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# Journal of Print and Media Technology Research

## Scientific contribution



## Professional communication



## Position paper



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To meet the need for a high quality scientific publishing platform in its field, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries is publishing a quarterly peer-reviewed research journal.

The journal is fostering multidisciplinary research and scholarly discussion on scientific and technical issues in the field of graphic arts and media communication, thereby advancing scientific research, knowledge creation, and industry development. Its aim is to be the leading international scientific journal in the field, offering publishing opportunities and serving as a forum for knowledge exchange between all those interested in contributing to or learning from research in this field.

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# Contents

# A letter from the Editor

*Gorazd Golob*
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The latest issue of 2019 is slightly different from previous issues, but it is also groundbreaking in terms of open access publishing mode. Despite several articles in review and revision, only three articles were accepted for publication in the last days of December.

The first one is an original scientific paper on color changes resulting from the lamination of prints, distinguished by a comparison of the heuristic and artificial neural network approach for predicting them. The authors have verified the suitability of both methods and proved the advantages of the latter one.

The second article is classified as professional communication and is based on a study of the adequacy of standards for quality assurance of inkjet printing when printing on coated cartons. The discussion and conclusions raise a number of questions, both regarding the continuation and deepening of the research, as well as the need for extension of accepted standards that do not fully cover the wide range of substrates and inks used in practice.

The third article is the position paper, the cathegory that appears in the Journal for the first time. Based on years of extensive experience, the author highlights his views on the problems of knowledge of technology fundamentals as general expertise in industrial environments, research in graphic technology, and teaching, liiustrated by examples of image reproduction quality with a focus on prepress. We hope his views will be a trigger of argumentative discussion, as we are still witnessing the rapid development of technology in this field, as well as changes in industrial practice and in the response of print-buyers and end-users to new challenges.

The editor Markéta Držková (marketa.drzkova@jpmtr.org) in the Topicalities prepared an overwiev of recent publications from CIE and some revised and new standards published by CIE/ISO are introduced, together with an update of Fogra research projects.

From the bookshelf, you can choose from a number of books covering inkjet print heads design, vision, color, typography, graphic design, and communication, including book production history.

Three doctoral theses are also presented, pointing to current research areas that cover a much broader range of content than just conventional printed paper, cardboard or packaging materials.

At Helmut-Schmidt-University in Hamburg, Felix Heinrich defended his thesis in the field of printed electronics, focusing on the mechanical strength analysis of multifunctional composites enhanced with printed electronics, which can be used as sensors for health monitoring and study of methods for improving their properties.

Clara Pérez Fuster defended her thesis in the field of design and characterization of organic thin-film transistors for chemical sensing and analytes at the Polytechnic University of Valencia. The functionality and applicability of these sensors, using screen printing technique among other methods, have been successfully verified. Her work also included the development and verification of low-cost measuring equipment for specific needs in this field.

Uttam Kumar successfully finished his thesis at the School of Materials Science and Engineering in Sydney. The topic of his research was environmental sustainability, especially electronic waste in the form of end-of-life printers and toner residuals. He implemented efficient methods for the production of synthetic oil and activated carbon, which can be used as electrodes in supercapacitors and batteries.

As usual, Topicalities conclude with the review of events in the first months of the year 2020.

With the decision of the iarigai Board, the publisher of the Journal, this publication is now available as full open access, meaning that the online edition will no longer be password protected for six months and thus freely available at <https://iarigai.com/publications/journals/>. For anyone who wants to receive a print Journal, this option remains available, of course at an appropriate price. It is also important that there is no fee charged for authors who intend to publish the results of their research work. In the coming months, we anticipate some more positive changes to the Journals publishing and indexing, and you will be informed in a timely and appropriate manner.

We again invite you to participate with your contributions, as only the publication of your research achievements and thus the open possibility of using them as a reference in any other publication, in further research or in the industry leads to success. May 2020 be a successful year for all of us.

Ljubljana, December 2019

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# Prediction of lamination-induced colour shifts for UV offset printings by using a heuristic approach as well as machine learning techniques

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## Abstract

To investigate two approaches for the prediction of spectral colour changes, UV offset-printed test charts were laminated with polybutylene terephthalate films in three thicknesses and measured spectrophotometrically before and after lamination. This enabled the identification of the resulting colour shift for each patch. Mean colour deviations of 3.4 $\Delta E_{00}$ were determined while the strength of a colour shift depended on the initial colour patch lightness and the presence of paper white. To predict spectral reflections, a heuristic approach, based on the calculation of wavelength-dependent transmission of the lamination, is presented. A mean accuracy of 1.44 $\Delta E_{00}$ between predictions and actual measured coated reflections was achieved. The method still shows potential for improvements in the prediction of the paper white after lamination. In a second approach, an artificial neural network (ANN) was applied to evaluate the performance of machine learning on this topic as well. After training and validation, using the ANN for spectral prediction led to a higher precision with a mean $\Delta E_{00}$ of 0.6. In conclusion, both approaches obtain useful results whereby the ANN predictions are significantly more accurate. The investigation also demonstrates the potential of machine learning in the field of print and media technologies in general and in colour science in particular.

**Keywords:** colour difference, spectral prediction, lamination, neural network, colour measurement

## 1. Introduction and background

To meet the requirements of an increasingly specialised printing market, a large number of printed products are finished achieving various physical properties for optical as well as barrier characteristics. Main surface finishing techniques are lamination and varnishing, which one could summarise under the term ‘coating’. It is known that coatings can affect the colour appearance of print products due to a number of optical effects that occur on interfaces between coating layer(s), printed ink(s) and substrate. Important coating-related optical phenomena are scattering, reflection, absorption and refraction, which can significantly influence the visible or measurable reflection (Galić, Ljevak and Zjakić, 2015). Modified colour appearances can be caused by multiple reflections between print and coating and/or scattering depending on surface roughness. Also relevant in this regard is light trapping during colour measurements caused by coating-induced change of the distance between measurement device and colour patch. To visualise these colour shifts, Figure 1 shows scanned CMYK wedges whose lower half is coated manually with a glossy film. Differences in colour appearance can be seen between coated and uncoated colours. This effect is particularly apparent for medium area coverages.

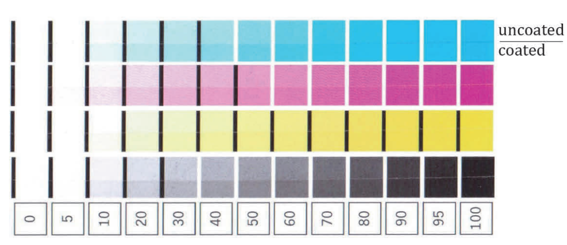


*Figure 1: Digital scan of UV offset CMYK wedges (printed in 80 l/cm AM screening), 13 patches per wedge in nominal tone values from 0 % to 100 %, the lower half of each wedge is coated with glossy film*

The colour change is attributed to a measurable coating-induced dot gain in many studies, i.e. by Gemeinhardt, Saba and Skoczowski (2009). It is also known that glossy coatings cause more saturated colour appearances while matte coatings result in more faded colours and decreased colour gamuts (Childers, et al., 2008). This can be attributed to the influence of surface reflected light on the measurements. In case of glossy surfaces, only a small quantity of these reflections reaches the sensor under 45°/0° geometry as opposed to matte coatings, where scattering leads to a larger amount of light reaching the sensor. Since surface reflections do not carry colour information of the print, the measured colours appear as mentioned (Gemeinhardt, Saba and Skoczowski, 2009).

Besides physical properties of coating materials, these optical phenomena are also affected by print specifications such as the substrate and screening used (Hoffstadt, 2004). In case of substrates containing optical brighteners, UV-absorbing coatings could attenuate the excitation of optical brighteners and, thus, their fluorescence emission. Applying UV-cured varnishes can also have a significant influence on colour appearance due to their specific polymerisation-induced yellowing properties. However, the two latter phenomena must be considered separately since they differ from the classic optical effects mentioned above. Any kind of reflection modification can naturally lead to visible and measurable colour deviations between the standard-conforming printing results and the finally coated products.

Keeping processes controllable and results predictable is of fundamental importance in print productions. While the press operator still has influence on the final colour appearance in case of inline coatings, this option is not available for post-press coating. This resulted in the development of a variety of approaches to examine or predict coating-induced colour shifts. Those approaches relevant for the object of this paper will be presented briefly in the following. As a very practical tool for print productions, *Fogra49* resp. *Fogra50* introduces special ICC profiles to generate coating proofs for matte and glossy OPP (oriented polypropylene) film laminations with regard to sheetfed offset (Kleeberg, et al., 2018). These proofs are intended to simulate only the final visual appearance to simplify colour communication in print productions. Galić, Ljevak and Zjakić (2015) focused on the characterisation of varnish-influenced colour shifts on spot colours using different substrates and found significant colour changes of $\Delta E_{00} > 2$ for all glossy UV-coated samples. Hoffstadt (2005) describes an approach using modified ICC profiles: for each coated patch, a colorimetric counterpart in the uncoated profile must be identified and both be connected with modified gradation curves to predict the colour appearances for coated colour patches on this basis. By doing so, Hoffstadt reaches predictions with a mean accuracy from 1.5–1.7 ± 0.6 $\Delta E^*_{94}$ compared to initial colour shifts ranged from 3.4–4.0 ± 1.2 mean $\Delta E^*_{94}$ for various glossy coatings. Hébert, Emmel and Hersch (2002) adapt existing reflectance models for the specific requirements of varnished metallic plates as a first step for further improved prediction methods.

In our work, two new spectral-based approaches to predict lamination-induced colour shifts are presented. The first is a heuristic one, the second applies machine learning techniques. In addition, both approaches will be compared in terms of their attainable accuracy and practical potential.

## 2. Methods

### 2.1 Sample preparation and measurement settings

To evaluate both approaches, adapted EFI Fiery profiling charts IT8 i1IO with 936 patches (Figure 2) were printed with a Heidelberg Speedmaster 52-4+L UV Anicolor in 80 l/cm AM screening. Printing was done with Heidelberg Anicolor UV LM Process Inks in KCMY sequence on a glossy CHROMOLUX 700 215 g/m² substrate, which has a faint fluorescence emission of 1.3 $\Delta b_{00}$. The fluorescence emission is determined as the difference $\Delta b^*$ between M2 and M1 measurements, using a Konica Minolta FD-7 spectrodensitometer with D50 illuminant and 2° CIE standard observer. Lamination of the sample was implemented with polybutylene terephthalate (PBT) lamination film from the manufacturer Richter & Menzel in thicknesses of 42 µm, 75 µm and 125 µm using an offline laboratory laminating device in operating temperature of 70 °C. Three samples were measured spectrophotometrically before and after lamination using a Konica Minolta FD-9 Auto Scan spectrophotometer in 45°/0° geometry, M1, D50 illuminant, 2° CIE standard observer, 10 $\Delta\lambda$ (wavelength pitch), 3 mm measuring spot configuration. Each patch was measured on 2 spots, and 4 times in total. For evaluation and comparison, the reflection spectra were converted to the CIELAB colour space and colour deviations were expressed in CIEDE2000 ($\Delta E_{00}$) (International Organization for Standardization / International Commision on Illumination, 2014).

### 2.2 Heuristic approach

The heuristic approach calculates uncoated reflection spectra with the transmission of a lamination, which is also adjusted for corrected area coverages of each colour separation. It does not follow a physical model but takes into account some observations one could make based on Figure 1. One can see that the colour shift

*Figure 2: EFI profiling chart IT8 i1IO (originates from software EFI Fiery XF 6), 936 randomised patches in 39 columns and 24 rows, patch size 7 mm × 9 mm, printed in 32 cm × 23 cm*

depends on the presence of unprinted paper white. This is presumably caused by coloured back reflections which are mostly noticeable on paper white. For further improvement, the lamination's specific surface reflection is added. In the following, the approach with its related calculations are presented, beginning with the necessary symbols.

| | |
|---|---|
| $R(\lambda)$ | spectral reflection over 380–730 nm |
| $\Delta R(\lambda)_{surface}$ | difference in spectral surface reflection without colour information, measured at a dark colour patch |
| $T(\lambda)$ | spectral transmission over 380–730 nm |
| $AC_{nom}$ | nominal area coverage, acquired from printing data for each colour separation of each patch |
| $AC_{corr}$ | calculated corrected area coverages for each colour separation of each patch |
| $n$ | exponent for adjustment of $T(\lambda)$ |
| $f, k$ | parameters for fitting |

Spectral transmission $T(\lambda)$, the quotient of printed colours and the blank substrate reflection gives the transparency of the ink layer of each patch by Equation [1]:

$$T(\lambda) = \frac{R(\lambda)_{\text{patch unlaminated}}}{R(\lambda)_{\text{substrate unlaminated}}} \quad [1]$$

The sinus in Equations [2] to [5] represents the sinusoidal course of the dot gain as it is lowest at areas of small and high area coverages and highest in the range of medium area coverages. Therefore, Equation [6] considers the amount of paper white for each patch.

Corrected area coverage $AC_{corr}$ must be calculated separately for each colour separation of each patch using Equations [2] to [5].

$$AC_{corr,C} = [1 - T(\lambda)] \cdot [AC_{nom,C} + f \cdot \sin(\pi \cdot AC_{nom,C})] \quad [2]$$

$$AC_{corr,M} = [1 - T(\lambda)] \cdot [AC_{nom,M} + f \cdot \sin(\pi \cdot AC_{nom,M})] \quad [3]$$

$$AC_{corr,Y} = [1 - T(\lambda)] \cdot [AC_{nom,Y} + f \cdot \sin(\pi \cdot AC_{nom,Y})] \quad [4]$$

$$AC_{corr,K} = [1 - T(\lambda)] \cdot [AC_{nom,K} + f \cdot \sin(\pi \cdot AC_{nom,K})] \quad [5]$$

The exponent $n$, calculated by Equation [6], is for adjustment of $T(\lambda)$ and refers to the calculation of corrected area coverages $AC_{corr}$.

$$n = k[(1 - AC_{corr,C}) \cdot (1 - AC_{corr,M}) \cdot (1 - AC_{corr,Y}) \cdot (1 - AC_{corr,K})] \quad [6]$$

The $\Delta R(\lambda)_{\text{surface}}$ represents the differences in surface reflection between coated and uncoated patches and is determined exemplarily for a dark colour patch by Equation [7]. As the surface reflected light did not penetrate into the laminated sample but reflected directly without changes in spectral distribution from the surface, it is assumed as being free of colour information.

$$\Delta R(\lambda)_{\text{surface}} = \frac{R(\lambda)_{\text{patch unlaminated}}}{R(\lambda)_{\text{patch laminated}}} \quad [7]$$

Following the heuristic approach, the spectral reflection after lamination is calculated by Equation [8]:

$$R(\lambda)_{\text{predicted}} = R(\lambda)_{\text{unlaminated}} \cdot T(\lambda)^n + \Delta R(\lambda)_{\text{surface}} \quad [8]$$

The calculation method is set up in accordance with the equations with freely chosen start values for $k$ and $f$ and the resulting colour differences $\Delta E_{00}$ between $R(\lambda)_{\text{predicted}}$ and $R(\lambda)_{\text{laminated}}$ are calculated. Now, factors $k$ and $f$ must be fitted by minimising the mean $\Delta E_{00}$. In this work, fitting is done by using the MS Excel Solver with the Generalized Reduced Gradient – GRG nonlinear solving method. However, it would be just as feasible to use any other numerical-analysis software one is familiar with. Once calculated for the specific print and lamination parameters, $k$ and $f$ can be used to make further spectral predictions. To enhance evaluation, only 80 % of all colour patches (749 patches per chart) are considered for fitting while the remaining 187 ‘unknown’ patches of each chart are used as start and target data for predictions generated by both approaches to enable comparability. As the chart is already randomised, we simply take the desired number of patches starting at patch 1 (position 1A) line by line for each approach.

### 2.3 Artificial neural network approach

An artificial neural network (ANN) was set up to realise and examine colour shift prediction applying machine learning techniques. Generally, ANNs can be understood as a technical implementation of machine learning within technologies of artificial intelligence. For the purpose of this paper, ANNs are seen as an existing tool for solving a specific task in research. As it is more important to describe the basic functional principle and the actual setup of the network used than to explain the technical and mathematical principles of ANNs in detail, which are widely described in relevant literature (Hagan, et al., 2014; Chollet, 2018), only a brief explanation of the ANN fundamentals is given here.

Figure 3 shows the schematic architecture of a fully connected multilayer feedforward network which consists of three layers (input layer, hidden layer, output layer) with $n$ number of nodes, the so-called ‘neurons’. Every neuron represents a single computing unit and, in case of fully connected networks, is connected to all previous and subsequent nodes by weighted connections represented by matrices $v$ and $w$. The number of input nodes must be chosen in accordance with the character of input data, the output nodes must comply with the output data. In this particular case, both the input and output have 36 nodes because the data sets consist of spectral data with 36 digits each (380–730 nm spectral range in 10 $\Delta\lambda$ wavelength pitch). The hidden layer setting must be chosen and has some

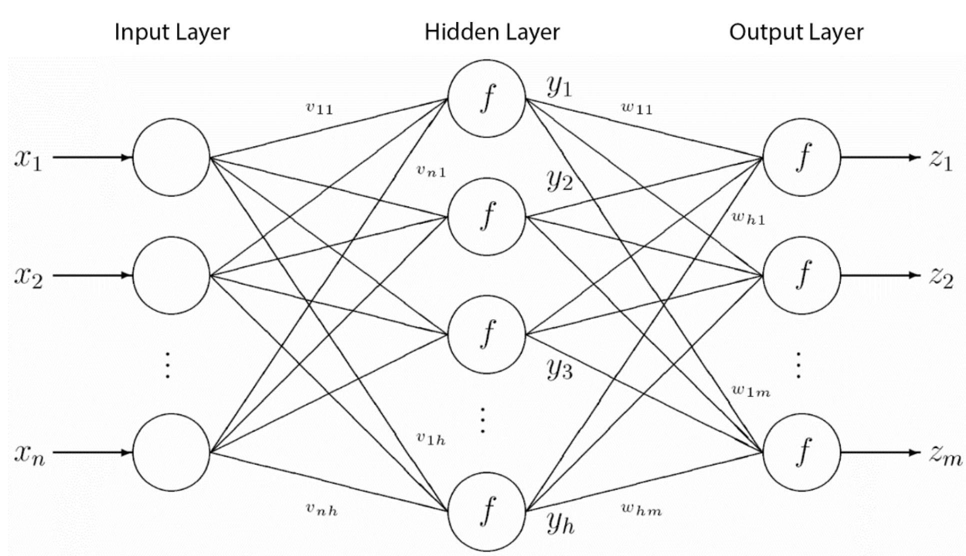


*Figure 3: Schematic representation of a triple-layered artificial neural network with input x, hidden y and output layer z, weighted connections v and w and activation function f (Selle, 2018)*

influence on the learning and results quality. To apply an ANN to a specific task, it is necessary to first train it using known examples of the problem to be solved. The process used for the purposes of this paper was 'supervised learning': by feeding the ANN with initial input data and related target data, it can learn that a specific input leads to a specific output.

Consequently, the training process requires sets of start and target data, which need to be split into sets of training (in this case: 70 %) and validation data (10 %). Furthermore, it is important to withhold test data (20 %) to ensure generalisation after training. Generalisation is the capability of a trained ANN to perform on unknown data from the same type as well as it does on the training data. On the other hand, memorisation or overfitting means the exact opposite: the ANN only remembers specific training targets but fails on unknown samples. (Hagan, et al., 2014)

As the test charts are already randomised, all colours in different combination of area coverages were considered. The learning process involves the feed-forward data processing and the backpropagation mechanism for an automatic weight adjustment. During feed-forward processing, the input data is processed through the network. For each neuron, its single input is calculated from all incoming values considering the weights. By a so-called 'activation' the input leads to a specific output which is processed to the subsequent nodes up to final outputs $z_1$ to $z_m$. (Chollet, 2018)

The resulting output error at each node is calculated by comparison with the actual target data. Now, using the method of backpropagation, the errors are propagated backwards into the ANN and the weights are adjusted in an automated process to minimise the output loss for each node, starting with the output layer. The direction of weight modification is identified by using the gradient descent approach. Feed-forwarding the inputs and backpropagation of resulting errors with weight adjustments jointly form a so-called 'epoch'.

The entire training routine usually consists of numerous epochs to successively minimise the output losses. The learning rate defines the intensity of the weight adjustments whereas the batch size specifies the number of processed single data between two weight adjustments. To evaluate the ANN's performance after training, the test data set can be used as input data for which the network should predict the corresponding target.

The Python programming language is used to set up an ANN based on the Keras framework (version 2.2.4). Keras is a high-level API (application programming interface) for Googles TensorFlow backend (version 1.12.0) and, as well as Python and all other software components used for implementing the ANN, available as open source software. For detailed information about possible functions and configurations, the authors refer to the relevant literature. (Hagan, et al., 2014; Chollet, 2018)

Besides a suitable data base and its proper preprocessing, the obtained performance of an ANN depends on actual realisation and task-specific adaption of all parameters (Chollet, 2018). The detailed setup and training configuration of the ANN used are summarised in Table 1 and Table 2, respectively. Apart from the parameters listed in the tables, the default settings for the given Keras version are used.

*Table 1: Setup of the Keras-based ANN*

| Parameter | Input layer | Hidden layer | Output layer |
|---|---|---|---|
| Nodes | 36 | 18 | 36 |
| Activation func. | Hard sigmoid | Softmax | *default* |

*Table 2: The ANN training configuration*

| Parameter | Setup |
|---|---|
| Optimiser | Adam |
| Loss function | Mean square error |
| Learning rate | 0.01 |
| Epochs | 2 000 |
| Batch-size | 2 |

## 3. Results

### 3.1 Short presentation of lamination-induced colour shifts

First, the obtained lamination-induced colour shifts are to be outlined. In the course of this paper, 'colour shift' means any modification in the spectral reflection. The findings presented in the following are always valid for all lamination thicknesses unless the contrary is noted. Looking at the spectral characteristics of coated and uncoated colours, significant lamination-induced colour shifts are revealed. Figure 4 exemplarily shows four spectral reflections of cyan in nominal area coverages of 20, 60, 80, and 100 % (C100 = cyan in 100 % nominal area coverage) and their corresponding coated reflection spectra. The shown spectra were selected in order to show differences in solid and halftone printed colours. While C100 shows only slight deviations (0.9 $\Delta E_{00}$), the other patches show increasing colour shifts with increasing presence of blank paper white (0.9–4.0 $\Delta E_{00}$).

