Visual Appearance of Printed Special Effect Colors

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Abstract

This paper investigates the visual appearance of printed special effect colors that become increasingly popular in high-quality printing. Since traditional colorimetry is insufficient to assess the unique visual appearance of such prints, improved perception-based measures and tolerances are necessary for process control and quality assurance. A prerequisite for developing such measures is a transformation of measurable physical quantities (e.g. Bidirectional Reflectance Distribution Function or Bidirectional Texture Function) into a space of relevant appearance attributes. In this study we determine the latent appearance dimensionality of a selected set of printed special effect colors and analyze suitable attributes for describing its appearance.

Samples were produced by screen printing employing 22 special effect inks and two paper grades. A subset of 14 samples was selected showing a high variability with respect to visual appearance, material and spectral reflectance. In a first experiment, subjects rated the difference of the visual appearance between samples. In the second experiment, the magnitudes of twelve reasonable appearance attributes were assigned to each sample.

Subsequent statistical evaluations include classical multidimensional scaling and correlation analysis. Our results show that the latent dimensionality of the sample set is at most five. The set of appearance attributes for describing the samples includes the color attributes, one attribute for gloss and one for texture.

Introduction

Today, special effect pigments can be found in coatings, plastics or cosmetics aiming to enhance their visual appearance. They also become increasingly popular in printing products where the pigments are included into the inks [1]. Special effect pigments may induce a geometry-dependent color, a metal to pearlescent gloss, or a clearly visible texture. Due to this unique visual appearance, they are particularly interesting for high-quality printing applications.

Special effect pigments are composed of a transparent, flaky substrate covered with one or more thin coating layers [1]. The goniochromatic appearance is caused by thin-layer interference on the strong refracting coating. The distinct specular reflection at the ink surface as well as multiple inter-reflections in the ink layer induce gloss that is similar to gloss observed on metallic surfaces or pearls. The texture is caused by the large particle size of up to 500 μm. Special effect inks are printable by all conventional printing technologies.

For special effect colors, traditional colorimetry is insufficient to predict differences and tolerances that correlate well with our perception. Such perceptually-based measures are a prerequisite for controlling the printing process and for quantifying the quality of the resulting printout without tedious visual experiments. For this purpose, an improved appearance-related measure is required.

In this paper, we investigated the number and nature of relevant visual appearance attributes of a selected set of printed special effect colors. In future research, we plan to scale these appearance attributes and to relate them with physically measurable optical properties of the printout, e.g. with the Bidirectional Reflectance Distribution Function (BRDF) or Bidirectional Texture Function (BTF). Such a relationship allows us to measure the corresponding appearance attributes and enables further research on perceptual differences of printed special effect colors.

Overview of Visual Appearance Research

Eugène [2] subdivided a material's visual appearance into components for **color**, **gloss**, **texture** and **translucency**. Since translucency can be neglected for printed special effect colors we confine our overview to color, gloss and texture appearance.

Color Appearance

Color appearance can be described by five attributes: *brightness*, *lightness*, *colorfulness*, *chroma* and *hue*. These attributes are defined in standards [3] or books [4, 5, 6] and multiple models are proposed to predict these attributes from a spectral stimulus considering the viewing conditions (e.g. adapting luminance, tristimulus value of the white point, relative luminance of the surround etc.).

In their book on special effect pigments, Pfaff et al. [1] describe the *color flop* and the *lightness flop*. The *hue flop* was introduced by Kehren et al. [7] as a related attribute for describing printed special effect colors.

Gloss Appearance

The appearance of gloss becomes increasingly important in computer graphics and was recently investigated by Wills et al. [8], Pellacini et al. [9] and Ferwerda et al. [10]. Several attributes were proposed to describe the appearance of surface gloss by Hunter [6].

In addition to *contrast gloss*, *absence-of-bloom gloss*, *absence-of-texture gloss* and *surface-uniformity gloss*, gloss attributes named *specular gloss*, *luster*, *bloom*, *haze*, *sheen* and *distinctness-of-image gloss* are defined in standards [3]. Pfaff et al. [1] use the gloss attributes *metal gloss* and *pearl gloss* in the context of special effect pigments.

