Bidirectional Reflectance and Texture Database of Printed Special Effect Colors

Katharina Kehren, Philipp Urban, Edgar Dörsam
Institute of Printing Science and Technology, Technische Universität Darmstadt, Germany
kehren@idd.tu-darmstadt.de

Abstract

A research project is underway to create a bidirectional reflectance and texture database of printed special effect colors. Such data is needed in the printing industry to determine the required measuring geometries characterizing the bidirectional reflectance distribution function (BRDF) and texture function (BTF), to develop quality measures for process control, and to simulate the prints' appearance on displays (soft proofing).

Flexo printing was used to apply 28 special effect inks with three tonal values on a matt and glossy paper substrate. The inks were selected to cover a wide range of different pigment classes and with respect to their demand in the printing market. To allow for multiple usage scenarios the inks were printed on a black and white background and partly finished with a glossy varnish resulting in a total of 672 different samples. The patches were measured in a preliminary stage with the BYK-mac multi-angle spectrophotometer. Evaluations on the diversity of the samples in terms of selected appearance parameters such as color flop or sparkle intensity are determined based on these measurements. The data is provided on our website and will be supplemented with additional measurements performed by a gonio-imaging system.

Introduction

In high-quality printing, e.g. in packaging, special effect inks are applied more frequently. The unique visual appearance, such as sparkle or geometry-induced color shifts, is caused by the optical properties of the comprised special effect pigments. Printing on top of particular background colors or applying gloss varnish might further boost these features.

A major problem in the industry is the absence of a quality measure for process control if special effect inks are used. Desired effects are realized in a try-and-error manner that is time consuming and costly. Much research effort is needed to find the relevant appearance dimensions and to establish a visual distance measure for defining tolerances and to control the printing process. Furthermore, measuring geometries need to be determined that allow a sufficiently accurate estimation of the *Bidirectional Reflectance Distribution Function* (BRDF) or the *Bidirectional Texture Function* (BTF) of special effect prints.

A database with BRDFs and BTFs of printed special effect prints covering a large number of pigment types and usage scenarios is required for this research. This paper describes an ongoing project of creating such a database including the selection of pigments and additional process steps for modifying the appearance of the final print. Bidirectional spectral and color data of the samples as well as texture parameters measured with a commercial multi-angle spectrophotometer are provided on our website.

In addition to the needs in the printing industry, this database could be an interesting source for computer graphic rendering and complement existing databases such as *MERL* [1], *CUReT* [2] or the *Artist Material BRDF Database* [3].

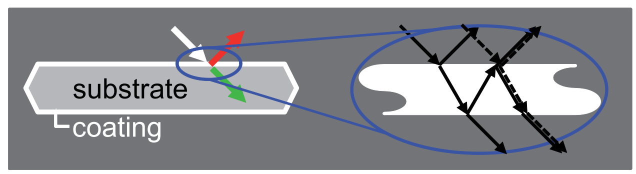

Figure 1: Sketch of a special effect pigment. The light directly reflected from the thin coating layer interferes with the light traveling back and forth through the layer.

Special Effect Pigments and Inks

Special effect pigments are composed of a flaky base material (substrate) covered with one or more thin layers of a coating material as shown in figure 1 [4, 5, 6, 7].

The transparent substrate consists of natural mica or of synthetic aluminum oxide, silicon dioxide or borosilicate. Synthetic substrates are bigger in particle size, more even in surface structure and free of impurities causing less adverse absorption and light scattering on edges and bumps.

The coat consists of a strong-refracting metal oxide, such as titanium dioxide, tin oxide or iron oxide. Some metal oxides like iron oxide have noticeable absorption characteristics. The induced geometry-independent coloring can be amplified by adding more absorbing material.
Interference on thin layers is the main optical effect that causes the geometry-dependent visual appearance. The gonio-chromatic properties mainly depend on the thickness of the thin layer and on the refraction index of the involved materials. Typical material compositions are used to classify special effect pigments, e.g. into silver white, gold, iron oxide, interference effect, multi-color and sparkle pigments.

In addition to varnishes, plastics and cosmetics, special effect pigments are utilized in printing inks. Due to the large diameter of the flaky pigments of up to 500 μm, special effect inks cannot be used for inkjet printing. However, they are suitable for all conventional printing technologies [8, 9, 10].

