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A letter from the Editor

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Dear Readers,

With this closing issue of Volume 13, we round off a year that has powerfully demonstrated how print and media technology continues branching into new functional domains while refining its classical strengths. The three peer-reviewed articles collected in this issue reflect that dual dynamic of process insight and function integration.

The first article in this issue, titled "Development of a 3D-Formed and Thin-Film Back-Lit HMI," by Gunter Hübner, Katrin Mayer, Wolfgang Kaefer, and Klaus Schmidt (Hochschule der Medien – IAD; Marquardt; Motherson) charts a decade-long, tri-project journey. It begins with screen-printed capacitive and piezo sensors on transparent polycarbonate, moves through thermoforming and overmoulding, and culminates in the integration of electroluminescent layers and innovative varnish-suspended micro-LEDs. The review offers both a state-of-the-art map and a technology roadmap for seamless, lightweight user-interface surfaces in automotive and consumer devices.

The second paper, "Optimization and forecasting models of the sublimation printing process on textile materials" by Vyacheslav Repeta, Yurii Petriv, and Yurii Kukura (Lviv Polytechnic National University), applies Taguchi design and fuzzy-logic modelling to transfer printing. Their analysis reveals temperature and substrate absorbency as the dominant factors for optical density. The authors' fuzzy knowledge base then forecasts CMYK density with remarkable accuracy, laying a data-driven foundation for tighter control of colour in high-throughput textile lines.

The final paper of this issue, by Cecilia Rydefalk, Sofia Thorman, Anton Hagman, and Artem Kulachenko (KTH Royal Institute of Technology / RISE Research Institutes of Sweden), is titled "Separating the Effects of Maximum Pressure and Printing-Nip Length on Flexographic Print Quality." The authors devised the use of a lab printing press to decouple peak pressure from nip length, performing controlled load cases to study their independent effects. Printing was done in solid tone and halftone, with results evaluated for mottle, density, and dot gain. They found that increasing the maximum pressure boosts color density. Conversely, increasing the nip length at a fixed maximum pressure slightly decreases colour density, a change attributed to an alteration in the ink split point. This nuanced finding offers direct implications for packaging printers aiming to optimize both coverage and mottle control.

Together, these studies remind us that scientific rigour – whether carried out with precision sensors, extended matrices based on Design of Experiments, or rule sets derived from artificial intelligence – remains the clearest path to reliable industrial application.

Our Topicalities pages, expertly compiled by Markéta Držková, survey the latest standards, as well as progress briefs from Fogra's Print 4.0 research programme.

The Bookshelf highlights, alongside monographs on printed electronics, textile functionalisation, and immersive-media workflows, three AI-centred volumes – Artificial Intelligence in Manufacturing: Enabling Intelligent, Flexible and Cost-Effective Production Through AI; Artificial Intelligence in Manufacturing: Applications and Case Studies; and Intelligent Fractal-Based Image Analysis: Applications in Pattern Recognition and Machine Vision. Three freshly defended doctoral theses then round out the panorama of emerging scholarship.

We also mark the passing of Dr. J. Anthony Bristow, honorary member of iarigai and former Technical Editor of Advances in Printing Science and Technology, who died on 7 June 2025 at the age of 93. Less than two years ago, in Vol. 12 No. 3 (2023) in this Journal, Tony contributed the position paper "What about the surphase?"– a concise but insightful plea for distinguishing a material's surphase from its mathematically defined surface layer, which powerfully illustrates his unceasing dedication to precision in paper science and scientific terminology. Tony's insistence on meticulous peer review and clear scientific English laid much of the groundwork on which iarigai publications, including this Journal, still rely. We dedicate the present issue to his memory.

Looking ahead, I encourage you to join the iarigai annual conference in Pardubice, Czech Republic, from 2 to 5 September 2025.

My heartfelt thanks go to our authors, reviewers, and editors – and to you, our readers – or another year of rigorous exchange. Your curiosity and critical eye keep the field vibrant.

Wuppertal, June 2025

Daniel Bohn

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Development of a 3D-formed and thin-film backlit HMI

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Abstract

During three subsequent research projects in co-operation with industrial partners, thin printed touch sensors were developed and investigated. In the first project the touch sensors employing the capacitive or piezoelectric principle were screen-printed as thin-film sheets of transparent polycarbonate. In the second project, these thin-film sheets were 3D-formed through thermoforming and over-moulding process. In the third project, a thin-film light source was printed onto the backside of the transparent sensors. The backlighting was achieved using either electroluminescence or an innovative technique of micro-LEDs suspended in a printed varnish, a proprietary method developed by the company NthDegree.

Keywords: screen-printing; micro-LED lighting, touch sensors, Human Machine Interface (HMI), 3D forming

1. Introduction

In recent years, the interior design of cars has undergone significant changes. Mechanical switches have almost completely disappeared, replaced by smart controls with touch-sensitive activation. However, for simplicity, large TV-like touch screens currently dominate dashboards. To allow designers to return to curved shapes, touch controls implemented in thin 3D-formed parts would be desirable. This goal has been pursued through three consecutive research projects funded by the Ministry of Science and Culture of the federal state Baden-Württemberg under the “Innovative Projekte” (innovative projects) program.

Thus, at the Institut für Innovative Anwendungen der Drucktechnologien (IAD) in co-operation with industrial partners thin, printed touch sensors were fabricated and thoroughly investigated. In the first project, touch sensors operating on the capacitive principle, were produced as thin-films made of transparent polycarbonate using a screen-printing process. An attempt was made to provide haptic feedback to the user upon switch activation through vibration of a printed piezo element placed beneath the capacitive touch sensor. The printed piezo element was found to vibrate optimally at frequencies between 250 and 300 Hz, but the amplitude proved too be too low for user perception in a moving vehicle environment. However, the printed piezo stack itself demonstrated potential as a sensor, as it generates a detectable transient signal that can be detected easily and reliably by the evaluation software when pressed. This capability proved to be even more advantageous than that of a capacitive sensor, as the

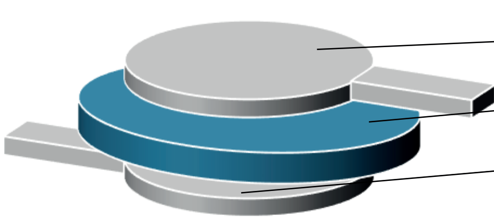


Figure 1: Schematic of the printed piezo-effect touch sensor

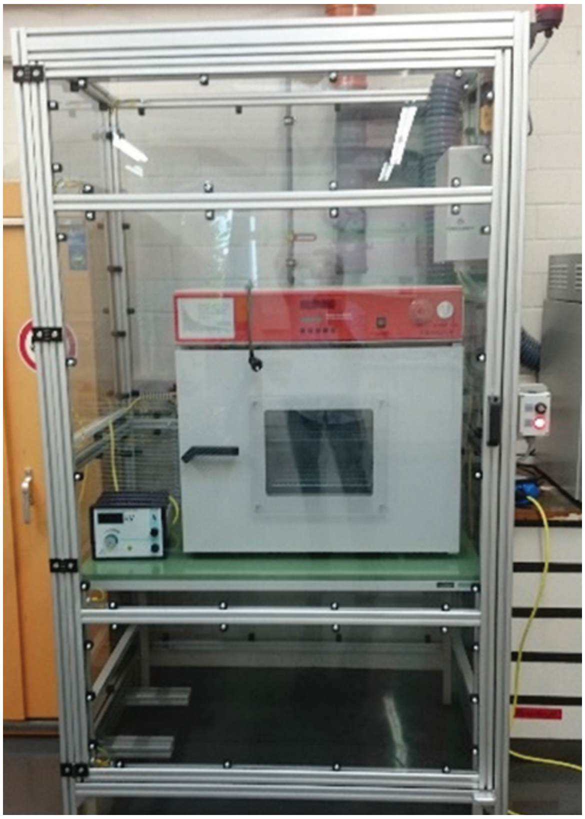


Figure 2: Safety housing around an oven to polarise the printed piezo-effect touch sensor permanently at elevated temperature and high electrical voltage

Figure 3: Large sample printed piezo-effect touch sensor

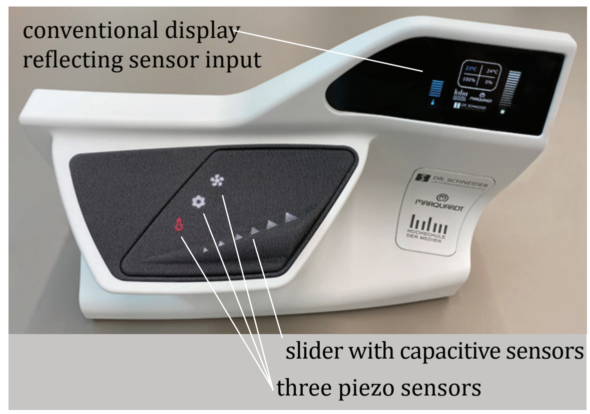


Figure 4: Demonstrator with three piezo sensors, a slider with capacitive sensors and a conventional display reflecting sensor input

piezo sensor's force requirement provides protection against unintentional activation.

The piezo sensor developed in the first two of these three projects was already reported on at the 2018 iarigai conference (Huebner, et al., 2018). Figure 1 illustrates the basic concept of the touch sensors based on the piezo-effect. The challenge was the layer of PVDF-TrFE (poly(vinylidene fluoride-co-trifluoroethylene)material. The solids content of the paste is very low and several successive prints (at least four print passes) were necessary to achieve a desired layer thickness of 16 to 20 μm while maintaining sufficient electrical dielectric strength.

After printing of the PVDF-TrFE layer (figure 3) with several print runs the layer must undergo polarization at elevated temperatures. High voltage (several thousand volts) is applied to the top and bottom electrodes during the stay in the oven. The oven therefore is placed in a safety housing (see Figure 2), with the voltage automatically disconnecting when the housing door is opened.

In the second project, the thin-film sheets were 3D-formed (thermoforming and subsequently over-moulding). The challenge is to maintain the function after the forming and over-moulding process. The result of this second step was a demonstrator (Figure 4). The sensors have conventional LED-lighting from behind. This demonstrator won the OE-A price at LOPEC 2023.

In the third project, which is the focus of this paper, a thin-film light source was printed onto the backside of the transparent sensors. In comparison to classical, rigid SMD-LED placements, the idea was to print light-emitting layers that are extremely thin in the range of a few microns (excluding substrates).

Two techniques for lighting up from behind were investigated. First, the well-known electroluminescence (EL) was employed and second, a proprietary technique of micro-LEDs suspended in a printed varnish (a method developed by the company NthDegree, Tempe AZ, USA).

Figure 5 shows sample light sources printed by NthDegree. Their process accommodates both screen-printing and flexography.

It can clearly be seen that the micro-LEDs are distributed randomly. The dimensions of the micro-LEDs are about 20 μm in diameter as can be seen on the SEM-photo (Figure 6) taken from US Patent 9,425,357 B2 (Lowenthal, et al., 2016).

Figure 5: Printed micro-LED lamps

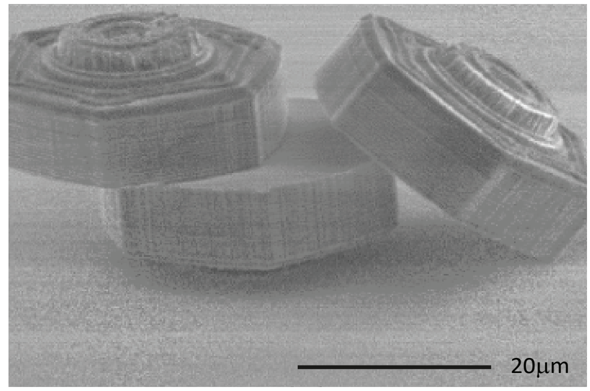


Figure 6: Micro-LED lamps (Lowenthal, et al., 2016)

The micro-LEDs feature electrodes at the top and bottom and the light is emitted upwards. The patented technology somehow makes it possible for the lower electrode of the LEDs to sink downwards and orientate itself to the conductive silver layer underneath. The dielectric layers are necessary so that the transparent top conductor layer does not get in touch with the bottom conductive layer. According to NthDegree, approximately 70 % of the LEDs can be illuminated using this method. The phosphor layer is applied to make the light of the blue micro-LEDs appear white (wavelength shifting with the help of YAG, yttrium-aluminium-garnet). NthDegree's innovative approach to printing the micro-LEDs also made it possible to print in reverse order, i.e. the transparent conductive electrode first and the Ag electrode last, so that the light is directed onto the substrate. This project utilized screen-printing in reverse order.

The visibility of the lighting is determined by the illuminance, which is specified in candelas per square metre (cd/m^2). Automotive applications typically require illuminance exceeding 500 cd/m^2, with 1 000 cd/m^2 representing ideal conditions. For night design applications, around 10 cd/m^2 is sufficient.

2. Research methods

The third step, implementing the light-emitting layer, utilized the same layout as previous steps due to the existing thermoforming and moulding tools, as creating new tools would be cost-prohibitive. The key difference now is that the function, i.e. the touch sensors and the illumination layers are printed on the same substrate, the illumination on the top side and the touch sensors on the bottom side. This substrate is referred to as the B-surface, i.e. the back of the side facing the user. Both, the sensors and the lighting, are printed on the B-surface, with the lighting being printed first. The decorative surface visible to the end user is called A-surface. To finalize the part, both foils (A-surface and B-surface) are placed into an injection moulding device, where the stiffening plastic is injected between the two substrates. This setup is depicted in Figure 8.

In this project, piezo sensors were not employed as capacitive touch sensors offer simpler manufacturing processes and more reliable functionality. Moreover, the forming capability of the piezo sensors was already shown in the second project step.

The investigation covered two thin-film illumination techniques: electroluminescence and the printed micro-LED approach.

2.1 Lighting with electroluminescence

This technique is well known, and it has been shown that the printed sheets can be thermoformed quite easily (e.g., Chang, 2019). Figure 9 shows the basic struc-

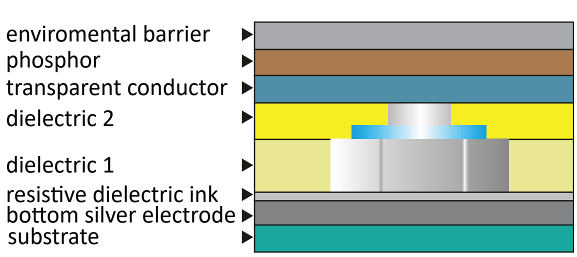


Figure 7: Sequence of printed layers with micro-LEDs (Claypole, 2019)

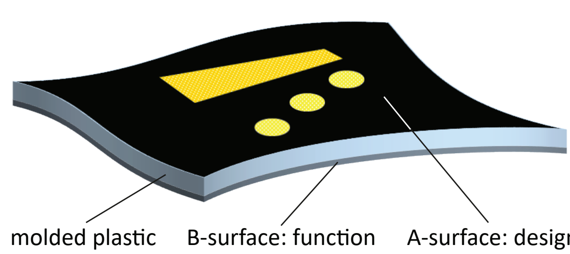


Figure 8: Basic design of the demonstrator with three buttons and a slider

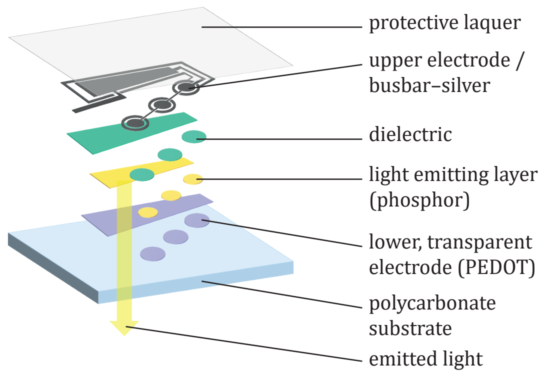


Figure 9: Layer sequence of printed electroluminescent lamp. PEDOT is the cationic species of poly(3,4-ethylenedioxythiophene)

ture of the screen-printed EL lamp used in this project, comprising substrate (polycarbonate, PC), transparent electrode, emitting layer (commonly referred to as 'phosphor', typically doped zinc sulphide), dielectric (insulating layer), electrode, and protective layer.