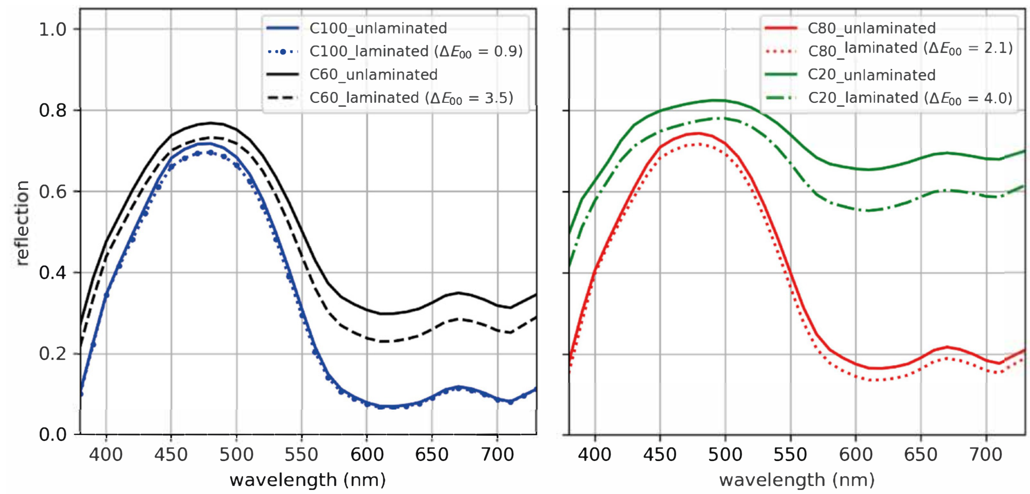


*Figure 4: Spectral colour shift due to lamination with a 42 μm PBT film, exemplarily shown for reflection spectra of cyan in nominal area coverages of 100, 80, 60 and 20 %, in two graphs for better clarity*

Since a rising presence of paper white is usually accompanied by an increasing brightness of a colour patch, a link between colour brightness and resulting colour shift can be assumed.

To verify this, Figure 5 shows the $L^*$ values of an entire colour chart and resulting $\Delta E_{00}$ values after 42 µm lamination. It can be clearly seen that in areas of low lightness there is the smallest colour shift while it first increases at lighter colours and tends to have its spectral maximum in areas of medium lightness. Figure 6 shows changes in lightness between unlaminated and laminated colour patches, expressed in $\Delta L_{00}$. To obtain a clearly arranged diagram, both the $L^*$ and $\Delta L_{00}$ values were averaged in lightness intervals of 10 (arithmetic mean of all $L^*$ values between 100 and 90, etc.) and spline interpolated with curves using Python's SciPy library with *interp1d* function. The curves correspond quite well with the scatter plot distribution in Figure 5.

This indicates not only that the resulting colour shift depends on colour lightness, but also that it is mainly caused by changes in lightness due to lamination. Furthermore, significant differences in lightness modification between the thickest and the two thinner films can be seen for areas of medium and high reflections.

For CIE chroma and hue, no connection can be found between these colorimetric characteristics and colour shifts. It is also noted that the laminations do not affect the substrates fluorescence emission which still has a value of 1.3 $\Delta b_{00}$. In conclusion, lamination does result in a significant colour shift, the size of which is principally related to colour patch lightness, in other words, the presence of paper white. In the following section, it will be discussed whether the approaches mentioned above can make useful spectral predictions.

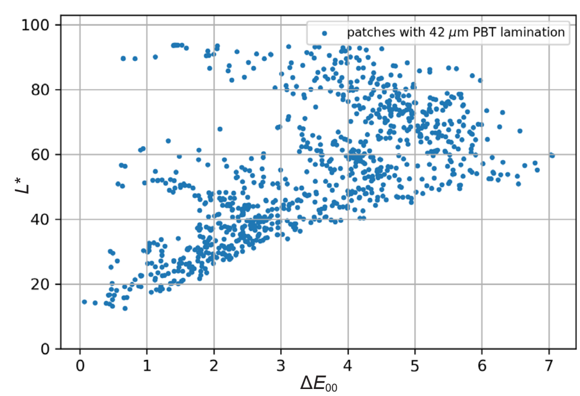


*Figure 5: Relationship between lightness L* for 936 unlaminated colour patches and corresponding lamination-induced colour shifts in $\Delta E_{00}$ due to lamination with 42 μm PBT film*

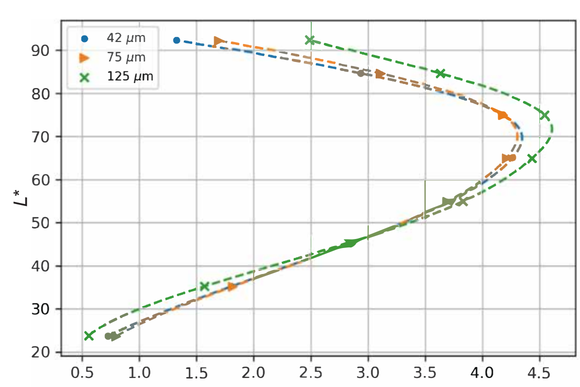


*Figure 6: Relationship between lightness L* (arithmetic mean values in intervals of 10) for 936 unlaminated colour patches and corresponding mean lamination-induced shifts in lightness $\Delta L_{00}$ due to lamination with 42, 75 and 125 μm PBT films; curves are spline interpolated*

### 3.2 Spectral predictions by both approaches

As described in the Section 2, factors *f* and *k* must be fitted for each specific lamination to adjust the heuristic approach. For fitting purposes, only 80 % of the data set (749 patches per chart) is considered – thus, predictions can be made for 'new' data. Table 3 shows the relevant fitting results for each lamination.

*Table 3: Optimised correction factors f and k for each lamination*

| Lamination thickness [µm] | *f* | *k* |
|---|---|---|
| 42 | 6.60 | 0.46 |
| 75 | 5.56 | 0.41 |
| 125 | 12.02 | 0.44 |

Next, selected spectral reflections with related predictions will be shown to give an impression about the performance of both approaches. Figure 7 shows four reflection spectra of coated patches and the predicted reflections using the heuristic approach. Figure 8 provides the same scenario for the ANN. The nominal area coverages for each spectrum are indicated as well as the achieved prediction accuracy in $\Delta E_{00}$ while the specific numbering c1, c2, c3 is of no significance. With regard to Figure 7, the heuristic approach gives good results for colour spectra. Weaknesses become visible for the paper white prediction which does not differ from the measured uncoated spectrum and the calculation method seems to have no impact. In the interest of completeness, it is noted that no functional interrelation between the colorimetric parameter lightness $L^*$, hue $h$, chroma $C^*$ and the achieved prediction accuracies could be found during analysis.

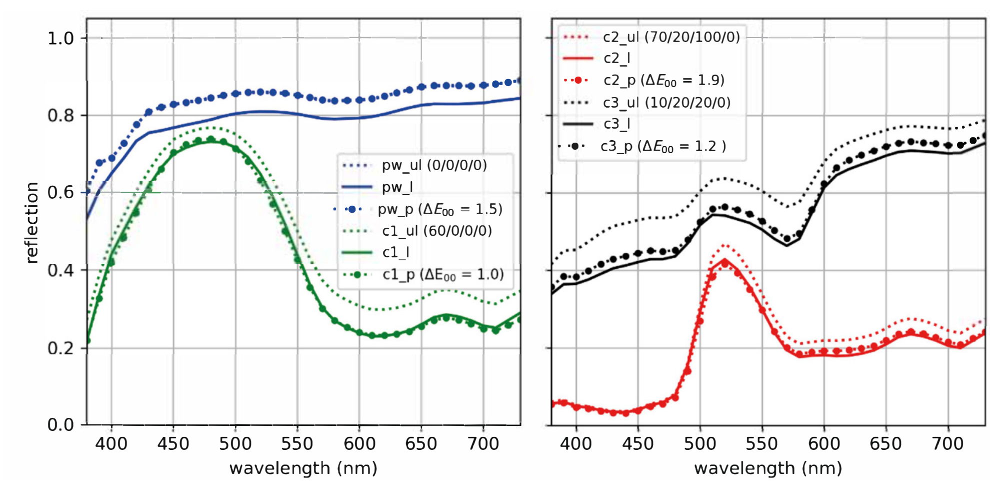


*Figure 7: Laminated (l) and unlaminated (ul) reflection spectra for four patches (nominal area coverages expressed with C/M/Y/K in percent) with related spectral predictions (p) and their accuracies in $\Delta E_{00}$ by the heuristic approach for 42 µm PBT lamination*

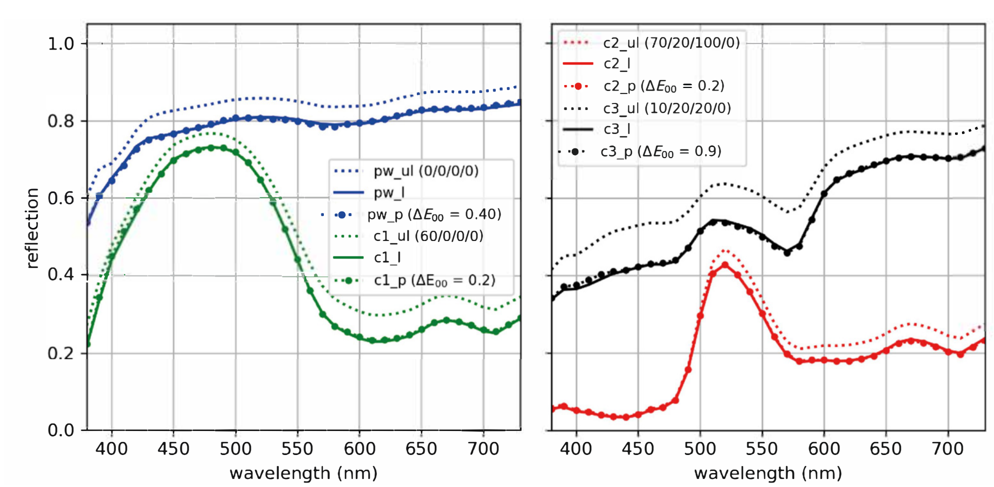


*Figure 8: Laminated (l) and unlaminated (ul) reflection spectra for four patches (nominal area coverages expressed with C/M/Y/K in percent) with related spectral predictions (p) and their accuracies in $\Delta E_{00}$ by the neural network approach for 42 µm PBT lamination*

*Table 4: Final results for both approaches: initial colour shifts and prediction accuracies in arithmetic mean $\bar{x}$ $\Delta E_{00}$ and 90th percentile for the 187 'unknown' patches of each lamination*

| **Lamination** (thickness) µm | **Initial** (uncoated to coated) $\bar{x}$ $\Delta E_{00}$ | $p = 0.9$ | **Heuristic** (coated to predicted) $\bar{x}$ $\Delta E_{00}$ | $p = 0.9$ | **ANN** (coated to predicted) $\bar{x}$ $\Delta E_{00}$ | $p = 0.9$ |
|---|---|---|---|---|---|---|
| 42 | 3.4 | 5.3 | 1.3 | 2.2 | 0.7 | 1.2 |
| 75 | 3.4 | 5.2 | 1.3 | 2.1 | 0.5 | 0.8 |
| 125 | 3.6 | 5.3 | 1.7 | 2.6 | 0.7 | 1.3 |

Predictions made by the ANN are quite close to the actual measured coated patches and show colour deviations of < 1 $\Delta E_{00}$. Averaged over all 561 predicted spectra, a mean prediction accuracy of 1.4 $\Delta E_{00}$ for the heuristic approach and 0.6 $\Delta E_{00}$ for the ANNs prediction can be attained.

Table 4 presents relevant colorimetric data including initial colour shifts and prediction results for both methods. In addition to the arithmetic mean values, the 90th percentiles $p$ are given to allow a further evaluation of the results.

## 4. Discussion

Significant colour shifts can be seen, which tend to have their maximum at colours of medium brightness. Among other optical effects, the colour shifts are presumably caused by interreflections between ink or paper white surface and lamination. In darker colours, the greater initial absorption and the absence of paper white leads to a smaller light potential for multiple reflections compared to middle-toned colours. This effect slightly reverses at colours of high brightness since they have only low absorptions and therefore multiple reflections have reduced impacts. Good prediction results with mean colour deviations of < 2 $\Delta E_{00}$ are demonstrated for both approaches. Looking at the heuristic approach (Figure 7), a poor prediction accuracy for paper white reflection spectra is revealed. The reason for this lies in the calculation method of this approach as the transmission $T(\lambda)$ in Equation [8] for blank substrates is 1 due to the absence of ink. Therefore, the correcting exponent $n$ is ineffective and a prediction is not possible.

With mean accuracies of 0.6 $\Delta E_{00}$, the ANN shows spectral predictions with only slight deviations to the actual measured spectra, which are even hardly perceivable for human observer. Here it should be mentioned that phenomena of overfitting can be ruled out since predictions were made for test data sets which are completely unknown to the ANN until then. The prediction of a numerical series, as it was done in the present case, basically means to solve a regression problem which is a common application for this kind of ANNs. Nevertheless, the accuracy achieved seems to be impressive in their own right. In the past, many physically reasonable models and associated colorimetric calculations were developed. Using an ANN is a fundamentally different way to calculate or converte colours as it does not rely on the current technical or physical backgrounds of phenomena but on training based on known examples. One does not need to comprehend a process with all its parameters entirely and yet can achieve useful results, as is demonstrated in this paper with nearly matching spectral predictions. Based on initial lamination-induced colour shifts and obtained prediction accuracies for different approaches found in literature (cf. the introduction) and in this paper, it seems conceivable that a suitable ANN provides better results than existing physically grounded mathematical models. This hypothesis requires further investigation to prove or disprove it. It must be clear, however, that good results can only be expected for the process parameters represented by the training data set. In this investigation, only one type of lamination was examined. Other lamination materials may have different refraction indices and transmission quantities and, therefore, other influences on colour appearance. Consequently, this ANN should be retrained with suitable training data to make predictions for other lamination and print parameters.

Future work in this field could implement laminations with different parameters (e.g. refraction index, thickness) as additional input channels in a multimodal ANN to find out if a generalised network for colour shift prediction is possible. As most computing work is needed for an ANN's training, the actual utilisation of an already trained ANN has comparably low needs for computing power and provides instantaneous outcomes. The ANNs offer great potential for process improvement in a broad field of applications, including in print and media technologies – it should be easy for an expert reader to imagine other application cases. The availability and constant further development of machine learning environments and technologies also contribute to a practical implementation in e.g. colour science, colour management or quality control systems for dealing with existing and future problems.

## 5. Conclusions

Notable lamination-induced colour shifts of 3.46 mean $\Delta E_{00}$ were identified and spectrally predicted using two different approaches. The heuristic approach represented the lamination-induced effects on reflection spectra for colours quite well and made predictions with an accuracy of 1.43 mean $\Delta E_{00}$, but always requires the nominal area coverages. It can be concluded, however, that this approach still has potential for improvements to enable not only prediction of colour, but also of paper white after lamination. The ANN performed equally well on average for all kind of spectra and provided an accuracy of 0.63 mean $\Delta E_{00}$ between predictions and actual measured spectra. The heuristic approach requires the fitting of only two variables whereas the ANN's training with fitting of 2592 variables (36 × 36 × 2) requires significantly more computing effort. However, once implemented and set up, both offer immediate predictions. For a further validation of both approaches and possible scenarios for implementation, future investigations should take different lamination and print configurations into account – e.g. matte laminations, varnishes, other substrates and screenings as well. We have indications that the heuristic approach is applicable even with only a few tens of spectra for fitting, but this must be examined more closely in a future work. Another challenge is to establish and to train an ANN that is able to predict spectra for various lamination and coating scenarios with only minor adjustments. In general, ANNs offer great potential for process improvement in a broad field of applications.

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# Professional communication

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# Comparing quality attributes of coated cardboards for inkjet printing by using different methods

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### Abstract

The reproduction of fine details is an important aspect in print quality and influences both the legibility and thus readability of texts and the decodability of 1D and 2D codes. Technical standards related to digital printing, such as ISO/IEC 24790:2017, predominantly evaluate printing systems. In this study, the focus is on media as the object of analysis. The evaluation of character and line image quality attributes was used to analyze the reproduction on different media comprising seven primed and non-primed cardboards printed with dye and pigment based inks. The tests were compared with the resolution of Siemens stars, line reflection and dot gain values. This study demonstrates the applicability of ISO/IEC 24790:2017 for inkjet media evaluation and shows a proper correlation between different methods of print evaluation.

**Keywords:** print media evaluation, ISO/IEC 24790:2017, ISO/TS 15311-2:2018, dot gain, Siemens star

## 1. Introduction

Inkjet printing requires three substantial components to be compatible with each other: ink, printer (or, more precisely, printhead) and media, i.e., printing substrates. These three components are usually predetermined from the printer manufacturer. The development of a printing system is based on the characteristics of a particular media, such as plastic, ceramic or plain paper or based on an application such as packaging or books (Pond, 2000, p. 65).

As a basic principle, an ink is developed for a particular printhead. The ink parameters such as viscosity, amount and size of solid particles and surface energy influence the drop formation and the size of the ink droplets. The ink will be properly ejected when these ink parameters fit the ejection parameters of the printhead (voltage, frequency and pulse for particular drop size and shape). The droplets are placed on the media correctly when the relative movement and the speed of the printhead and media are compatible.

The media should have morphological (porosity, roughness, leveling) and physicochemical characteristics (pH, surface energy) compatible with the ink. Incompatibility between media and ink causes defects in the image reproduction and results in problems like irregular spreading, sorption (too high or too low), wicking, inefficient wetting, adhesion and/or drying. Coated cardboards printed with water based inkjet inks can suffer all of these drawbacks.

In order to enable inkjet printing of coated cardboards with water based inkjet inks (pigment and dye based) using industrial inkjet printing systems, a printer concept with priming and drying units was developed and presented in a previous paper (Rosalen and Backhaus, 2018). The cardboards were pretreated with a polyvinyl alcohol (PVOH) bonding agent/primer (PVOH solution) that increases the wetting and the adhesion by means of high amount of OH-groups available for ink bonding. After printing, the boards are post treated with infrared (IR) radiation that accelerates water evaporation. After the radiation the ink is held close to the paper surface, but protected by the primer, avoiding ink smearing. Primers and IR radiation can influence the ink flow behavior and other drawbacks of print quality can occur. Too strong ink spreading or sorption can reduce the decodability of 1D or 2D codes and the legibility and thus readability of a text due to, for example, poor edge contrast, imperfect edge determination, inadequate modulation or erroneous unused error correction. In composite images these factors can cause incorrect color reproduction. When an object can be visually well defined, it is – said in common words – sharp. For experts it means, in case of very small dot spacing, that the image has a high resolution.

According to the standard ISO/TS 15311-1:2016 (International Organization for Standardization, 2016) sharpness and resolution are different qualities. Sharpness is capability of a printer to produce distinct edges. Resolution is the ability to reproduce fine details. Sharpness and resolution are thereby interdependent and it can be assumed that "the more details a printing system is able to reproduce the higher the print quality of the resulting image will be" (Cisarova, et al., 2013). During the last decades, specific technical standards for digital printing provided procedures for measurement and reference values for print quality evaluation. Particularly for 8 bit or 1 bit images there are three standards related with the aim of this present study.

The third part of DIN 53131 (Deutsche Institut für Normung, 2010) suggests procedures to measure optical resolution, optical density and image point disturbances as ink spreading and fraying. This standard was developed to evaluate inkjet media. To use it, specially designed software for the evaluation of image point disturbances and optical resolution is necessary, but according to the DIN institute this software is no longer available.

The standards ISO/TS 15311-1:2016 and ISO/TS 15311-2:2018 (International Organization for Standardization, 2016; 2018), also called digital printing production standards, reference ISO/IEC 24790:2017 (International Organization for Standardization / International Electrotechnical Commission, 2017) to measure detail rendition capabilities that can be also called reproduction of fine details. This standard was developed to evaluate monochrome office equipment. In comparison with a long list of published articles (Briggs, et al., 1999) about the previous version, ISO/IEC 13660:2001, which was later revised by ISO/IEC 24790:2017, to the best of our knowledge, no studies with application and experiences were published about the current version/standard until now.

With aspects similar to ISO/IEC 24790:2017, ISO/IEC TS 29112:2012 (International Organization for Standardization / International Electrotechnical Commission, 2012) is used to evaluate monochrome office printers and also includes measurement of addressability that is not relevant for this study.

The objectives of this study were to understand:
- Whether the standard ISO/IEC 24790:2017 can be used to classify media for inkjet printing (for inkjet printed coated cardboards there are no guidelines available to evaluate the print quality).
- How the measurements obtained by means of ISO/IEC 24790:2017 correlate with other measurements of print reproduction quality.
- How the developed primer/bonding agent (Rosalen and Backhaus, 2018) influences the reproduction of fine details.

As in the previous study dealing with coated cardboards printed with water based inkjet inks cyan, magenta and yellow had no drawbacks, this study is focused on black inks, both pigment and dye based.

## 2. Materials and equipment

Tested materials, equipment for production and spectrophotometric measurement of the samples as well as further information about laboratory equipment and software used for testing are listed in Table 1 to Table 6.