Creating the Samples
Printing Substrates

Two wood-free art papers, LumiArt and LumiSilk, were selected as printing substrates. The papers are typically used for high-quality printing applications and have both grammages of

120 g/m^2, which is the upper limit in graphic printing and the lower limit in package printing. Two 330 mm wide rolls of the selected papers were provided by the Stora Enso.
We selected these papers because they differ in their surface finish that influences the pigment orientation [5, 7]. The glossy coated paper LumiArt has a smooth surface forcing a plane parallel orientation of the flaky pigments. If the pigments are designed to show a color flop we assume a sharp transition from one color to the other about the respective incident/detection angle. Furthermore, the gloss intensity should be higher if the pigments are aligned equally. For the matte coated paper LumiSilk with a rough surface, the pigments are less oriented. Thus, color flops are expected to be blurry and the texture more distinctive.

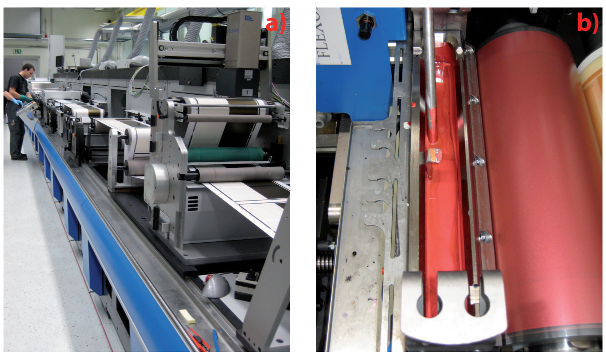

Figure 2: Printing press: a) modular design and b) flexo unit

Printing Press and Digital Masters

The modular web-fed printing press Gallus RCS 330 shown in figure 2a was used to produce the samples. All conventional printing technologies are realized in this printing press utilizing individual printing units that can be plugged into the press. In this project, we installed the flexo unit shown in figure 2b.
The used anilox roll has a theoretical dispersion volume of 13 cm^3/m^2 and a cell size of 100 lines/cm as recommended in literature [5, 7]. Photo-polymer printing plates from BASF SE named FAH D with a thickness of 1.14 mm were used. They measure 330 mm in cross direction and 451 mm in main direction.

Three printing plates were used for three subsequent printing sequences called pre-print, main-print and post-print. The designed digital masters and the resulting samples of each printing sequence are shown in figures 3, 5 and 6. Detailed information about the three printing sequences and the involved materials is given in the following.

Pre-Print with Black Absorption Ink

A water-based flexo ink called Aqualabel Black from Siegwerk Druckfarben AG was used to cover half of the paper web in the pre-print stage (see figure 3). The reason of the pre-print is to show the possible variations of color, gloss and texture achievable with a special effect pigment.
To illustrate the light travel we separate the background from the special effect ink layer as shown in figure 4. Light that passes through the ink layer is mostly absorbed from a black background and does not contribute to the overall emitted light that has a

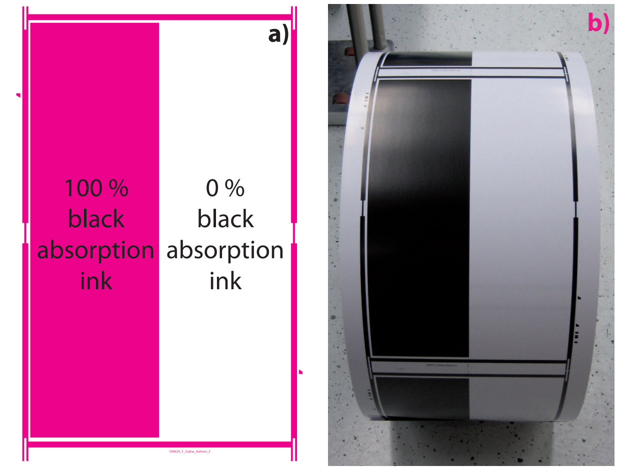

Figure 3: Pre-print: a) master and b) sample

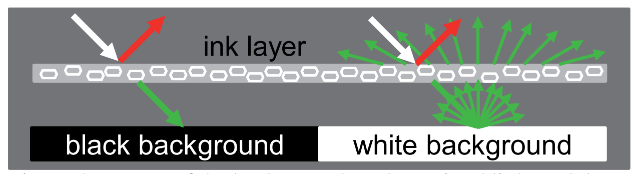

Figure 4: Impact of the background on the emitted light. Ink layer and background are separated to illustrate the light travel.