During testing, forming process challenges led to cracking of printed layer, compromising lamp functionality. A protective coating from the ink manufacturer Pröll, which was specially developed for in-mould electronics (IME), showed better results, particularly when applied as a double layer, but could not guarantee 100 % yield. Figure 10 (a) shows such a crack that occurs after thermoforming. The cracks occur where the conductor track merges into the slider. To overcome the cracking issue, the design was modified by trying to avoid the hump and thus, some working lamps could be produced. However, the achieved illuminance was only around 50 cd/m^2, which is not sufficient for the desired application. In addition to the project partner Dr Schneider GmbH (now Motherson DRSC Deutschland GmbH), a further industrial partnership was established with Niebling GmbH during the project. Niebling has developed a forming method called high pressure forming (HPF), which is somewhat 'gentler' than the classic 'vacuum forming' at Dr Schneider, as the preheating temperature of the film is significantly lower, while the temperature of the forming tool is quite similar. Ten EL lamp prints were formed using Niebling's HPF process and remained functional but achieved illuminance no higher than 70 cd/m^2. Niebling reported successful EL forming in previous industrial trials (unpublished).

2.2 Lighting with micro-LEDs

The most challenging part of the research is the 3D forming and overmoulding of the printed structures, especially as the suspension of the micro-LEDs in a printing paste is quite expensive and the risk of damage during the forming and moulding tests is high. Preliminary testing of printing ink stretchability and formability was therefore conducted. Various silver pastes marketed for in-mould electronics were evaluated using a test moulding tool featuring 0.5 and 1 mm wide lines with increasing stretch factors (1 to 2.5) and defined edge radii. Figure 11 shows the printing layout (a) and the moulded plastic part (b).

Another aim of the test prints was to find out whether PET could be used instead of PC, as NthDegree had better experience with PET than PC for its products, but PC is used almost exclusively in the automotive industry.

As the silver print has direct contact with the moulding tool, a protective lacquer is also used, which is applied in a second printing process and is intended to further support successful forming. For this purpose, both the varnishes corresponding to the respective paste and two different varnishes from Pröll GmbH were tested, namely the solvent-based varnishes Noriphan HTR N 093/444 (one-component) and Noriphan N2K (two-component).

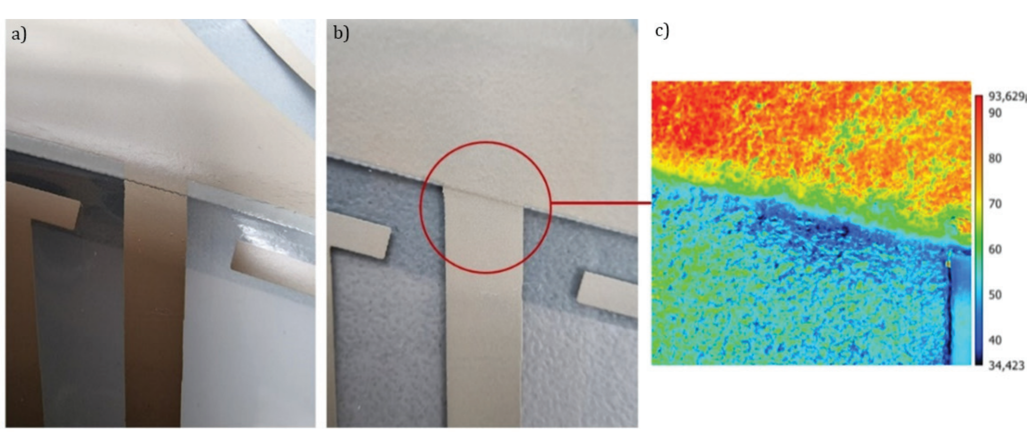


Figure 10: a) Crack after forming; b) enlarged before forming; c) height profile of the print before forming (ranging from 34.423 to 93.629 µm)

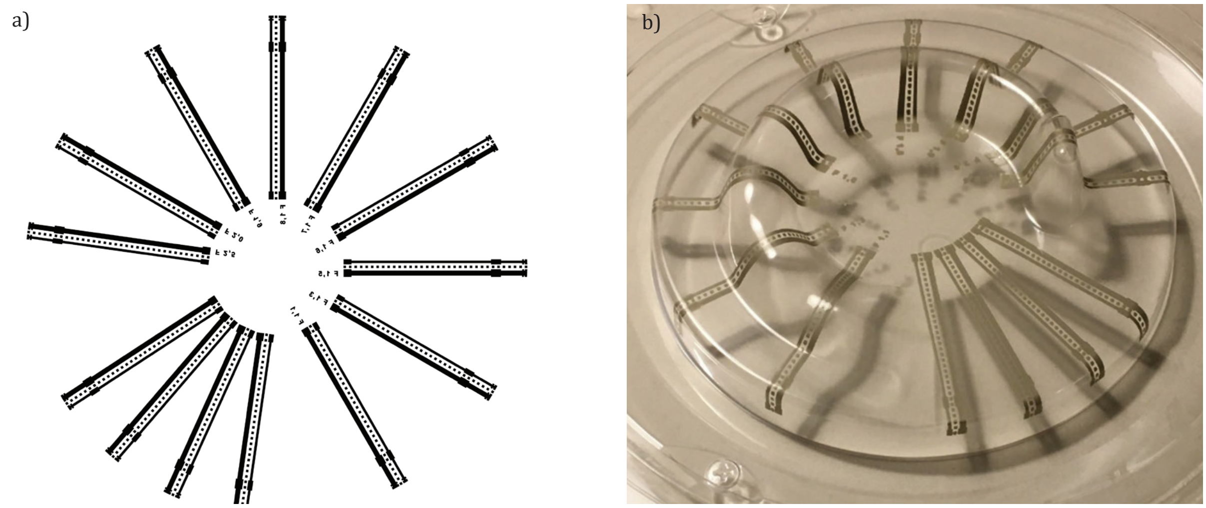


Figure 11: Printed test pattern (a); formed polycarbonate sheet (b)

Some prints were produced at NthDegree and some at the HdM in order to subsequently carry out the forming tests at Niebling (HPF) and also at Dr Schneider (vacuum thermoforming process). With HPF, it is possible to work with comparatively low film-forming temperatures. The results show that there are virtually no differences between the various silver pastes in terms of electrical performance and visual inspection before thermoforming, regardless of whether PET or PC was used.

After thermoforming, the picture is different:

- The printed lines on PET are interrupted at significantly lower stretch factors and therefore lose conductivity.
- When comparing the varnishes recommended by the manufacturer with those from Pröll, the Pröll HTR N 093/444 is particularly favourable.
- All silver pastes showed comparable conductivity when using Pröll varnish.
- Visual inspection of the forming with the HPF technology shows always better results than with the classical vacuum forming.

As the B-surface is also to be printed with silver paste on the front and then over-moulded with plastic in the further course of the project, adhesion to the injection moulding material is crucial. Peeling tests were carried out for this purpose. Peeling tests identified the Elantas silver layer (Bectron CP 6680) with Pröll protective coating (HTR N 093/444) as the best-performing combination, which was adopted for subsequent work.

As the micro-LEDs emit blue light (450nm), but a white colour is desired, a phosphor layer is "phosphor" is necessary. The term "phosphor" refers to cerium-doped yttrium aluminium garnet (YAG), which functions as a wavelength shifter similar to standard white LED production. Tests were carried out whether this phosphor layer is also formable without defects. The phosphor is supplied as a powder and is stirred into the clear lacquer HTR N 093/444 from Pröll GmbH for printing. The forming tests showed no cracks, and a homogenous layer was maintained. Without illumination with blue light, the print appears yellowish as shown in Figure 12. NthDegree has some experience and provided empirical values for the recommended CIE b^*-values. They were measured with a spectrophotometer and showed sufficiently high values.

Based on these preliminary tests the layout of the B-surface was fixed as shown in Figure 13.

Figure 14 details the layout and specifies screen–printing form mesh counts (threads per cm) in the legend. The structure resembles that of the electroluminescent lamp, with the micro-LED-containing layer replacing the electroluminescent layer.

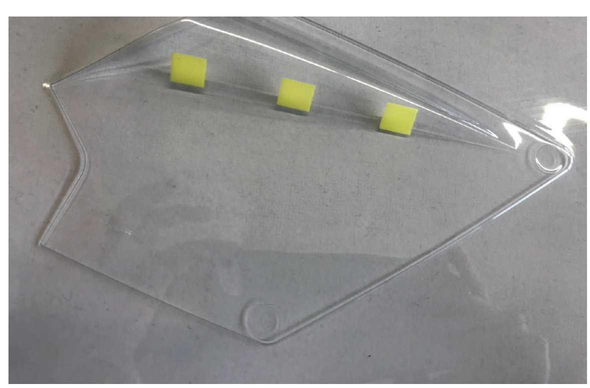


Figure 12: Test prints with phosphor layer after forming

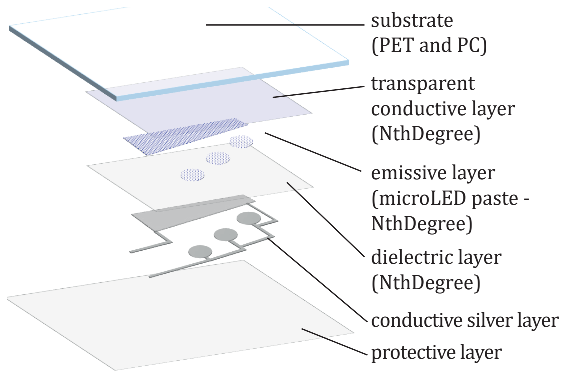
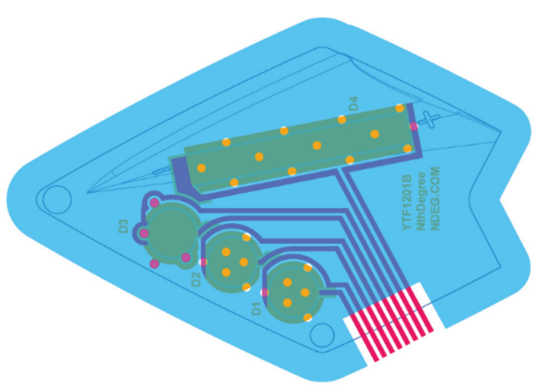


Figure 13: Printing of the illumination part onto the B-surface

Figure 15 depicts how the B-surface is finished by adding the layer with the capacitive switch pattern and the phosphor layer. NthDegree's special proprietary know-how is that during and immediately after the printing process, most of the micro-LEDs align themselves in such a way that the upper contact of the LEDs points downwards towards the transparent conductive layer (e.g. PEDOT/PSS) and the upward-facing opposite pole is not 100 % covered by the surrounding insulating paste. If the entire surface is then covered with a conductive layer (not transparent) applied on top, a sufficiently high percentage of the LEDs start to light up, which resembles a kind of starry sky. Figure 16 shows an example of the glowing blue background of the slider. To achieve white illumination with improved homogeneity, the phosphor was applied at HdM to the film's front alongside the capacitive sensor and final transparent protective coating. Figure 17 shows the required printing steps.



electrode: transparent conductive paste (NthDegree) – 140 mesh
emitting layer: LED-paste (NthDegree) – 160 mesh
dielectric (NthDegree) – 165 mesh
electrode: silver paste (NthDegree) – 61 mesh
conductive tracks/busbar: silver paste (Elantas) – 61 mesh
protective varnish (Pröll) – 110 mesh

Figure 14: Layout (top view) of the B-surface foil showing which layer is printed by NthDegree and which by HdM including mesh count specifications. Some circular spots left open for measurement purposes

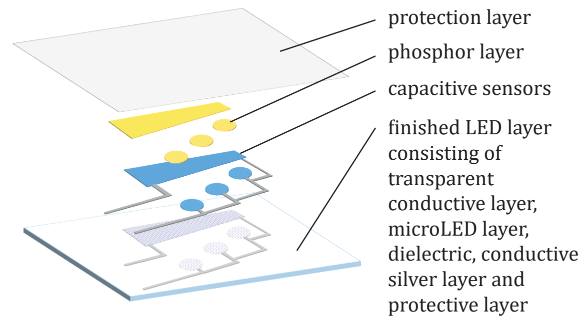


Figure 15: Adding capacitive switch and phosphor layer to the B-surface foil

3. Results

In the following the results are shown for both EL and micro-LED illumination.

3.1 Lighting with electroluminescence

3.2 Figure 18 shows the result with the EL technique. With the HPF technique from Niebling GmbH it was possible to thermoform the foil while maintaining the function.

Beyond the disadvantageous EL driving requirements (approximately 400 Hz with 100 V AC current), electroluminescence's primary limitation remains its low lumi-

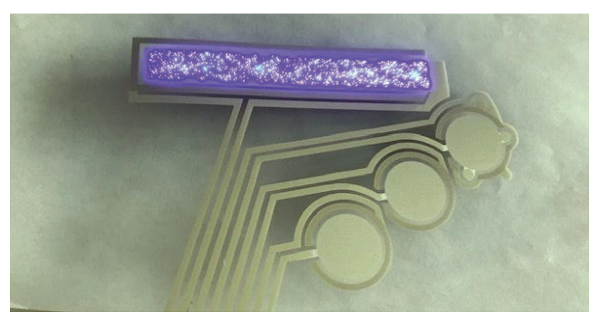
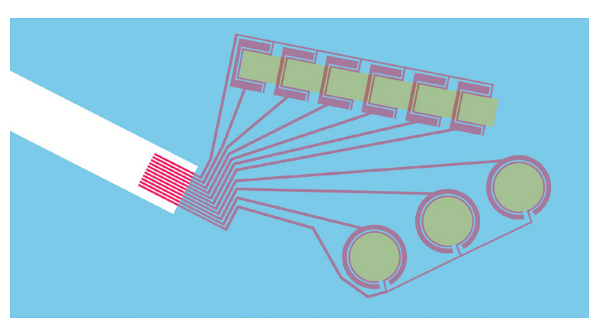


Figure 16: Background illumination of the slider area printed with micro-LEDs by NthDegree



capacitive sensors – 100 mesh
phosphor layer – 110 mesh
protective coating layer – 120 mesh

Figure 17: Printing steps to finalize the B-surface foil

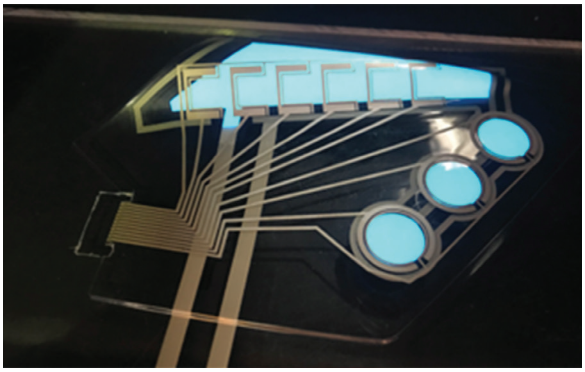


Figure 18: Fully functioning 3D-formed EL illumination and capacitive sensors (6 on slider and 3 buttons)

nous efficacy of approximately 70 cd/m^2. This inadequate brightness for automotive applications led to discontinuing EL investigation within this project, omitting overmoulding to focus on the more promising micro-LED technology. While superior EL materials may exist currently, their investigation fell outside this project's scope.

3.3 Lighting with Micro-LEDs

Figure 19 shows the result with the micro-LED technique.

Following functional testing of B-surface foil sensors and micro-LED illumination at Marquardt GmbH, the PC films (B-surface) were successfully bonded to the decorative film (A-surface) through intermediate injection moulding at Dr Schneider.

