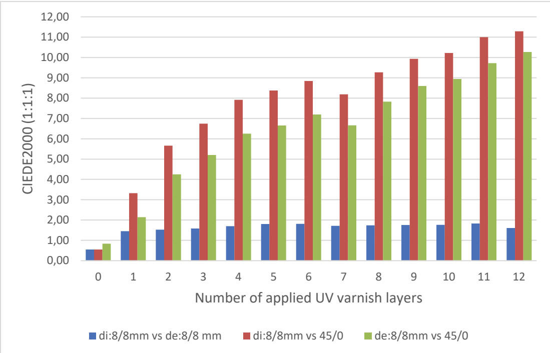


» **Figure 3:** *The CIEDE2000 (1:1:1) colour difference of the unprinted sample before and after applying certain number of UV varnish layers, between d/8° spectrophotometer with measurement aperture 3mm, both SCI and SCE, and 45°/0° spectrophotometer measurements*

In Figure 4. are presented colour difference values of measured sample before and after printing different number of UV varnish layers, from 1 to 12, measured with di:8/8mm, de:8/8mm and 45/0 measuring geometry. From the presented results, it can be noticed, again, that spectrophotometer measurement geometry influences the colour coordinates of UV varnished samples. Differences between measured Lab values of unprinted plastic, before applying UV varnish, are in range from 0.55 to 0.84. After applying UV varnish, differences between measurements are higher, especially between di:8/8mm and 45/0 geometries. When comparing di:8/8mm or de:8/8mm with 45/0, these differences are significantly higher with every additional layer of varnish, while they are not changing significantly between di:8/8mm and de:8/8mm. Differences between measured Lab values between di:8/8mm and de:8/8mm are changing in range from 1.45 to 1.83 after applying different number of UV varnish layers, from 1 to 12, and these changes are not regular, but they are also not significant.

Differences between di:8/8mm or de:8/8mm with 45/0 are much higher. They are higher between di:8/8mm and 45/0. After first and second layer of UV varnish, difference between measurements is extremely higher, and after applying third layer of UV varnish difference is not changing drastically, and with every additional layer of UV varnish, this difference is smaller. This is case both for di:8/8mm and de:8/8mm measurements compared to 45/0. Changes are smaller for de:8/8mm measurements, but trend is same for both types of measurements – di:8/8mm and de:8/8mm.

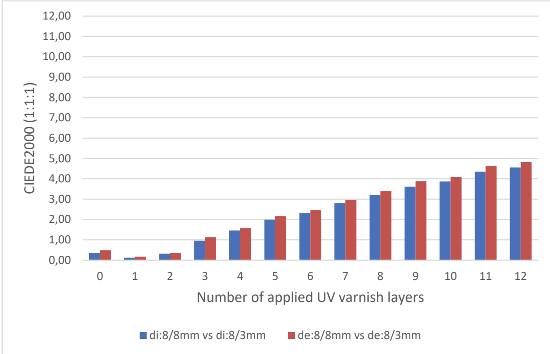
There is some unusual colour difference drop at 7 layers of UV varnish, and there was no logical explanation for this occurrence. Maybe it could be related to the position of patch with 7 layers of UV varnish. The test form was printed in the way that in one row were printed patches with 1 to 6 layers, and in second row were patches with 7 to 12 layers of UV varnish (Figure 2). Although, there is no certain connection between position and measured values. Also, compared to measurements done with measurement aperture 3mm, difference is much higher, and it also increases, almost linear, with every additional layer of UV varnish.



» **Figure 4:** *The CIEDE2000 (1:1:1) colour difference of the unprinted sample before and after applying certain number of UV varnish layers, between d/8° spectrophotometer with measurement aperture 8mm, both SCI and SCE, and 45°/0° spectrophotometer measurements*

Finally Figure 5. presents colour difference values of measurements with di:8/3mm and de:8/3mm compared to di:8/8mm and de:8/8mm. From the presented results, it can be noticed, that spectrophotometer measurement aperture also influences the colour coordinates of UV varnished samples. Difference between measured Lab values of unprinted plastic, before applying UV varnish is 0.36 for SCI and 0.49 for SCE. After applying first and second layer of UV varnish, differences are a little bit smaller. This can be caused by flattening sample surface, which leads to more similar results obtained with different aperture. Since surface irregularities influence measured results, more even surface will lead to closer results, independent of aperture size. After applying third layer of UV varnish, this difference is higher. With applying every additional layer of UV varnish, colour difference between measurements with same geometry, but different aperture size, is higher. This change is almost linear, and is a little bit higher in case of de:8 measurements.