pigment-dependent interference effect color in specular direction. For a white background the intense interference color in specular direction is superimposed with a diffusely reflected light from the background that passes again through the ink layer and has a nearly complementary color [5, 7]. Furthermore, the black background increases the gloss contrast as well as the sparkle contrast.

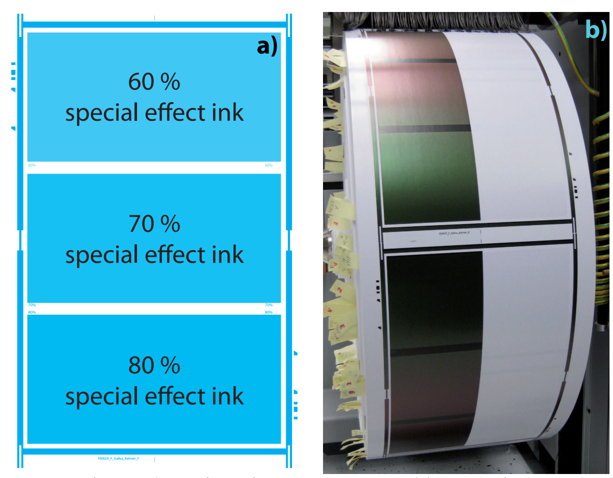

Figure 5: Main-print: a) master and b) sample

Main-Print with 28 Special Effect Inks

In the main-print stage, special effect inks are applied on the partly pre-printed paper. The Merck KGaA provided 28 water-based inks including special effect pigments of the product series Iriodin, Colorstream and Miraval. The concentration (mass ratio) of pigments dissolved in the inks was 25 % (Iriodin), 20 % (Col-

Table 1: Pigments

No.	Name	Class	Concentr. [%]	Diameter [μm]
01	I123	SW	25	5 - 25
02	I103	SW	25	10 - 60
03	I153	SW	25	20 - 100
04	I323	G	25	5 - 25
05	I305	G	25	10 - 60
06	I300	G	25	10 - 60
07	I520	IO	25	5 - 25
08	I4504	IO	25	5 - 50
09	I500	IO	25	10 - 60
10	I201	IE	25	5 - 25
11	I211	IE	25	5 - 25
12	I221	IE	25	5 - 25
13	I231	IE	25	5 - 25
14	I205	IE	25	10 - 60
15	I215	IE	25	10 - 60
16	I225	IE	25	10 - 60
17	I235	IE	25	10 - 60
18	CF1000	MC	20	5 - 50
19	CT1001	MC	20	5 - 50
20	CT1002	MC	20	5 - 50
21	CT1003	MC	20	5 - 50
22	CT1004	MC	20	5 - 50
23	CT1005	MC	20	10 - 60
24	CT1006	MC	20	10 - 60
25	M5311	S	15	10 - 100
26	M5320	S	15	10 - 100
27	M5321	S	15	10 - 100
28	M5325	S	15	10 - 100

orstream) and 15 % (Miraval). Based on their material compositions the pigments can be classified into six different categories titled: silver white (SW), gold (G), iron oxide (IO), interference effect (IE), multi-color (MC) and sparkle (S). Table 1 shows the name, class, concentration and particle size.

In order to cover many usage scenarios we selected the pigments with respect to their demand in the printing market and their diversity of material compositions. Furthermore, they have to be applicable to flexo printing, which limits the particle size to 200 μm.

In addition to the process-related specifications, the print quality is another important factor. The visually relevant amount of pigments should be controlled without changing the concentration of pigments in the ink. We used the tonal value as an alternative control parameter. In preliminary printing tests with some special effect inks satisfactory results were achieved with tonal values of about 70 %. Even though the pigments are distributed uniformly for lower surface coverage, the color effect decreases with tonal value. The color effect is most intense for a complete surface coverage. However, the pigments tend to build visually disturbing agglomerates for a tonal value of 100 %. For potential deviations from the presumably optimal tonal value of 70 %, additional patches with tonal values of 60 % and 80 % were printed.