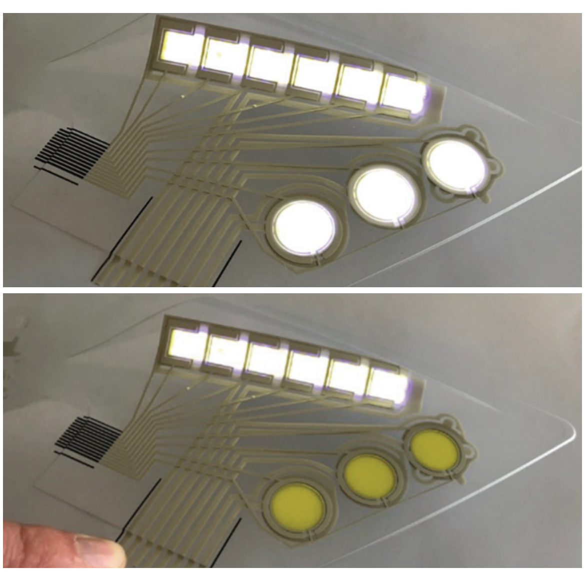


Figure 19: Fully functioning 3D-formed micro-LED illumination and capacitive sensors (six sensors on the slider and three buttons) left: all fields illuminated, right only slider illuminated. The yellow phosphor can be well observed

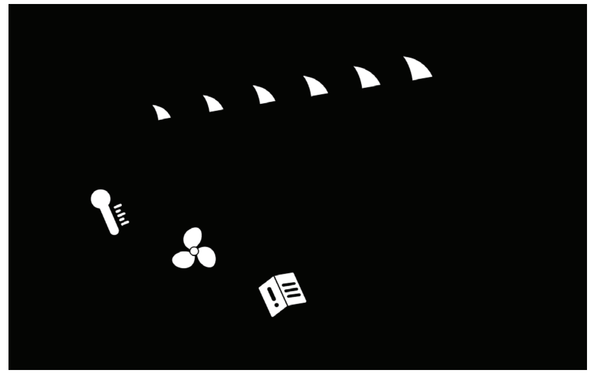


Figure 20: Decorative layout for A-surface

Figure 21: Final result of the injection moulding action

Figure 22: Final demonstrator with micro-LED illumination

The final goal of the project, however, is a demonstrator showing the fully functioning stiffened part by intermediate plastic injection and having a nice-looking surface, the A-surface. For the final demonstrator assembly, the 3D-formed, functional B-Surface has been bonded to the decorative film (A-Surface) by Dr Schneider using intermediate injection moulding. The decor features a black negative print displaying button symbols and descending-sized ‘claws’ for the slider (Figure 20).

The film joining process involves vertical insertion of both films into the injection moulding machine’s mould, followed by injection of polycarbonate melted at approximately 280°C between the films. Figure 21 shows the final injection moulding result.

For the dissemination of the results a demonstrator has been built by the industrial partners with slightly modified icons on the A-surface. The final demonstrator is shown in Figure 22.

4. Conclusions

Although the EL technique has some decisive drawbacks it could be shown that in general the technique works, and fully functional 3D formed parts can be produced. The micro-LED system can definitely be considered a success. The deformation of the micro-LED paste used had never been tested before, so subsequent functionality was not guaranteed. It is therefore even more pleasing that sensors with extremely thin-film-like backlighting are now available for the further process after the injection moulding process and connection to the A-Surface. The industrial project partners now have the opportunity and the challenge of bringing this innovative technology to the market. However, the stability and longevity of the system must now be checked in further investigations.

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Optimization and forecasting models of the sublimation printing process on textile materials

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Abstract

The paper presents the results of the analysis of the sublimation printing process on fabrics by the Taguchi method and forecasting the process quality using the fuzzy logic principles. Imprints obtained in different technological modes and on textiles with different absorbency. Based on the results of the analysis, it was established that the temperature and the material absorption capacity have the greatest influence on the optical density of imprints. Using the Taguchi method it was determined that the optimal parameters of the printing process to achieve high optical density are the material moving speed of 18 m/h, the temperature of the printing process of 215 °C and the textile absorption of 19 mm. Taking into account that the influence of the material moving speed in the range of 18–32 m/h showed to be insignificant, two factors were selected to forecast the process quality: the temperature and the material absorption capacity. The formed fuzzy knowledge base made it possible to construct forecasting models of the influence of these two factors on CMYK ink printing process quality. The comparison of the simulated values of optical density with the values that were obtained experimentally shows the adequacy of the models for CMK colours. Significantly higher optical density deviations are observed for the yellow colour (Y), which indicates a less controlled thermal transfer process. This is also indicated by the value of the signal-to-noise ratio, which is minimal for yellow.

Keywords: sublimation printing, process factors, optimization, Taguchi method, fuzzy logic, forecasting model

1. Introduction

The development of the digital inkjet printing method has created new possibilities for producing images on fabric materials by sublimation. This process is an indirect printing method: the image is first printed by inkjet onto special paper and then transferred to the textile under high pressure and temperature. A high-quality thermal transfer is possible on fabrics containing more than 60 % polyester, which allows the inks to diffuse into the fibers in vapor form (Leber, 2016).

According to market research by Global Information Company, the sublimation printing market was estimated at USD 15.97 billion in 2024 and projected to reach USD 26.23 billion by 2029, growing at a compound annual growth rate (CAGR) of 10.44 % during the forecast period (Mordor Intelligence, 2024). Sublimation printing on textiles continues to dominate the European individual printing-services segment because the printed image is extremely durable compared to other textile-printing methods, thanks to ink penetration into the material rather than layer formation on the surface (Allied Market Research, 2021). The sublimation-paper market also confirms these trends, with an average annual growth rate of 8.9 % forecast for 2024–2032 (Business Research Insights, 2024).

The growth trends are driven by technology improvements, improved energy efficiency, the creation of sublimation paper recycling capabilities, and the minimization of environmental impact compared to traditional fabric printing methods. The world market of sublimation paper is provided by companies Guangdong Guanhao High-Tech, Hansol, Sappi Group, Neenah Coldenhove, Ahlstrom-Munksjö, McCoulin Jasper Inc., Felix Schoeller, Beaver Paper, Jiangyin Allnice Digital Technology.

Publication analysis indicates two main research directions in textile printing: studying imprint quality under various process factors and evaluating operational performance of imprints on fabric materials. Several studies focus on wash resistance of images produced by direct, sublimation, or screen printing methods. The article of Toshikj and Prangoski (2022) reports a slight color difference (>1 ΔE) between imprints on sublimation transfer paper printed at 270 % and 100 % total ink limitation levels, which could reduce unnecessary costs in the sublimation printing process. Toshikj and Prangoski (2023) describe the effect of transfer temperature and dwell time of the ink-black layer on textile image quality, achieving low print mottle, high color strength, and optimal cost–performance balance. Other studies examine wash resistance of imprints obtained by direct, sublimation, or screen printing methods (Stancic and Kasikovic, 2014; Prybeha, et al., 2021).

Özdemir, et al. (2021) highlight optimization of the printing process using Taguchi methods. Vujčić (2019) applied a Taguchi design to assess how printing parameters affect wash resistance. Jung, Kim and Park (2016) used the Taguchi method to optimize screen printing, maximizing color intensity to reduce color difference of imprints while minimizing ink consumption.

Fuzzy logic methods have yielded positive results in forecasting process quality. Repeta, et al. (2023) constructed prognostic models predicting flexographic printing quality based on printing plate parameters, anilox roller characteristics, ink viscosity, and surface energy. Repeta, Kukura and Kukura (2018) described forecasting models for factors influencing solventless lamination of flexographic imprints. Tymchenko (2022) used fuzzy logic calculations to define a forecast-level indicator and visualized process quality through infographics.

Given the diversity of inkjet printing modes, substrate materials, and thermal transfer regimes, further research using the Taguchi method is reasonable, as it has proven effective for forecasting technological process quality.

2. Research methods

2.1 Methods of experimental research

The sublimation printing process comprises two stages. In the first stage, a test chart was printed on an Epson SC-F7100 printer using Epson UltraChrome DS ink on 65 g/m^2 Kaspar Dye Sub Lite (Kaspar Papir) sublimation paper. Print settings were Quality Mode: 720 × 1440 dpi, six-pass, ink limit 250 %. In the second stage, the printed image was thermally transferred onto the textile using a Termon KP-1728 calender thermopress at material speeds of 18, 24, and 32 m/h and temperatures of 200 °C, 215 °C, and 240 °C.

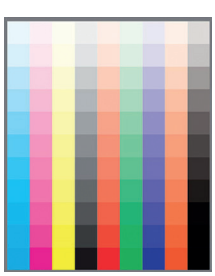

Figure 1: Fragment of the test scale

The optical density of CMYK color imprints was measured with an X-Rite SpectroEye spectrodensitometer on a fragment of the test chart shown in Figure 1, where CMYK vector patches were printed in 10 % increments. These patches show how accurately single- and multi-color areas are reproduced under the selected printing conditions. Fabric absorption capacity was determined by the height of ink capillary rise using the Klemm capillary-rise method, measured 60 seconds after immersion of the fabric strip (Figure 2). Accounting for the fabric's anisotropic properties, strips were cut along the direction of greatest ink spread, onto which a known ink weight had been previously applied. The characteristics of the textile materials are presented in Table 1.

Using the Klemm method, fabric absorption capacities were determined as follows: K190 – 19 mm, S013 – 24 mm, and F02 – 29 mm.

Table 1: Studied textile samples from Janmar Sport (Poland), showing brand, composition and weight (PES = polyethylene terephthalate; EL = elastane)

Brand	Composition	Weight
K190	82 % PES, 18 % EL	0.20 g/m^2
S013	82 % PES, 18 % EL	21.24 g/m^2
F02	100 % PES	2.294 g/m^2

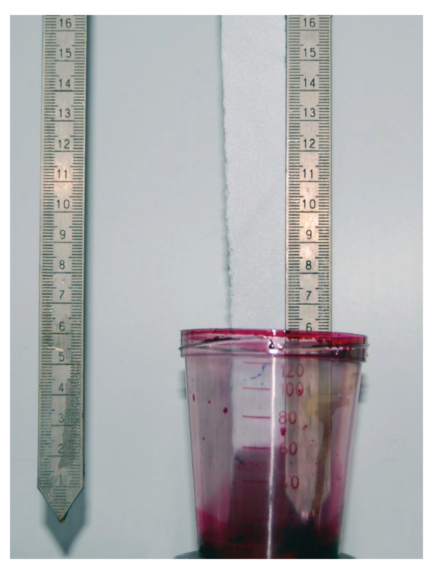

Figure 2: Klemm-type-capillary-rise method

2.2 Analysis of the sublimation process using the Taguchi method

Multi-factor analysis typically requires numerous experiments, making it time-consuming. The Taguchi method enables reducing the number of samples by employing an orthogonal matrix, thereby decreasing the required experiments (Taguchi, 2005). Data were processed with Minitab 21 software.

A larger-the-better objective function was employed to evaluate the optical density response. The larger-the-better signal-to-noise *(S/N)* ratio, based on a base-10 logarithm, was calculated as:

$$S/N = -10 \times \log\left(\frac{\Sigma(1/Y^2)}{n}\right) \quad [1]$$

where Y is the response for a given factor-level combination, and n is the number of responses in that combination (Methods and Formulas for Analyze Taguchi Design, 2024). Each sublimation process factor was studied at three levels, as shown in Table 2.

The orthogonal matrix was selected to minimize the number of experiments required for process-parameter optimization. Minitab offers standard orthogonal matrices based on the number of factors; here, an L9 matrix was used.

2.3 Construction of a forecasting model using fuzzy logic tools

Fuzzy logic was introduced in 1960s by Lotfi Zadeh to mathematically represent uncertainty and vagueness in human reasoning (Zadeh, 2008). Fuzzy logic has found wide application across diverse technological fields. It can handle uncertainty and imprecision, making it particularly valuable for AI applications.

Table 2: Factors and levels of the sublimation process

№	Factors	Levels		
		1	2	3
1	Speed of the material movement (S), 10^{-1} m/h	1.8	2.4	3.2
2	Temperature (T), °C	200	215	240
3	Absorption (A), mm	19	24	29

Table 3: Linguistic variables of factors influence on the sublimation printing quality

Variable	Universal set	Assessment terms
Temperature, °C	200–240	low, medium, high
Absorption, mm	19–29	low, medium, high

To implement fuzzy logic, follow these steps:

1. Define linguistic variables and terms corresponding to process factors.
2. Construct membership functions.
3. Create a fuzzy knowledge base with “If–Then” rules.
4. Obtain a fuzzy output.
5. Perform defuzzification.

Table 3 lists the universal sets and terms for the linguistic variables. Therefore, we divided each input variable into three levels for our membership functions. Symmetric Gaussian membership functions were used to describe the fuzzy set terms. The “Centroid” principle (TutorialsPoint, n.d.; Rotshtein and Shtovba, 2002) was used for defuzzification.

3. Results and Discussions

The factor-distribution matrix for image sublimation on textile materials is presented in Table 4. Table 5 presents CMYK optical densities measured across test-scale areas under the orthogonal factor combinations. Table 6 presents the calculated S/N ratios.

Taguchi analysis yields the following interpretation. A larger difference (Δ) in average S/N ratio indicates a greater influence of that control factor on the process. Based on S/N ratio calculations, factors are ranked by influence in the sublimation process: temperature (Rank 1), material absorption (Rank 2). Material moving speed has a negligible influence (Rank 3).

Figure 3 depicts the main effect of each factor on optical density. Factor levels corresponding to maximum S/N values indicate the system’s optimal conditions. Therefore, optimal process parameters for high optical density are: a material transfer rate of 1.8 m/min, a process temperature of 215 °C, and textile absorption of 19 mm.

Pareto analysis of the results that are presented in Table 6 indicates that temperature and absorption capacity account for 93 % of heat-transfer process variation, with the remaining influence attributable to the speed parameter. Data processing enabled the construction of models predicting how temperature and absorption affect CMYK ink optical density presented in Figure 4 a–d. The plots illustrate that increasing temperature enhances ink-layer formation up to 215 °C – yielding peak optical density for all colors – after which density decreases gradually, with the rate dependent on absorp-

Table 4: Orthogonal array L9 and distribution of the process factors

№	Orthogonal array			Value of factors by levels		
	S	*T*	*A*	*S*	*T*	*A*
1	1	1	1	1.8	200	19
2	1	2	2	1.8	215	24
3	1	3	3	1.8	240	29
4	2	1	2	2.4	200	24
5	2	2	3	2.4	215	29
6	2	3	1	2.4	240	19
7	3	1	3	3.2	200	29
8	3	2	1	3.2	215	19
9	3	3	2	3.2	240	24

Table 5: Values of the optical density according to the experiment options

№	Optical density			
	C	M	Y	K
1	0.92	1.04	0.65	1.57
2	1.22	1.35	0.85	1.78
3	0.98	1.13	0.79	1.58
4	0.85	0.95	0.58	1.47
5	1.16	1.21	0.76	1.57
6	1.16	1.29	0.84	1.83
7	0.83	0.94	0.56	1.37
8	1.3	1.36	0.77	1.78
9	1.2	1.32	0.84	1.85

tion capacity. Although the general factor effects are similar across colors, they vary slightly due to differences in inkjet pigment chemistry and corresponding physical and chemical properties.

As optical density represents a "larger-is-better" objective, it was used to calculate the *S/N* ratio. *S/N* ratios for all experimental conditions are given in Table 7. Comparison of maximum S/N values shows that yellow ink exhibits the lowest *S/N* ratio, indicating reduced process controllability and suggesting additional influencing factors – particularly the unique physical and chemical properties of yellow ink.