*Table 1: Materials used in the tests*

| Materials | Identification | Data |
|---|---|---|
| Cardboard | "B-01" to "B-07" | Commercial cardboard (see Table 2)<br>folding box board (FBB) and solid bleached board (SBB) |
| Ink | "K" | Dye based black ink (Canon dye ink: CLI-551) |
| | "PBK" | Pigment based black ink (Canon pigment ink: PGI-550) |
| Primer | "Primer" | PVOH 20-98 (a mass fraction of 4 %) and high-performance liquid chromatography (HPLC) water (a mass fraction of 96 %) prepared by means of magnetic stirrer with constant temperature until the mixtures became homogenous |

*Table 2: Properties of cardboards*

| Cardboard [ID] | Grammage [g/cm²] | Thickness [µm] | Moisture [%] | Roughness (Top) [µm] | Layers [-] | Type [-] |
|---|---|---|---|---|---|---|
| B-01 | 300 ± 5 % | 365 ± 5 % | 5.5 ± 1 | 1.8 ± 6 % | 2 | SBB |
| B-02 | 300 ± 4 % | 474 ± 5 % | 8.2 ± 1 | < 1.3 | 2 | FBB |
| B-03 | 295 ± 2 % | 505 ± 3 % | 8.1 ± 1 | 1.0 (max. 1.3) | 1 | FBB |
| B-04 | 300 ± 2 % | 345 ± 3 % | N/A | 1.0 | 1 | SBB |
| B-05 | 300 ± 4 % | 365 ± 4 % | 6.5 ± 1 | 0.9 (max. 1.4) | 2 | SBB |
| B-06 | 300 ± 4 % | 395 ± 4 % | 6.0 ± 1 | 0.9 (≤ 1.4) | 3 | SBB |
| B-07 | 295 + 3 % / – 5 % | 505 ± 5 % | 8.2 ± 1 | 1.0 (max. 1.7) | 3 | FBB |

*Table 3: Surface energy (total, disperse and polar components) and contact angle (CA) with different liquids for unprimed and primed substrates*

| Cardboard [ID] | B-01 | B-02 | B-03 | B-04 | B-05 | B-06 | B-07 |
|---|---|---|---|---|---|---|---|
| **Unprimed substrates** | | | | | | | |
| Total [mJ/m²] | 42.67 | 39.60 | 35.33 | 27.97 | 32.99 | 38.84 | 35.65 |
| Disperse [mJ/m²] | 27.89 | 32.50 | 28.52 | 23.43 | 24.81 | 23.61 | 29.93 |
| Polar [mJ/m²] | 14.78 | 7.10 | 6.81 | 4.54 | 8.17 | 15.22 | 5.71 |
| CA – Diiodomethan [°] | 50.56 | 50.04 | 51.64 | 55.38 | 52.72 | 57.16 | 49.76 |
| CA – Water [°] | 62.66 | 74.90 | 77.42 | 87.24 | 77.36 | 65.32 | 79.08 |
| CA – Ethylene glycol [°] | 44.46 | 56.04 | 56.34 | 72.34 | 63.58 | 52.98 | 56.04 |
| **Primed substrates with PVOH-primer** | | | | | | | |
| Total [mJ/m²] | 56.52 | 42.43 | 49.67 | 28.04 | 41.47 | 54.92 | 44.30 |
| Disperse [mJ/m²] | 31.90 | 23.56 | 29.80 | 22.94 | 30.98 | 27.68 | 30.62 |
| Polar [mJ/m²] | 24.62 | 18.87 | 20.18 | 5.10 | 10.48 | 27.24 | 13.68 |
| CA – Diiodomethan [°] | 40.56 | 51.98 | 54.90 | 51.68 | 58.70 | 50.76 | 54.86 |
| CA – Water [°] | 42.92 | 63.68 | 53.56 | 83.40 | 71.24 | 42.62 | 63.68 |
| CA – Ethylene glycol [°] | 15.96 | 23.88 | 15.02 | 71.52 | 20.02 | 17.08 | 26.52 |

Ink surface tension [mN/m] for K = 37.18 and for PBK = 38.29

*Table 4: Spectrophotometric measurements*

| Equipment Manufacturer / Model | Measurements [number of measurements / samples]* | Measurement data |
|---|---|---|
| Spectrophotometer Techkon / SpectroDens | Dot gain [16 / ink coverage, ink, cardboard, treatment] | Geometry: 0°/45°, Illuminant: D50, Observer: 2°, Measurement illumination condition: M1 |
| | Maximal reflectance of cardboard surfaces [25 / cardboard, treatment] Minimal reflectance of printed surfaces [25 / cardboard, ink, treatment] | Geometry: 0°/45°, Illuminant: D50, Observer: 2°, Measurement illumination condition: M1, Pol-Filter: No, White Calibration: Absolute, Wavelength: 550 nm (to avoid optical brightening and fluorescent whitening agents influence) |

*Ink coverage: 10 % to 100 %, ink: K and PBK, cardboard: B-01 to B-07, treatment: primed and unprimed

Table 5: Production equipment

| Equipment Manufacturer / Model | Data |
|---|---|
| Printer Canon / PIXMA iX6850 | Thermal printhead technology – 1200 dpi<br>Quality printing mode: Standard<br>Media quality: Standard |
| Mayer rod | Wire wound rod – primer transferred weight 1.2 ± 0.1 $g/m^2$ |
| Infrared dryer Elstein / HTS | Panel radiators wavelength 2–10 µm, panel temperature 500 ± 5 °C, distance panel to cardboards 38 ± 1 mm |

Table 6: Laboratory equipment and software used for testing

| Equipment and test charts | Data |
|---|---|
| Scan conformance test chart ISO/IEC 24790:2017 | Developed by the Japanese committee for ISO/IEC with patches for determination of: banding, graininess, mottle, mark, void, haze, line width and halftone tints |
| Scanner Epson / Perfection 4990 Photo | Flatbed scanner – Optical resolution: 4 800 × 9 600 dpi, Color depth: 16 bits/pixel, Optical density: 4.0 |
| Print test charts | Self-developed in Photoshop and Illustrator CS3<br>Output file: PDF without embedded profile |
| Image processing software | ImageJ (for image cropping) |
| Evaluation program for target: Siemens star | Programmed in Matlab R2017b |
| Evaluation software for target: fine details reproduction | Package Tool TS24790_Tool_vers.1.5.1., default configuration |
| Surface energy / contact angle | Data Physics OCA 30,<br>Fluids: water, diiodomethane and ethylene glycol (15 measurements each fluid), calculations by means of Owens, Wendt, Kaelble and Rabel method with three fluids (Deutsche Institut für Normung, 2011) |
| Bubble pressure tensiometer | SITA T60, measured points 5 to 50 s (interval 5 s), 10 measurements |

## 3. Method

### 3.1 Test chart based on ISO/IEC 24790:2017

For the analysis with the standard ISO/IEC 24790:2017 the Package Tool, a quality analysis system, developed by ISO/IEC JTC 1/SC 28, Work Group 4, was used. The measurements were made in conformance with the procedures described in ISO/IEC 24790:2017, Sections B.1 to B.4.5, B.4.6.1 and B.4.6.2. The printed test chart is illustrated in Figure 1.

The test chart was developed based on the specifications of ISO/TS 15311-2:2018 (International Organization for Standardization, 2018, p. 26). The standard suggests a chart with vertical and horizontal lines. The test chart was created with 1200 ppi (pixel ≈ 21.16 µm × 21.16 µm) 8 bits and saved as uncompressed TIFF file. For each line width, 5 and 6 pixels (px in Figure 1), respectively, there are 10 lines parallel and 10 lines perpendicular to the printing direction (length 400 pixels).

For the reflectance $R$ measurement from lower and upper limits ($R_{max}$ and $R_{min}$ in Figure 1, respectively) there are 10 squares (500 µm × 500 µm), five of them printed with 100 % black for the measurement of the lower reflectance limit $R_{min}$ (printed areas) and five defined areas for the measurement of the upper reflectance limit $R_{max}$ (background). For the measurements, 5 test charts were printed on unprimed cardboard, 5 on primed cardboard, and 5 on primed cardboard with IR drying assistance. For each parameter, for example, line width of a 5 px-line in horizontal print direction, the final result is the average of 50 measurements. The region of interest (cropped image area) has around 3 mm × 9 mm.

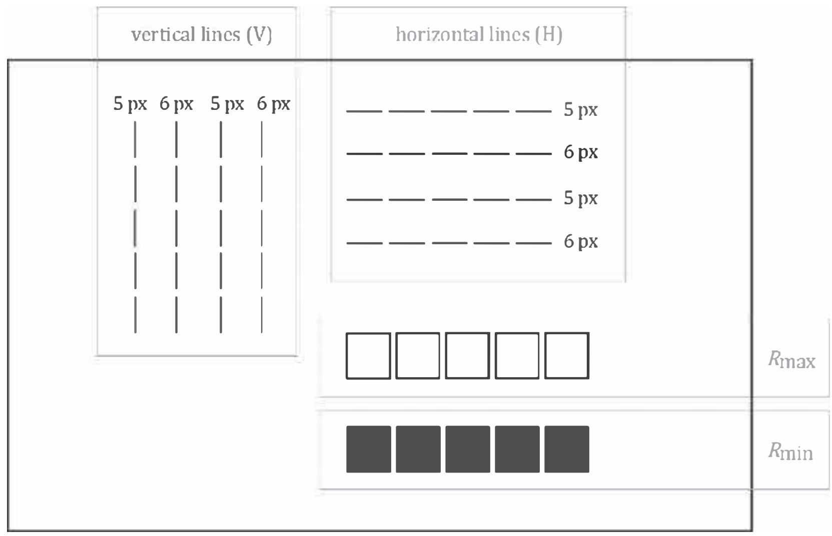



*Figure 1: Test chart for measurement of reflectance and line image quality attributes*

### 3.2 Line reflection

The reproduction of fine details is determined by means of the reflectance grade $\varrho$ from Equation [1] (Kipphan, 2001, p. 465). As explained in Section 3.1 the maximal and minimal reflectance are measured to define the limits for the calculations. Each substrate background (maximal reflectance) and each printed patch (minimal reflectance), depending on ink type, has different reflectance grades. These data are used in the description of the different reflectance zones for the calculation of, for example, blurriness (Equation [2] from ISO/IEC 24790:2017, p. 19) and line and character darkness (Equation [3] from ISO/IEC 24790:2017, p. 19). Line width is the average width of the stroke line (printed line). The measurements are made along the line from edge to edge (ISO/IEC 24790:2017, p. 18). The line raggedness calculations (Equation [4] from ISO/IEC 24790:2017, p. 20) are based on residuals along the printed line (Figure 2).

$$\varrho = \frac{\Phi_R}{\Phi} = \frac{reflected\ light\ flux}{incident\ light\ flux} \quad [1]$$

$$Line\ blurriness = \frac{Dis_{70-10}}{\sqrt{LID}} \quad [2]$$

where $Dis_{70-10}$ is the distance between $\varrho 70$ and $\varrho 10$ in [mm] and $LID$ is the line image density [dimensionless].

$$Line\ and\ character\ darkness = LID \times \sqrt{LW} \quad [3]$$

where $LW$ is the line width [mm].

$$Line\ raggedness = \frac{1}{N}\sum_{j=1}^{N}\sqrt{\frac{1}{k-1}\sum_{i=1}^{k}(RFL)} \quad [4]$$

where $N$ is the count of edges, left and right edge in case of measuring the single line, and $k$ is the pixel-row within an region of interest (ROI) that delivers a local edge postition which is repeated across the height of the ROI, and $RFL$ are residuals from a line [mm].

The Figure 2 illustrates the different reflectance zones, definitions and how the distances in relation to reflectance areas are read to calculate the results.

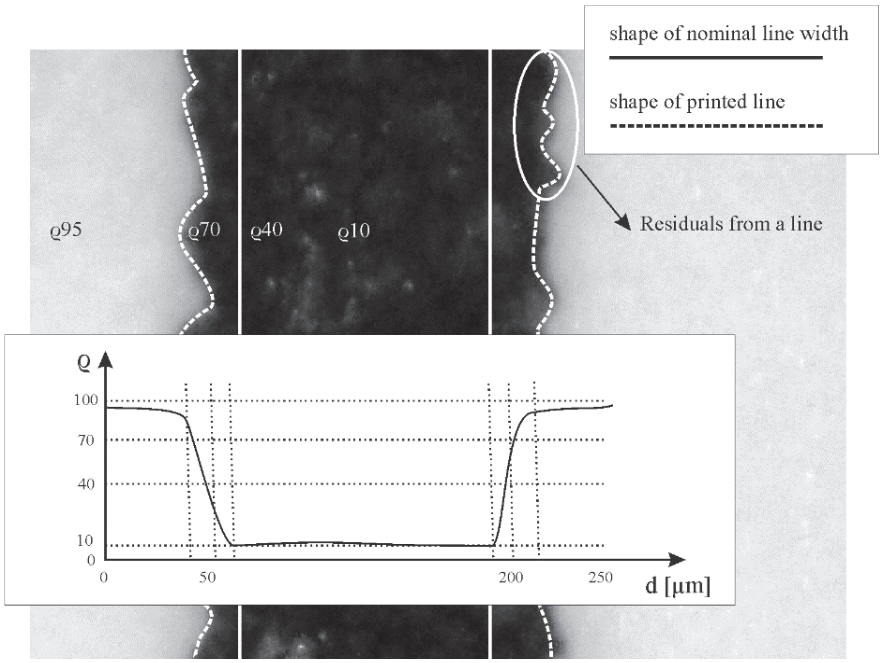



*Figure 2: Reflectance areas of a printed line, based on ISO/IEC 24790:2017, p. 58*

### 3.3 Siemens star

Siemens stars or sine wave stars are used to measure the spatial frequency response (SFR) of scanners or digital cameras. According to ISO 12233:2017 (International Organization for Standardization, 2017) resolution and SFR are related metrics and "generally, contrast decreases as a function of spatial frequency to a level where detail is no longer visually resolved." This is illustrated in Figure 3.

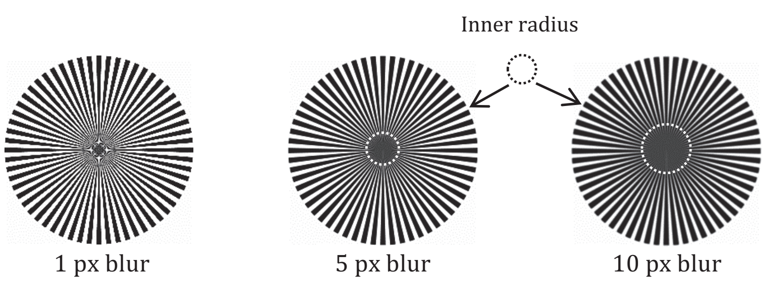



*Figure 3: Loss of resolution in function of blur increase*

The three stars were generated in Matlab with the same cycle numbers, diameter and three different levels of blur: 1, 5 and 10 pixels. They were exported with the same output resolution (1 200 dpi). When loss of resolution occurs, the center of the star tends to lose contrast and becomes predominantly black, forming an inner radius. The larger this inner radius, the lower the resolution. This will be illustrated in detail in Section 4.2.

In the tests, a Siemens star with 13.5 mm outer radius, and 60 spokes in black and white (60 cycles) was designed in Matlab. The image was saved in TIFF format without compression, dot gain or anti-alias with 1200 dpi, 8 bits. The stars were cropped with ImageJ and imported into Matlab Evaluation program, where the center of each star, focal point, radius, Siemens star diameter, and number of cycles were calculated. The final resolution is calculated by means of Equation [5] (Prinzmeier, 2009).

$$Resolution\ [\text{dpi}] = \frac{Cycles\ [\text{dimesionless}] \times scan\ resolution\ [\text{dpi}]}{\pi \times radius\ [\text{px}]} \quad [5]$$

### 3.4 Print dot gain

Since digital printing systems do not use either a film or other image carrier, the difference between real tone values of digital data (file) and measured tone values of a print can be defined as dot gain. Figure 4 shows the test chart design for dot gain measurement. For the calculation of dot gain, 16 test charts were printed on unprimed cardboards, 16 on primed cardboards and 16 on primed cardboards using IR drying assistance. The printed charts were read with a spectrophotometer using the Murray-Davies dot gain calculation.


*Figure 4: Test chart for dot gain measurement*

## 4. Results and main observations

The measurements were performed in three groups:
- printed charts on unprimed cardboards (called "unprimed")
- printed charts on primed cardboards (called "primed"), and
- printed charts on primed cardboards and dried with IR drier (called "primed-IR").

The results of primed and primed-IR do not differ significantly. Therefore, only the measurements of unprimed and primed will be shown and discussed in the following.

### 4.1 Line width, blurriness, raggedness and darkness (ISO/IEC 24790:2017)

Figures 5 and 6 present the line width measurements. These data are the difference between the lines on unprimed vs. the lines on primed cardboards. This calculation method was also used to present the line blurriness, raggedness and darkness measurements. All lines printed on unprimed and primed cardboards have widths greater than the nominal line widths. Table 7 compares, based on measurements, the line width on unprimed and primed cardboards.

*Table 7: Visual assessment – line width on primed cardboards (H and V means horizontal and vertical or parallel and perpendicular to the printing orientation, respectively)*

| **Ink** | **Dye** | | | | **Pigment** | | | |
|---|---|---|---|---|---|---|---|---|
| Line | 5 px H | 5 px V | 6 px H | 6 px V | 5 px H | 5 px V | 6 px H | 6 px V |
| On primed cardboards the lines become: | wider | thinner | thinner | thinner | wider | thinner | wider | wider |

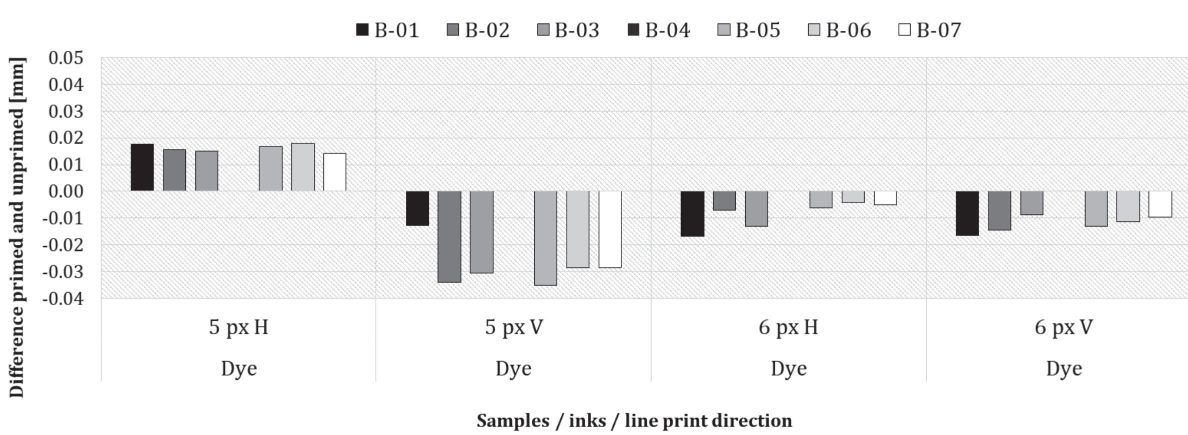



*Figure 5: Measurements – line width – 5 px and 6 px – dye based ink (H and V means horizontal and vertical or parallel and perpendicular to the printing orientation, respectively), for B-04 the measurements are not presented*

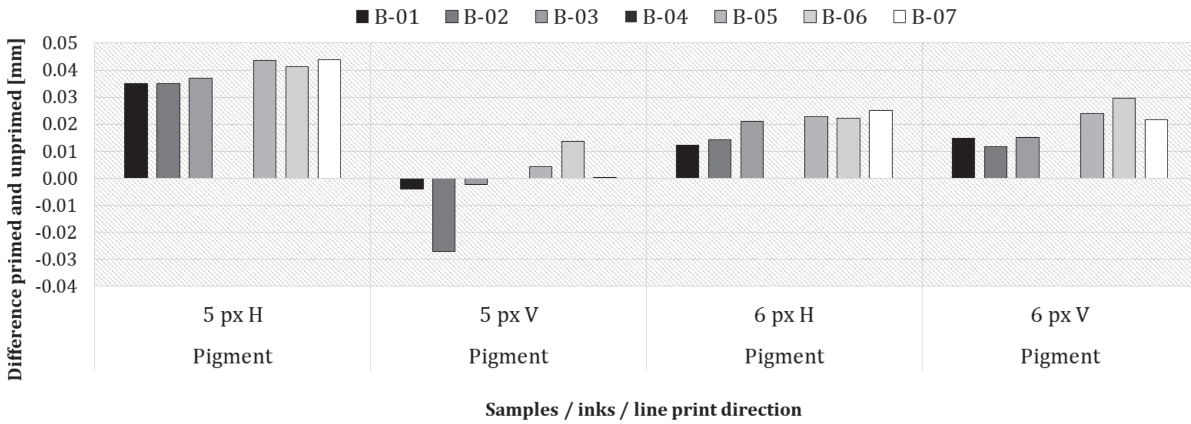



*Figure 6: Measurements – line width – 5 px and 6 px – pigment based ink (H and V means horizontal and vertical or parallel and perpendicular to the printing orientation, respectively), for B-04 the measurements are not presented*

Considering surface energy only, it might have been expected that the lines on primed surfaces might be wider than lines printed on unprimed surfaces, because the primer increases the surface energy of the media and reduces the contact angle between ink and media causing more ink spreading (Rosalen and Backhaus, 2018). The measurements show different trends that will be discussed in Section 5. For B-04 the measurements could not be presented. This cardboard is cast coated and particularly pigment inks have serious wetting drawbacks on unprimed cardboards. The measurements show large standard deviation (over 10 %) and more than 70 % of the samples could not be read in the Package Tool.

For 5 px lines the measurements show a traceable course: horizontal-lines (see Figure 1) on primed cardboard printed both with pigment and dye based ink became wider than lines on unprimed cardboards. The vertical-lines (see Figure 1) on primed cardboard became thinner due to mechanical limitations of home/office printers to reproduce vertical lines as they are in the literature already known and can affect this kind of measurement (Briggs, et al., 1999; Guiping, et al., 2010).

For 6 px line the measurements show another traceable course. The difference of results were not related with the print direction, but with the ink type. Lines printed with dye ink became thinner and lines printed with pigment became wider. As this deviation happens by all cardboards, which were printed and scanned independently, a measurement error is unlikely.

Blurriness and raggedness of both sides of the line are calculated in the Package Tool; LR stands for lower or right and UL stands for upper or left (Figure 7). This is relevant for printer quality evaluation, but not for the evaluation of media or primer. Both reading directions presented the same trend. In Figure 8 to Figure 11 the measurements of line blurriness and line raggedness, respectively, are presented.

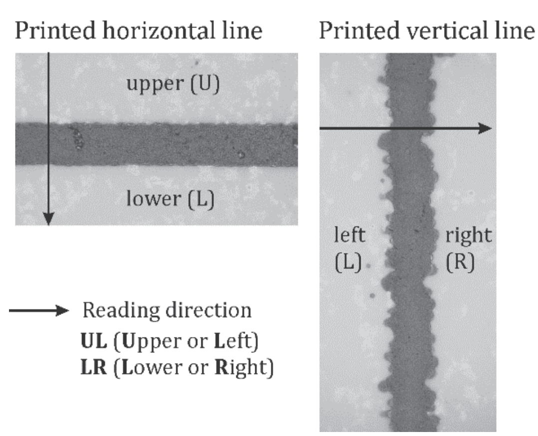



*Figure 7: Reading directions for blurriness and raggedness calculations*

Overall the primer increased blurriness in all samples printed with dye based ink and in all 5 px and 6 px horizontal lines printed with pigment based ink. Probably this happens also with the 5 px and 6 px vertical lines, if the standard deviation is considered. It is important to indicate that the absolute measurement values vary predominantly between 0.010 mm and 0.013 mm which in 1200 dpi resolution means between around 1 pixel and the standard deviation is below 1 pixel. In this amplitude it is probable that some measurements cannot be correctly calculated, since little alterations will be rounded, causing distortions in the result, but it is possible to observe a trend.