Post-Print with Clear Gloss Varnish

The post-print shown in figure 6 is an optional application of a clear gloss varnish. Half of the patches created for each paper-ink combination was finished with an UV-curing varnish

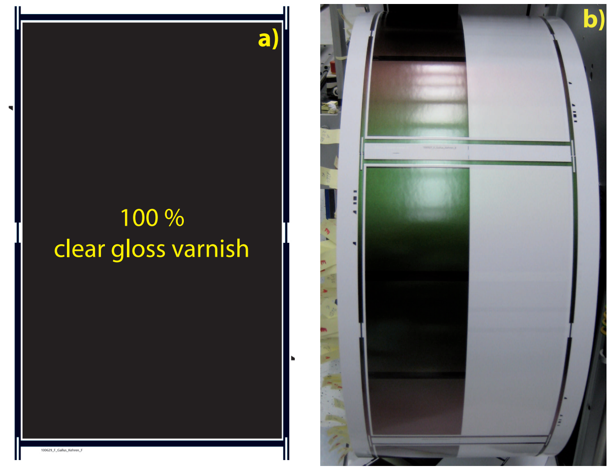

Figure 6: Post-print: a) master and b) sample

called Senolith from Weilburger Graphics GmbH.
Our aim was to level the printed surface with this additional transparent layer. The reflection on even surfaces is less diffuse and the specular reflection of the incident light induces a high gloss contrast.

Applying 28 special effect inks with three tonal values on two types of papers with and without a clear gloss varnish and a black absorption ink results in 672 different samples. Two professional printers required nearly three weeks to create all patches. Cutting and measuring took another two weeks.

Measurements

All gonio-chromatic and spatially resolved measurements of the samples were performed with the portable hand-held multi-angle spectrophotometer BYK-mac of the BYK-Gardner GmbH.

Spectral Multi-angle Measurements

The BYK-mac is equipped with a lamp that illuminates the sample in an incidence angle of 45° and six photo detectors located at aspect angles of -15°, 15°, 25°, 45°, 75° and 110°. The aspect angle corresponds to the angular difference between detection and specular direction. The lamp and all detectors are located in the same plane. The geometry is typically denoted by 45asδ, which indicates an incident angle of 45° and an aspect angle of δ°.
The measured spectral reflectance factors are internally used to determine CIELAB and CIELCH coordinates for CIE D65 and the 10° CIE standard observer. The spectral reflectance factors as well as the color coordinates are recorded for all six geometric configurations. Connecting the color coordinates measured for increasing aspect angles, i.e. 45as-15,...,45as110, form the so-called aspect line [5, 7].

Spatially Resolved Measurements

Spatially resolved measurements were performed with the integrated gray-scale camera located perpendicular to the sample. The sample is illuminated directionally under 15°, 45° and 75° counted to the sample normal. In addition, also diffuse illumination is used for capture.

Appearance related quantities for texture are automatically determined by the BYK-mac device based on the captured images. Sparkle intensity, sparkle area and sparkle grade are given for the three directional geometries and graininess for the diffuse illumination. These parameters rely on visual experiments conducted by Kirchner et al. [11, 12, 13].

Evaluation

In addition to the sparkle and graininess parameters we computed a color and a gloss related quantity to show the diversity of the samples in the database. These are the hue difference sum and the distinctness-of-image gloss.

Hue Difference Sum

We are especially interested in hue changes along the aspect line, which indicate color flops particularly desired in many applications. To quantify these hue changes we simply sum up the Euclidean hue differences between the six measurements $p_i \in$ CIELAB, $i = 1,\dots,6$ corresponding to the geometries $45as\delta_i$, $\delta_1 = -15$, $\delta_2 = 15$, $\delta_3 = 25$, $\delta_4 = 45$, $\delta_5 = 75$, $\delta_6 = 110$. The resulting *hue difference sum* (HDS) is defined as follows

$$\text{HDS} = \sum_{i=1}^{5} |\Delta H^*_{ab}(p_i, p_{i+1})| \tag{1}$$

where $\Delta H^*_{ab} = \sqrt{(\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*_{ab})^2}$ is the Euclidean hue difference [14].