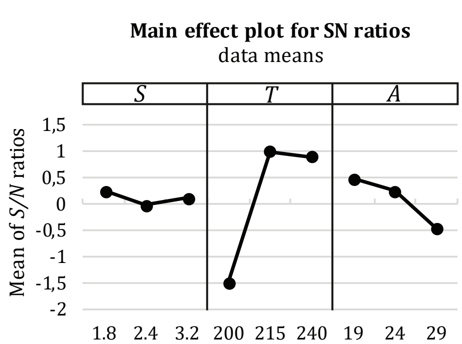

Figure 3: Graph of the average values of S/N ratio for the sublimation process factors

Table 6: Ranks of the process factors according to the analysis

Level	Factors		
	S	*T*	*A*
1	0.23192	-1.51555	0.45330
2	-0.01414	0.97579	0.31330
3	0.12142	0.87896	-0.42741
Δ	0.24606	2.49135	0.88071
Rank	3	1	2

Regression analysis yielded the following predictive equations for the optical density of each CMYK inkjet ink:

$$D_{\mathrm{C}} = 0.536 + 0.0403\,S + 0.0049\,T - 0.0247\,A \quad [2]$$

$$D_{\mathrm{M}} = 0.151 + 0.0279\,S + 0.0064\,T - 0.0176\,A$$

$$D_{\mathrm{Y}} = 0.312 - 0.0399\,S + 0.00327\,T - 0.0067\,A$$

$$D_{\mathrm{K}} = 1.555 + 0.0372\,S + 0.0023\,T - 0.0183\,A$$

where D_c to D_K is optical density of CMYK inkjet inks; S is speed of the material movement; T is temperature; A is absorption.

In general, the results of the analysis of the sublimation image transfer process show that 200 °C and 215 °C is not enough for the complete transfer of the ink layer to the fabric, while reducing the moving speed and, accordingly, increasing the thermal contact time slightly improves this process. At a higher temperature, 240 °C,

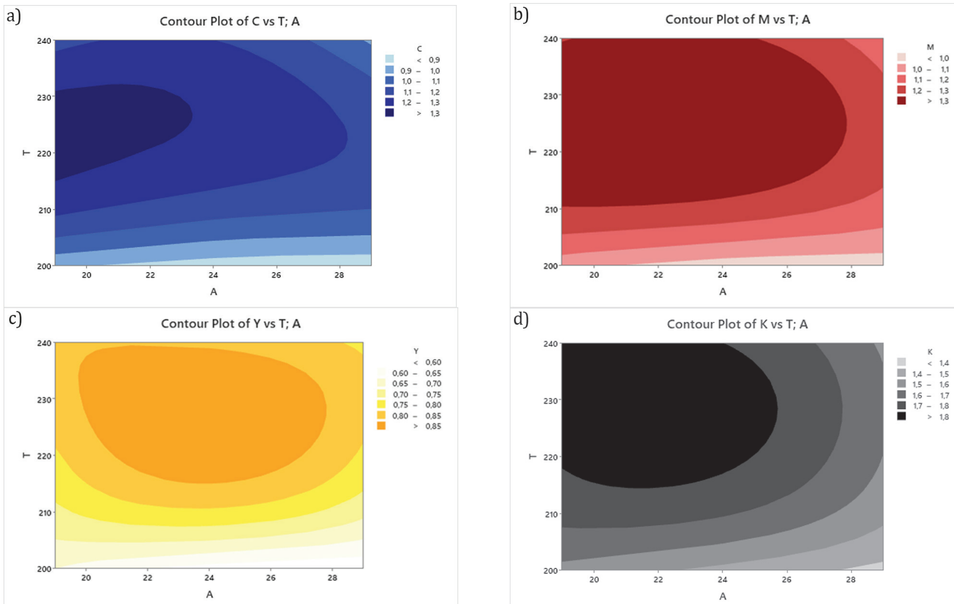

Figure 4: Contour plots of influence of transfer temperature and material absorption on the optical density of the image: a – cyan ink; b – magenta ink; c – yellow ink; d – black ink

and a low material moving speed, the ink layer begins to diffuse into the material thickness and, as a result, the optical density begins to decrease.

In the following, the factors with the highest priority will be used, which will be presented in the form of the following linguistic variables: the temperature (*T*) and the material absorption (*A*). The scheme of logical formation of the overall quality of the image sublimation formation process on textile material is presented in Figure 5.

When constructing the membership function for "Temperature" variable, its value is determined on the universal set: u_1 = 200 °C; u_2 = 210 °C; u_3 = 220 °C; u_4 = 230 °C; u_5 = 240 °C. For the linguistic assessment of this indicator, a set of fuzzy terms is used:

T(x) = <low, medium, high>.

The value for the variable "Absorption" for the construction of membership functions is determined on the universal set: u_1 = 19 mm; u_2 = 21,5 mm; u_3 = 24 mm; u_4 = 26,5 mm; u_5 = 29 mm. For the linguistic assessment of this indicator, a set of fuzzy terms is used:

T(y) = <low, medium, high>

For the initial indicator – optical density, the distribution of membership functions by terms is applied:

T(z) = <very low, low, medium, high, very high>

Table 7: Analysis results of S/N Ratio

Factors			**S/N Ratio**			
S	*T*	*A*	**C**	**M**	**Y**	**K**
1.8	200	19	-0.724	0.341	-3.741	3.917
1.8	215	24	1.727	2.607	-1.412	5.008
1.8	240	29	-0.175	1.062	-2.047	3.973
2.4	200	24	-1.411	-0.445	-4.731	3.346
2.4	215	29	1.289	1.656	-2.383	3.917
2.4	240	19	1.289	2.212	-1.514	5.153
3.2	200	29	-1.618	-0.537	-5.036	2.734
3.2	215	19	2.278	2.671	-2.270	5.008
3.2	240	24	1.583	2.411	-1.514	5.106
		Max	2.278	2.671	-1.412	5.153

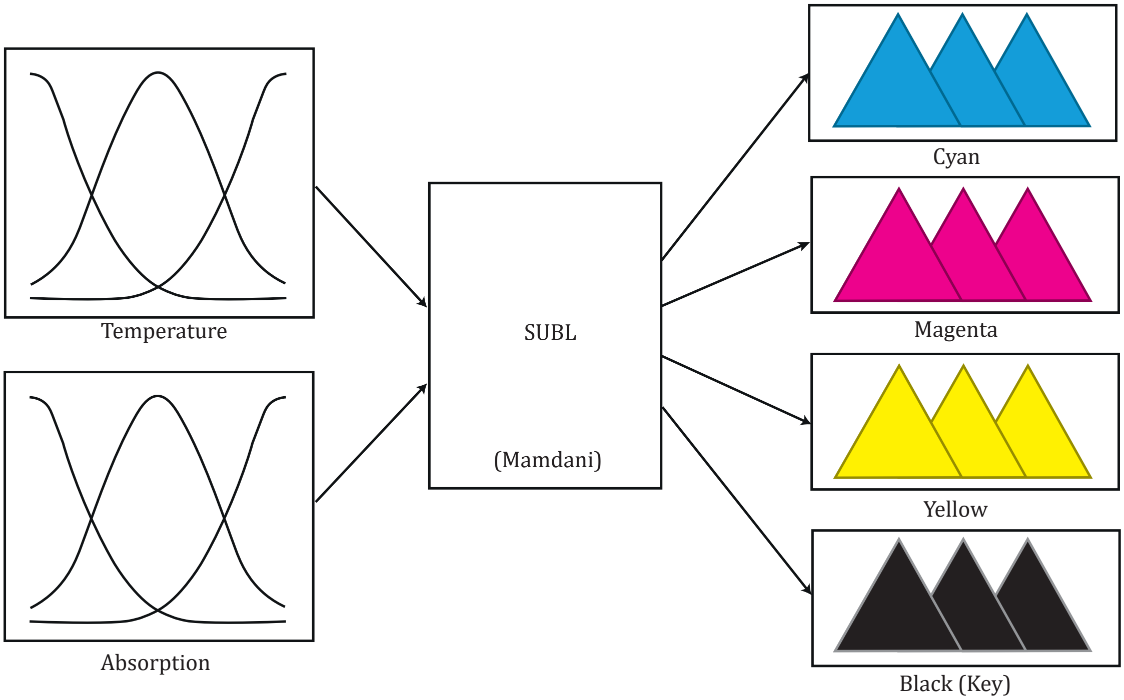

Figure 5: Scheme of the logical formation of the quality of the image formation process on textiles

Let one form a fuzzy knowledge base for determining the optical density using a set of fuzzy rules “if – then”:

– if (T is “low”) and (A is “low”) then (D is “low”);

– if (T is “low”) and (A is “medium”) then (D is “very low”);

– if (T is “low”) and (A is “high”) then (D is “very low”);

– if (T is “medium”) and (A is “low”) then (D is “very high”);

– if (T is “medium”).and (A is “medium”) then (D is “high”);

– if (T is “medium”) and (A is “high”) then (D is “medium”);

– if (T is “high”) and (A is “low”) then (D is “high”);

– if (T is “high”) and (A is “medium”) then (D is “medium”);

– if (T is “high”) and (A is “high”) then (D is “low”).

To check the formed knowledge base and construct a forecasting model of the influence of priority factors, a package for developing fuzzy control systems was used – the Fuzzy Logic Toolbox system of the Matlab technological calculation environment and the Mamdani principle (Mamdani and Assilian, 1975). The result of modeling by fuzzy logic tools is shown in Figure 6. In this case, the influence of the temperature and the fabric absorption capacity on the optical density of black ink is demonstrated. To forecast the influence of these factors for CMK colors, when forming the membership functions for the initial value D (optical density), its maximum and minimum values, which were previously obtained experimentally, are indicated. In this way, D range is formed on the graphic models of each colour separately.

After obtaining models of the influence of temperature and absorption, a comparison of the results obtained experimentally and the results obtained on the basis of the formed fuzzy knowledge base is carried out using the Matlab capabilities in the graphical representation of logical equations.

Figure 7 (a–d) demonstrates the adequacy of the simulated results, in comparison with the results of measuring the optical density of experimentally obtained imprints, except for the yellow colour. For it, a slightly larger difference in optical density values is observed in the experiment and the model, which indicates a lower controllability of the thermal transfer process in this case. This is also indicated by the value of the S/N ratio according to the Taguchi method, which is presented in Table 7 and is minimal for yellow. One possible explanation for this result could be significant changes in the properties of the yellow pigment system in a narrow temperature range, which in turn depends on the speed of the material movement.

4. Conclusions

In this work, the imprints were obtained on inkjet paper and at the stage of the image thermal transfer, the influence of temperature, the material moving speed (as the time of the contact point in the thermal press) and the textile material absorption capacity were studied. Various options, the value of the optical density of CMYK colours were determined. Using the Taguchi method, it is established that the temperature and the material absorption capacity have the greatest influence on the optical density of imprints. In general, the use of the method made it possible to establish the optimal parameters of the sublimation process, namely, to achieve a high value of optical density: the material moving speed of 18 m/h, the process temperature of 215 °C, and the textile absorption capacity of 19 mm (Klemm method). Taking into account that the influence of the material moving speed in the range of 18–32 m/h is insignificant, two factors were selected to forecast the process quality: the temperature and the material absorption capacity. Accordingly, a fuzzy knowledge base was formed and forecasting models of the influence of these two factors on the quality of the CMYK ink sublimation process were constructed. The comparison of the simulated values of optical density with the experimentally obtained values showed the adequacy of the models for CMK colours. For the yellow colour, a slightly larger difference in optical density values was observed in the experiment and the model, which indicates a lower controllability of the thermal

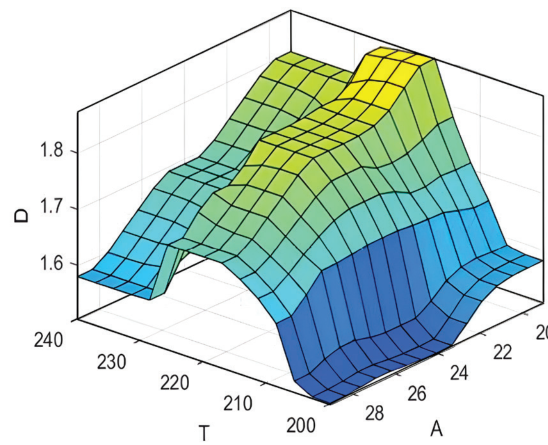

Figure 6: A model for forecasting the influence of the temperature and the absorption capacity on the optical density of a black ink layer

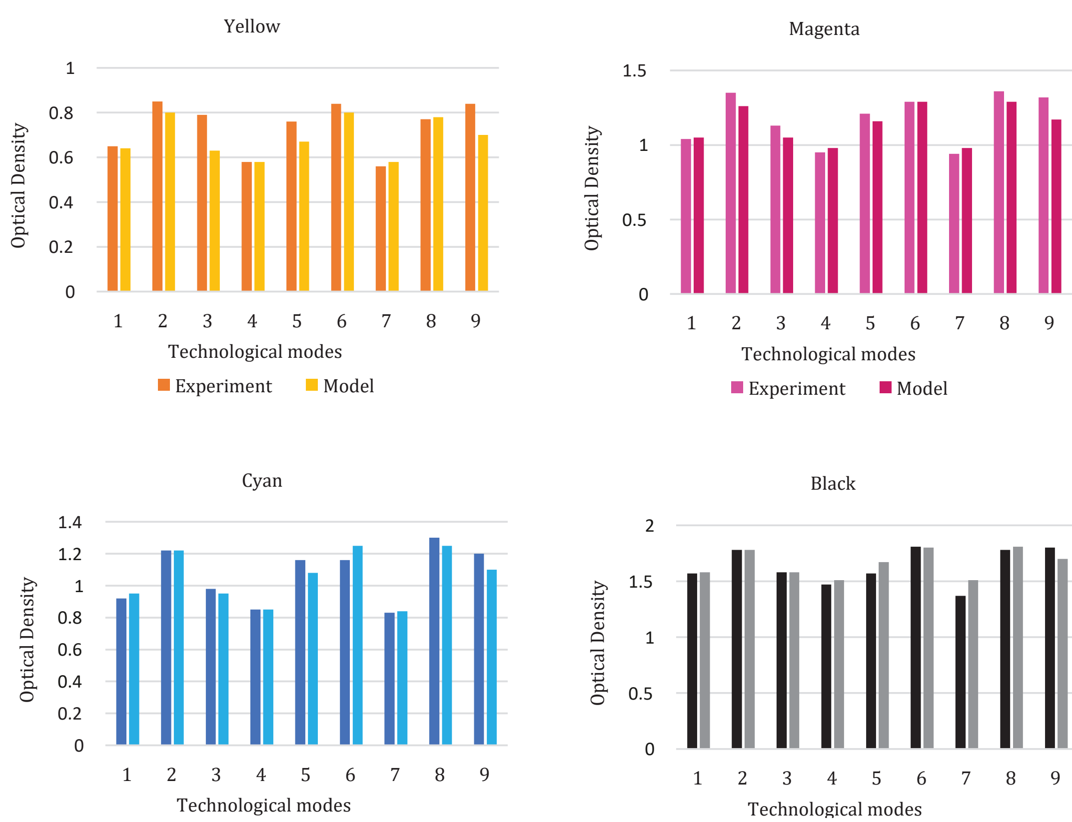

Figure 7: Experimental and simulated values of the optical density of the ink layer for nine technological modes (see Table 4): a – cyan ink: b – magenta ink; c – yellow ink; d –black ink.

transfer process in this case. This is also indicated by the value of *S/N* ratio according to the Taguchi method, which was minimal for yellow. In this case, the material movement speed will also affect, which determines the contact duration during thermal image transfered. All this requires further additional research and the construction of a separate model of the factors, influence specifically for a yellow ink. In general, the use of fuzzy logic and the construction of graphic models will allow developing a simulation model for a priori forecasting the quality of the thermal transfer stage of a sublimation image.

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Separating the effects of maximum pressure and printing nip length on flexographic print quality

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Abstract

When adjusting the impression in a printing press both the maximum pressure induced and the contact length between the print form and the substrate are simultaneously altered. In the present study, lab printing was performed with controlled load cases. The load cases were chosen to achieve varying nip lengths or maximum pressure. A lab-scale printing press was augmented with a pressure sensor that measures the width of the print over a square area. By altering the print forms and the force settings in the machine, the print nip pressure pulse was controlled. Printing was performed in both solid tone and halftone, and the printed result was evaluated for mottle, density, and dot-gain. By increasing the maximum pressure, the color density increases. By increasing the nip length at a fixed maximum pressure, the color density decreases. The variation within the settings in the present study is small and appears to originate from the split pattern. The change in the nip exit angle with increased nip length is sufficient to alter the ink split point and, thereby, the density. A higher maximum pressure can instead enable a higher ink transfer.