Texture Appearance

Rao and Lohse [11] evaluated twelve attributes with respect to their suitability for describing the appearance of textured surfaces. They discovered that three dimensions are sufficient for a space able to represent a wide range of textures. The first dimen-

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sion of this space highly correlates with attributes called *repetitiveness*, *randomness*, *directionality*, *regularity*, *orientation* and *uniformity*. Texture attributes called *contrast* and *directionality* strongly correlate with the second dimension. The third dimension correlates with *granularity*, *complexity* and *coarseness* of the texture.

In the context of special effect pigments, Kirchner et al. [12, 13] used texture attributes named *coarseness* and *glint*. The related terms *graininess* and *sparkle* are used by Renschler [14], Ďuricovič and Martens [15], Ďuricovič et al. [16] and by Ershov et al. [17, 18].

Experimental Setup

Preparation of Samples

Printing of Samples: 22 special effect inks were applied on two paper grades by screen printing [19] resulting in 44 samples of printed special effect colors.

The employed papers mainly differ in bulk color and surface finishing. We used a white glossy coated paper (WGCP) called Luxo Magic manufactured by Sappi Ltd. with a grammage of 150 g/m^2 and a black uncoated paper (BUCP) produced by Arjo Wiggins with a grammage of 120 g/m^2 named PopSet. The influence of the background color and substrate roughness on the optical properties of the printout was described in Ref. [7].

Kammann's screen printing unit K14Q SL was employed to create the samples. In screen printing [19], a squeegee presses the ink onto the substrate through open areas of a meshed stencil. We used a flexible polymer squeegee with a hardness of 65 Shore. The screen printing plate consists of a frame stringed with a fabric called PET 1500 43/100-80Y produced by the Sefar AG. The open stencil area was a square with an edge length of 120 mm.

Each of the 22 printing inks consists of special effect pigments suspended in a binder-thinner system. A UV-curing binder called OMNIPLUS UL 360 and an appropriate thinner called UVIPLAST ZE 834 were supplied by Fujifilm Sericol GmbH. 220 g of the binder and 11 g of the thinner were mixed with 55 g of each special effect pigment. Thus, the pigment concentration is 19.2 % by weight. After the UV-curing ink was applied on the paper, the samples were fed through a drying system of IST Metz GmbH. The drying of each ink is individually optimized by adjusting the velocity of a conveyor belt that transports the printed sample underneath an UV-light source.

The employed 22 special effect pigments were provided by the BASF SE Ludwigshafen. They are listed in figure 1 specified by their ink code, particle size and pigment class: Silver white (SW), gold (G), iron oxide (IO), interference effect (IE), multi-color (MC) and sparkle (S). More information on the visual properties of the pigment classes can be found in Ref. [7].

From the set of 44 samples, a subset of 14 samples was selected for the experiments. Reducing the number of samples was necessary to keep the duration of the experiments reasonable. The selection procedure aimed to ensure a large inter-sample variability with respect to reflectances (measured by X-Rite's MA98 multi-angle spectrophotometer), visual appearance and employed materials. Figure 2 shows the selected samples.

Shaping of Samples: Each sample was glued onto a black cylinder with a diameter of 46 *mm* and a height of 160 *mm*. Since a sample does not completely cover the black cylinder, handling without touching the printed surface was possible.

Ink Code	Pigment Name	Class	Ø [µm]
BO90C0Z	Black Olive	SW	6-48
F9G630L	Firemist Blue	SW	5-300
F9G680D	Firemist Colormot. Blue Topaz	MC	13-180
F9G480D	Firemist Colormotion Ruby	MC	13-180
F9G230L	Firemist Gold	S	5-300
F9G830L	Firemist Green	S	5-300
F9G130L	Firemist Pearl	S	5-300
F9G430L	Firemist Red	S	5-300
F9G730L	Firemist Turquoise	S	5-300
F9G530L	Firemist Violet	S	5-300
G9S130D	Glacier Frost White	SW	8-45
L9A30D	Lumina Aqua Blue	IE	8-48
L9232D	Lumina Brass	G	8-48
L9359D	Lumina Copper	IO	8-48
L9Y30D	Lumina Gold	IE	8-48
L9G30D	Lumina Green	IE	8-48
L9R30D	Lumina Red	IE	8-48
L9680H	Lumina Royal Blue	IE	6-48
L9450D	Lumina Russet	IO	8-48
L9T30D	Lumina Turquoise	IE	8-48
SF9332D	Santa Fe Desert Blush	G	8-48
SF9832D	Santa Fe Kiwi	G	8-48

Figure 1: Printing ink with ink code.