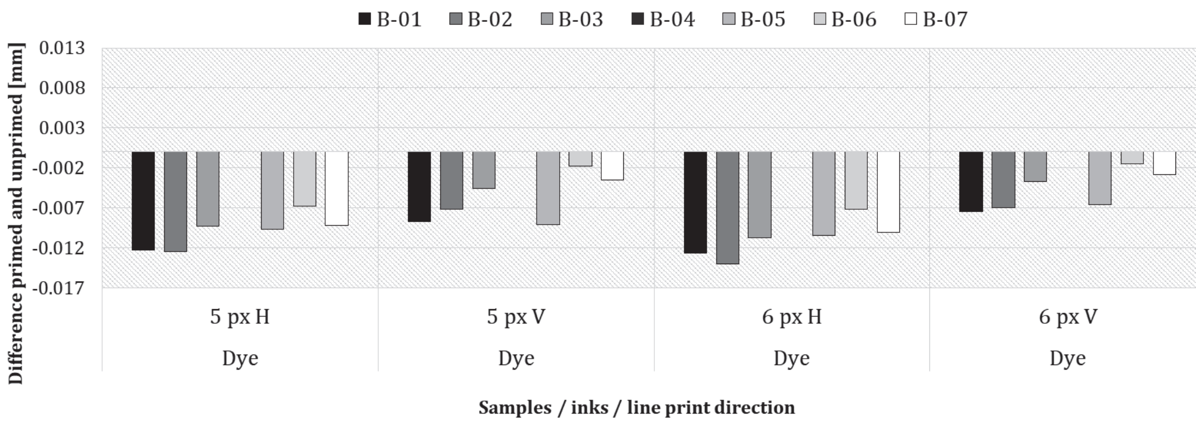



*Figure 8: Measurements – line blurriness 5 px and 6 px – dye based ink (H and V means horizontal and vertical or parallel and perpendicular to the printing orientation, respectively), for B-04 the measurements are not presented*

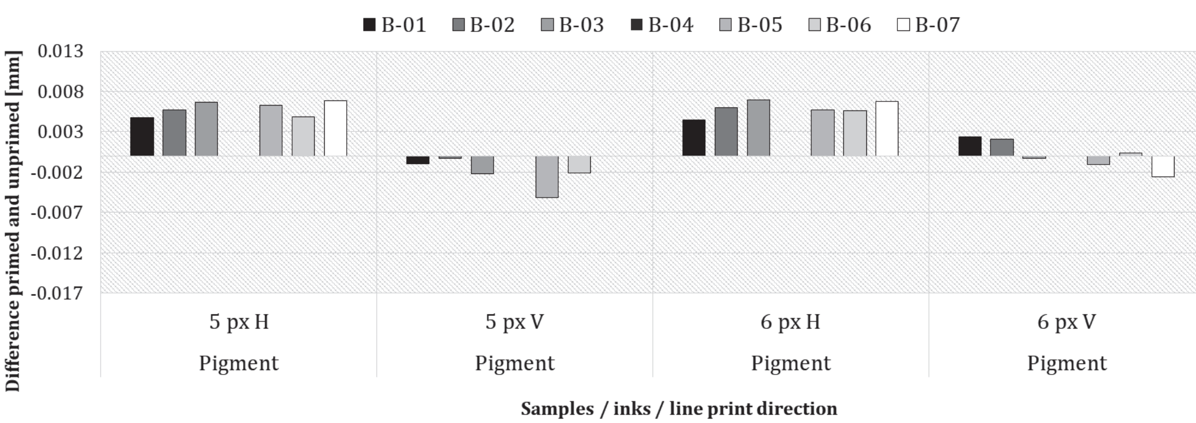



*Figure 9: Measurements – line blurriness 5 px and 6 px – pigment ink (H and V means horizontal and vertical or parallel and perpendicular to the printing orientation, respectively), for B-04 the measurements are not presented*

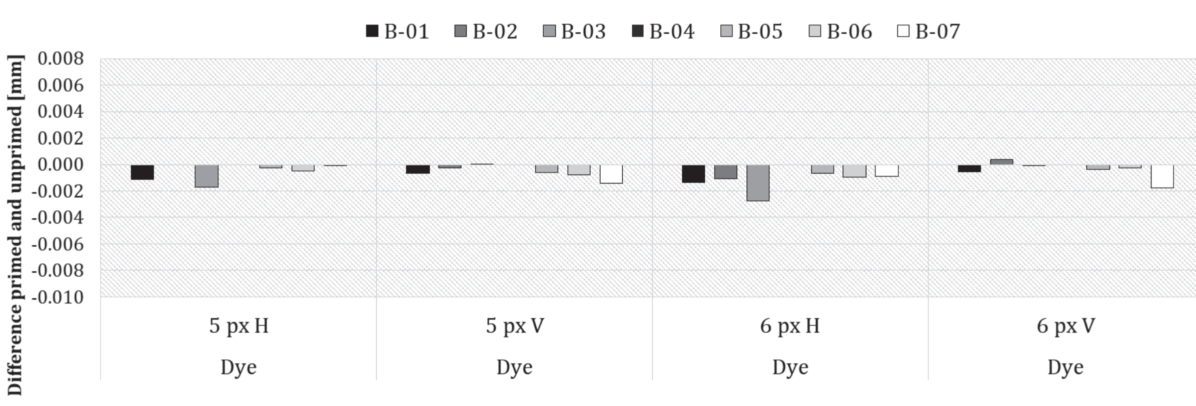



*Figure 10: Measurements – line raggedness 5 px and 6 px – dye based ink (H and V means horizontal and vertical or parallel and perpendicular to the printing orientation, respectively), for B-04 the measurements are not presented*

The measurements of line raggedness with dye based ink do not show any relevant difference between primed and unprimed cardboards (Figure 10). From the measurements of the samples printed with pigment ink it is possible to observe a clear difference between horizontal and vertical lines (Figure 11).

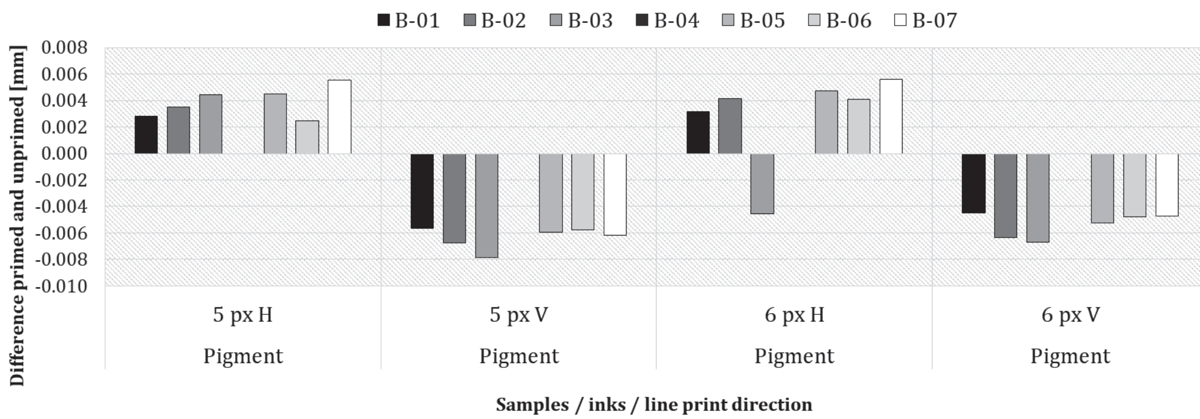



*Figure 11: Measurements – line raggedness 5 px and 6 px – pigment based ink (H and V means horizontal and vertical or parallel and perpendicular to the printing orientation, respectively), for B-04 the measurements are not presented*

The measurements of line/character darkness (ISO/TS 15311-2:2018 calls this attribute line darkness, ISO/IEC 24790:2017 calls it character darkness and it is a dimensionless parameter) show that lines printed on primed cardboards are darker than the lines printed on unprimed cardboards, but with an outlier: 5 px-vertical line printed with both pigment and dye based ink (Figures 12 and 13).

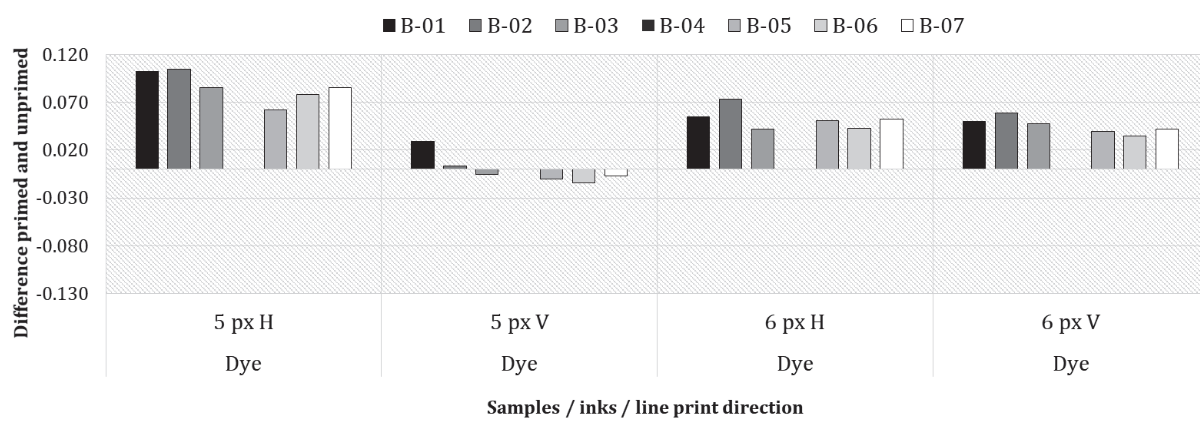



*Figure 12: Measurements – line/character darkness 5 px and 6 px – dye based ink (H and V means horizontal and vertical or parallel and perpendicular to the printing orientation, respectively), for B-04 the measurements are not presented*

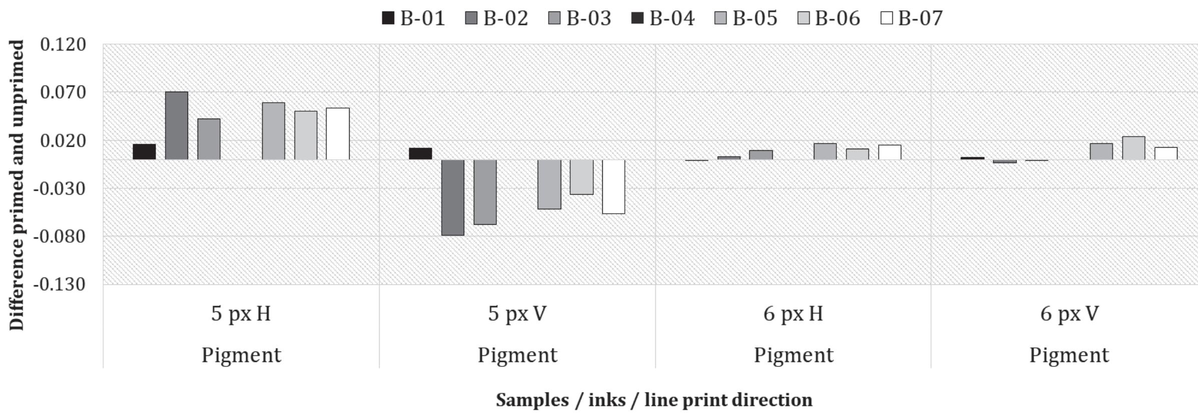



*Figure 13: Measurements – line/character darkness 5 px and 6 px – pigment based ink (H and V means horizontal and vertical or parallel and perpendicular to the printing orientation, respectively), or B-04 the measurements are not presented*

It is observed that there is no direct correlation between measured line width (Table 8) and darkness. This supports the fact that darkness is not related to print area but related to print density, which, in turn, is proportional to the amount of dye or pigment present per unit area, and so less spreading will lead to a darker image provided there is sufficient spreading to provide surface coverage by the inkjet droplets.

*Table 8: Comparison between line width and line darkness measurements (H and V means horizontal and vertical or parallel and perpendicular to the printing orientation, respectively)*

| **Ink** | **Dye based** | | | | **Pigment based** | | | |
|---|---|---|---|---|---|---|---|---|
| Line | 5 px H | 5 px V | 6 px H | 6 px V | 5 px H | 5 px V | 6 px H | 6 px V |
| On primed cardboards the lines become: | wider | thinner | thinner | thinner | wider | wider and thinner | wider | wider |
| On primed cardboards the lines become: | darker | lighter | darker | darker | darker | lighter | darker | darker |

*Table 9: Reflectance measurements and difference Δ between unprimed and primed patches, by equation*

$$(\Delta = \frac{unprimed}{primed} - 1) \cdot 100\ [\%]$$

| **Patches (see Figure 2)** | $\boldsymbol{R_{max}}$ | | **Dye (K) –** $\boldsymbol{R_{max}}$ | | **Pigment (PBK) –** $\boldsymbol{R_{max}}$ | |
|---|---|---|---|---|---|---|
| Media | Unprimed | Primed | Unprimed | Primed | Unprimed | Primed |
| B-01 | 0.8687 | 0.8624 | 0.1003 | 0.0298 | 0.0116 | 0.0134 |
| Δ | | 1 % | | 237 % | | −13 % |
| B-02 | 0.8768 | 0.8673 | 0.0917 | 0.0244 | 0.0134 | 0.0151 |
| Δ | | 1 % | | 275 % | | −12 % |
| B-03 | 0.9048 | 0.8955 | 0.0837 | 0.0247 | 0.0128 | 0.0196 |
| Δ | | 1 % | | 238 % | | −34 % |
| B-04 | 0.8990 | 0.9049 | 0.1553 | 0.1204 | - | - |
| Δ | | 0 % | | 29 % | | - |
| B-05 | 0.9100 | 0.9046 | 0.0804 | 0.0213 | 0.0116 | 0.0174 |
| Δ | | 1 % | | 277 % | | −33 % |
| B-06 | 0.9141 | 0.9048 | 0.0538 | 0.0183 | 0.0120 | 0.0174 |
| Δ | | 1 % | | 194 % | | −31 % |
| B-07 | 0.8776 | 0.8648 | 0.0982 | 0.0253 | 0.0135 | 0.0241 |
| Δ | | 1 % | | 288 % | | −44 % |

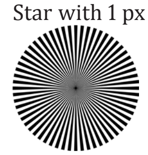
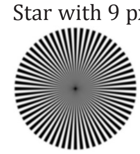
The measurements of line/character darkness were compared also with the reflectance measurements (Table 9). Dye inks printed on primed cardboards show less reflectance, i.e. they are darker than inks printed on unprimed cardboards. The opposite happens with pigment inks on primed cardboards were the reflectance is higher than without primer.

### 4.2 Siemens star

The inner radius is a core component to measure the resolution using Siemens stars. It is the distance between the geometric center of the star until the white and black segments can be differentiated. That is, the larger the inner radius, the poorer the resolution. The challenge of printing fine spokes in the center of the star may be a limitation of the printer, but also of the media.

For better understanding of the results, ten Siemens stars with 2 400 dpi – 13.5 mm outer radius, 60 cycles (black/white segments) with different grades of blur were created and measured in Matlab Evaluation Program. The results are listed in Table 10. A star without blur obtained a resolution close to the image output resolution itself, 2 378 dpi (blur = 0). As the center of the image loses focus, the resolution decreases.

*Table 10: Exemplary resolutions of Siemens stars with different grades of blur*

| Applied blur [px] | Measured resolution [dpi] | Examples |
|---|---|---|
| 0 | 2 378 | Star with 1 px blur |
| **1** | **2 083** |  |
| 2 | 1 554 | |
| 3 | 996 | |
| 4 | 777 | |
| 5 | 720 | Star with 9 px blur |
| 6 | 655 |  |
| 7 | 566 | |
| 8 | 443 | |
| **9** | **365** | |

The measurements of Siemens stars (Table 11), printed with 1200 dpi – 13.5 mm outer radius, 60 cycles (black/white segments) show that stars printed with dye ink on primed cardboards show higher resolution than stars printed on unprimed cardboards. This result was not expected, because, as mentioned above, considering surface energy only, the primer increases the media surface energy and reduces the contact angle between ink and substrate causing more ink spreading and decreasing the resolution (Rosalen and Backhaus, 2018). Stars printed with pigment inks show the inverse result, that is, on primed cardboard, the resolution decreased. This will be discussed further in section 5.

*Table 11: Siemens star resolution measurements with standard deviation σ*

| | Unprimed K Resolution [dpi] | σ | Primed K Resolution [dpi] | σ | Unprimed PBK Resolution [dpi] | σ | Primed PBK Resolution [dpi] | σ |
|---|---|---|---|---|---|---|---|---|
| B-01 | 377 | 3 % | 596 | 2 % | 584 | 4 % | 474 | 8 % |
| B-02 | 574 | 5 % | 607 | 2 % | 585 | 4 % | 530 | 6 % |
| B-03 | 473 | 8 % | 564 | 8 % | 581 | 5 % | 500 | 7 % |
| B-04 | - | - | 606 | 2 % | - | - | 641 | 17 % |
| B-05 | 508 | 6 % | 587 | 5 % | 588 | 4 % | 471 | 10 % |
| B-06 | 593 | 3 % | 595 | 5 % | 585 | 4 % | 449 | 9 % |
| B-07 | 510 | 8 % | 605 | 3 % | 588 | 5 % | 502 | 10 % |

### 4.3 Print dot gain

The dot gain curves for B-01 to B-07, except B-04, are presented in Figure 14. All curves, for K and PBK on primed and unprimed cardboards, have similar profiles. The patches of 70 % and 80 % are marked in the graphics as areas where in average, due to dot gain, dot area increases to 90–95%. The dot gain analysis in this section is relevant for this study, because they are read in the Package Tool as solid areas (lines). In this patches the dot gain of K ink is almost identical for primed and unprimed cardboards and for PBK ink the primed cardboards have more dot gain than unprimed.

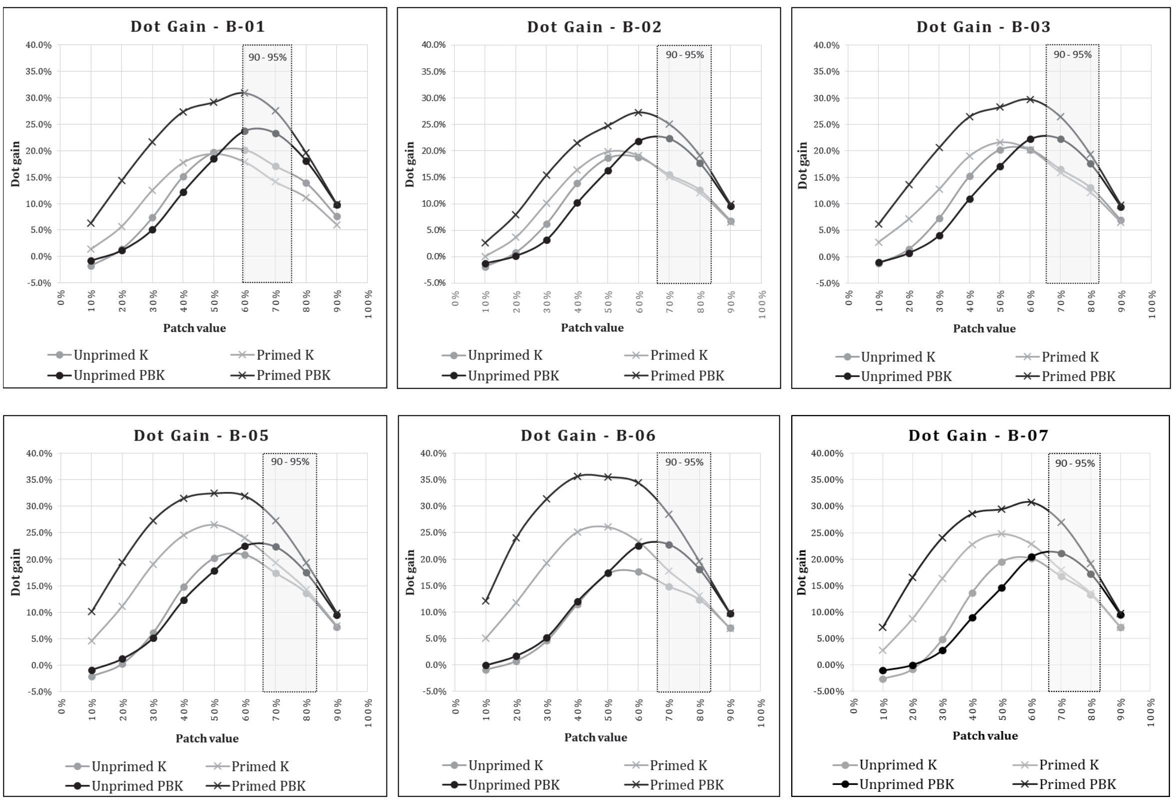



*Figure 14: Dot gain of B-01, B-02, B-03, B-05, B-06 and B-07*

It is not considered here that the measured dot gain refers only to ink spread. Part of the value refers to optical dot gain. In addition, the primed surface is more transparent and glossy, which affects the dot gain measurements. What is relevant here is that in relation to both treated and untreated surfaces the areas with the higher dot gain in the region of interest are related to the fact it is printed with pigment based ink.

Dot gain measurements of B-04, a cast coated cardboard not suitable for inkjet, are not displayed here. The charts present severe drawbacks of homogeneity (Figure 15), particularly for PBK on unprimed cardboard.

*a)* *b)*

*Figure 15: Printed charts B-04 (60–100 %) with PBK on primed surface (a) and on unprimed surface (b)*

## 5. Discussion

The ISO/IEC 24790:2017 standard was developed to evaluate printing systems. To understand if this standard can be used to classify media for inkjet print, a correlation with other well-known measurements was used. In Table 12 all measurements are summarized. Because one objective of this study is to understand the effect of the primer on the reproduction of fine details, this comparison shows what tendentially occurs with the printed objects on primed cardboards vs. unprimed cardboards.