Distinctness-of-Image Gloss

For evaluating gloss we look at the luminance of the measurements for geometric configurations near at and far from the specular direction. For this purpose we calculate the *near-at-gloss luminance* (NAGL) and the *far-from-gloss luminance* (FFGL) as follows

$$\text{NAGL} = \max(Y_{45\text{as-}15}, Y_{45\text{as}15}),\ \text{FFGL} = \max(Y_{45\text{as}75}, Y_{45\text{as}110}) \tag{2}$$

where $Y_{45\text{as}\delta}$, $\delta = -15, 15, 75, 110$ denotes the luminance of the investigated sample for the specified geometries.

Far from the specular direction, diffuse reflection is dominant. The diffusely reflected light is superimposed with directionally reflected light near the specular direction. Subtracting FFGL from NAGL can be interpreted as the luminance induced by the directional reflection. Dividing the luminance difference by NAGL yields the *distinctness-of-image gloss*

$$\text{DOI} = \frac{\text{NAGL} - \text{FFGL}}{\text{NAGL}} = 1 - \frac{\text{FFGL}}{\text{NAGL}} \tag{3}$$

This formula is adapted from the ASTM standard [15] but uses different measurement geometries. Furthermore, luminance is employed instead of gloss reflectance factors.

Results

The aim of our analysis is to show the variation of appearance related parameters covered by the samples in our database. We want to show the impact of pigment type, gloss varnish, and black background on these parameters. In contrast to our assumption the paper's surface finish has only small influence on these parameters and will be, therefore, not considered in our evaluations.

Color spread

The *hue difference sum* (HDS) is shown in figure 7 for all samples printed with a tonal value of 70% on the matte coated paper. The HDS is small for the silver-white, gold, iron-oxide and sparkle pigments and, as expected, high for the so-called multicolor pigments. The special composition of synthetic substrate and coating materials induces an intense interference effect. Especially for the interference effect and multi-color pigments the application of the clear gloss varnish increases the HDS. Except for the silver-white, gold and iron oxide pigments with considerable absorption properties, the HDS is higher for the samples pre-printed with the black absorption ink.

Distinctness-of-Image Gloss

The *distinctness-of-image gloss* (DOI) is shown in figure 8, for all samples printed with a tonal value of 70% on the matte coated paper. As expected the DOI is close to one for samples comprising a black background. This was expected since light that passes through the ink layer is nearly completely absorbed and does not contribute to the emitted light in off-specular direction (see figure 4). For samples with white background the results do not validate our expectations since the DOI decreases if the gloss varnish is applied. However, visual inspections show that the DOI is higher for the samples with gloss varnish. The reason is the inappropriate approximation of the luminance in specular direction ($45as0$) by near specular measurements ($45as-15$ and $45as15$). If gloss varnish is applied, the luminance at these measurement geometries already dropped significantly compared to the luminance in specular direction. This simple example shows that the BYK-mac measurements are not sufficient to characterize the appearance of the samples. Please see in this regard our outlook section at the end of this paper.

Texture intensity

The influences of printing conditions on texture appearance is shown in figure 9 for the sparkle intensity measured for an illumination angle of 15° to the surface normal. As expected, the sparkle pigments show the highest sparkle intensity due to their even synthetic substrates and large maximum particle size. Gloss varnish amplifies the sparkle intensity especially for the sparkle-based samples. In general, the sparkle intensity is higher if the pigments are printed on a black background.