Keywords: flexography, lab printing, mottle, print density, ink transfer

1. Introduction

The assessment of print quality ranges from code legibility thresholds to fine-tuned image rendering aesthetics based on human perception. Tools to pinpoint and evaluate gloss, reflectance variations (mottle), tonal density, or uncovered areas (UCA) have been developed to put a number to the defects that disturb the visual appearance of a printed product. On the other hand, there are investigations into the mechanisms that induce wanted or unwanted effects and defects. In flexographic printing, there is a delicate interplay between the material properties of the substrate, the print plate, the foam backing, and the ink. Their individual stiffnesses, structure, wettability, and rheology add to that process parameters such as impression and print speed. The ink transfer from the print plate to the paperboard involves wetting of two solid surfaces with ink, one by the other, in a nip between two rolling cylinders. Upon exiting the nip, the fluid film splits between the plate and the substrate, whereupon the ink on the paperboard levels and sets. The visual appearance of the printed surface will depend on the thickness and uniformity of the ink layer. The amount of transferred ink depends on the ink available and where the film split occurs. Due to instabilities, the menisci at the nip exit will not be uniform but take on a wavy pattern. The cross machine direction (CD) wavelength depends on surface roughness, ink viscosity, and print speed (Brumm, Sauer and Dörsam, 2019). The liquid bridge between the print plate and the paperboard will stretch and rupture while the paperboard moves, which can create ink streak patterns in the machine direction (MD). The MD pattern is influenced by the elasticity of the ink (Morgan,, et al., 2018) and the asymmetry of the split that determines which surface will retain the larger amount of the ink. These finger-like patterns have even been specifically utilized to print biomimetic networks in a flexographic printer (Brumm,, et al., 2022). In packaging printing, this pattern is located in sub-millimetre wavelengths (Gil Barros, 2006) and is barely visible to the naked eye. Larger varieties, more noticeable to the eye, stem largely from structural variations of the paperboard.

Since contact is a requirement of ink transfer, the impression is one of the essential process parameters in contact printing. If the impression is too low, the contact between the uneven paperboard and the print plate becomes insufficient to transfer ink. On the other hand, in flexography, a high impression can cause defects such as dot gain due to deformation of the raster dots. Too high impression in post-printing of corrugated board can crush the fluting (Holmvall, 2007). Printing with higher impressions can also cause the print plates to deteriorate faster.

It has been noted that optical density increases with impression (Tollenaar and Ernst, 1961) and that there is a significant improvement in density or tone value from engagement and during the initial increases in impression. However, at some point, an optimum impression is reached where further increasing of the impression provides none or minor increases in density (Bould, et al., 2011). Beyond the optimum impression, either the ink transfer has reached an equilibrium, or the ink transfer is still increasing, but the ink is forced into the paperboard coating. Using optical cross-section microscopy, Bohlin, Johansson and Lestelius (2016) concluded that a higher print force did not increase the penetration depth of the ink into the coating to any greater extent.

Several factors impact the liquid film split and the liquid distribution in meniscus rupture when stretching a liquid bridge. In the context of printing, this phenomenon has been studied most extensively with regard to gravure printing. It has been observed in studies regarding pick-out from a gravure cell that both shear and extension play an important part in the amount of fluid transferred, especially for non-Newtonian fluids (Khandavalli and Rothstein, 2017). The influence of ink elasticity on the split pattern compared to Newtonian ink was shown to alter the ribbing pattern in flexographic printing from straight lines to shorter structures in MD (Morgan, et al., 2018). Additionally, a difference in wettability between the two separating surfaces will affect the amount of liquid transferred between them. If the liquid being transferred is shear thinning, this has been found to enhance liquid transfer to the more wettable surface compared to the Newtonian case at the same capillary number (Wu, Carvalho and Kumar, 2019). Add to that the structure and surface energy of the paperboard, which will have its own effect on the ink spreading. A coated paperboard is often slightly hydrophobic due to the latex in the coating (Bohlin, Johansson and Lestelius, 2016). Applying pressure can mitigate the poor wettability (De Grace and Mangin, 1984). Forced wetting has even been shown to enable offset printing on a very hydrophobic Teflon surface (Liu and Shen, 2008).

Since the impression is an important parameter in the printing process, its isolated effect has been studied (Bohan, et al., 2003; Borbély and Szentgyörgyvölgyi, 2011). However, the impression is altered by closing the distance between the print cylinder and the impression cylinder, whereupon both the maximum pressure and the nip length will increase. The same applies to an increase in line load in a force-controlled lab press, both the maximum pressure and nip length is affected by the force setting. Additionally, the print plate, plate mounting sleeve or foam tape backing, and substrate are a combination of materials with a non-linear compression response. Additionally, all the materials can vary in thickness, and the resulting pressure pulse exerted on the substrate can both be asymmetric and change with print speed. The shape of the pressure pulse between two rolling cylinders, with or without deformable cover, has been extensively studied in the context of printing and other rolling processes (Hannah, 1951; Hunter, 1961; Bentall and Johnson, 1968; Margetson, 1971, 1972; Kerekes, 1976; Dobbels and Mewis, 1978; Watanabe and Amari, 1982; Coyle, 1988; Keller, 1992; Wang and Knothe, 1993; Xue, Gethin and Lim, 1994; Lim, et al., 1996; Luong and Lindem, 1997; Bohan, et al., 1997; Hinge and Maniatty, 1998; Yoneyama, Gotoh and Takashi, 2000; Johnson, 2003; Ascanio and Ruiz, 2006; Holmvall, 2007; Litvinov and Farnood, 2010; Austrell and Olsson, 2013; Abdel Rahman, El-Shafei and Mahmoud, 2014; Ceccato, Kulachenko and Barbier, 2019). Just to mention a few.

Many studies are numerical, or experiments confined to lab scale since measuring the pressure pulse in a full-scale printing press is difficult. However, Johnson, et al., (2004) measured the pressure pulse and ink transfer in a flexographic central impression printing press and showed that the nip length increased while the maximum pressure remained stable for an increased speed. They also measured the ink transfer in terms of copper content on the printed paperboard, showing that the amount of transferred ink decreased with increasing print speed. Something that had been previously noted in the literature for the optical density (Tollenaar and Ernst, 1961).

In the present study, we separate the maximum pressure from the nip length to study their separate effect on the print quality. The desired pressure pulses were achieved by altering the soft foam tape between the print plate and the cylinder and the force settings in the lab printer.

2. Material

2.1 Paperboard

The paperboard used in the present study was a multiply, coated, commercial liquid packaging paperboard. The mean local thickness (measured according to the method described by Schultz-Eklund, Fellers and Johansson (1992) was approximately 450 µm with a standard deviation of approximately 5 µm.

The grammage was 295 g/m^2. The surface roughness of the coated side (measured with an FRT MicroProf from Fries Research & Technology) had a standard deviation of approximately 3.3 µm around the mean surface height. The mean out-of-plane stiffness in compression was 23 MPa. The measurements on the paperboard were all performed in a climate-controlled laboratory (23 °C, 50 % RH) after conditioning the samples for 24 hours.

2.2 Printing plate

The printing plate was a photopolymer plate from XSYS. The plate was a 1.14 mm thick Xsys Nyloflex ACE with a hardness according to DIN 53505 of 62 and a Shore A of 78. The print plate had one solid tone area and one halftone area. The halftone was 30% on the printing plate (i.e., no dot gain compensation was applied) with a screen ruling of 48 lpi. The resulting print had roughly the same usable area of each.

2.3 Plate mounting foam tape

Three different plate mounting foam tapes were used to alter the pressure pulse. All three were from Lohmann and 0.5 mm thick. They are denoted 52, 53 and 54 with increasing stiffness.

2.4 Ink

The ink used was PremoNova WIPP-512N Cyan (FlintGroup).

3. Method

3.1 Print settings and resulting pulses

To print the samples in this study an IGT F1 laboratory flexographic printer was used. The printing speed was kept constant at 0.5 m/s. The speed is much lower than a full-scale printer. The lab printer is force-controlled and to evaluate the pressure pulses during printing a pressure sensor, Tekscan I-Scan 5040, was utilized. The setup was previously used and evaluated by Hedström (Hedström, 2023). The sensor is embedded in the sample holder and maps an area of 44 × 44 mm as it rolled through the nip together with a paperboard sample. A mean pulse has been calculated for each force setting used. The sensor was not present during printing, i.e. all the pressure measurements were performed during initial dry runs to determine the appropriate force settings for printing.

In Hedström's study, print plates of different thickness were used to achieve different pulses, but the conclusion was that the effect of changing the print plate overshadowed any other results. In the present study, only one print plate was utilized to ensure that the contact conditions between the plate and paperboard remained the same. The print force setting, and the foam tape were the only process parameters used to alter the pulse shape. Therefore, the resulting pulses could not achieve the large differences possible when using thin and hard plates and thicker, softer ones. The settings used in the present study are presented in Table 1 and the resulting mean pulses are shown in Figure 1. The pulses all have a unique force setting and will be denoted thereafter. As is marked in color in Table 1 and seen in Figure 1, some cases with different force settings achieve either the same max pressure or the same nip length. The relative change in nip length and maximum pressure are the same size; approximately 30 %. The testing was performed in a climate-controlled lab at standard climate (23 °C, 50 % RH).

In addition to the selected pulses, printing was performed at lower force settings, 20, 30 and 40 N, to evaluate if the optimum mottle and UCA had been reached.

3.2 Print evaluation

To evaluate the print quality in terms of mottle, density, reflectance, and tone value increase (TVI), all printed samples were scanned together with a reflectance calibration set at 600 dpi, RGB, in a flatbed scanner. One sample of each set was additionally scanned at 1200 dpi to evaluate dot reflectance, dot area, and the split

Table 1: Plate, tape, and print settings

Tape	Force setting [N]	Max pressure [kPa]	Nip length [mm]
Hard (54)	60	100	7
Medium (53)	70	100	8
Soft (52)	80	100	9
Soft (52)	125	150	10
Hard (54)	150	220	9
Medium (53)	175	220	10
Hard (54)	225	300	10

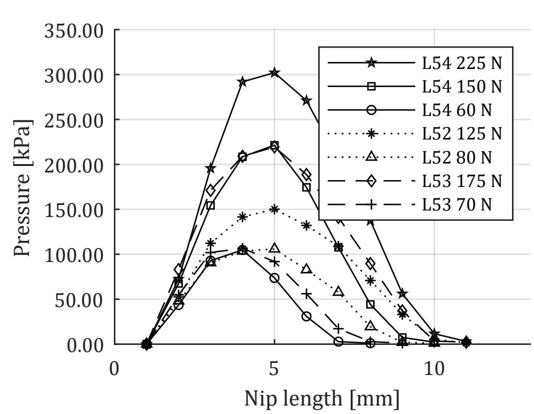

Figure 1: Pressure pulses during printing

pattern. The evaluation was performed using the software "STFI Mottle Expert" (RISE) (Christiansson, 2019) and "Dot Stat" (RISE)(described in a degree project of Kalicinski (2014).

3.2.1 Mean reflection, density and tone value increase

To calculate the mean (relative) density (Eq. [1]) and TVI (Eq. [2]), the red image channels of printed and unprinted areas calibrated to reflectance were used. The optical density presented is the relative density calculated from the calibrated reflectance of both the unprinted and printed surfaces. A decrease in reflectance from adding ink to the surface gives an increase in optical density.

$$\text{Relative Density} = \log_{10} \frac{\text{mean}\left(\text{Refl}_{\text{unprinted}}\right)}{100} - \log_{10} \frac{\text{mean}\left(\text{Refl}_{\text{printed}}\right)}{100} \qquad [1]$$

The TVI is calculated against the relative density and the nominal tone value of the print plate using the Murray–Davies equation.

$$\text{TVI} = \frac{1 - 10^{-\text{RelDensity}_{\text{halftone}}}}{1 - 10^{-\text{RelDensity}_{\text{solid tone}}}} \cdot 100 - \text{nominal tone} \qquad [2]$$

The TVI does not distinguish between physical and optical dot gain. The mean TVI information is augmented by analyzing the dot area and dot reflectance.

3.2.2 Mottle and uncovered areas

The mottle and UCA are calculated from grey-scale images calibrated to reflection. In the solid tone areas, the threshold for detecting UCA was 13 % above the mean reflectance. The feature in STFI-Mottling Expert called "Remove false UCA" was used. Areas larger than 500 mm^2 and fiber shaped areas with a reflectance above thresholds of 13 % above the mean reflectance were considered false UCA. The areas were replaced with the mean reflectance of their surroundings. The mottle is given as the coefficient of variation of the reflectance. The information is filtered and is divided into the following wavelength spans: 0.13–0.25, 0.25–0.5, 0,5–1, 1–2, 2–4, 4–8 and 1–8 mm.

4. Results

Several print quality metrics were utilized to evaluate the effect of the maximum pressure and nip length. All error bars represent 95 % confidence interval.

4.1 Optimum plateau for uncovered areas and mottle

Both the UCA and the detected false UCA decrease with increasing force setting, as shown in Figure 2. This is expected when the plate-paperboard contact increases. At the lower end of the settings, the software has discovered some false UCA's, which might be actual UCA's since they appear more prevalent in low-pressure cases. However, for the selected range of settings, both UCA and false UCA have plateaued near to or at zero.

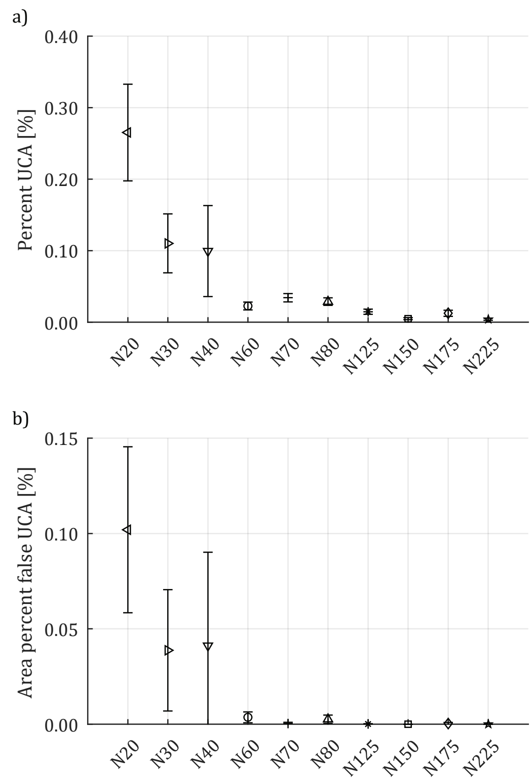

Figure 2: Uncovered areas (a) and false uncovered areas (b)

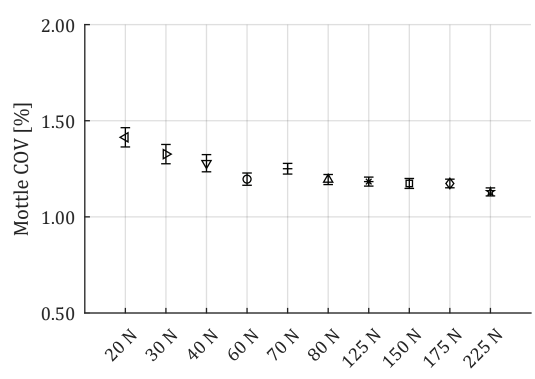

Figure 3: Solid tone mottle 1–8 mm. COV denotes the uncovered areas

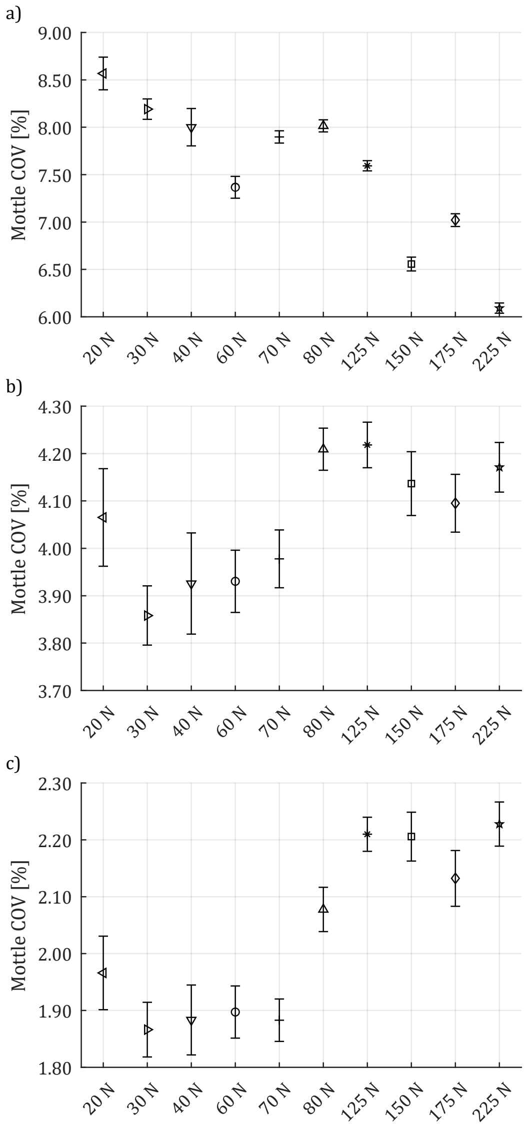

Figure 4: Solid tone mottle

In Figure 3 the 1–8 mm mottle in the solid tone is presented. For a set combination of plate and paperboard, the increased impression will improve the 1–8 mm mottle until it plateaus. As can be seen in Figure 3 the plateau is reached for the selected settings. However, it should be noted in Figure 4 that although the 1–8 mm mottle plateaus, it keeps improving in the 0.13–0.25 mm wavelengths. Additionally, in 0.25–1 mm there is a jump between 70 N and 80 N.