Multiple illuminating and viewing geometries are simultaneously realized by the cylindrical shape of the sample. Some of these geometries are labeled in figure 3. These geometric configurations influence the visual appearance. Color changes with the geometric configuration due to thin-layer interference on the special effect pigments. Gloss depends on the combination of the direct highlight in near-at-specular geometries and the diffuse shining for far-from-specular geometries. The texture appearance varies due to different tiltings of the flaky pigments in the binder matrix relative to light source and observer.

The Observer Panel

For the first experiment, 38 subjects were employed: 12 females and 24 males, with an average age of 34 years and a standard deviation of 10 years. Only a subset of 22 subjects participated in the second experiment: 9 females and 13 males, with an average age of 31 years and a standard deviation of 6 years.

All subjects had a normal visual performance according to multiple standard tests of visual acuity and color vision. The visual acuity was tested using the Landolt C Detection Test, the Snellen E Detection Test and the Snellen Letters Recognition Test. The Ishihara Color Deficiency Test [20] and the Farnsworth-Munsell D15 Test [21, 22] were employed to ensure that each observer had normal color vision.

The Geometric Setup

We used X-Rite's Spectra Light III booth for diffusely illuminating the samples by a tungsten-filtered CIED65 illuminant. The booth was covered on the inside with black velour to reduce stray light. A sample holder and a chin rest ensured a viewing distance of 264 *mm*. For this distance a sample height of 46 *mm*

Figure 2: Selected samples marked with ink and paper code.

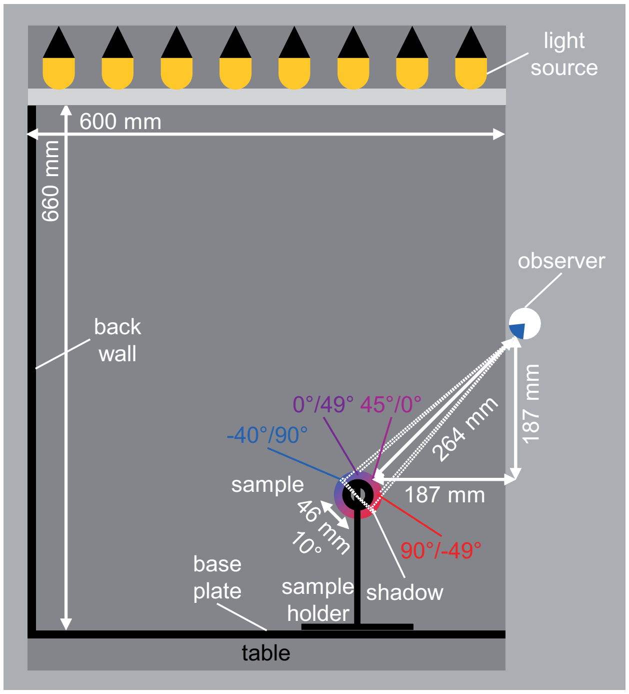

Figure 3: Experimental Setup.

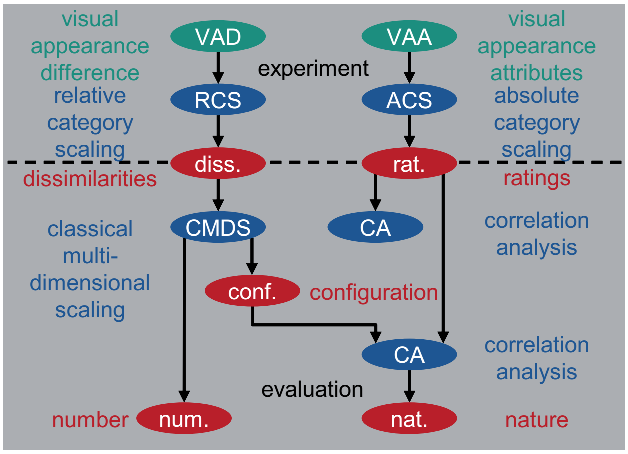

Figure 4: Methodical concept for experiment and evaluation.

(diameter of the cylinder) covers 10° of the visual field. The geometric setup is shown in figure 3. The sample holder allows the placement of two samples for a side-by-side comparison.

Figure 3 shows four geometric configurations labeled by two numbers that are separated by a slash: the first number is the angle of incident light and the second number the viewing angle. Both are given relative to the surface normal. Assuming only directed light that falls vertically from the booth's ceiling onto the sample cylinder, the incident angle covers a range of $[-40°, 90°]$ and the viewing angle a range of $[90°, -49°]$. Please note, that in our setup this directed light is superimposed by diffuse light.