Conclusion

This paper describes the creation of samples for a bidirectional reflectance and texture database of printed special effect colors covering multiple usage scenarios in the printing and packaging industry. Three subsequent flexo printing sequences on the modular web-fed printing press Gallus RCS 330 were required to create 672 special effect prints varying in pigment type, paper type, gloss varnish and background color. A total of 28 different special effect pigments were used that can be classified into six categories of different material compositions. Preliminary evaluations of the samples' appearance features were performed based on spectral and spatially resolved measurements using the BYK-mac multi-angle spectrophotometer. Some pigment categories comprise special appearance properties such as high sparkle intensity or distinct hue shifts between different measurement geometries. Hue shifts increase for samples belonging to the inter-

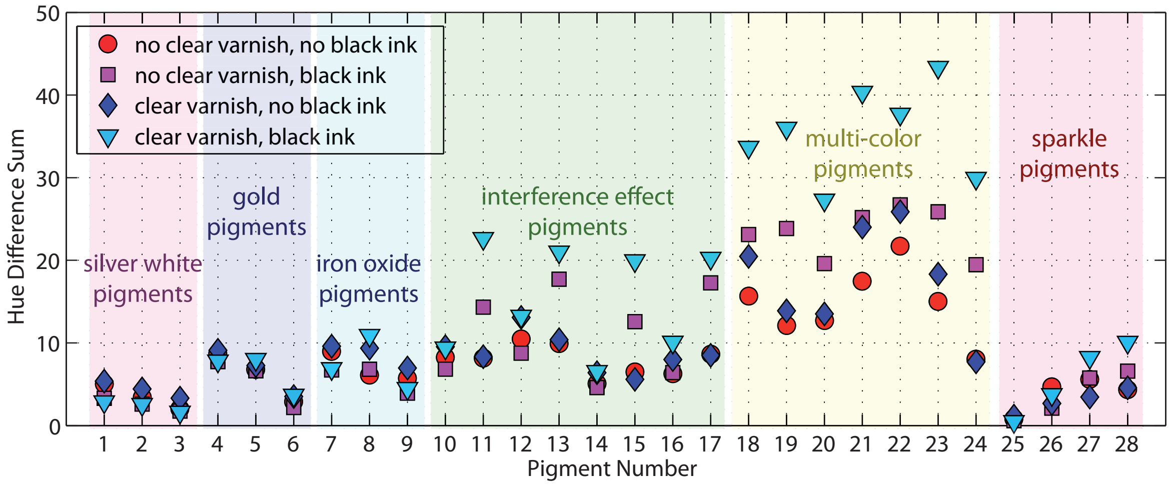

Figure 7: Hue difference sum

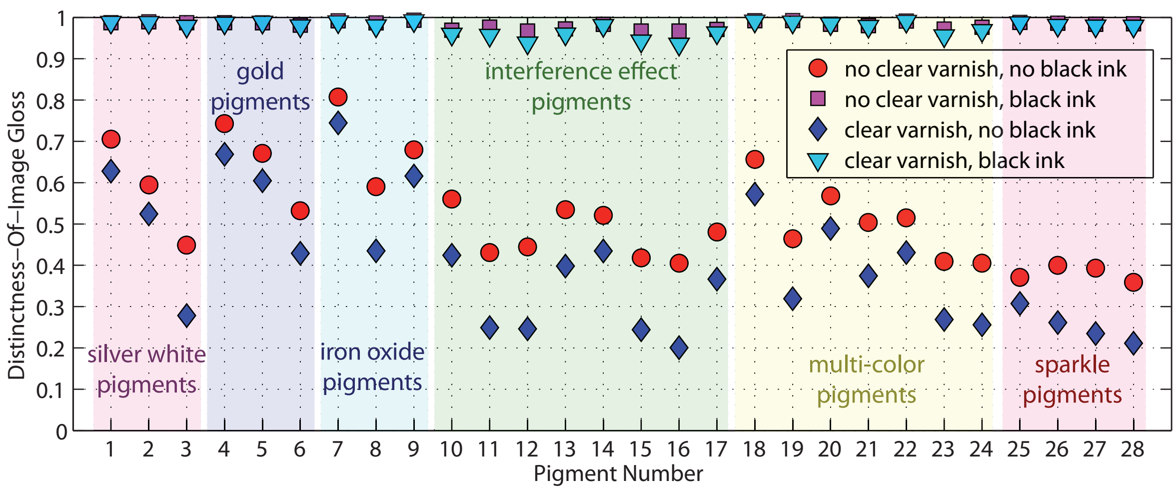

Figure 8: Distinctness-of-image gloss

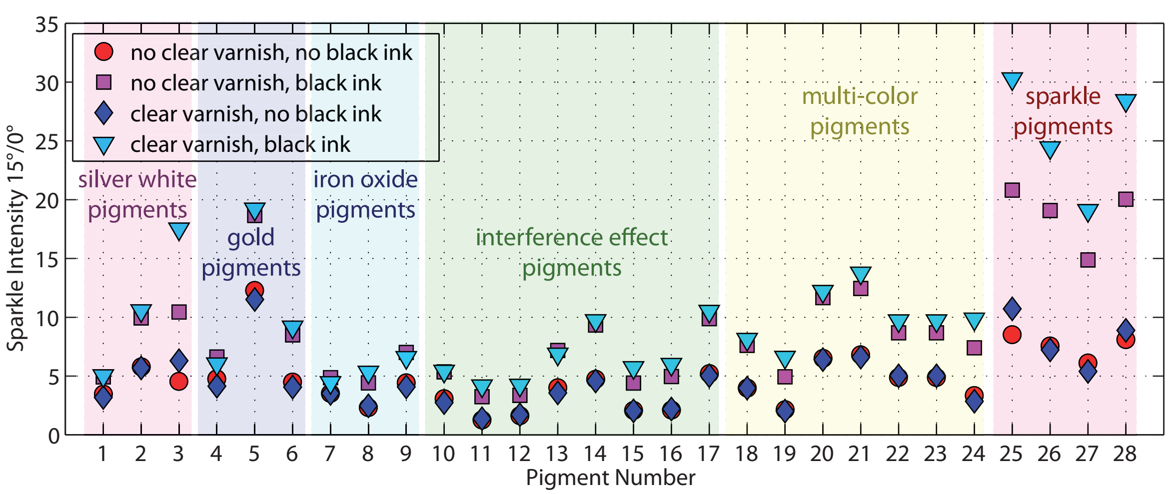

Figure 9: Sparkle intensity

ference effect pigments and the multi-color pigments if they are printed on a black background and if a gloss varnish is applied. The sparkle intensity is generally higher if the samples have a black background. For the sparkle pigment category the sparkle intensity can be further boosted by adding a gloss varnish.

We believe that the database is a unique source for future research in the area of material appearance, computer graphics and soft proofing. All measurements are provided on our website as supplemental material.

Outlook