4.2 Solid tone reflectance and density

The solid tone reflectance scans are shown Figure 5 and the values are presented in Figure 6. Using Equation [1] the density is calculated and presented in Figure 7. Increasing the maximum pressure while keeping the nip length constant reduces the reflectance and thereby increases the density. However, increasing the nip length while maintaining the same maximum pressure increases the reflectance and decreases the density. The density range for all the cases presented here is, however, within acceptable boundaries for a full-scale print run.

4.3 Halftone reflectance and density

The halftone reflectance and density are shown in Figure 9 and Figure 9. The halftone follows the same trend was observed in the solid tone in Figure 6 and Figure 7. The effect is slightly larger in the halftone compared to the solid tone, especially for the higher forces, which could be explained by an expanded dot area at higher impressions. The dots are more easily deformed than the solid surfaces on the print plate. Additionally, in the halftone, the line load is distributed over a surface that is 30 % of the solid tone area.

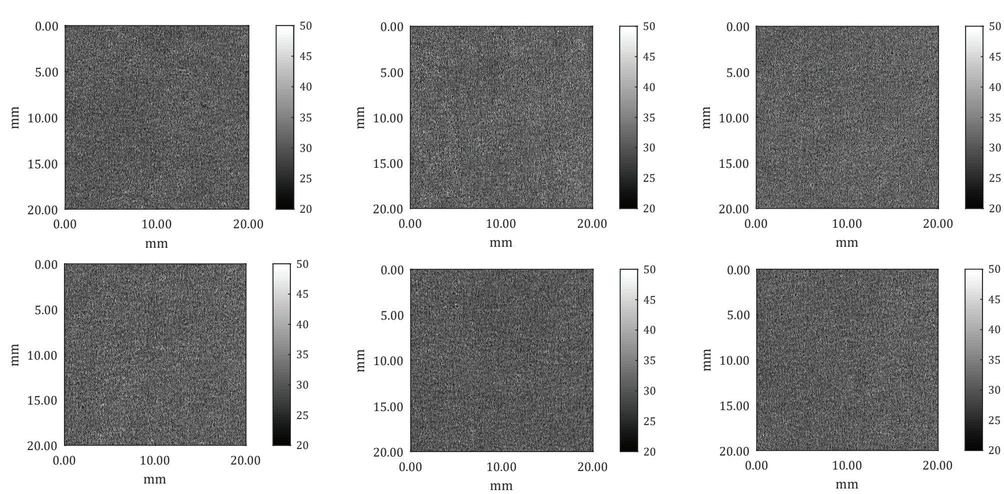

Figure 5: Calibrated reflectance patterns 20 × 20 mm

4.4 Dot area, dot reflectance and tone value increase

The TVI in the halftone is calculated according to Equation [2] and presented in Figure 10. It follows the same trend as the density in both the solid and halftone (Figures 7 and 9, respectively). The TVI is expected to increase with increased pressure due to the mechanical deformation of the dots and squeeze out of the ink at the rim of the dots. However, the fact that the dot gain decreases with nip length at a fixed maximum is surprising and indicates a different mechanism in the ink transfer.

The TVI presents a value for the entire printed surface but does not account for if the TVI is caused by larger and/or darker dots. Therefore, the reflectance of the individual dots was analyzed from the higher resolution scans and were presented in Figure 11. The reflectance of the individual dots follows the same pattern as the solid tone reflectance. However, the results show that the area of the dots are also affected. A longer nip at the same maximum pressure produces smaller and slightly lighter dots. An increased maximum pressure with maintained nip width creates larger, darker dots. This indicates that the halftone density of the whole area in

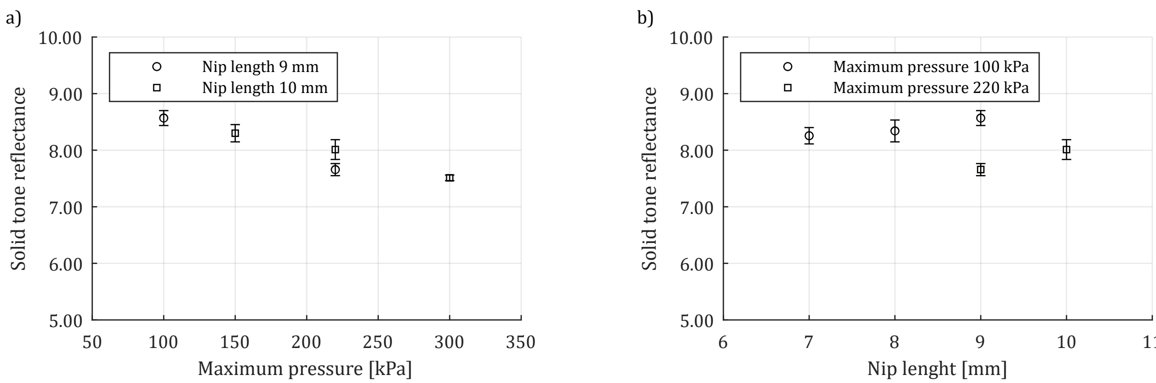

Figure 6: Solid tone reflectance versus maximum pressure (a) and nip lengt (b)

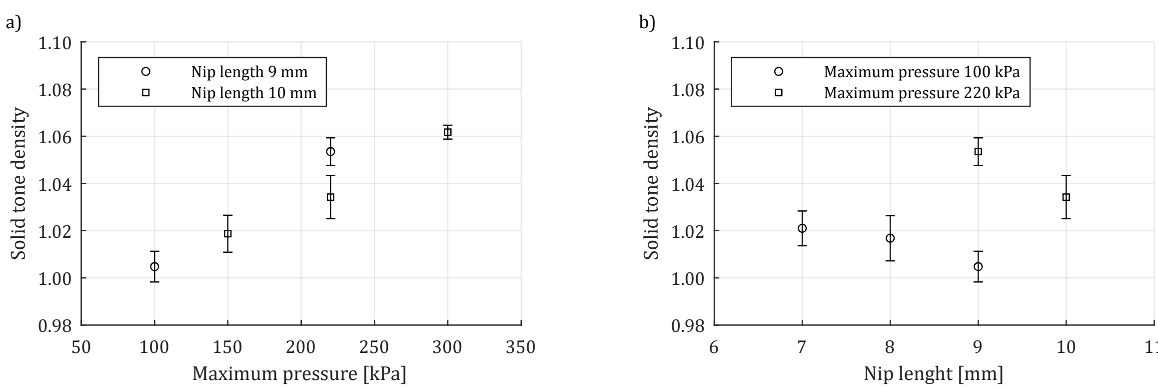

Figure 7: Solid tone density versus maximum pressure (a) and nip lengt (b)

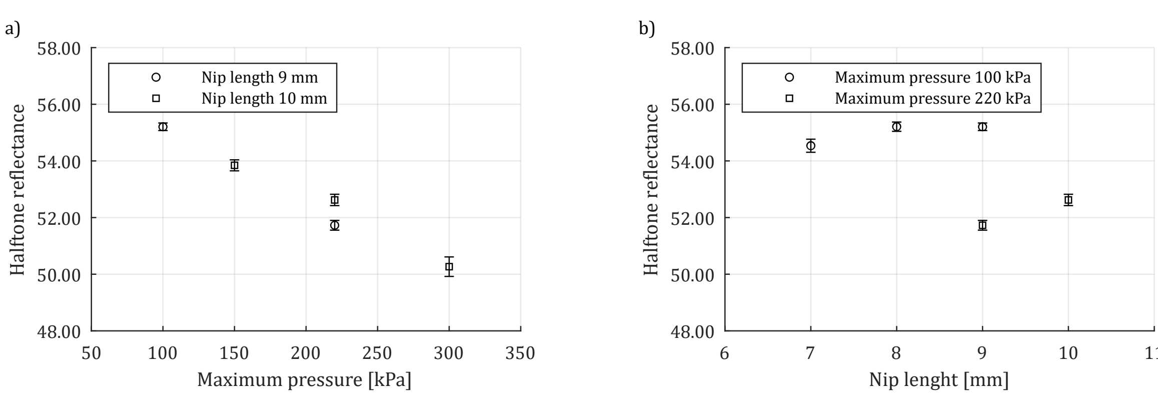

Figure 8: Halftone reflectance versus maximum pressure (a) and nip length (b)

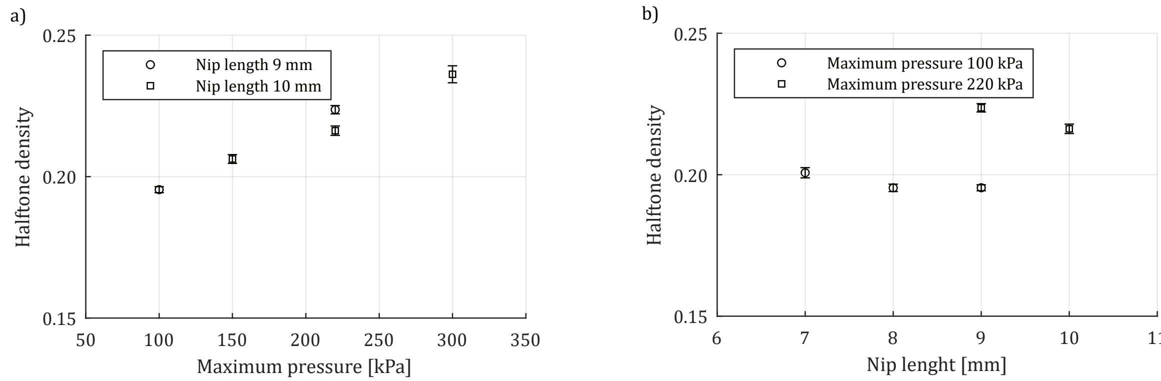

Figure 9: Halftone density versus maximum pressure (a) and nip length (b)

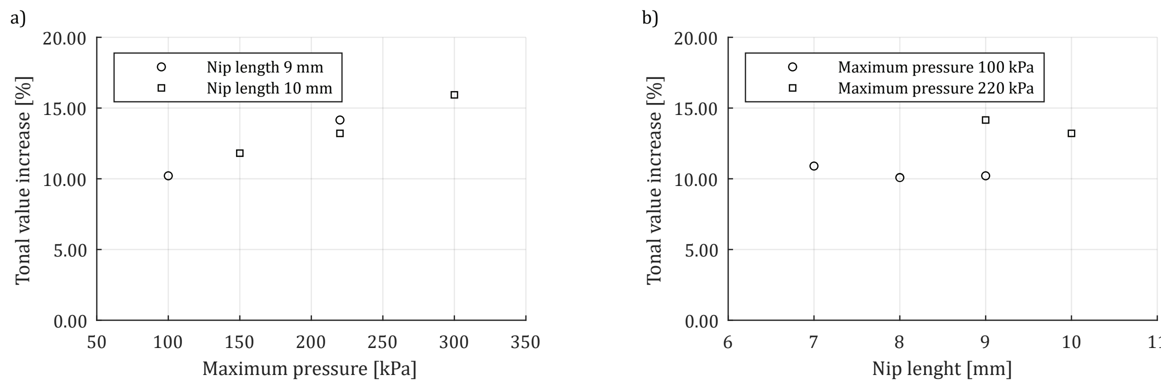

Figure 10 Dot gain (% increase from nominal tone value) versus maximum pressure (a) and nip lenght (b)

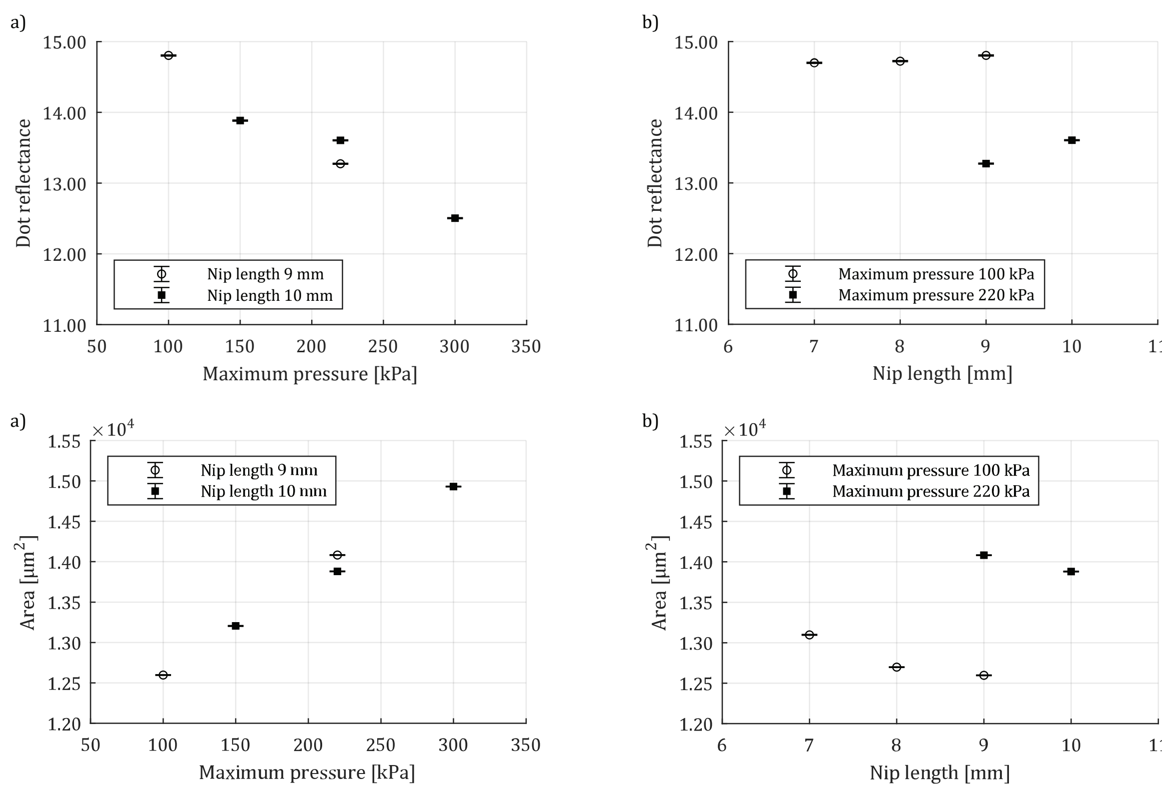

Figure 11: Dot reflectance and area versus maximum pressure (a) and nip length (b)

Figure 9 and the TVI in Figure 10 are due to a change in both the area and reflectance of the individual dots. Less ink appears to have been transferred when the nip length is extended at the same maximum pressure in the dots as well as in the solid tone.