Methodology

We conducted two visual experiments to obtain the perceptual dimensionality of the sample set and to correlate existing appearance attributes with the resulting dimensions. The concept is illustrated in figure 4.

The first experiment was a relative category scaling (RCS) experiment [23] of the visual appearance difference (VAD). The results are perceived dissimilarities between the samples. Classical multi-dimensional scaling (CMDS) processed these data to compute the so-called configuration, i.e. an arrangement of the samples in an n-dimensional space reflecting the dissimilarities. CMDS provides also information on the dimensionality of this visual appearance space.

The second experiment was an absolute category scaling (ACS) experiment [23] of visual appearance attributes (VAA). The perceived magnitude of given appearance attributes is assigned to each sample. These data were used for two correlation analyses (CA). Inter-attribute correlations were obtained by the first correlation analysis. The second correlation analysis revealed how well each dimension of the appearance space obtained by the first experiment represents a particular attribute.

Visual Experiments

Experimental Procedure

Relative Category Scaling (RCS)

To become familiar with the appearance range covered by the sample set, all samples were shown to subjects at the beginning of the relative category scaling (RCS) experiment [23]. Then, all 91 combinations of sample pairs were shown. For each pair, subjects were asked to judge the magnitude of the visual appearance difference on a scale from zero to ten. Zero means no difference and ten maximum difference. All 91 difference ratings were stored in an upper triangular matrix, the so-called dissimilarity matrix.

Absolute Category Scaling (ACS)

For the absolute category scaling (ACS) experiment [23], twelve attributes were selected that were expected to describe the appearance of the samples. The selected attributes are redness (ap), yellowness (bp), greenness (an), blueness (bn), chroma (C), lightness (L), hue flop (dH) [1, 3, 4, 5, 6, 7]. Lightness flop and gloss contrast were assumed to be similar and were utilized as one of two gloss attributes (dLCG). The second gloss attribute employed in this study was the distinctness-of-image gloss (DOIG) [3, 8, 9, 10]. Three texture attributes were considered: texture contrast (TC), graininess or coarseness (GC) and sparkle or glint (SG) [11, 12, 13, 14, 15, 16, 17, 18].

This experiment requires subjects who understand the meaning of the investigated appearance attributes. Therefore, all considered attributes were explained at the beginning of the experiment. Several samples were used to illustrate distinct appearance attributes.

To estimate the magnitude of each visual appearance attribute for all 14 samples, twelve individual sessions were carried out. In each session, subjects were asked to sort the samples with respect to the magnitude of the investigated attribute. Then they were asked to assign a number between zero and ten to each sample. This number should represent the perceived magnitude of the investigated attribute possessed by the sample. Zero means that the sample does not possess this attribute. Ten means that it has the maximum magnitude found in the sample set. For each of the twelve sessions, 14 numbers were stored in a column vector and combined to the so-called rating matrix with 14 rows for the samples and twelve columns for the attributes.

Evaluation of Visual Experiments

Classical Multidimensional Scaling (CMDS)

Multidimensional scaling is a collection of multivariate statistical methods [4, 24, 25]. Dissimilarity or similarity data between objects are used to find the latent dimensions in the dataset and to arrange the objects in a low-dimensional space representing the dissimilarities or similarities. This geometric representation of the data is invariant under rotation, translation and reflection and is called **configuration**.

The quality of the configuration is described by a quality measure called **stress**. The stress-versus-dimension plot named **scree plot** reveals the latent dimensionality of the data indicated by a sharp drop of the stress values.

In this study, we use classical multidimensional scaling (CMDS) to calculate the configuration and to estimate the dimensionality. In classical multidimensional scaling, one symmetric dissimilarity matrix is processed using the Euclidean distance metric. Each entry of the dissimilarity matrix represents the mean of all corresponding normalized observer ratings.

Correlation Analysis (CA)

We compute the Pearson correlation coefficient to uncover and examine linear relationships between variables. The correlation coefficient is a value in the range of [−1, 1]. A correlation coefficient of one indicates a perfect positive linear relation. A perfect negative linear relation is indicated by a correlation coefficient of minus one. Zero indicates that there is no linear relationship between two variables. Inter-attribute and dimension-to-attribute correlation coefficients were computed.