Measurements with the BYK-mac multi-angle spectrophotometer provide only a rough sampling of the material's BRDF. For this reason we have sent selected samples to the Physikalisch-Technische Bundesanstalt (PTB) that is the German metrology institute. The PTB has a robot-based camera gonioreflectometer that shall be employed to measure the samples for a large number of geometries [16, 17, 18]. These measurements shall be used to fit BRDF and BTF models to describe the database. Furthermore, the degree of the BRDFs' anisotropy caused by the alignment of pigments in the printing process shall be analyzed.

In addition, visual experiments shall be conducted on the samples to determine the number of visually relevant appearance correlates by multidimensional scaling techniques.

Acknowledgment

We thank Paul-Heinz Dähling of the Stora Enso Research Center Mönchengladbach for the paper reels, Andreas Becker of Merck KGaA for the printing inks and Martin Schmitt-Lewen for the machine runtime. We also thank Thorsten Euler and Evgeny Kurmakaev for printing and Tobias Schwind for measuring.

References

[1] W. Matusik, H. Pfister, M. Brand, and L. McMillan. A Data-Driven Reflectance Model. In *Proceedings of 30th Siggraph Conference, San Diego*, pages 759–769, 2003.

[2] K. J. Dana, S. K. Nayar, and J. J. van Ginneken, B. Koederink. Reflectance and Texture of Real-World Surfaces. *ACM Transaction on Graphics*, 18(1):1–34, 1999.

[3] J. C. Ashbaugh, R. S. Berns, B. A. Darling, and L. A. Taplin. Artist material BRDF Database for Computer Graphics Rendering. In *Final Program and Proceedings of 17th Color Imaging Conference, Albuquerque, New Mexico*, volume 17, pages 62–68, 2009.

[4] F.-W. Bach, K. Möhwald, A. Laarmann, and T. Wenz. *Moderne Beschichtungsverfahren*. Wiley-VCH, Weinheim, 2005.