*Table 12: Overview – Comparison primed vs. unprimed cardboard*

| | Line width | | Blurriness | | Raggedness | | Darkness | |
|---|---|---|---|---|---|---|---|---|
| | **K** | **PBK** | **K** | **PBK** | **K** | **PBK** | **K** | **PBK** |
| 5 px H | wider | wider | more | less | more | less | darker | darker |
| 5 px V | thinner | thinner | more | more | more | more | lighter | lighter |
| 6 px H | thinner | wider | more | less | more | less | darker | darker |
| 6 Px V | thinner | wider | more | more | more | more | darker | darker |

| Siemens star (resolution) | | Reflectance | | Dot gain (70–80 %) | |
|---|---|---|---|---|---|
| **K** | **PBK** | **K** | **PBK** | **K** | **PBK** |
| Resolution increases | Resolution decreases | darker | lighter | no difference | more dot gain |

Regarding the effect of PVOH primer there was expected: more dot gain, the resolution decreases and lines becomes wider in comparison with printed lines on unprimed cardboards. These hypotheses were fulfilled by pigment based inks. Although exactly the opposite happened with dye based black inks, the logical correlation between line widths, resolution of the Siemens stars and dot gain is in overall correct. The main finding is that the primer can influence both dye and pigment based inks in opposite ways.

According to Lamminmäki, Kettle and Gane (2011) the time and amount of absorption of a liquid is dependent on the surface structure defined as network pore structure, surface chemistry and diffusion effects. In this work, it was demonstrated that the use of PVOH in pigment coatings helps to keep dyes on the cardboard surface what increases the color density and darkness. In Ridgway, Kukkamo and Gane (2011) it has been shown that PVOH in anionic dispersed coatings formulations can increase absorption/adsorption from dyes. However, PVOH used in the experiments demonstrated here is non-anionic. In this case, the authors assume that the diffusion of ink water molecules, an effect known as swelling, opens the PVOH polymer chain and the dye enters the amorphous part of the polymer.

Despite the hydrophilic character of PVOH it was also demonstrated that the absorption properties depend on the concentration of PVOH in the pigment coating. This is based on the assumption, that PVOH can also reduce media permeability by connecting previously opened pores and cavities. This effect is observed in both modified calcium carbonate and precipitated calcium carbonate, usual pigments in cardboard coatings. The higher the amount of PVOH the lower the permeability. Authors further demonstrate that bleeding increases with increasing PVOH fraction in the coating formulation. It is indicated that dye based inks "locate more uniformly in the coating structure because PVOH covers the pigment coating surfaces and masks any surface cationicity of the pigment" coating. (Ridgway, Kukkamo and Gane, 2011; Lamminmäki, et al., 2009)

Another study (Lamminmäki, et al., 2011) demonstrates interesting effects of PVOH through tests performed by means of thin layer chromatography. On the one hand PVOH reduces the available surface for dyes absorption but on the other hand the water molecules present in the ink (vehicle) open the PVOH polymer chain allowing anchoring of the dye, i.e. the same effect explained before.

In Lamminmäki, et al. (2010) the liquid uptake is analyzed as a function of time. It has been shown that up to 2 seconds after water application in pigment coatings with PVOH and different calcium carbonate the rate of absorption reduces compared to pure calcium carbonate coating. They claim that in this short timescale the rate and velocity of ink vehicle imbibition is predominantly controlled for the smallest pores. Because of the swelling effect the capillarity and absorption rate reduces. At longer timescale the dominant force controlling the rate of liquid imbibition is the permeability flow in the porosity of the coating.

It can be assumed that this effect also occurs by pigment based ink but not in the same order, because pigments exist as particles in the order of nanometers in the ink vehicle. Cross-section micrographs in Svanholm (2007) showed that both types of inks penetrate between the particles voids of pigment in coatings produced with silica and PVOH. It was shown that dye based inks penetrate the pores of the pigment coating, whereas pigment based inks stay on the surface. Since these observations were made on silica coatings, a correlation with what can happen on not microporous surfaces is only an assumption.

It is therefore possible that the IR-radiation absorbed by the assembly (media, ink and primer) changes the polymer chain either by rapid evaporation of water or by heating the PVOH above the glass-transition temperature (about 75–85 °C). Thus, both dyes and pigments are enveloped by the flexible and amorphous part of the polymer. After returning to environment temperature the colorant components are fixed and protected in the PVOH.

With respect to the correlation between the measurements it is possible to observe a proper numerical correlation among them, but with outliers. The measurements of lines with line thickness around 100 µm in vertical orientation can be also questionable for home office printers. This can explain the trend differences between measurements in vertical and horizontal 5 px lines. Albeit a lab printer (Dimatix) could have been used to minimize the print direction influence, the printing speed of this printer is not compatible with the print speed of commercial printers, which would be adverse for a correct analysis.

It is also necessary to verify if the measured values of the lines are within an acceptable range. In the Annex C (Informative) of ISO/TS 15311-2:2018 representative FOGRA print quality measurements results are listed. For full-page color advertisements, large-format professional studio photos (fine art) the typical measured differences from goal (digital image) are: for line width ≤ 100 µm, for line blurriness ≤ 100 µm and for line raggedness ≤ 50 µm. All results from K and PBK on primed cardboards fit this range.

## 6. Conclusion and outlook

This study demonstrates the use of the standard ISO/IEC 24790:2017 (detail rendition reproduction part) to compare quality attributes of inkjet media, exemplary here, between coated cardboards with and without pretreatement and post treatment. Other qualitative parameters to analyze print quality as resolution by means of Siemens stars, reflectance and dot gain were compared with generally accepted correlations between the parameters with the expectations of some outliers. The effect of a primer/bonding agent to coated cardboards could be also numerically analyzed.

However, the reference values are for other types of substrates. Reference values for packaging, to the best of our knowledge, do not exist. The correct reproduction of fine details, as explained before, is relevant to the legibility and thus readability of texts and decodability of codes. Standards with open parameters that can be measured in the graphics industry still need to be developed.

Lastly, the differences of the results between dye and pigment based inks are relevant and should be the next variable to be analyzed by means of ink flow behavior and dependence of the ink volume on spreading.

### Acronyms

| | |
|---|---|
| 1D codes | One-dimensional data representation as code 39 or UPC-A |
| 2D codes | Two-dimensional data representation as dataMatrix or QR-Code |
| dpi | Dots per inch |
| FBB | Folding box board |
| HPLC | High-performance liquid chromatography |
| PVOH | Polyvinyl alcohol |
| $R_{max}$ | Maximal reflectance |
| $R_{min}$ | Minimal reflectance |
| SBB | Solid bleached board |
| σ | Standard deviation |
| Φ | Light flux |

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# To take for granted or question the technology fundamentals in research and learning?

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### Abstract

With growing variety of novel printing methods and facilities for their computerized control the rethinking becomes urgent for some fundamental technology issues which just pretend to be clear but are, in fact, the empirical data taken for granted from a long term industry experiences. Based on the research results and educational competencies of author the philosophy of choosing the screen frequency, geometry and press settings, the dot gain nature and multipurpose use of black ink in CMYK are analyzed and experimentally illustrated.

**Keywords:** educational paradigm, technology fundamentals, new knowledge, source image, print channel

## 1. Introduction

Educational paradigm of today focuses on teaching the skills of producing a new knowledge rather on just transfer of what is already known. One of the ways of such knowledge revealing is in questioning discipline fundamentals with finding the explanation to issues, taken for granted on the basis of empirical data and long term professional experiences. Some of them, being familiar to professionals from everyday practice, are used as general basis in defining the values and parameters for industry standards without proper explanation of the physical nature of related phenomena. Lack of such clarity in the questionable issues disclosure makes sometimes the research efforts and educational content to bypass the development mainstream declining to a priori non-actual, low--efficient direction.

Unlike such products of modern "precise" knowledge as radio, TV and internet, the print media stems, to the great extent, from the medieval crafts. Several basic features of the obsolete or still used printing techniques weren't completely researched or disclosed at nowadays scientific level. It is to certain extent concerned of the philosophy of screen frequency and geometry, of press settings choice, of dot gain nature, of multipurpose use of black ink in CMYK color print reproduction, etc. However, their proper comprehension becomes especially urgent with growing variety of novel printing methods and facilities for their computerized control.

A lot of misconceptions had at the same time appeared as result of superficial interpretations in some handbooks, manuals and professional communication. Helping to adequately appreciate, for example, the "color myths", Giorgianni and Madden (1998) placed in their book the separate paragraph of such misconceptions analysis in the way of myth/reality withstanding. Similar attempt in relation to "halftoning myths" was also done in Kuznetsov (2009; 2016).

Looking back in the latest history of graphic technology developments one can find a number of scientifically approved recommendations on color values correction for print quality improvement. However, even at the times of electronic prepress, there was a lack of means for proper control of desired variations.

The digital image processing of today allows for practically unlimited print parameter variation with the discretion of just about 25 square microns of ink coverage. Meanwhile, quite a contrary situation of adequate resources but lacking in knowledge of what should be done is often met and the need arises of additional research or training which could substantiate the recommendations and performing methods for effective use of such precise, rather recently appeared control facilities.

Expediency of fundamentals rethinking is far from being confined by below given examples. It can each time arise with appearing the novelties changing the accustomed workflow. They have influence on training content and make an educator to “trim” the “old” knowledge with providing its and “new” one optimal conformity within a course credits limit (Kuznetsov, 2014).

So, it isn’t out of place to logically discern some basic notions which just seem to be clear on the shallow questioning background.

## 2. Optimal print data encoding

In the light of communication theory, the graphic arts picture processing is the optimal encoding by criteria of transfer onto a print through physical press channel as much as possible of a source image data perceivable for a viewer. Such encoding undermines the mutual conformity for properties of original image, channel with its output print and human visual system (HVS).

### 2.1 Screen orientation in halftones

Representative, useful example of such conformity providing is in the empirically found and over a century used non-orthogonal, 45° screen orientation on a black and white print and, as well, for black separation in CMYK color print reproduction. Its usual explication as making the halftone structure less visible is not exhaustive because the screen is similarly rotated at rulings over 175 lpi when it is not visually acute. Such angling makes the print more informative in general due to taking into account the angular anisotropies inherent in three above mentioned basic components: source image data, channel and HVS. Explanation for the greater informative capacity of image sampling in chessboard order as compared to an orthogonal one was given in the digital TV research (Grudzinsky, Tsukkerman and Shostatsky, 1978) and later on experimentally illustrated for halftone printing (Kuznetsov, 1998).

The first of those anisotropies is in the statistics of contours orientation distribution in images, replicas of a visually perceived world where, due to gravitation, the vertical and horizontal contours prevail over the inclined ones and are, at the same time, of greater importance for a viewer. The other one relates to transmitting channel and is in $\sqrt{2}$ greater spatial frequency response of an orthogonal screen for diagonal lines than in vertical and horizontal directions. The third anisotropy is, at last, in about the same degree less HVS frequency response in diagonal direction.

#### 2.1.1 Angular anisotropies of image data and human visual system

The HVS and above image data properties natural conformity can be demonstrated by the image “Fall” of Bridget Riley (1963) in Figure 1a. Its parallel sinusoids are distinct at reading distance where their lines are vertical. However, the horizontal piece of this picture (marked at side and comprised of inclined lines) looks blurry. Such blur disappears if the image is rotated by 45° making the lines within a stripe vertical.

It is interesting to notice the same stripe looking also quite definitely when separated from the other picture content (Figure 1b). It allows for suggestion that on some higher, cognitive viewing level the brain sacrifices inclined detail definition by redistributing its visual resources on behalf of an adjacent, more important vertical and horizontal ones.

The above specific of visual perception is in a natural way consistent with the mentioned anisotropy in the statistics of contours distribution by their directions in the visually perceived surround. Such harmony does not apply only to a narrow class of images, which include aerial photographs or images of the earth’s surface, obtained from space. For them, the concepts of “top”, “bottom”, “right” and “left” are conditional. At the same time, artificially created images as the typefaces, abstract paintings and the like can hardly be considered isotropic in this sense. Artists choose the strength of lines and contours of different orientations intuitively, taking into account this feature of vision.

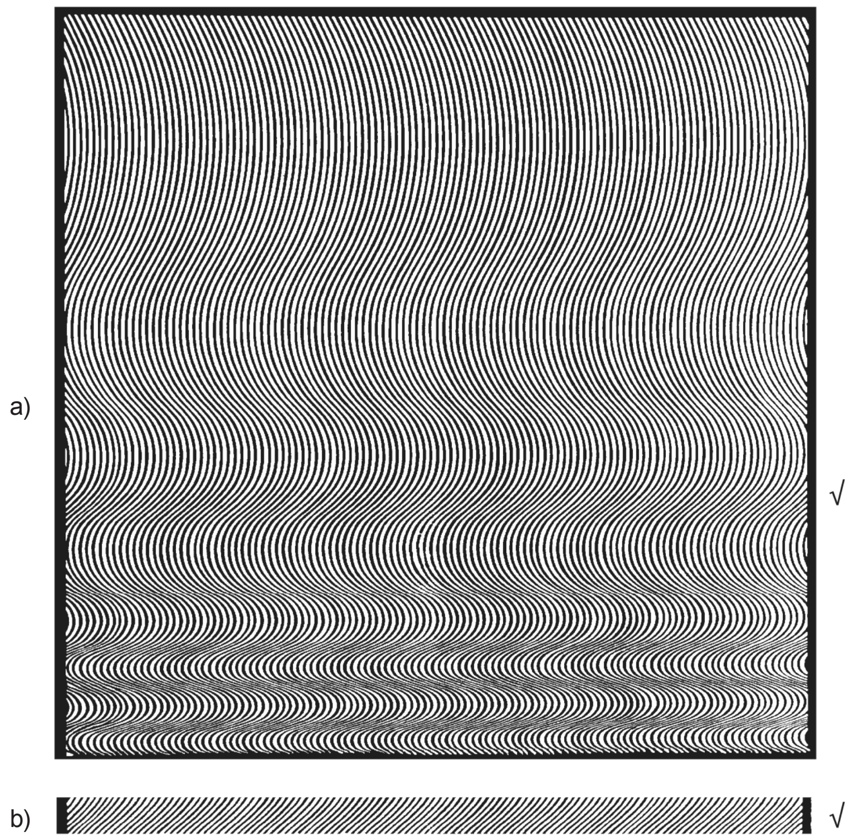



*Figure 1: With its inclined lines the marked horizontal stripe of the image looks blurry (a); the same stripe is discerned quite sharply if the image is rotated by 45° or when looking at the separated part of a picture (b), adapted from Riley (1963)*

2.1.2 Response anisotropy of a periodic grid

Providing the conformity of the above features of images and vision with the properties of the intermediate graphic processing stage is the prerogative of technology. In this regard, the regular sampling grid resolution can be considered for different directions, not forgetting that the image is divided in printing into separate elements at least twice: in electro-optical analysis and coding of the original, and then in halftoning.

The distance between the dots of the orthogonal grid in Figure 2a is $\sqrt{2}$ times larger diagonally than in vertical and horizontal directions. To the same extent, from 100 % to 70.7 % with an angular period of 45°, the spatial response period of the samples arranged in this order differs. The directions for which the grid resolution is minimal and maximal are indicated there by solid and discontinuous lines.

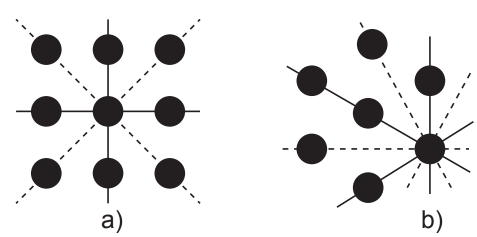



*Figure 2: Directions of maximum (- - -) and minimum (—); the response frequencies of the orthogonal sampling grid are repeated after 90° (a); and at hexagonal after 60° (b)*

More isotropic in this sense, as shown in Figure 2b, is the hexagonal grid. Its anisotropy ranges from 100 % to 58 %, alternating every 30°. The quality of the transmission by samples arranged in this order depends on the detail orientation to a lesser extent.

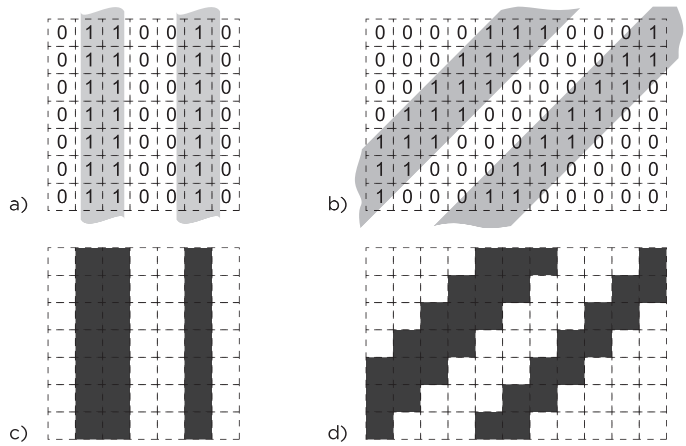



*Figure 3: Influence of the vertical (a) and inclined (b) stripes spatial phases in the sampling grid on their width on a corresponding print copy (c) and (d), respectively*

For the orthogonal grid, this difference is explained in Figure 3, by the model of digital reproduction of a pair of the same thick black stripes (Figures 3a, 3b). Their spatial phases differ from the original by half the grid period in its horizontal (Figure 3a) and diagonal (Figure 3b) directions.

Line matter is encoded using a simple two-level operator assigning “1”, if the black occupies more than half of a sample area, and “0” otherwise, with the resulting “bitmap” use to print the image (Figures 3c, 3d). From a comparison of the original vertical stripes, their bitmaps in Figure 3a and printed copies in Figure 3c, it is seen that the uncertainty of the stripe width reproduction is equal to the grid period.

As far as the stripes phases periodically replace each other at the smallest inclination from 90° or 45°, the periodic stepwise distortion is added to the error in a stripe width transfer (Figure 4a). If the width is close to the grid step, then the stripe is periodically interrupted on the copy (Figure 4b). For the same reason, the system of thin strokes with an increase in its frequency is reproduced by the false pattern (Figure 4c). Interference of the periodic pattern (texture) of original and the sampling grid is related to the “subject (object) moire” in contrast to the result of color separations interaction in printing resulting in “multi-color moire”.

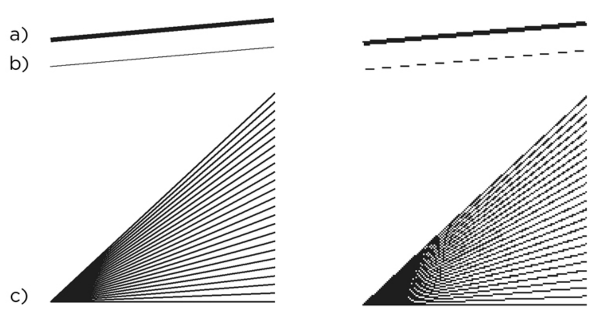



*Figure 4: Sampling errors appear in the form of stepwise contour distortion (a), thin stroke interruptions (b) and false patterns in textures (c)*

For diagonal stripes, the sampling error is square root of two minus the grid period (Figures 3b, 3d). All mentioned distortions are shifted to the region of about one and half times higher frequencies and become less noticeable.

The considered properties of the originals, reproduction system and vision are made consistent by turning the orthogonal grid by 45°. This position is confirmed by the long term practice of 45° angling the halftone screen for the monochrome pictures and K ink in CMYK printing, chessboard location of the “needles” in matrix printers as well as by the geometry of color sensors placement in the digital camera matrix (Figure 5). Green-sensitive elements are most responsible for the brightness component of the color image and its contours transmission. Therefore, they are doubled in relation to the blue and red ones and are set in the chessboard fashion.

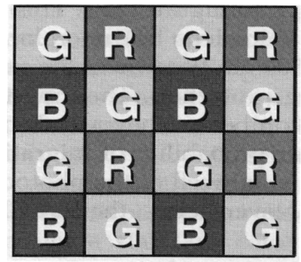



*Figure 5: Green-sensitive sensors responsible for image definition are placed in the CCD matrix in chessboard order*

It was also proposed to take into account this anisotropy of vision in the formation of irregular screen structures under the conditions of restricted printer resolution, allowing for coarser granularity in the less sensitive diagonal directions (Delabastita, 1993; Allebach, et al., 1994).

Comparison of the effect of different sampling geometries in relation to the reproduction quality is complicated by the problem of keeping equal the all other conditions such as, for example, the screen ruling, sampling rate and source image file volume. Graphical models show in Figure 6 the results of line images sampling and reproduction in the orthogonal (Figures 6b, 6c), and diagonal (Figures 6d, 6e) order. On the right side (Figures 6c, 6e) they were obtained for twice less sampling rate than on the left (Figures 6b, 6d). These images allow for demonstrating the possible signal volume decrease due to the sampling grid optimal orientation at almost the same copy quality.

As in the case of Figure 3, the type fonts in Figures 6b to 6e were obtained for two spatial phases of the original (Figure 6a) in the sampling grid differing by about half at both coordinates. The effect of sampling errors on the quality could be clearly seen by the difference in the uncertainty (variation) of thin lines widths reproduction in each of pairs. At 10 times reduced scale the Figures 6b, 6d correspond to the sampling rate of 100 spi (40 samples/cm), and Figures 6c, 6e to 62 spi (25 samples/cm).

From the pairwise comparison of copies shown in Figures 6d, 6e and in Figures 6b, 6c it can be seen that the spatial phase has less effect on the width of thin vertical and horizontal lines in the diagonal (45°) grid than in the orthogonal (0°) one. This effect remains at the same level for half as many samples if the grid is rotated by 45°, as the comparison of models in Figure 6b and 6e shows. In spite of the error by the root of two higher for the diagonal lines and contours on the model shown in Figure 6e compared to 6b, this does not significantly affect the quality due to the above viewing property. Conversely, the lack of this feature consideration in orthogonal sampling degrades reproduction. Copies presented in Figure 6b and 6e are much closer in quality than in Figure 6c and 6d obtained with the same difference in sample rates.