4.5 Print mottle and ink splitting pattern

The solid tone mottle is presented (one wavelength span per subplot) in Figure 12 (plotted against the maximum pressure) and in Figure 13 (plotted against the nip length). There is a very slight improvement in 1–8 mm when the maximum pressure is increased. The shortest wavelength, 0.13–0.25 mm, displays the most noticeable improvement in mottle when the maximum pressure is increased. However, when increasing the nip length at the same pressure the mottle increases. The same trend as seen in the reflectance in Figure 6 is seen here in Figure 13 in the reflectance variation (mottle) in 0.13–0.25 mm. This wavelength is where the split pattern can be found (Gil

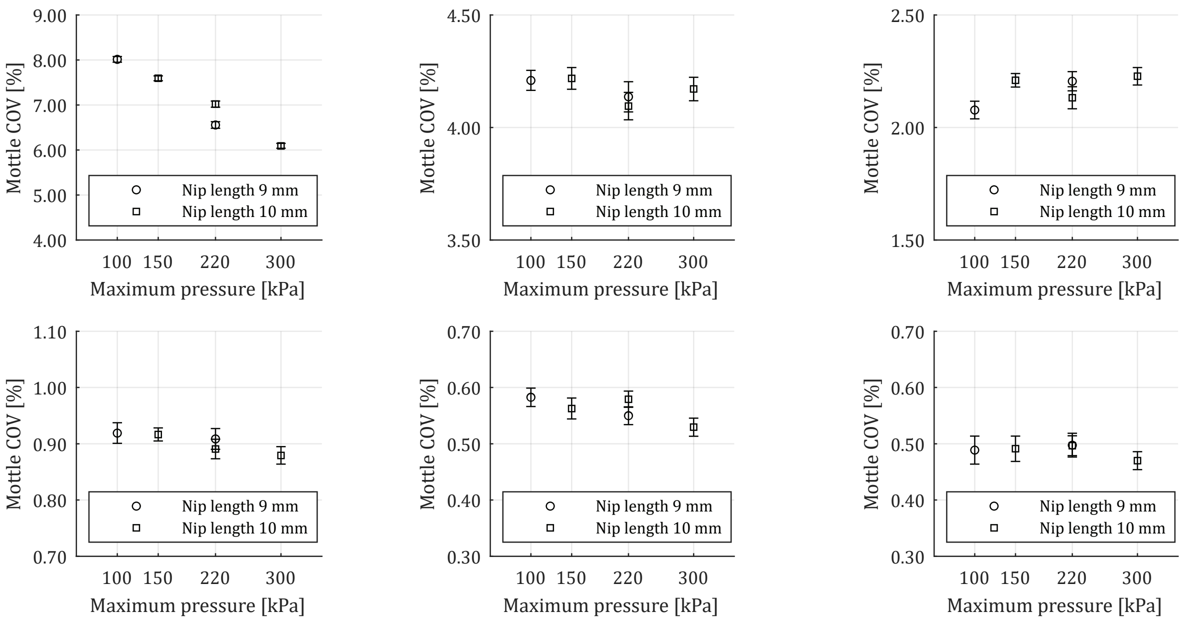

Figure 12: Solid tone mottle versus maximum pressure per wavelength span (COV)

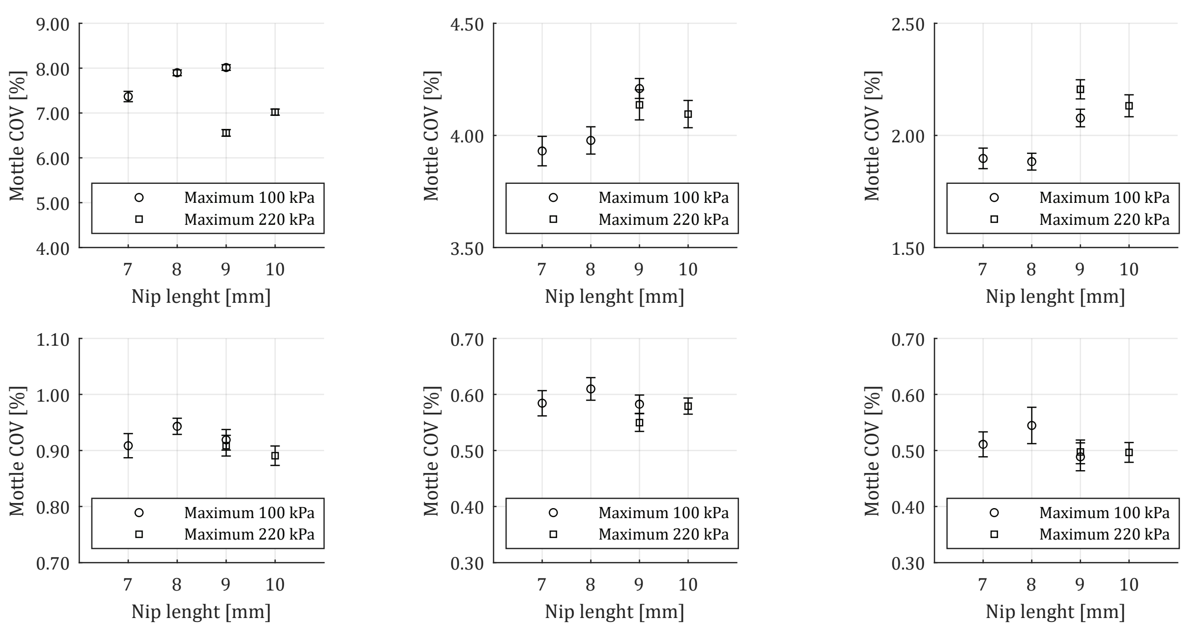

Figure 13: Solid tone mottle versus nip length per wavelength span (COV)

Barros, 2006). Even if the split pattern is similar for the different settings, the variation in the smallest wavelength could indicate how much ink is in the liquid bridge on the paperboard side when it ruptures.

The split patterns are visible in the plots of the calibrated reflectance in Figure 5. A closer look at the local ink density is visualized in Figure 14 where the data has been interpolated in MATLAB to make the gradients smoother. The split pattern is formed by the ribbing instability of the moving contact line and the liquid filament or bridge between the plate and paperboard that breaks and leaves small-scale dots or streaks in the machine direction on the substrate. The patterns show no obvious differences, but there are reflectance variations in 0.125–0.3 mm shown in Figures 12 and 13. The mottle trend in this wavelength span follows the reflectance difference between the settings. A decrease in reflectance means an increase in density, thus indicating that there is a small change in the split point. On one hand, increasing the density and reducing the variation in the shortest wavelength with increasing maximum pressure, and on the other hand, decreasing the density and slightly increasing the variation when the nip length is extended were observed.

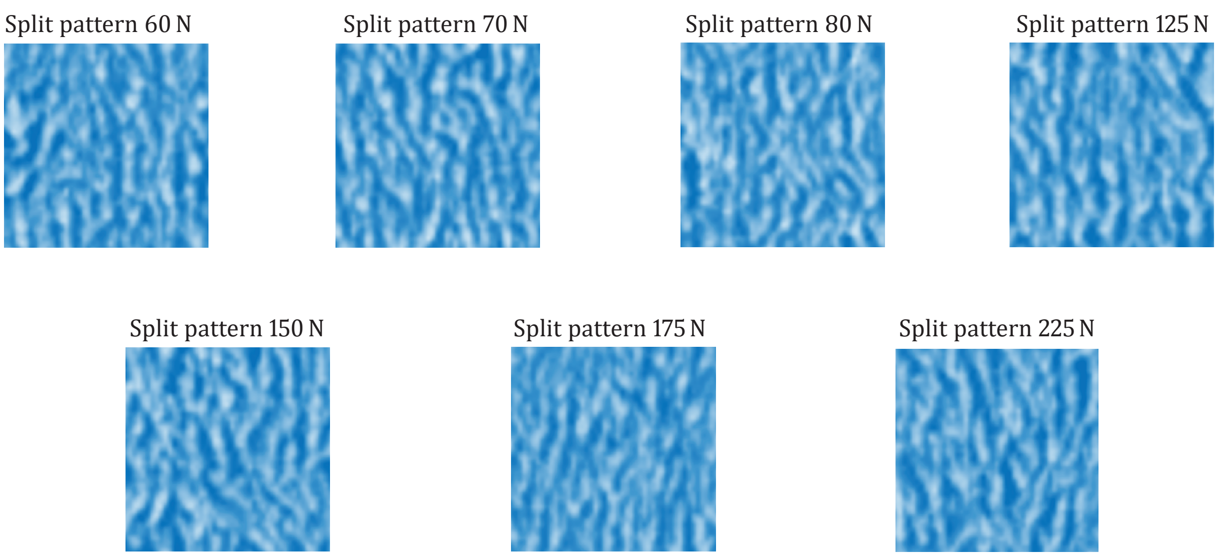

Figure 14: Visualization of the local ink density showing the split pattern

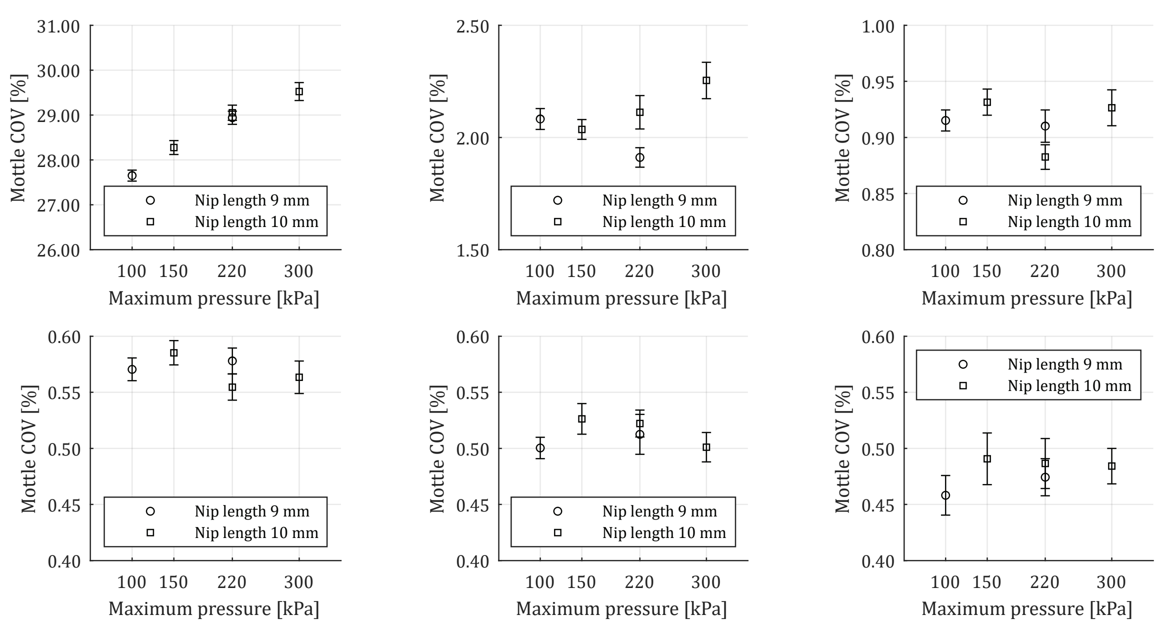

Figure 15: Halftone mottle vs. maximum pressure per wavelength span [COV]

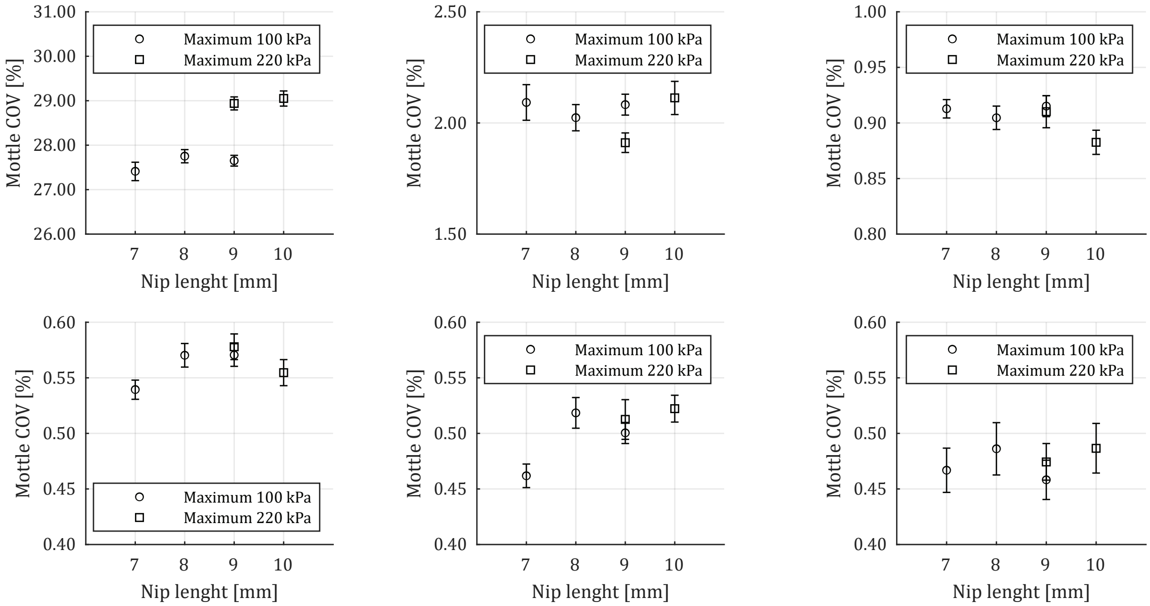

Figure 16: Halftone mottle vs. nip length per wavelength span [COV]

The halftone mottle is presented in Figures 15 and 16. The wavelength 0.13–0.25 mm is heavily influenced by the dot pattern due to the dot size in the halftone. The largest variation between the cases occurs in the shortest wavelengths, 0.25–0.5 mm. In the middle span, 1–4 mm, only the lowest force setting sticks out with a lower value. At the longest wavelengths, 4–8 mm, there is a large variation in all force settings but no significant difference between the settings.

5. Discussion

The result that the UCA's decreased with print force was expected, as well as the stabilization of print mottle in the higher wavelengths. However, the reduced solid tone density with nip length was one unexpected result. Another unexpected result was that the density of the dots as well as their area also decreased with a longer nip length at the same maximum pressure.

The optical density alone cannot completely rule out the possibility of another mechanism that could "hide" the ink, making the surface appear lighter compared to how much ink was transferred. However, Bohlin, Johansson and Lestelius (2016) concluded using optical cross-section microscopy that an increased force did not make the ink penetrate deeper into the substrate to any greater extent. Additionally, the halftone density can be affected by effects such as optical dot gain. As the substrate was the same in all cases, we assume that the optical dot gain remains on a similar level and that the halftone density differences are mostly a result of the actual differences in ink transfer. Another way to measure the ink transfer is to measure the copper content on the paperboard using Atomic Absorption Spectroscopy, AAS. This will provide an amount of g/m^2 of dry ink, regardless of the optical qualities of the print. A study of the pressure pulse and ink transfer at different speeds has been performed by Johnson, et al. (2004). In the paper, they show that for the hard flexographic print plate (comparable to the one used in the present study), the increase in speed resulted in a longer nip, unchanged maximum pressure, and a decrease in g/m^2 of ink transferred. With consistent maximum pressure and increasing nip length, we observe a decrease in density just as they observe a decrease in ink transfer. We therefore assume that the decrease in optical density is due to less ink transferred. In Johnson's study, the speed was increased (and the ink transfer decreased), while in this study, the print speed in the IGT F1 was kept constant. In their study they could not rule out that the shortened duration (time) in the nip was the cause of the decrease in ink transfer. However, in both studies, the nip length was increased with a maintained maximum pressure.