[5] R. Glausch, M. Kieser, R. Maisch, G. Pfaff, and J. Weitzel. *Perlglanzpigmente*. Vincentz, Hannover, 1996.

[6] R. Maisch and M. Weigand. *Perlglanzpigmente - Physikalische Grundlagen, Eigenschaften, Anforderungen*. Moderne Indusrie, Landsberg am Lech, 1991.

[7] G. Pfaff, P. Gabel, M. Kieser, F. Maile, and J. Weitzel. *Special Effect Pigments - Technical Basics and Applications*. Vincentz Network, Hannover, 2 edition, 2008.

[8] K. Böhm, G. Paff, and J. Weitzel. Ein effektvolles Farbenspiel - Wie Perlglanzpigmente in Druckfarben für verschiedene Druckverfahren eingesetzt werden können. *Farbe und Lack*, 105(10):30–42, 1999.

[9] K.-C. Ullmann. Perlglanz-Effektpigmente im Tiefdruck. *Flexo- und Tiefdruck*, 14(6):4–8, 2003.

[10] V. Hall-Goulle, G. Fern, R. Schmid, and M. McGarvey. Für den gewissen Aha-Effekt - Mit neuen Effektpigmenten für Druckfarben Aufmerksamkeit gewinnen. *Farbe und Lack*, 116(5):28–32, 2010.

[11] E. Kirchner, G.-J. van den Kieboom, L. Njo, R. Supèr, and R. Gottenbos. Observation of Visual Texture of Metallic and Pearlescent Materials. *Color Research and Application*, 32(4):256–266, 2007.

[12] E. Kirchner, K. de Haas, and L. Njo. Objektiv glitzern und funkeln - Effektlacke mit Textur instrumentell charakterisieren. *Farbe und Lack*, 114(2):32–36, 2008.

[13] E. Kirchner, N. Dekker, R. Supèr, G.-J. van den Kieboom, and R. Gottenbos. Quantifying the influence of texture on perceived color differences for effect coatings. In *Proceedings of the 11th Congress of the International Color Association, Sydney*, 2009.

[14] R. S. Berns. *Principles of Color Technology*. John Wiley and Sons Inc., New York, 3 edition, 2000.

[15] ASTM. Standard Test Methods for Instrumental Measurement of Distinctness-of-Image Gloss of Coating Surfaces, ASTM D 5767-95 (reapproved1999). Technical report, ASTM International, West Conshohocken, 1999.

[16] D. Hünerhoff, U. Grusemann, and A. Höpe. New robot-based gonioreflectometer for measuring spectral diffuse reflection. *Metrologia*, 43(2):11–16, 2006.

[17] A. Höpe, S. Teichert, and K.-O. Hauer. Appearance characterisation of reference materials for reflectometry: Measurement of the reflection indicatrix. In *Poster at the 1oth International Conference on New Developments and Applications in Optical Radimetry, Daejeon, Republic of Korea*, volume 10, 2008.

[18] A. Höpe and K.-O. Hauer. Three-dimensional appearance characterization of diffuse standard reflection materials. *Metrologia*, 47(3):295–304, 2010.

Author Biography

Katharina Kehren graduated with a diploma (equivalent to a master degree) in paper science and technology in September 2008. She is a research assistant at the Institute of Printing Science and Technology, Technische Universität Darmstadt since October 2008. Her research focuses on the optical properties and the visual appearance of printed special effect colors.

Philipp Urban has been head of an Emmy-Noether research group at the Technische Universität Darmstadt (Germany) since 2009. His research focuses on color science and spectral imaging. From 2006-2008 he was a visiting scientist at the RIT Munsell Color Science Laboratory. He holds a MS in mathematics from the University of Hamburg and a PhD from the Hamburg University of Technology (Germany).

Edgar Dörsam has been full Professor and Director of the Institute of Printing Science and Technology at the Technische Universität Darmstadt, Germany since 2003. From 1994-2003 he was responsible for research and development at MAN Roland AG in Offenbach, Germany. He has more than 30 patents and is member of IS&T, VDD, VDI and OE-A. He holds a MS and a doctoral degree in Mechanical Engineering from Technische Universität Darmstadt.