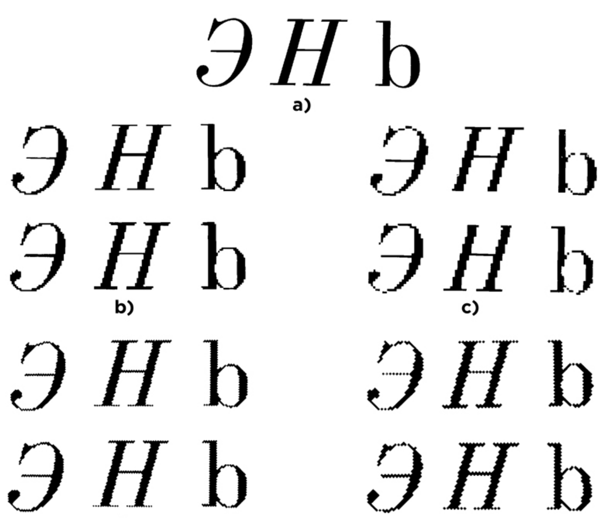



*Figure 6: Original details (a) and their copies as result of sampling in the orthogonal (b, c) and chessboard order (d, e); at double (b, d) and single (c, e) number of input samples*

Real reproduction is limited with respect to the processed data volume, channel bandwidth and input/output resolution. Under these conditions, orthogonal sampling significantly reduces the representativeness of pictorial data or, as can be seen from the comparison of models shown in Figure 6b and 6e, it is accompanied by its almost double redundancy. Its subsequent elimination by optimal coding (compression) in the system itself gives only an additional effect.

Figure 7 illustrates in real scale the influence of the orientation of both the first (sampling) and second (screening) grids on the print quality. It was prepared on a digital scanner with a screen ruling of 150 lpi (60 lines/cm) and an input resolution of 120 samples/cm. The reproduction quality increases when coming from Figures 7a to 7c with:

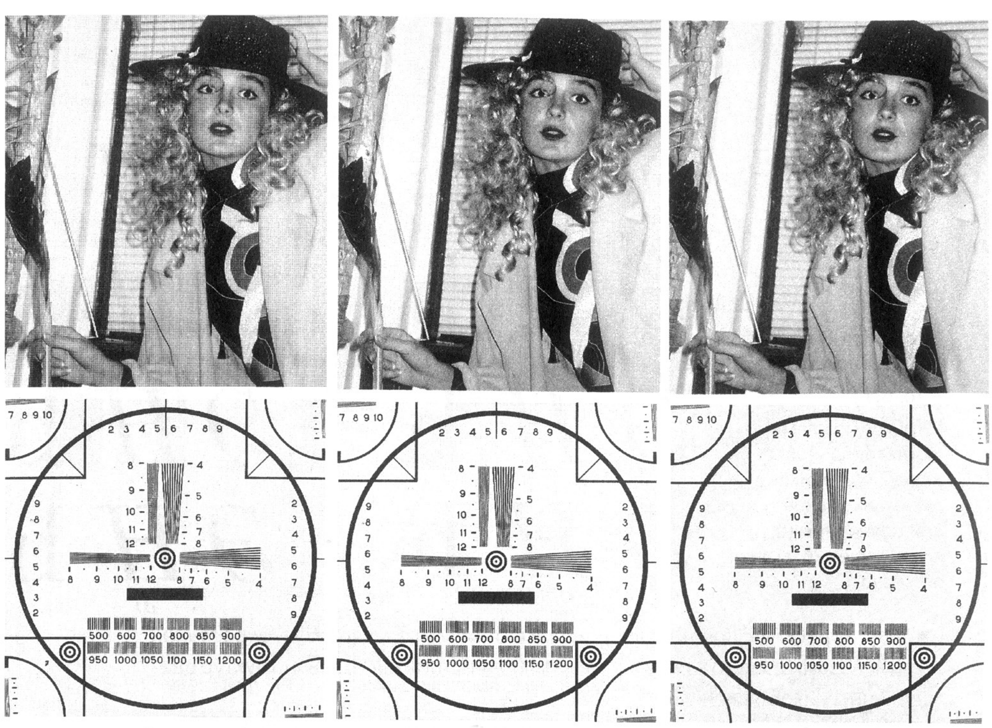
a. both image input and screening grids at 0° (conventional mode for yellow separation);
b. scanning at an angle of 0° and screening at an angle of 45° (as it is used for K ink separation);
c. scanning and screening in a chessboard order.

To establish the difference in quality on the upper realistic images the qualified judgment is required. However, no expert can objectively and even quantitatively assess this difference in form and position of the false pattern on the vertical stripes of TV test placed below.

Presenting the picture in an orthogonal grid at the set file volume unduly lowers the print quality. The same also limits the information content of multi-element light panels, information boards, printing devices, liquid crystal displays and other similar arrangements, although this is not always justified by their design specific.

Theory prescribes at least two-fold excess of the sampling rate in relation to an original image frequency desired to be reproduced on the copy, as well as the sampling and screen ruling ratio, so-called “screening factor” (SF) equal to 2. However, it becomes clear from above why the smaller SF of only 1.5 is quite satisfactory used by the most of prepress operators.

Above considerations on choice of the screen orientation give also some explanation to ignoring the hexagonal halftones by printing practice in spite of their favorable printability. Round dots stay there isolated within about a whole tone range (up to 91 %) while in the square meshes of conventional orthogonal screen they produce the tone




a) b) c)

*Figure 7: The quality of vertical strokes shows the influence of the scanning and screening grids orientation on image definition: a) 0° and 0°; b) 0° and 45°; c) 45° and 45°*

rendition trouble when touching each other at 79 % ink coverage creating the peak on a dot gain curve, or tone value increase (TVI) curve, respectively. However, the hexagonal screen, with its spatial frequency response variation just on about 20 % for different directions, is more isotropic. So, its rotation is not such effective for providing the conformity of HVS and image data properties.

It is not also out of place to notice that the "electronic/digital" generation of hexagonal halftones, being tested yet fifty years ago (Hallows and Klensch, 1968; Kuznetsov and Uzilevskey, 1976), was later on again proposed with rather disputable motivation of their preferable rosette pattern (Wang and Loce, 2012).

The considered example of taking into account the angular anisotropies of the three main system components (the original image – the carrier lattice – vision) is a clear example of the so-called optimal encoding, the purpose of which is to reduce the volume of the transmitted signal without compromising the print copy quality.

## 2.2 Press settings and dot gain in halftone printing

Uniformity of "painting" a substrate by some spot color may comprise the basic criteria of press settings in certain packaging job being controlled by the ink solid density distribution over a sheet or the target density match on a control bar patch. However, the strategy of such settings choice for a halftone job should be quite different with taking into account also that halftone reproductions have limited range of tone values (ink coverage), excluding solid tones. Its upper "black level" relates to the ink coverage of 95–97 %, as well as for a "white level" there is prescribed the tint of 3–5 % ink coverage instead of unprinted substrate in ISO 12647-1:2013 (International Organization for Standardization, 2013). These values correspond, in fact, to minimal sizes of a printed and blank elements steadily provided over a sheet within a run for given kind of a substrate, plate, ink, press and, altogether, define the "effective", manageable range of gradation and the picture contrast within the halftone reproduction.

So, the basic criterion of an optimal pressure and ink supply adjustments is, in fact, the providing of minimal possible size $d_{min}$ of a dot. It puts the ink solid standard density value aside as an auxiliary, secondary factor derived from such practice.

The conditions of a tiny ink drop transfer onto substrate are physically different of that for vast inked area. To the pity, a lot of ink–plate–substrate interaction researches proceed from such area properties but are not based on the behavior of a minute ink formation, which size is comparable to a substrate roughness period. Such a tiny meniscus is lacking adhesion as far as it can be just pierced by a filament or hangs over substrate microscopic cave as schematically shown at the left side in Figure 8. For the meniscus of a certain critical size this lacking can be compensated by some excess of a pressure comprising, in its turn, the basic reason of greater drops squash recognized as TVI phenomena. Without said excess there is no problem of gain, for example, for 40 % dots as far as they could be printed of the same or even fewer size which is, however, accompanied by the complete, irretrievable loss of a highlight dots and related tone data. To the contrary, the "natural" tone value increase at press settings aimed on providing said effective range can be compensated in pre-press and it is not out of place to notice here that the effect of such correction in a greater degree depends not on the increase rate but its stability.

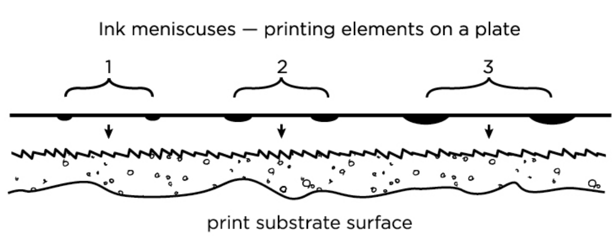



*Figure 8: The transfer of an ink meniscus, which smallest size is comparable to average roughness period of a substrate, is unreliable (1); halftone dots of particular area, inherent in given ink–plate–substrate system, are confidently transferred at a certain pressure (2); at such a condition the greater dots are inevitably squashed (3)*

It follows from above that the TVI is null for the dot of "white level" on a halftone and the smaller dots are not transferred if they are even present on a plate. Moreover, in flexography their thin stems bend marking the substrate even excessive to a nominal value. Therefore, the TVI curve cannot originate from the origin of coordinates except for analytical models of optical dot gain. Otherwise, it will indicate some imperfection of such a model.

Tone value increase is also caused by the extra inked area at adjacent dots contacting each other. It determines the position of TVI curve maximum cardinally depending on screen and dot geometry. Other reasons are in the 2–3 % dot area change in (obsolete, but still considered) plates photo copying and in optical dot gain. This natural increase becomes even greater due to such obvious causalities as the dot slur and doubling.

These relatively obvious considerations are mostly ignored in the halftone printing modeling research and even in the standards. Pretending on processing the unreal, infinitely small dots they present, for example, tone reproduction curves (TRC) and TVI curves starting from zero value instead of factual, recommended ink surface coverage $S_{min}$ = 3–5 %. This can be seen already in the formulation of the research task itself, such as "The investigation of the effects of different ink density values on color gamut in offset printing" (Tutak, Beytut and Ozcan, 2018) in relation to halftone printing at 175 lpi, rather than "painting" paper with CMYK solids, and gamut estimations, again, within the color boundaries of such layers.

Another example of ignoring the above basic considerations is in almost total shift, since the end of the '80s, of halftoning research to frequency modulated screening which explores the digital data processing advantages with the use of a mathematically elegant error diffusion algorithm. Over two decades the papers, patents, doctoral theses, handbooks bypassing the developments of traditional and still widely used halftoning but exclusively devoted to its, so called, "stochastic" version, dominating in the literature. Ignoring the above discussed fundamental issues of a plate–ink–substrate interaction, this version had, however, found rather limited practical application (Kuznetsov and Schadenko, 2017). Use of a minimal dot within the whole tone range makes them very sensitive to printing tolerances. (It is easily evidenced by the attempt to print a 50 % tint of the chessboard located minimal dots and blanks).

These considerations on seeking the "sweet spot on a press" by criteria of providing the effective tone range may serve as a starting point for the philosophy of halftones frequency choice.

### 2.3 Logic of the screen ruling choice

Ruling value for given kind of job is usually set according to the industry experience but the particular meaning is not somehow substantiated in spite of its cardinal effect on informative content of a print. Halftone of 100 lpi incorporates twice greater amount of data than at 70 lpi and the print area cost is usually estimated per square inch in advertising.

There are met the superficial conclusions of ruling upper level of 150 lpi (60 lines/cm) being quite sufficient for all kinds of jobs as related to HVS frequency response limit of about 6 lines/mm at reading distance (Raskin, et al., 1989; Kipphan, 2001). Such a halftone can however reproduce just the 3 lines per mm of pictorial data. So, the practically unreal, twice higher ruling of 300 lpi is required to completely satisfy that kind of "theoretical" supposition.

It is not out of place to mention that halftone structures at all practically used ruling values, in spite being, if desired, resolved by normal viewing, are usually ignored by observer on behalf of discerning a thereby carried informative detail. Vision behaves similar to the low pass spatial frequency filter with its threshold adaptively moved according to viewed content. Lattice of 35 samples/cm is appreciated as sufficient pictorial data on a halftone of 175 lpi (70 lines/cm) in a magazine. However, the same frequency of 35 samples/cm is ignored as not related to an image data when screening with 90 lpi (36 lines/cm) for a picture in newspaper. Such phenomena are confirmed by sincere surprise of some people unfamiliar with the "trick" of halftoning when their attention is put on a specific dot structure of such images. It often happens that they have earlier appreciated them as usual continuous tone photographs.

Overall image quality can be, in general, estimated by the sum of its multiple parameters weighted according to their "just noticeable differences" relative importance for a viewer. As far as the ruling value $L$, responsible for image sharpness and definition, is in wide practice reduced at coming to coarser print substrates and processes it is possible to propose that these parameters are somehow sacrificed on behalf of providing some others. Such, much more important, principle parameter is the image contrast. It is defined by the reflection ratio of "white" and "black" point settings in the reproduction process.

With the measurement tolerances at that lower bound it is quite possible to assume the tiny dot value, characterizing above mentioned process facilities, as $S_{min}$ = 4 %. At presumably square form of such a dot its size $d_{min}$ comprises the fifth part of a screen period $1/L$ which gives the rule of thumb for ruling calculation: $L = 1/(5d_{min})$.

Inverse equation $d_{min} = 1/(5L)$ allows, from the other hand, for rough judgment of certain screen ruling value and process facilities conformity in providing the desired image definition and sharpness.

Table 1 contains $L$ and process characterizing $d_{min}$ values which conform to such a rule and quite correlate to practice. Meanings from ISO 12647-1:2013 do not, however, completely follow certain logic. While recommending the “white” point of 3 % for rulings of 60–175 lpi, it prescribes 5 % for 200 lpi, i.e. advises, by unknown reason, to lower contrast for “art” printing by making this point 2 % darker. In spite of the use of higher quality substrates and precise processes, the minimal dot becomes at such a condition even greater than at 150 lpi.

*Table 1: Screen ruling L and process characterizing $d_{min}$ (approximate) values conforming to the rule $L = 1/(5d_{min})$ at a “white point” of 4 % and correlating to industry practice of contrast priority over print sharpness and definition*

| | $d_{min}$ [μm] | $L$ [lpi] | [lines/cm] | $S_{min}$ [%] |
|---|---|---|---|---|
| Newspapers | 80 | 60 | 25 | |
| | 50 | 100 | 40 | |
| Magazines | 40 | 130 | 50 | 4 |
| | 33 | 150 | 60 | |
| Commercial | 29 | 175 | 70 | |
| | 25 | 200 | 80 | |

Another example of ignoring the logic of screen ruling choice is in the often met boosting of processes, consumables and equipment potential by stating the facility of operating with a tiny dot of 1 % or 2 %. Such dot availability (if properly measured) allows for twice or one and half greater ruling which results, in its turn, in four or two times larger volume of pictorial data at a print of the same size.

Neglecting above logic of ruling choice had place in flexography greatly demanded in recent years for colorful packaging. Overestimated screen frequency created there a problem of tone “breakage” in highlights, which had required the special solution of development the modified, so-called hybrid halftoning.

A large number of articles devoted to screening opens with a figure of the “original”, issued as a continuous tone test image. Further comparison of the effectiveness of the proposed and alternative methods is illustrated by copy versions thereof. That in itself the original is printed in the edition with use of a regular screen and therefore is not the continuous tone, and that its quality far surpasses all other images given by the author is not taken into account. So, we have had to underline the importance of well-grounded relationship of process facilities and screen ruling value for the correct comparison of different halftoning methods (Kouznetsov and Alexandrov, 1999).

The relatively low resolution made an obstacle in obtaining the conventional screens and their frequencies in digital printing. In spite of providing the proper image contrast it had the shortened halftone dots alphabet reducing the amount of tone responses within reproduced range due to the limited discreteness of a screen cell. The number of patented technical solutions of various vendors was used to overcome this problem (chapter 4 in Kuznetsov, 2016). In ink jet it was, for example, solved by means of the *multilevel* screening with adding the diluted CMY inks to the CMYK process ones. In electrophotographic, “laser” printers there are for the same purpose used the increased spot function addressability as well as the partial frequency modulation of dots placement (the hybrid screening).

The above principles of screen ruling selecting stay meanwhile true against the background of an extensive range of halftoning options in modern raster image processors (RIPs) for computer to plate (CtP) output and digital printing.

### 2.4 Black ink in CMYK color reproduction

Other example relates to the use of a fourth, black process ink in color reproduction. Seemed familiar to each printer it, at the same time, as was shown in Kuznetsov and Ermoshina (2015), is rather tangled even in its definitions. Some attempt was done there to logically discern the multiple purposes and functions of theoretically infinite continuum of CMY to CMYK transformations. One of these functions (achromatic CMY component replacement by K) is stipulated in its volume and range of applying by the number of such technologic, economic, operating and image quality considerations as:

- total ink limit;
- ink consumption costs;
- fidelity and stability of the grey balance within a run;
- color disbalance, moiré and rosettes visibility due to their geometry variation;
- gamut mapping intents;
- use of inks of complementary to CMY colors in Hi-Fi printing, etc.

However, there are also the other reasons of K ink combined use with CMY such as:

- reproduction of achromatic colors themselves;
- providing the darker chromatic ones to expand a print color gamut.

Black ink applying can also differentiate from the vast, stationary image area to its sharp boundaries and fine details. Due to considerable reflectance in near to infrared illumination it is even used for the print security purposes.

Black ink complementing to CMY process ones has started at the times of camera prepress where facilities of its control according to certain rendering intent and, especially, for its one particular effect on the resulting color were rather restricted. However, the mostly heuristic found, scanty collection of black ink settings is until now used in wide practice. One of the reasons is in some isolation of numerous participants (publishers/advertisers, prepress operators, quality managers, printers…) from each other. Moreover, coming from one under color removal (UCR) or grey component replacement (GCR) curve of Photoshop to the other inevitably changes color of the same print area due to variations in halftone dots overlap, their summary perimeter, etc. resulting in the shift of an ink trap, physical and optical dot gain, etc. Resulting color also strongly depends on the “dot-on-dot” or “dot-off-dot” strategy choice of inks placement (Rhodes and Hains, 1993). So, almost an each time of K use variation the new color profile is formally required through an accurate press “fingerprinting” procedure.

Lack of facilities to find the optimal adjustments ultimately matching the job/process specific makes practitioner to follow the narrow path of guaranteed, standard parameters (Euroscale, SWOP, etc.) or of settings stipulated by the accustomed ICC profile.

One else reason of non-optimal black ink use is in vague interpretation of its settings and their essence in “black boxes” of prepress software applications or commenting manuals. When appealing to their “help” option the user is sometimes sent to get an advice from a printer. In this relation was noted, for example, that only about a quarter of the Swedish print houses have people ever heard of the UCR and GCR functions of Photoshop (Enoksson, 2004).

Not so much “help” the user can get from academic sources. Problems start here from the lack of these functions proper definitions. For example, both UCR and GCR indicate in fact the “removal of chromatic inks (CMY) achromatic component by replacing it with the black (K) one”. Meanwhile the “Complete Color Glossary” defines the UCR procedure as related just to the dark neutral colors (Southworth, McIlroy and Southworth, 1992). In the “Handbook of Print Media” (Kipphan, 2001) the UCR, GCR, UCA are distinguished by just the volume of CMY achromatic part variation replaced by black, though this volume can be as well changed along the tone range within each of these procedures. The GCR is also stood out as a “generalization” of UCR and K addition (Balasubramanian, 2003). There were also the attempts to modify K use under the names of programmed color removal (PCR), integrated color removal (ICR), etc., and the new ones were proposed (Enoksson, 2004). The number of other explanations of a fourth ink applying suffers from mixing the purpose and method of destination.

On background of a “Black and White” importance “in color” (Hunt, 1997) the lack of a K-ink use adequate clarity results, in its turn, in generating the persistent, widespread myths in related technology aspects. One of them was until now used for stochastic screens promotion, however, the moire problem can also arise with introduction of complementary RGB colors in CMYK color reproduction process within the Hi-Fi print concept. In reality the complete, 100 % removal of one of CMY inks is compulsory to make worthwhile the use of an additional ink of opposite, complementary color for gamut expanding. So, the conventional, periodic screen is safely used at an angle of corresponding process ink as far as the chroma increase can be achieved just at condition of entire removal of the latter in particular image area. It is appropriate to mention at the end of this section the relatively recent problem of achieving the reliability of color in printing.

For many years the hard copy (slide, photograph, drawing…) was used as a source image for print production. Its properties could be objectively measured by the densitometer or colorimeter in job characterizing. For modern open, network printing environment there was also the "color management system" developed providing the identical image data defining at different locations.

New challenge to such data adequate interpretation is in digital photography of today presenting it in an image file. Factual color meaning of its values are properly defined just at a special professional level by the use of profiles accounting all the conditions of an image capturing in the so called "reference input media metric" (RIMM). However, in a wider, common use of such files the reproduction stays rather colorimetrically indefinite which negatively affects a print result and its prediction. So, the generalized solution for an input color meaningful interpretation is in the direct providing an image three component colorimetric value from the signals of multispectral camera.

## 3. Conclusions

Along with reducing the screen visibility its rotation on 45° doubles the image data volume in given printing technology and to the same extent reduces the image file size.

The basic criteria of an optimal pressure and ink supply adjustments for halftone job is the providing a dot of minimal possible size $d_{min}$. So, all the TRC and TVI curves should start not from the zero but from corresponding $S_{min}$ tone value of about 4 % since there is no gain at all for such a dot.

At presumably square this dot form the rule of thumb $L = 1/(5d_{min})$ can be used for the screen ruling choice quite correlating with practice. Inverse equation $d_{min} = 1/(5L)$ allows for checking the screen ruling value and process facilities conformity in providing the desired image definition and sharpness.

The use of black ink in CMYK printing is due to many factors not fully investigated in their totality and very conservative, since the change of K ink settings affects the output color requiring the renewal of a printer profile.

In the widespread use of digital photography files as originals for reproduction, the interpretation of object color meanings remains rather uncertain. The potential solution of this problem lies in the spectral image capturing.

Approach, which reveals the principle questions have still to be answered on the background of intensive technology innovations, makes the researcher or learner more encouraged to creative professional activities than the simple transfer and assimilation of existing knowledge leaving the impression of everything had been already explained and solved.

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# TOPICALITIES

*Edited by Markéta Držková*

CONTENTS

# News & more

## Recent publications from CIE

The following text brings a yearly update on standards, reports, conference papers and other documents published by the International Commission on Illumination (CIE) in 2019, with the more relevant to the field of print and media technology presented individually in the sections below. The international standards prepared jointly with the International Organization for Standardization (the technical committee ISO/TC 274 Light and lighting) include ISO/CIE 17166:2019 specifying the erythema reference action spectrum and standard erythema dose, which reflects the strong wavelength dependence of the elicitation of erythema (redness) in human skin, and the two dealing with lighting, namely ISO/CIE 20086:2019 specifying the methodology for evaluating the energy performance of lighting in buildings and ISO/CIE 8995-3:2018 with the lighting requirements for safety and security of outdoor workplaces. In this area, the joint technical specification ISO/CIE TS 22012:2019 outlining a way of working to determine the maintenance factor for both outdoor and indoor lighting installations was also published.