Results

Results of Classical Multidimensional Scaling

Figure 5 shows the scree plot. A clear drop of stress values cannot be observed. Since the stress value does not decrease noticeably for dimensions higher than five, we can assume this as an upper limit of the dimensionality.

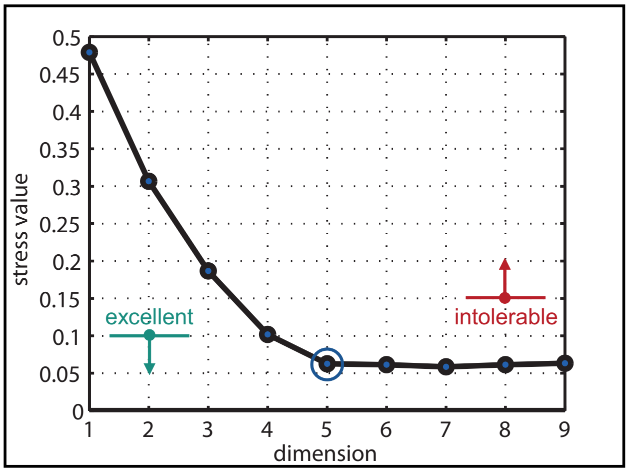

Figure 5: Scree plot with rule of thumb regarding how much stress is tolerable according to [24].

Figure 6 shows the configuration projected onto the first and second dimension. Samples with similar visual appearance properties form local groups.

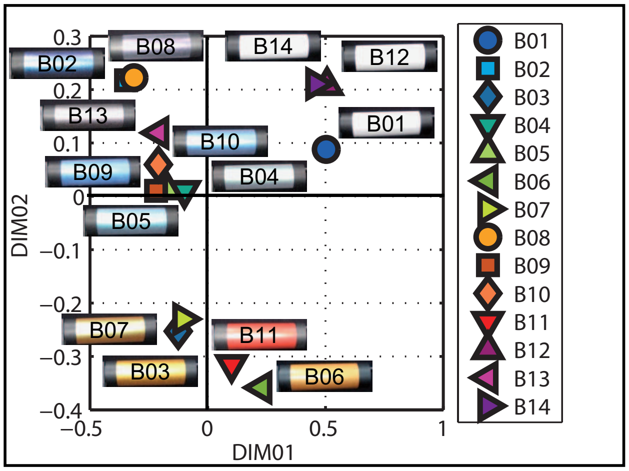

Figure 6: Configuration projected onto the first and second dimension.

White samples with high lightness are located within the first quadrant. In the second quadrant, green and blue samples are grouped together. With an increasing distance from the zero point, the texture is here more pronounced. Orange and red samples with high chroma can be found in the third and fourth quadrant. The intensity of gloss increases towards higher values in the first dimension.

Results of Correlation Analyses

Inter-Attribute Correlations

The gloss attributes (dLCG, DOIG) are highly correlated. The same applies to the considered texture attributes (TC, GC, SG). The correlation coefficients within these groups are in the range of [0.84, 0.97]. This indicates a high redundancy within each group and it is likely that only one attribute for gloss or texture is sufficient to describe our sample set. Please note that we cannot give any statement about the importance of other gloss or texture attributes not considered in our study.

One weakness of our study is revealed by this correlation analysis. The small number of 14 samples cannot be representative for all printed special effect colors. This can be seen from some superficial inter-attribute correlations. For instance, redness (ap) and chroma (C) show a high correlation of 0.79.

Dimension-to-Attribute Correlations

It is worth to mention that a perfect agreement between a dimension computed by CMDS and an attribute is unlikely. One reason is the intrinsic uncertainty of the visual data. Another reason is that an appearance attribute space has not to be Cartesian. One example is a color space consisting of lightness, chroma and hue attributes. We rather expect that the attributes correlate with multiple dimensions.

Figure 7 shows the correlation coefficients and p-values between the dimensions (DIM) of the configuration and the visual appearance attributes (VAA). Only values for the first six dimensions are shown. Correlations for higher dimensions are negligible.