Comparing differences for d/8 measurement geometry between same measurement mode and different aperture size (3 mm and 8 mm), with differences between same aperture size but different mode (SCI and SCE), it can be concluded that aperture size has greater influence on measured results, than measurement mode. This can be explained by part of surface sample taken into observation and measurement, since surface is glossy and transparent. Influence of applied UV varnish on measurement is different, if different part of surface sample is observed, due to different transmission and reflection of light.



» **Figure 5:** *The CIEDE2000 (1:1:1) colour difference of the unprinted sample before and after applying certain number of UV varnish layers, between d/8° spectrophotometer with measurement aperture 3mm and measurement aperture 8mm, for SCI and SCE measurements*

In order to express the difference in obtained measurements for each sample, but using different measuring geometries and aperture sizes, with one number, mean colour difference from the mean (MCDM) calculating method was used. This means that the CIEDE2000 between each measurement and the average Lab coordinates of the data set (data sets are Lab measurements obtained with different measuring geometries and aperture sizes for the unprinted sample and each layer of UV varnish) was calculated. The calculated average of each set of CIEDE2000 are the MCDM values presented in Table 2 (Nadal, Cameron Miller & Fairman, 2011). It can be noticed that with every additional layer of UV varnish, MCDM between measurement geometries is larger. This confirms influence of number of layers of UV varnish on difference between obtained values for different measuring geometries.

Table 2

Mean colour difference of the mean between measurement geometries for sample before and after applying each layer of UV varnish

	MCDM between measurement geometries
PVC plastic	0,33
1 UV varnish layer	1,06
2 UV varnish layers	1,67
3 UV varnish layers	2,08
4 UV varnish layers	2,41
5 UV varnish layers	2,62
6 UV varnish layers	2,71
7 UV varnish layers	2,65
8 UV varnish layers	2,96
9 UV varnish layers	3,22
10 UV varnish layers	3,30
11 UV varnish layers	3,67
12 UV varnish layers	3,67

Conclusions

From presented results it can be concluded that measuring geometry has great influence on measurement results of samples covered with UV varnish. Also, it can be concluded that with increase of numbers of UV varnish layers, difference between measurements also increases. Difference is largest between di:8/8mm and 45/0 measurements. Differences between d/8 and 45/0 geometries were generally larger when measurement aperture for d/8 geometry was larger. With increase of numbers of varnish layers, difference between measurements was also increasing, especially after application the first few layers of UV varnish, where difference between them is drastically changing. Differences in case of SCE geometry have the same trend as differences for SCI geometry, but they are a little bit smaller.

Differences between different modes, SCI and SCE, and also different measurement aperture size were also compared. In case of different mode, despite measurement aperture size, differences after applying UV varnish were fairly uniform, and not so significant. In case of measurement aperture size 3 mm, differences between SCI and SCE modes were in range from 1.29 to 1.74 for different number of applied layers, and in case of measurement aperture size 8 mm, differences were in range from 1.45 to 1.83. It can be noticed that difference between modes is not so pronounced, and this is probably due to imperfection of specular port.

In case of same mode, but different measurement aperture size, differences were linearly increasing with increased number of UV varnish layers. Differences for both modes were almost same. They are slightly lower in case of SCI mode. At first two layers of UV varnish, difference between measurements is lower than before applying UV varnish. This could be explained by flatter sample surface after applying UV varnish. This cause more similar results obtained with different aperture size. Since irregularities of surface influence results of measurement, more even surface will generate more uniform results, independent of aperture size, since influence of varnish gloss is still not so significant. With increasing number of UV varnish layers, difference is also increasing and becoming more significant. This is probably due to part of surface sample that is measured, since surface is glossy and transparent. Influence of UV varnish is different, if different part of surface sample is measured, due to different transmission and reflection of light. Considering all this, it can be concluded that aperture size has great influence on measured results, in case of extreme application of UV varnish.

Comparing obtained colour differences for different modes and different aperture sizes, in case of diffuse geometry, for PVC plastic UV varnished samples, with different amount of applied varnish, it can be concluded that aperture size has greater influence on measured results, than mode used.

Further research should be focused on examination of samples first printed with process colours, before applying UV varnish, to see how colour affects measurement results with different measurement geometries.

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