Due to the recent improvements in the technology and availability of lighting products based on organic light-emitting diodes, CIE S 025-SP1/E:2019 Test method for OLED luminaires and OLED light sources was published as a supplement to CIE S 025:2015 Test method for LED lamps, LED luminaires and LED modules standard. The technical reports include CIE 140:2019 with the 2nd edition of road lighting calculations, CIE 083:2019 with the 3rd edition of the guide for the lighting of sports events for colour television and film systems, CIE 232:2019 dealing with the discomfort caused by glare from luminaires with a non-uniform source luminance, which is typical for light-emitting diodes, CIE 234:2019 providing a guide to urban lighting master planning and CIE 235:2019 describing the optical measurement of LED modules and light engines. Among the documents that are freely available on the CIE website, there are the technical notes CIE TN 009:2019 The use of "accuracy" and related terms in the specifications of testing and measurement equipment and CIE TN 010:2019 Determination of the optical beam axis, centre beam intensity, and beam angle of directional light sources, CIE position statements on the blue light hazard and on non-visual effects of light, as well as all individual conference papers of the 29th Quadrennial Session of the CIE, held in Washington, DC, USA in June 2019.

### ISO/CIE 11664-1:2019, ISO/CIE 11664-3:2019 and ISO/CIE 11664-4:2019 Colorimetry
### Part 1: CIE standard colorimetric observers
### Part 3: CIE tristimulus values
### Part 4: CIE 1976 L*a*b* colour space

Since July 2019, three parts of ISO 11664 are cancelled and replaced by these corresponding ISO/CIE documents, with minor revisions. Part 5 on CIELUV colour space and the related chromaticity diagram and Part 6 on CIEDE2000 colour-difference formula were published in 2016 and 2014, respectively, while Part 2 on CIE standard illuminants is still under development. Part 1 specifies two sets of colour-matching functions for use in colorimetry, for

## A brief update on Fogra research projects in 2019

During the last year, several research projects of Fogra, the research institute for media technologies based in Germany, were finished. In the area of prepress, it was a project investigating the common colour appearance – in particular, whether it can be measured and evaluated using a suitable metric. The work employed the hard-proof and soft-proof versions of the paired comparison experiment and included the development of the web-tool for evaluation of colour reproductions produced via different output channels. Another project was concerned with digital printing, namely with the integration of high-speed inkjet into the conventional production environments of the offset lithography. It comprised a detailed investigation of the performance range of commercially available inkjet systems, both sheet-fed and reel-fed, evaluating their suitability for individual types of products traditionally printed by offset.

Another two finished projects dealt with smart ID cards and functional products. The first one addressed the need for alternative test methods for the rapid testing of smart card functionality. The approach was based on the testing of the card's physical properties, namely the resonant frequency and Q factor, benefiting from the availability of suitable testing devices. The second project, in research cooperation with the Textile Technology Institute of RWTH Aachen University, was focused on printing processes for organic photovoltaics on textile substrates and studied the relationships of textile surfaces, functional materials and printing parameters to identify the fundamental technical parameters as well as the process and application limits of flexible organic photovoltaics on textiles, thus enabling further developments and optimisation.

The Fogra Materials & Environment department finished in 2019 the project revising the test standard for the assessment of the corrosiveness of offset printing damping solutions, to increase the efficiency of the method developed in 2000 in terms of speed and labour intensity and extend it to consider the influence of differing water quality. By the end of the year ends the project developing the test system for evaluating surface wettability and cleanness conducted in research cooperation with the wfk – Cleaning Technology Institute.

In addition to the ongoing projects, two new projects started in 2019, both in the area of technology for prepress. The objective of the first one, scheduled till March 2021, is to improve the printability and readability of inkjet-printed barcodes and 2D codes. The project comprises the development of a PDF-based proofing and correction tool for these codes and a test forme with practical quality indicators, the systematic experiments to identify optimal process parameters in water and UV-based inkjet, and the investigation focused on the performance of reading devices and applications as well as on the codability of metadata through a bar code integrated into a print control strip to allow the automated combination of job data with print quality data. The second one is a joint one-year project with the Fraunhofer IGD aimed at the development of a 3D soft proof for full colour capable 3D printers utilising Polyjet and Multijet fusion technology, which started this autumn.

## PhD research opportunities

Students worldwide can apply for the funded PhD projects on different topics, including the suppression of coffee-ring effect for printing pharmaceuticals (University of East Anglia), hybrid soft material printing (Northumbria University), 3D printing of smart shape-memory materials (Nottingham Trent University), 3D printing of electronic ceramic materials (West Virginia University), and computational materials design (Karlsruhe Institute of Technology).

the CIE 1931 and CIE 1964 standard colorimetric observer. Both sets are representative of the colour-matching properties of observers with normal colour vision, differing in visual field sizes and requirements on photopic levels and spectral power distributions. Part 3 specifies the methods of calculating the tristimulus values of colour stimuli produced by self-luminous light sources or by reflecting or transmitting objects. The colour stimulus spectral distributions tabulated at measurement intervals of 5 nm or less in a wavelength range of at least 380–780 nm are required, with the standard method defined as summation at 1 nm intervals from 360 to 830 nm. The alternative abridged methods for larger intervals and shorter ranges should be used only when appropriate and after considering the impact on the final results. For cases where the measured wavelength range is less than 380–780 nm, extrapolation methods are suggested. Part 4 specifies a method of calculating the coordinates of the CIELAB colour space based on the CIE tristimulus values, including correlates of lightness, chroma and hue, as well as the Euclidean colour difference values. In addition, calculating the reverse transformation is presented.

## CIE 018:2019 – The basis of physical photometry

This publication is a major revision of CIE 18.2:1983, jointly developed by CIE and the Consultative Committee for Photometry and Radiometry of the International Committee for Weights and Measures. The 3rd edition implements the new definitions of the photometric units in the International System of Units (SI) that came into force on 20 May 2019, where the definition of the candela is based on the constant $K_{cd} = 683\ \mathrm{lm\ W^{-1}}$, the luminous efficacy of monochromatic radiation of frequency $540 \times 10^{12}$ Hz. The report presents the photometric quantities with their names, symbols and units, basic equations relating them to radiometric quantities, relations of photochemical and photobiological quantities to photometric quantities, as well as colorimetric quantities and spectral luminous efficiency functions, including those for mesopic and 10° photopic vision.

## CIE 230:2019 – Validity of formulae for predicting small colour differences

Prepared by the corresponding committee of Division 1, Vision and Colour, this technical report addresses colour differences of adjacent colours. Visual responses are compared with colour differences calculated using five colour-difference formulae: CIELAB, CMC, LABJND, CIE94, and CIEDE2000.

## CIE 231:2019 – CIE classification system of illuminance and luminance meters

This technical report prepared under Division 2, Physical Measurement of Light and Radiation, by the appointed committee outlines the existing systems and recommends the classification system explicitly considering the uncertainty of the determination of the quality indices.

## CIE 233:2019 – Calibration, characterization and use of array spectroradiometers

Also elaborated under Division 2, this comprehensive technical report presents the characteristics of array spectroradiometers important to obtaining accurate measurement results, along with possible corrections improving the accuracy. It also proposes the instrument performance indices for spectral broadening, stray light and linearity.

# Bookshelf

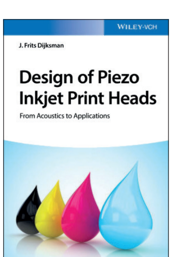
## Design of Piezo Inkjet Print Heads: From Acoustics to Applications

The author presents this book as a result of his lifetime dedication to the development of the theory behind piezo inkjet printing. The main point is that "the fluid motion inside a pump of an inkjet print head can be very accurately described by the behaviour of an acoustic cavity filled with ink and set in motion by pulse-wise actuation".

After a brief description of drop-on-demand inkjet printing and a general mechanism of droplet generation, the book introduces the piezo-driven printheads, their working principle and possible arrangements allowing to cover the area of a substrate, along with the aspects that must be considered in order to understand their action. The first chapter also explains the approaches and solution strategies applied in theoretical modelling, presented in a clear and comprehensive manner in the next chapters.

First, the printhead is modelled as a single cavity with a nozzle (or a single-opening Helmholtz resonator), that is, a system with a single degree of freedom represented by a single mass–spring–damper oscillator. The chapter explains the governing equations and solution for square pulse driving and provides the solutions for ramped-pulse driving, exponential-pulse driving and harmonic driving. It also discusses non-linear effects associated with non-complete filling of the nozzle. The system with two degrees of freedom (a Helmholtz resonator with two openings – the nozzle and the throttle) is similarly treated in the following chapter, followed by a multi-cavity Helmholtz resonator theory describing the interaction between pumps in a multi-nozzle printhead. As the next step, pump chambers with the length much larger than their cross-sectional dimensions are considered, enabling to achieve a small nozzle pitch. Their behaviour is described using a waveguide theory for a single-nozzle printhead, which is then extended for multiple cavities. For the waveguide design, it is also possible to leave out the throttle, with an open connection to the main supply channel. The analysis of cross-talk is provided for different configurations and activation scenarios. Finally, the last two chapters deal with droplet formation, analysed for both positive and negative pulse and projected into modelling, and present theories on droplet flight, evaporation, impact, spreading, permeation and drying.

Besides the index, reading of the book is facilitated by the appendices on solving algebraic equations, Fourier decomposition of a pulse and toroidal coordinate system, as well as by the list of symbols related to geometric and material data, kinematics and dynamics, calculations of evaporation, droplet temperature, air drag and spreading, solution methods, pulse data, co-ordinate systems and dimensionless numbers. On the other hand, most of the experimental data could not be included to support the theoretical findings, because they are company confidential.



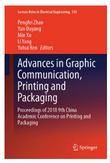

*Author: J. Frits Dijksman*

Publisher: Wiley-VCH
$1^{st}$ ed., February 2019
ISBN: 978-3-527-34266-2
472 pages
Hardcover
Available also as an eBook

## Advances in Graphic Communication, Printing and Packaging

*Editors: Pengfei Zhao, Yun Ouyang, Min Xu, Li Yang, Yuhui Ren*

Publisher: Springer
1st ed., April 2019
ISBN: 978-9811336621
1030 pages, 615 images
Hardcover
Also as an eBook

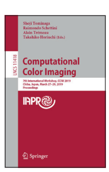



These Proceedings of the 9th China Academic Conference on Printing and Packaging held in November 2018 in Shandong consist of 138 reviewed papers selected from 236 submissions covering a wide variety of topics. These include the colour prediction model for digital printing, image restoration method for multiple degradation factors, interactive e-book for programming courses, feasibility of flexographic platemaking based on stereolithography, anti-counterfeiting system with augmented reality, UV-curable fluorescent inks with quantum dots, conductive films based on nanocrystalline cellulose, and durable superhydrophobic surface material with its application in packaging, to name a few.

## Computational Color Imaging

*Editors: Shoji Tominaga, Raimondo Schettini, Alain Trémeau, Takahiko Horiuchi*

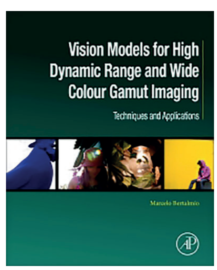
Publisher: Springer
1st ed., February 2019
ISBN: 978-3030139391
349 pages, 215 images
Softcover
Also as an eBook




The refereed proceedings of the 7th Computational Color Imaging Workshop held in Chiba, Japan in March 2019 bring three invited talks and a selection of the best 22 papers that were accepted for presentation and cover the areas of computational colour imaging, multispectral imaging, perceptual model and application, colour image evaluation, filtering and applications, and colour imaging for material appearance.

## Vision Models for High Dynamic Range and Wide Colour Gamut Imaging: Techniques and Applications

Based on the current knowledge of human vision and adaptation characteristics gained through neuroscience and psychophysics, this book discusses solutions for high-quality imaging applications with a focus on the issues of tone and colour gamut mapping. The introduction briefly presents the basic concepts and reviews the challenges connected with the adoption of high dynamic range and wide colour gamut technology. There is the need for new tools for colour management, grading, conversions and personalisation, as well as new projection systems for movie theatres. The following chapters provide the background on the biological basis of vision, describing the structure and function of the retina, lateral geniculate nucleus and visual cortex, together with the linear–nonlinear models. The next chapters deal with the phenomena crucial for efficient encoding of image information – adaptation, happening at all stages of the visual system to adjust its sensitivity, and brightness perception, depending on many factors. The book then explores the colour appearance problem and the utilisation of theoretical models in image processing for colour and contrast enhancement. Finally, the resulting algorithms for gamut and tone mapping in cinema are presented. The book concludes with a discussion of possible extensions and applications, as well as open problems. Overall, the author argues that the best-performing imaging techniques are those based on vision models while stressing the need for further study of visual perception to better utilise the emerging imaging and display technologies.




*Author: Marcelo Bertalmío*

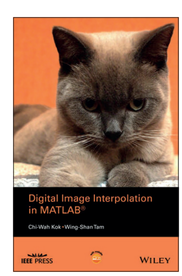
Publisher: Academic Press
1st ed., November 2019
ISBN: 978-0-12-813894-6
324 pages
Softcover
Available also as an eBook

## Digital Image Interpolation in Matlab

This book is intended to be the reference suitable also for courses and training in the field. The content is organised into chapters that present the basics of signal sampling, digital image processing and quality measures and then deal with the available image interpolation methods, going from nonadaptive interpolation, over transform and wavelet domain, to edge-directed, covariance-based and partitioned fractal interpolation. Besides the included exercises, the book is accompanied by Matlab source code available online.

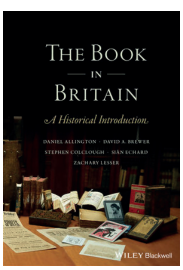
*Authors: Chi-Wah Kok, Wing-Shan Tam*

Publisher: Wiley-IEEE Press
1st ed., February 2019
ISBN: 978-1-119-11961-6
336 pages
Hardcover
Available also as an eBook



## The Book in Britain:
## A Historical Introduction

This book is a result of collaborative efforts of Zachary Lesser and his four co-authors sharing their expertise in different historical periods to present the long history of the book in Britain as a clear, up-to-date narrative with the coherence and readability of a monograph. After the introduction, the book has four parts, with three chapters each, spanning the period from the beginnings of book production in Britain up to the present time. The part on the Middle Ages and the Renaissance covers the early beginnings, changes after the Norman Conquest, technical vocabulary for the production and study of medieval manuscripts, rise of the urban scribe in the later Middle Ages, coming of print and growth of specialisations within the book trade, clarifying the roles of printer, publisher, bookseller and binder. The part on the Interregnum and the 18$^{th}$ century discusses the periodicals, journals, circulating libraries, dependence of politics on print and attempts at press regulation. The third part then deals with the consolidation at the turn of the century, the expansion of print culture and innovations that allowed the so-called distribution revolution during the 19$^{th}$ century, leading to the mass production and significant changes in copyright arrangements. Finally, the last part follows the developments in the 20$^{th}$ and 21$^{st}$ centuries, marked by the interactions of print with other mass media, mass-market paperback publications for the variety of audiences and all kinds of changes brought by the new materials and technologies, up to the digital publishing.




*Editor: Zachary Lesser*

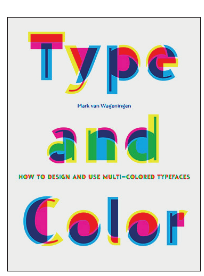
Publisher: Wiley-Blackwell
1$^{st}$ ed., March 2019
ISBN: 978-0-470-65493-4
512 pages
Hardcover
Available also as an eBook

## Type and Color:
## How to Design and Use Multicolored Typefaces

Being a pioneering designer of colour fonts, the author stresses that this book reflects his personal ideas and visions on type and typography, aiming to spark a debate about the legibility and usefulness of multicoloured typefaces, also known as chromatic type. The book introduces different approaches to their design and construction, starting with individual letters and then considering words and entire paragraphs. Further, it discusses the new possibilities that bring the applications of colourful fonts in print and digital media. As a bonus, the Typewood project is presented.

*Author: Mark van Wageningen*

Publisher: Princeton Architectural Press
1$^{st}$ ed., October 2019
ISBN: 978-1-61689-846-5
176 pages
Hardcover




## Advances in Human Factors in Communication of Design

*Editor: Amic G. Ho*


Publisher: Springer
1$^{st}$ ed., June 2019
ISBN: 978-3030204990
205 pages, 67 images
Softcover
Also as an eBook

This collection of reviewed papers is published as the Proceedings of the AHFE 2019 International Conference on Human Factors in Communication of Design, held in Washington, DC, USA in July 2019. It includes twenty papers divided into sections on communication design and practices, design in advertising and media communication, creative arts and communication in design. Within the research on the enriched communication and optimised design experience, the topics report on humanistic approaches, including the roles of human needs, emotions, thoughts and actions, discussing e.g. the essential transformation of the imaging techniques from conventional media to 3D scanning.

## Logo Design:
## Global Brands

*Editor: Julius Wiedemann*

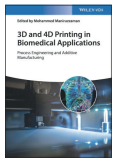

Publisher: Taschen
1$^{st}$ ed., August 2019
Multilingual edition:
English/French/German
ISBN: 978-3836576758
608 pages, Hardcover

This book is a second volume of the logo manual published in the Bibliotheca Universalis series, see Bookshelf section in 4(2015)3. This time, the catalogue focuses on corporate identity and presents approximately 4,500 trademarks together with information about the designers, year of creation, country and brand, covering the brands for consumer products and retail, fashion and apparel, finance, food and drink, government and institutions, industry, media, music and entertainment, service and business, and technology.

### 3D and 4D Printing in Biomedical Applications: Process Engineering and Additive Manufacturing

*Editor: Mohammed Maniruzzaman*

Publisher: Wiley-VCH
1st ed., March 2019
ISBN: 978-3527344437
496 pages
Hardcover
Also as an eBook

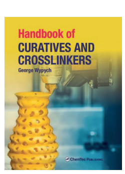



With 17 chapters written by authors or author teams representing both academia and industry, this book intends to be a professional source on 3D and 4D printing technology for biomedical and pharmaceutical applications, discussing also the trends, challenges and regulatory expectations. Several chapters present the advances in 3D and 4D printing, dealing with the technology, process engineering, optimisation and materials, including stimuli-responsive biomaterials and novel excipients. Further, the book explores the modification of drug release from 3D-printed pharmaceutical products, personalized polypills, bioscaffolding, metallic cellular scaffolds for bone implants, 3D and 4D scaffold-free bioprinting, orthopedic implant design and analysis, as well as the first example of a product approved for commercial use, which was made using the ZipDose technology for orodispersible dosage forms.

### Handbook of Curatives and Crosslinkers

*Author: George Wypych*

Publisher:
ChemTec Publishing
1st ed., March 2019
ISBN: 978-1927885475
258 pages, Hardcover
Also as an eBook




This volume presents both groups of additives that convert soluble monomers, prepolymers, oligomers or polymers to the insoluble polymer network, including their chemical and physical properties, mechanisms of their action, process parameters, etc.

### 3D and 4D Printing of Polymer Nanocomposite Materials: Processes, Applications, and Challenges

The main focus of this book, contributed by over 50 authors, is on the latest developments in polymer-based materials for the advanced 3D printing processes and also for 4D printing applications, where the printed part changes its shape and function with time in dependence on external conditions. The first chapter provides the overview of current technology, materials, software and hardware, 4D printing and recent trends. The next one presents processing considerations for reliable 3D/4D-printed nanocomposites, discussing the influence of nanoparticles on viscosity, thermal properties, vitrification, crystallisation and light interaction. The following chapters then deal in more detail with various applications and types of materials for 3D and 4D printing, including conductive composites for electrical circuits with both metal-based and carbon-based fillers, such as those based on carbon nanotubes or reinforced with graphene, graphene oxide or carbon black, electrically conductive, dielectric and insulating polymer composites for electronic applications, pH-responsive polymers and their composites, shape-memory polymer blends and composites, multifunctional polymer composites, photoactivate resin formulations and composites for optical applications, hydrogels and hydrogel composites, as well as fabrication of polymer micro- and nanostructures based on electrospinning. Three chapters deal with biomaterials and bioinspired composites and various medical and biomedical applications, such as medical devices and scaffolds for tissue engineering. The last chapter discusses challenges in polymer processing and prospects of future research in 3D and 4D printing of polymers.

*Editors: Kishor Kumar Sadasivuni, Kalim Deshmukh, Mariam AlAli AlMaadeed*

Publisher: Elsevier
1st ed., November 2019
ISBN: 978-0-12-816805-9
592 pages
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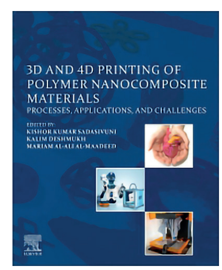
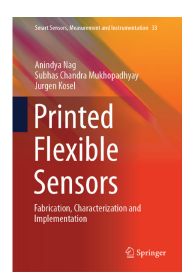



### Printed Flexible Sensors: Fabrication, Characterization and Implementation

This book provides the background in the first half and then explores novel routes for sensor fabrication using laser cutting and 3D printing. All four types of presented sensors are based on interdigitated electrodes made from carbon nanotubes and polydimethylsiloxane nanocomposite, aluminium, photo-thermally induced graphene and graphite, respectively, and were successfully implemented in various sensing applications.