DIM VAA	01	02	03	04	05	06
ap	-0.22 (0.45)	-0.69 (0.01)	-0.63 (0.02)	0.13 (0.66)	-0.04 (0.89)	-0.15 (0.61)
bp	-0.08 (0.79)	-0.84 (0.00)	0.07 (0.82)	-0.38 (0.18)	0.05 (0.86)	-0.32 (0.26)
an	-0.32 (0.27)	-0.10 (0.74)	0.60 (0.02)	0.21 (0.46)	-0.46 (0.10)	-0.44 (0.12)
bn	-0.62 (0.02)	0.26 (0.38)	0.24 (0.42)	0.52 (0.06)	0.39 (0.16)	-0.12 (0.68)
C	-0.50 (0.07)	-0.68 (0.01)	-0.25 (0.39)	0.22 (0.44)	0.31 (0.28)	-0.27 (0.35)
L	0.84 (0.00)	0.13 (0.65)	0.41 (0.14)	0.15 (0.61)	0.04 (0.89)	-0.20 (0.48)
dH	-0.56 (0.04)	0.17 (0.65)	-0.02 (0.94)	0.04 (0.88)	0.05 (0.85)	-0.67 (0.01)
dLCG	0.68 (0.01)	0.29 (0.32)	-0.52 (0.06)	-0.09 (0.76)	-0.02 (0.94)	-0.35 (0.21)
DOIG	0.88 (0.00)	0.17 (0.56)	-0.33 (0.25)	0.03 (0.91)	0.05 (0.87)	-0.23 (0.42)
TC	-0.60 (0.02)	0.43 (0.13)	-0.32 (0.27)	-0.45 (0.11)	0.04 (0.90)	-0.37 (0.20)
GC	-0.69 (0.01)	0.38 (0.18)	-0.24 (0.40)	-0.49 (0.07)	0.13 (0.65)	-0.21 (0.47)
SG	-0.24 (0.41)	0.61 (0.02)	-0.29 (0.31)	-0.55 (0.04)	0.18 (0.54)	-0.35 (0.22)

Figure 7: Correlation coefficients with p-values between attributes and dimensions.

Any color attribute correlates strongly with at least one of the first four dimensions obtained by CMDS. We assume that ”strong correlations” are indicated by a p-value smaller than 0.05. The related p-values are marked in figure 7, where blue refers to a negative and red to a positive correlation coefficient.

Conclusion

In this paper, the visual appearance of a selected set of printed special effect colors was investigated. A detailed description of the preparation, realization and evaluation of two category scaling experiments was given.

Classical multidimensional scaling applied on the results of the first experiment revealed that the sample set has at most five latent appearance dimensions. An arrangement of the samples in the space reflecting their perceived difference is visualized by projection onto the first two dimensions.

An inter-attribute correlation analysis applied on the results of the second experiment shows that contrast gloss (dLCG) and distinctness-of-image gloss (DOIG) are highly correlated. It is likely that only one gloss attribute is sufficient to describe the sample set. The same applies for the investigated texture attributes. These are texture contrast (TC), graininess or coarseness (GC) and sparkle or glint (SG).

Every color attribute correlates strongly with at least one of the first four dimensions obtained by multidimensional scaling. In summary, the set of appearance attributes for describing the samples includes the color attributes, one attribute for gloss and one for texture. The first dimension highly correlates with the lightness and the gloss attributes.

It should be noted that the results are just valid for the selected sample set that possesses unevenly distributed differences and attributes. Apart from these drawbacks, the evaluation using classical multidimensional scaling has limits. Since the dissimilarity matrix includes values averaged over all observer ratings, important information of individual data was not considered. Other types of multidimensional scaling, such as replicated or weighted multidimensional scaling, might perform better.

Hence, the presented results cannot be generalized to all printed special effect colors. This study can be rather seen as a pilot experiment for a larger experiment sketched in the outlook.

Outlook

We plan to use a much larger sample set of printed special effect colors covering a wide range of optical properties [7]. Accurate spectral and texture measurements of this sample set are available for multiple geometries. A custom build multi-angle test bench shall be used to present the samples to observers in a specified sequence of geometric configurations. These geometries shall correspond to the measurement geometries.

The experiments will be confined to absolute category scaling of visual appearance attributes. Principal component analysis and exploratory factor analysis will be used for the evaluation. An extension with new results is planned by a confirmatory factor analysis. These techniques shall be used to develop a psychophysical equation connecting measurable parameters with appearance attributes.

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Biography

Katharina Kehren graduated with her diploma, equivalent to master degree, in paper science and technology in September 2008. Since October 2008, she is a research assistant at the Institute of Printing Science and Technology at Technische Universität Darmstadt, Germany. Her research focuses on the bidirectional 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 since 2009. His research focuses on color science and spectral imaging. From 2006 to 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 since 2003. From 1994 to 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.