*Authors: Anindya Nag, Subhas Chandra Mukhopadhyay, Jurgen Kosel*

Publisher: Springer
1st ed., March 2019
ISBN: 978-3-030-13764-9
198 pages
Hardcover
Available also as an eBook



# Bookshelf

## *Academic dissertations*

### On the Mechanics of Printed Electronics: Experimental and Numerical Investigations Using Cohesive Zone Models

Doctoral thesis – Summary

Author:
*Felix Heinrich*

Speciality field:
*Mechanics*

Supervisor:
*Rolf Lammering*

Defended:
*14 November 2018, Helmut-Schmidt-University / University of the Federal Armed Forces Hamburg, Department of Mechanical Engineering Hamburg, Germany*

Contact:
*heinrichfelix@gmx.de*

This thesis aimed to build a fundamental understanding of the mechanical behaviour of multifunctional composites enhanced with printed electronics. These can be used for structural health monitoring, where integrated sensors provide information about the monitored structure in order to identify damages in an early stage, which allows preventing serious failure. In particular, the thesis is focused on conductive nanosilver layers on carbon fibre reinforced polymers and their fracture behaviour, proposing the methods suitable for its study. The dissertation presents the relevant theoretical framework comprising fracture mechanics, with the comparison of cohesive zone models and explanation of principles of cohesive parameter identification. The experimental work employed mechanical testing of printed electronics on fibre reinforced composites, namely the double-cantilever beam and end-notched flexure tests for the investigation of normal separation and in-plane shear fracture behaviour, respectively. The experiments allowed to identify some of the damage relevant material parameters, which then helped to adjust and optimise the model in numerical simulations based on the finite element method. This enabled to find the remaining damage relevant material parameters. The results of testing and simulations are compared and discussed, as well the effect of cohesive zone model parameters on numerical simulations and the general applicability of the presented approach to investigations of multifunctional composites, including further considerations that are required in the case of more complex geometries. For the studied system, the application of printed electronics to the surface is less limited than its integration as a load-carrying component.

### Design and Characterisation of Sensors for Measuring Chemical and Biological Parameters Using Organic Thin-Film Transistors

Doctoral thesis – Summary

Author:
*Clara Pérez Fuster*

Original title:
*Diseño y caracterización de sensores para la medida de parámetros químicos y biológicos mediante Organic Thin-Film Transistors*

Speciality field:
*Electronic Engineering*

Supervisors:
*Eduardo García Breijo*
*Laura Contat Rodrigo*

Defended:
*18 February 2019, Polytechnic University of Valencia, Department of Electronic Engineering Valencia, Spain*

The general focus of research within this work was to design and characterise the organic thin-film transistors for chemical sensing of analytes. The main part comprised the study of two types of these devices, based on organic field-effect transistors and organic electrochemical transistors. The objective was to compare different structures and materials for the active, dielectric and conductive layers in order to select the most suitable materials and manufacturing technologies. The operation of sensors that utilise the organic field-effect transistors is mostly based on the exposition of the organic semiconductor layer to the analyte; the channel current modulated by the voltage applied to the gate electrode is then modified by charge doping or trapping due to the analyte. In the presented work, drop casting was used for the preparation of organic field-effect transistors with 6,13-bis(triisopropylsilylethynyl)pentacene (TIPS pentacene) as the organic semiconductor, and the electrical characteristics of the resulting transistors were obtained. In sensors based on the organic electrochemical transistors, the channel current is modulated by electrochemical doping or de-doping from the electrolyte that bridges the organic semiconductor film and the gate electrode, in dependence on the gate voltage applied. This thesis employed screen printing to prepare the organic electrochemical transistors using

Language:
*Spanish*

Contact:
*cperezf@eln.upv.es*

poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS) and investigated how the different ratios of channel and gate areas as well as the gate material affect the sensor sensitivity. The application for aqueous solutions of differently sized cations ($Na^+$ and Rhodamine B cation) yielded the response dependent on ion concentration in the case of transistors with non-polarisable Ag gate, while the all-PEDOT:PSS transistors showed weak modulation, as expected. The applicability of these sensors for detection of ascorbic acid was also successfully verified. In the former application, better performance was achieved for transistors with the gate electrode larger than the channel, whereas in the latter application it was vice versa.

Further, the research included the development of low-cost measurement equipment fulfilling the specific needs connected to the electrical characterisation of organic transistors. The system is controlled by a LabVIEW program allowing to determine most of the electrical parameters specified in the IEEE 1620-2008 standard that defines test methods for the characterisation of organic transistors and materials. To validate its function, the results measured with this equipment for the prepared organic field-effect transistors were compared with those obtained using the commercial instrument.

Doctoral thesis – Summary

Author:
*Uttam Kumar*

Speciality fields:
*Environmental Sustainability, Energy Storage*

Supervisors:
*Veena Harbhagwan Sahajwalla*
*Rakesh Kumar Joshi*
*Vaibhav Gaikwad*

Degree conferral:
*21 August 2019, UNSW, Faculty of Science, School of Materials Science and Engineering*
*Sydney, Australia*

Contact:
*uttam.kumar@unsw.edu.au*

## A Multi-Directional Approach to E-Waste Plastics Recycling: Ironmaking, Aromatic Oils and Energy Storage

The motivation for this thesis was to enhance environmental sustainability, in particular, to improve the situation in the recycling of electronic waste, which is challenging due to its complex composition, often containing hazardous materials. The presented approach is based on developing novel recycling routes and devising various value-added applications for the low-value plastic component of the e-waste, typically widely ignored compared to more economically interesting fractions. Namely, the work was focused on end-of-life printers and mainly on styrene-acrylonitrile type plastics that were identified as the dominant type of plastic in the mixture, with a carbon content of 79.67 %. The dissertation explains the issues connected to e-waste plastics and waste toner, along with the existing knowledge in areas of intended applications. It also introduces the related materials as well as the experimental and characterisation methods used within the study. The main part then describes the individual technologies proposed for recycling and utilisation of e-waste plastics. In the first application, the plastics from end-of-life printers were used as a source of carbon that assisted in iron extraction from toner powder through the reduction of $Fe_3O_4$ iron oxide to metallic iron. The remaining applications are based on a non-catalytic thermal transformation of e-waste plastics at isothermal conditions in an inert atmosphere. The gaseous degradation products generated by this process were trapped in dichloromethane to obtain hydrocarbon oils with a high calorific value (above 38 MJ/kg), comparable to commercial-grade fuels. According to analysis, toluene and styrene were the two most dominant aromatic hydrocarbons in these oils. The solid carbonaceous residues remaining after decomposition (about 5 %) were physically activated in the $CO_2$ atmosphere at 700–900 °C to produce porous activated carbons, which were then used for the preparation of electrodes in supercapacitors and anodes in sodium-ion batteries. The specific gravimetric capacitance of supercapacitor electrodes was approx. 220 F/g at 5 mV/s and the capacity of batteries stabilised at 190 mAh/g at 3 mA/g after 25 cycles. The batteries also exhibited superior rate capability. In the future outlook, the author proposes more possible energy-storage applications, including the development of a hybrid solution, combining the supercapacitor and battery systems.

# Events

## Color 2020

San Diego, California, USA
11–14 January 2020

Keeping the proven format, this conference presented by Printing Industries of America and SGIA (Specialty Graphic Imaging Association) first offers the afternoon pre-conference session on the fundamentals of colour management and for the 2020 volume also another one, which is focused on the truly challenging colour management processes in fine art reproduction. The latter one covers lighting, camera position, camera and printer profiling, points of control, customer expectations, special printing papers, viewing conditions and colour gamuts. Both sessions are free to all attendees. The keynotes announced for the three conference days are 'Colors of life' by Frans Lanting, a great photographer sharing how he interprets colour in the natural world, 'Improving printer–brand relations' by James Hillman, including practical examples, 'The power of the perfect color' by Scott Lucas, exploring the role of colour in defining a brand, "Hey man, I ordered a burger!" by Jason Troutman, discussing the relationship between designers and printers and how it impacts the customer experience, and 'Is color standardization more difficult than milking a duck? Let's ask the milkmaid' by Cecile van der Harten, presenting the specifics of colour management in museum imaging.

Further, the programme features almost thirty sessions with the fundamental, intermediate as well as advanced content in three tracks dedicated to print and production, brand and design, and standards, research and case studies. New to COLOR20 are Color Tools breakout sessions scheduled on Sunday in the mid-afternoon, concisely presenting the latest technologies and techniques.

## EI 2020 – IS&T International Symposium on Electronic Imaging

Burlingame, California, USA
26–30 January 2020

For the 2020 edition, this event includes 17 technical conferences covering all aspects of electronic imaging and offers 26 technical short courses in the areas of automotive imaging, 3D, augmented/virtual reality and stereoscopic imaging, computer and machine vision, deep learning, digital camera technology, mobile imaging, human vision, perception, art, image quality and security, and newly also the workshops on food and agricultural imaging systems. The plenary speakers are Katie Bouman with the lecture 'Imaging the unseen: taking the first picture of a black hole', Gary Hicok presenting 'Imaging in the autonomous vehicle revolution', and Douglas Lanman exploring the expected impact of individualised eye tracking on head-mounted displays in the talk 'Quality screen time: leveraging computational displays for spatial computing'. Besides the regular lectures and poster presentations, the event programme includes 21 joint sessions common for two or three conferences, over 20 keynotes, demonstrations, and more.

## EFI Connect 2020

Las Vegas, Nevada, USA
21–24 January 2020

For this edition, the EFI users' conference combines over a hundred sessions during the first three days. After the Tuesday morning sessions reserved for business management and reporting, the main programme begins with Jeff Jacobson, Ken Hanulec, Don Hutcheson, Gabriel Matsliach and Toby Weiss as plenary speakers and breakout sessions covering production management, web-to-print, display graphics, prepress, quoting, estimating, scheduling, variable data printing, cross-media marketing, information technologies, integration, customer and order management, shipping, logistics, finance and accounting. On the third day, also the first part of a two-day G7 training is scheduled, explaining in-depth the Idealliance's set of specifications. It continues on the last day as the only session.

## 3D Printing Electronics Conference

Eindhoven,
The Netherlands
28 January 2020

In 2020, this Jakajima event brings talks on various 3D-printed multi-functional structures, electronics for mechatronic systems, inkjet-based fabrication, roughness reduction and functional coating deposition with ultrasonic spray coating, advances in fused deposition modelling and non-contact measurement enabling in-line inspection of printed conductors, presenting also the insight of the strategy in the industry, non-obvious opportunities, innovations through cross-industrial consortium projects and several project cases connected to printed electronics.

## WAN-IFRA Events

In the first months of 2020, the World Association of News Publishers offers two events in India: the workshops on digital journalism for print and broadcast journalists in Cochin (20–21 January) and the 9th Digital Media India conference in Delhi (18–19 February). In March begins the Newsroom Transformation Programme 2020, lasting till the end of September. This learning and coaching programme for newsroom leaders takes place in Singapore, where also the Asian Media Leaders Summit is held on 11–12 March. From 31 March to 1 April, Digital Media Europe 2020 is organised in Vienna, Austria. It combines the Subscription Marketing conference (with the Local Digital Subscription Summit) and the Premium Advertising conference, complemented by the European Digital Media Awards 2020 ceremony.

## Optical Document Security 2020

San Francisco,
California, USA
29–31 January 2020

This biennial Reconnaissance event presents the developments in security features, substrates, inks, imaging technologies, smart printing, optically variable devices and micro- and nano-optics. The 2020 programme starts with an afternoon course on detection and techniques of banknote and identity documents counterfeiting. The conference sessions then cover the topics ranging from human factors and design, over novel materials and production innovations, such as selected photoactive compounds and partially automation of the intaglio image creation, up to optical security interaction with smartphones, examination and authentication.

Later in the year 2020, Reconnaissance organises the High Security Printing EMEA in Lisbon, Portugal (9–11 March) and the High Security Printing Latin America in Mexico City, Mexico (1–3 June).

## innoLAE 2020
## Innovations in Large-Area Electronics

Cambridge, UK
21–22 January 2020

This annual conference is organised by the EPSRC Centre for Innovative Manufacturing in Large-Area Electronics and successfully presents the academic and industrial advances in the field, with an emphasis on manufacturing. In its 6th year, the programme includes three plenary sessions with Emre Ozer, Mark D. Poliks and Richard Friend as keynote speakers, complemented by the lecture reviewing the steps towards volume manufacture by Mike Clausen. The individual sessions, dedicated to novel devices and systems, large-area electronics for energy, applications enabled by advanced manufacturing, bioelectronics, emerging technology for displays, high-performance materials for large-area electronics, wearables for healthcare, sensors and advanced manufacturing processes and equipment, are then scheduled in two or three parallel tracks and feature over ten invited speakers.

## IMI Events

Since September 2019, IMI Europe has become a partner of the above-presented innoLAE conference and provides two short courses covering the fabrication technologies for large-area electronics on the day preceding the conference, 20 January 2020. The wet-processing technologies include screen, inkjet, flexo and gravure printing and also several coating techniques, while the dry-processing technologies include vacuum deposition, photolithography, laser ablation and etching.

A week later, IMI Europe Inkjet Winter Workshop 2020 is organised in Bilbao, Spain (27–31 January). Again, the workshop comprises six technical courses, each scheduled for a day and a half. The participants can choose from three sets of concurrent courses: the Inkjet Academy and the course on digital textile printing as the first, then from the courses dealing with inkjet inks – either with their characterisation or their materials and applications and at the end of the week from the courses covering inkjet ink manufacturing and single-pass inkjet system design.

In 2020, IMI Europe also partners with TCM (Technical Conference Management) and provides the one-day Inkjet Technology for Décor Printing course at their established event, Decorative Surface Conference; its 2020 edition takes place in Vienna, Austria on 17–19 March.

In the USA, the IMI Inkjet Innovation Academy is held in Tempe, Arizona on 10–11 February 2020, followed by the IMI Inkjet Conference 2020 taking place in the same venue on 12–13 February. The first two days offer three courses. While the Inkjet Academy explains the theory of inkjet technology, the other two courses are more practice-oriented. One is focused on industrial inkjet system design and one deals with inkjet inks. The conference programme then covers the outlook for the inkjet industry in 2025, review of inkjet patents, situation on home and office inkjet markets, printhead technology responses to market trends, innovations presented by major producers, technology of interactive publications, waterless smart digital dyeing, heterogeneous imaging systems, software correction methods and waveform tuning, among other topics.

## SPIE Events

### Photonics West 2020

SPIE. PHOTONICS WEST San Francisco, California, USA
1–6 February 2020

This large event features over five thousand technical contributions, plenary presentations, panel discussions, poster sessions, numerous courses, workshops, student events, industry sessions and other networking opportunities, that all complemented by two exhibitions. Also for this edition, dozens of papers on innovative uses of 3D printing are highlighted within a dedicated application track, SPIE Applications of 3D Printing 2020. These present, among others, organic light-emitting diodes with the inkjet-printed transparent anode on the resin substrate produced by additive manufacturing. In addition, the Augmented, Virtual, and Mixed Reality Conference 2020 organised by SPIE is co-located on 2–4 February.

### Photonics Europe 2020

SPIE. PHOTONICS EUROPE Strasbourg, France
29 March to 2 April 2020

Similarly to its American counterpart, also the European optics and photonics event provided by SPIE brings rich programme covering many advanced topics, including the research that utilises some printing technology – for example, the paper presenting inkjet printing of multiple layers for large-scale, cadmium-free electroluminescent quantum dot light-emitting diodes.

## 7th Colour Management Symposium

fogra Munich, Germany
12–13 February 2020

The seventh edition of this event invites the participants to seven sessions. The first six cover the common topics, namely the customer expectations and colour management throughout the value chain, CMYK as well as the extended gamut printing, multicolour packaging implementations, high-speed inkjet in industrial printing applications, colour communication for fashion textile industry and colour proofing for packaging and textile applications. The last session deals with the 3D soft proof and appearance measurement.

## FLEX / MSTC 2020

FLEX MEMS & SENSORS Technical Congress
February 24–27 2020 | DoubleTree by Hilton | San Jose, CA

San Jose, California, USA
24–27 February 2020

The FLEX conference is co-located with the MEMS & Sensors Technical Congress. The programme opens the Women-In-Tech session with a discussion around diversity and workforce development in the electronics manufacturing industry. On the second day, it continues with keynotes exploring various advances beyond flexible hybrid electronics, such as the biodegradable electronics and design of organic electronic materials to mimic skin functions, followed by the regular sessions. The last day then offers four courses. In addition, the NextFlex Technology Hub Tour is organised on 28 February.

## Packaging, Labelling and Printing Events by EasyFairs

EASYFAIRS Visit the future

The ADF&PCD and PLD Paris event presenting the packaging for perfume, cosmetics and premium drinks is held in France on 29–30 January 2020. One month later, the Packaging Innovations Birmingham event takes place in the United Kingdom (26–27 February), combined with the Ecopack, Contract Pack and Fulfilment, Label&Print and Empack shows. Two events are then organised in The Netherlands: the Sign & Print Festival in Gorinchem (11–12 March) and the Empack in Utrecht (31 March to 2 April).

## C!print

Lyon, France
4–6 February 2020

C!print

As usual, the 2020 show schedule combines the conferences with theme tours, workshops and demonstrations. The discussed topics include, for example, the challenges of recruitment and training in the graphic arts industry, diversification in textile printing and succeeding in a web-to-print project.

## VISIGRAPP 2020
### 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications

Valletta, Malta
27–29 February 2020

The 2020 edition of this joint international event comprising four conferences is held in conjunction with the conferences on sensor networks (SENSORNETS), information systems security and privacy (ICISSP) and photonics, optics and laser technology (PHOTOPTICS). The topic of one of the keynote talks is how to deal with experimental pitfalls.

### Digiday Publishing Summits

At the beginning of March 2020, the Digiday Publishing Summit Europe takes place in Dubrovnik, Croatia on 3–5 March, examining how media owners across Europe are building products to monetise audiences, elaborating their advertising strategies without third-party cookies, and more. Three weeks later (25–27 March), the US edition of the Digiday Publishing Summit can be joined in Vail, Colorado.

### FESPA Events

After the first 2020 event organised by FESPA for the wide-format digital, textile and screen-printing sectors, which is the FESPA Global Summit in Bangkok, Thailand on 16–17 January, four exhibitions are scheduled in March. On 18–20 March, the FESPA Brasil is held in São Paulo, while the other three events are co-located in Madrid, Spain on 24–27 March. These include the Global Print Expo for speciality printing, the European Sign Expo for non-printed signage and visual communications and the Sportswear Pro, a brand new exhibition focused on the technology for on-demand and customised sports and activewear production.

### Asia Packaging & Printing Industry Expo

Shenzen, China
19–21 March 2020

This large international exhibition for packaging and printing companies, APPI 2020, aims to connect hundreds of quality exhibitors with global buyers. The trade fair showcases the printing technology together with a wide range of packaging products, including flexible packaging, functional packaging, luxury packaging, label identification and anti-counterfeiting features, as well as the related materials, accessories and equipment.

### TAGA 2020 Annual Technical Conference

Oklahoma City, Oklahoma, USA
15–18 March 2020

For 2020, the annual conference organised by the Technical Association of the Graphic Arts features the keynotes 'Circular economy and sustainability solutions in packaging' by Todd Fayne, examining how to address the many facets of sustainability while balancing other business imperatives, including changing consumer preferences, 'Industrial custom printing: a status report' by Craig Reid, reviewing the new possibilities in digital print packaging, direct-to-shape, direct-to-object, textile and industrial printing applications and discussing how to properly integrate chemistry, substrate, system components, process and workflow to take advantage of new high-quality graphic options, 'Technology innovation and the success of failure' by David Crawley, showing how to create an environment that breeds meaningfully unique solutions while leveraging the disciplines of systems-thinking processes and tools, and 'An ink supplier perspective on Industry 4.0' presented by Juanita Parris, discussing the changes in printing and related industries brought about by the digitisation of manufacturing and the trends towards the print manufacturing process controlled without human involvement.

Looking at the topics of the announced presentations, many papers deal with new materials, technology advancements or process improvements. These include the studies on hydrochromic ink used as a safety feature, soy-based flexographic inks for packaging, UV-LED low-migration laminating adhesives for flexible packaging, fabrication of crack-free $TiO_2$ thin film by 3D printing, progress in water-based processing of flexo plates, manufacturing and integrating printed electronics, corona treating technology for improving ink adhesion, eliminating banding in inkjet output, improving the workflow for personalised packaging, exposure risk assessment, using artificial intelligence for planning and imposition, etc. Several contributions are related to colour reproduction, such as those focused on quantification of metamerism in the graphic arts, consistent display of Clemson brand colours using artificial intelligence, comparison of proofing for offset presses using GRACoL and ICC profiles, investigation of process control based on near-neutral scale and tone value increase and colour gamut extension on four-colour sheet-fed offset press using ink fountain divider. The lectures dealing with characterisation include, for example, the talks on a consistent determination of the opacity of white inks, lay-flat degree for books, the whiteness of papers containing fluorescent whitening agents under CIE D50 and the evaluation of available ISO 13655 backing materials and measurement differences for the packaging industry. Other presentations cover the cybersecurity awareness in the variable data and direct mail printing industries and the deployment of tracking technologies in digital inkjet corrugated production. The schedule also includes the tour to Quad/Graphics.

### LOPEC 2020

Munich, Germany
24–26 March 2020

Traditionally, the 2020 programme starts with a plenary session each day of the conference, followed by short courses and business conference sessions on the first day and by technical and scientific presentations on the remaining two days, when the exhibition and LOPEC Forum can be attended as well.

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A PEER-REVIEWED QUARTERLY Research

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# Call for papers

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# Vol. 9, 2020

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### A – General

The text should be cohesive, logically organized, and thus easy to follow by someone with common knowledge in the field. Do not include information that is not relevant to your research question(s) stated in the introduction.

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### B – Structure of the manuscript

#### Preliminary

**Title:** Should be concise and unambiguous, and must reflect the contents of the article. Information given in the title does not need to be repeated in the abstract (as they are always published jointly), although some overlap is unavoidable.

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**Abstract:** Should not exceed 500 words. Briefly explain why you conducted the research (background), what question(s) you answer (objectives), how you performed the research (methods), what you found (results: major data, relationships), and your interpretation and main consequences of your findings (discussion, conclusions). The abstract must reflect the content of the article, including all keywords, as for most readers it will be the major source of information about your research. Make sure that all the information given in the abstract also appears in the main body of the article.

**Keywords:** Include three to five relevant scientific terms that are not mentioned in the title. Keep the keywords specific. Avoid more general and/or descriptive terms, unless your research has strong interdisciplinary significance.

#### Scientific content

**Introduction and background:** Explain why it was necessary to carry out the research and the specific research question(s) you will answer. Start from more general issues and gradually focus on your research question(s). Describe relevant earlier research in the area and how your work is related to this.

**Methods:** Describe in detail how the research was carried out (e.g. study area, data collection, criteria, origin of analyzed material, sample size, number of measurements, equipment, data analysis, statistical methods and software used). All factors that could have affected the results need to be considered. Make sure that you comply with the ethical standards, with respect to the environmental protection, other authors and their published works, etc.

**Results:** Present the new results of your research (previously published data should not be included in this section). All tables and figures must be mentioned in the main body of the article, in the order in which they appear. Make sure that the statistical analysis is appropriate. Do not fabricate or distort any data, and do not exclude any important data; similarly, do not manipulate images to make a false impression on readers.

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