An increase in nip length (for the same print cylinder) will result in a more acute exit angle and a larger vertical velocity component. It had previously been observed that an increase in print speed in the lab printer affected the split pattern, therefore the print speed was held constant in this study. The same print plate was used to ensure that the paperboard–print plate contact remained the same. The paperboard samples came from the same reel, and although the wettability of the paperboard and print plate are unknown, their relationship should remain unchanged within the present print run. However, the nip exit will change with the nip length.

At the nip exit the split point of the filaments between paperboard and print plate will influence the amount of ink transferred. And a pair of results that followed each other was the solid tone reflectance and the mottle in the shortest wavelength. The mottle that corresponds to the split pattern. The nip exit exhibits a complex load case. The fluid is both extended with the lifting print plate, but it is also sheared due to the moving paperboard. The extension also includes a rotation and acceleration of the print plate. It is therefore not necessarily sufficient to only consider the extensional rheology or shear of ink. Dodds, Carvalho and Kumar (2012) studied the behavior of a bridge of Newtonian fluid stretched under both extension and rotation in the context of gravure printing. The study concluded that the acceleration of one plate relative to the other has a significant effect on the bridge dynamics and the transfer of liquid. They commented that the implication is that by producing a difference in rotation of one surface against the other, the amount of liquid transferred can be slightly altered. In gravure printing, they noted, this could be performed by a mismatch in the size of the two rolls. In our case, by altering the angle at the split, the amount of ink transferred is slightly altered. This mechanism could explain why the density decreases with increasing nip length. The other mechanism working in the opposite direction is the maximum pressure. With an increase in maximum at the same nip length (and therefore exit angle conditions), more ink was transferred to the paperboard. At lower impressions or force settings the print is improved by increasing the pressure, establishing better contact, and reducing UCA and mottle towards their optimum. However, the printing was performed after reaching the plateau. The mechanism could be related to forced absorption of the liquid part of the ink due to the higher pressure while the pigments remain at the surface. It could also be an effect of forced wetting due to the increase pressure, thereby increasing the adhesion of the ink on the paperboard.

6. Conclusions

The velocity and exit angle differences in the nip exit are sufficient to alter the point of meniscus rupture so that the ink transfer becomes smaller with the longer nip. The mechanism that governs the effect of increasing the maximum remains unexplained but is in line with previous studies and observation. However, the combined result could help explain why an increase in speed requires an increase in impression. If the nip length is altered, there is more than just the shorter duration that could affect the ink transfer. The nip exit effect on the split point plays a role too. An increased pressure mitigates the effect of the longer nip length. However, both the area and the reflectance of the dots were affected by the settings and the longer nip length slightly reduced the tone value increase.

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TOPICALITIES

Edited by Markéta Držková

CONTENTS

News & more

The CIE activities in 2024

The current scope, structure, role and objectives of the International Commission on Illumination have recently been presented in a series of interviews with CIE President Jennifer Veitch and CIE Education, Technical and Standards Vice-Presidents in the LED Professional Review Magazine. The CIE Research Strategy 2023–2027, also presented in a webinar organised in October 2024, takes into account two overarching themes related to digital transformation and efforts towards inclusive, equitable lighting and defines six topical themes: (i) Advances in measurement & calibration, (ii) Integrative lighting for people, (iii) Ecologically respectful, high-quality exterior lighting, (iv) Fundamentals of photobiology for agriculture and aquaculture, (v) Enabling the application of safe & beneficial optical radiation, and (vi) Measuring, modelling, perceiving and reproducing colour. This last one also considers the visual appearance information for augmented, virtual and extended reality devices and the challenges of surface colorimetry and colour reproduction in 3D printing.

In August, the third edition of the CIE Position Statement on Integrative Lighting – Recommending Proper Light at the Proper Time was published. While the research into related phenomena still continues, although advancing rapidly, the key message is quite simple: the light exposure depends on light levels and spectra of all sources in proximity, both direct and reflected, and very high light exposure during the day, a much lower level in the evening, and near-darkness during sleep strongly support the circadian rhythm, and thus the physiological processes essential for well-being and the performance during the day. The topics of 'Light Pollution' and 'Light and Health' are also central to the CIE project 'Understanding Science – Understanding Light', running from 1 January 2025 to 30 June 2026 to foster public understanding of the impact of light on human lives.

Among the publications, the Proceedings of the 30th Quadrennial Session of the CIE were published as CIE x050:2023 at the very end of 2023, with a selection of 220 papers presented during the three-day technical conference (1 invited, 68 oral and 151 poster presentations). The papers are also available individually, 40 of them for free, e.g. those dealing with the effect of surface curvature on specular gloss evaluations, Hunt effect, or spectrally dependent non-linearity of charge accumulating pixel matrix sensors. The standards and reports published in 2024 include the revised standard ISO/CIE 10916:2024 Light and lighting – Energy performance of lighting in buildings – Calculation of the impact of daylight utilization, which helps optimising the energy demand for electric lighting and cancels and replaces ISO 10916:2014, the new technical report CIE 252:2024 Assessment of discomfort glare from daylight in buildings, the new standard CIE S 027:2024 Photometry of road illumination devices, light-signalling devices and retroreflective devices for road vehicles, the third edition of the joint standard defining photocarcinogenesis action spectrum of non-melanoma skin cancers, ISO/CIE 28077:2024, and four CIE documents prepared under Division 1, Vision and Colour, and presented in more detail on the next page as most relevant to the scope of JPMTR.

Fogra research projects and publications in 2024

The new projects that started in 2024 deal with image analysis using the metric imitating the characteristics of the human visual system for a more comprehensive and automated assessment of colour deviations of printed plastics and with colour matching for illumination without a UV component, which is typical for the sources based on light-emitting diodes.

The projects ending in 2024 covered four different topics. One was studied in partnership with the Fraunhofer Institute for Computer Graphics Research IGD and the Institute for Laser Technologies in Medicine and Metrology at the University of Ulm (ILM). It concerned 3D soft-proofing for an accurate simulation of volumetric light transport effects and geometric errors in 3D prints. The approach involved developing renderers for the correct visualisation of the translucency of 3D-printed objects, simplifying the characterisation of 3D-printing materials by estimating the optical properties using spectrophotometric measurements and deep-learning algorithms, and advancing colour communication in full-colour 3D printing by creating the exchange colour space and other standardisation efforts. The project outcomes include a beta version of the 3D Design RGB ICC profile and settings recommendations for translucency in Blender.

The aim of another project was to develop a cross-process print quality assessment procedure employing a simple score calculated from various image quality attributes. The approach was based on collecting and analysing the existing metrics, producing test prints with controlled variations and defining criteria for the planned score.

The third project completed recently by Fogra was focused on correlating visual and metrological characterisation of metallic effects to increase process reliability in packaging printing. Pairwise visual comparisons of the metallised prints with various characteristics under different lighting conditions enabled the creation of a sensitively equidistant scale for the metallic effect. Also, the relevant parameters of these samples were measured, and their relationship with the strength of the metallic effect was evaluated using regression analyses to enable an objective evaluation of metallised products. Most selected parameters correlated well with the visual assessment, except those measured with a multi-angle colorimeter, which was attributed to the relatively large distance from the specular angle.

The fourth of the projects ending in 2024 aimed to increase the economic efficiency and sustainability of print production with heatset offset presses, either by using the sources with UV light-emitting diodes or operating drying units with unheated air. The approach was based on acquiring and comparing the production data needed to develop a calculator of costs and CO_2 emissions for the processes considered. Another aspect was an experimental study of the suitability of papers for the so-called coldweb process.

Among other activities last year, Fogra published its third white paper, 'Metal particles in offset printing inks', summarising the research on the presence of metal shavings in the inks and their effects on metallic surfaces of dampening rollers. The white paper presents the developed process for extracting ferromagnetic particles, its application to ink series from four major manufacturers, and analyses of metal shavings and the surface of rollers. The results show that the metal particles, always present only in small quantities and having lower hardness than roller surfaces, cannot damage the latter. The June issue of Fogra Extra (No. 43) provides the fundamentals for reliable proofing of spot colours, both solid inks and their halftone tints.

ISO/CIE 11664-5:2024
Colorimetry – Part 5: CIE 1976 L*u*v* colour space and u′, v′ uniform chromaticity scale diagram

This document specifies the procedures for calculating the coordinates of the approximately uniform CIELUV colour space, the corresponding correlates of lightness, chroma, saturation and hue as well as Euclidean colour difference values representing the relative perceived magnitude, and a related chromaticity diagram. The standard applies to tristimulus values based on the CIE 1931 or CIE 1964 colour-matching functions and the specification of colour stimuli perceived as belonging to a reflecting or transmitting object, including self-luminous displays simulating such objects. To colour stimuli perceived as belonging to a primary light source or specularly reflected light, only the u',v' uniform chromaticity scale diagram and the correlates of hue and saturation apply. This second edition from June 2024 cancels and replaces the 2016 version. It was prepared by CIE in cooperation with ISO/TC 274, Light and lighting, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 139, Paints and varnishes. The changes include text, formulae and bibliography updates.

ISO/CIE 23603:2024
Standard method of assessing the spectral quality of daylight simulators for visual appraisal and measurement of colour

This document deals with quantifying the suitability of the spectral irradiance distribution of a daylight simulator for the visual appraisal and measurement of colours of fluorescent or non-fluorescent specimens. It specifies the maximum permissible deviation of the chromaticity of the simulator from the chromaticity of the illuminant being simulated (CIE standard daylight illuminant D50 or D65 or CIE daylight illuminant D55 or D75). The method uses pairs of virtual specimens that are metameric matches under the CIE daylight illuminant when evaluated with the CIE 1964 standard colorimetric observer; the evaluation is based on the special metamerism index for visible or ultraviolet range, quantifying the mismatch between these pairs with specified reflecting and fluorescing properties when illuminated by the daylight simulator tested. This joint standard, published in October 2024, cancels and replaces ISO 23603:2005; the new version includes updated terms, definitions and normative references.

CIE 253:2024 – Overview of Methods for Evaluating Colour Rendition of White-Light Sources beyond Colour Fidelity

Seven methods described in this technical report include Colour Quality Scale, Colour Rendering Index based Colour Rendition Properties, Colour Rendering Vectors and Colour Saturation Icon, Feeling of Contrast Index, IES TM-30 Method, Memory Colour Rendition Index, and Preference Index of Japanese Skin Colour.

CIE 254:2024 – A roadmap toward basing CIE colorimetry on cone fundamentals

This technical report summarises the main steps for developing a new system, explicitly considering the impacts of normal variations of the cone fundamentals due to age, field of view, and individual diversity, which requires to create colorimetric measures and approximately uniform colour space based on cone fundamentals, expand their wavelength range and study their diversity and its colorimetric effects.

Bookshelf

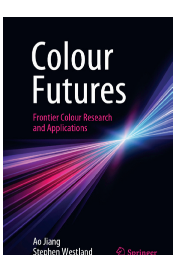
Colour Futures
Frontier Colour Research and Applications

This new book was published as a fifth volume in the Vision, Illusion and Perception series. It deals with colour from many perspectives, explaining and illustrating a wide range of its theoretical and practical aspects.

Seven chapters provide the fundamental background of colour perception, representation, and measurement, as well as its psychological and cultural effects and meanings. Here the text covers the elements of colour vision and blindness, colour attributes, the importance of colour vision in different fields, CIE chromaticity diagrams, $L^*a^*b^*$ and colour difference, spectral reflectance measurement, illuminants, light sources, colorimetry, metamerism and measurement instruments. Also, it discusses retinal imaging, colour constancy, contrast and assimilation, colour appearance models, colour harmony and mixing, colour preference and the influencing factors, including the ecological valence theory with its current limitations, and the impact of colour on human emotions and culture, behaviour, work performance and physiology, such as emotion and sleep cycle regulation or cognition and attention.

The following three chapters focus on using and reproducing colour in digital imaging, on the internet and in the metaverse of virtual and augmented realities (AR/VR), presenting the related terms, principles and challenges. The basics introduced in these sections range from colour gamut and fidelity, colour palettes and test charts, optical image formation, colour imaging tools, RGB and CMYK models, colour management systems, image quality and various colour-correction methods to colour standards and models in virtual environments, the influence of light and materials on virtual colour, the AR/VR display technology, and colour calibration of these devices. The more advanced tasks and concepts include infrared image colouring, the relationship between colour and user behaviour, inclusive colour design, the role of colour in virtual scenes in terms of information transmission and visualisation, navigation, interaction and immersion, the use of immersive virtual environments for colour research, and colour coordination in augmented reality.

In the remaining part of the book, two chapters explore colour in health design and the built environment, discussing the effects of colour on cognition, behaviour and productivity, non-visual effects of colour, psychological, spiritual and physiological effects of environmental colours, enhanced navigation, and adaptive design, among others. Two chapters on artificial intelligence and robotics describe, e.g., the use of machine learning for colour segmentation and transforms, generative artificial intelligence and imaging, colour-optimised image recognition, robot motion based on colour detection, and robot colour effects on humans. The last chapter outlines colour trends and forecasting.



Authors: Ao Jiang, Stephen Westland

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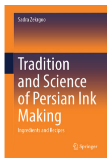
351 pages, 189 images
Hardcover
Available also as an eBook

Tradition and Science of Persian Ink Making
Ingredients and Recipes

Author: Sadra Zekrgoo



Publisher: Springer
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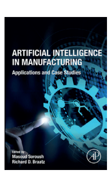
190 pages, 265 images
Hardcover
Also as an eBook

The author of this book builds on long-term, ongoing research into the topic. This volume presents a comprehensive account of constituents and recipes of Persian inks identified in 15 manuscripts studied. The ingredients are classified into seven groups. The largest one comprises almost 50 different colourants, from lamp black, vitriols and copper to henna, indigo, woad and myrtle, up to pigeon's blood and fish oil, to name a few. The remaining ones include binding media, thickening agents, aromatics, preservatives, glossing agents and mordants, mostly with five options each; for example, sugar, honey, Egyptian sugar candy, gold and silver to increase the sheen or lustre. Among the recipes, besides black inks and coloured inks or liqs, sympathetic, waterproof, colour-increasing, water-floating and other special inks, e.g. for printing or textiles, are described.

Artificial Intelligence in Manufacturing
Applications and Case Studies

Editors: Masoud Soroush, Richard D. Braatz



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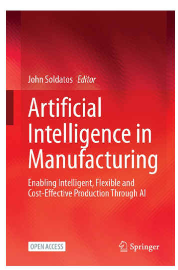
Ten case studies included in this book present, for example, implementing artificial intelligence for paints and coatings manufacturing, plasma-assisted semiconductor manufacturing and advanced manufacturing of touch-sensitive textiles.

Artificial Intelligence in Manufacturing
Enabling Intelligent, Flexible and Cost-Effective Production Through AI

This open-access book documents how the development of artificial intelligence (AI) technologies and applications follows and facilitates the transition of digital manufacturing systems toward human-centric, trustworthy solutions of Industry 5.0. In 27 chapters, it identifies the existing limitations and presents the most advanced systems currently deployed in Industry 4.0, along with the novel, complex AI architectures and approaches required in the emerging era.

The content is organised into three parts. The first describes suitable architectures, business models and semantic modelling techniques. The second deals with multi-agent systems, digital twin frameworks, the use of conversational agents, and approaches based on reinforcement learning and decentralised technical intelligence. The last part presents the trusted, explainable, and human-centred AI systems. Examples include human activity recognition utilising wearable sensors, object detection for human–robot interaction and worker assistance systems, anomaly detection in manufacturing, and different applications of explainable AI, e.g. for visual inspection or process and product quality optimisation.



Editor: John Soldatos

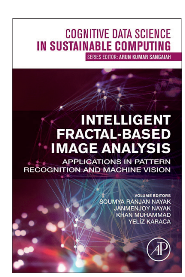
Publisher: Springer
1st ed., February 2024
ISBN: 978-3-031-46451-5
532 pages, 175 images
Hardcover
Available also as an eBook

Intelligent Fractal-Based Image Analysis
Applications in Pattern Recognition and Machine Vision

The basic concepts presented in this volume include pattern recognition, image compression and texture segmentation using fractal features, feature extraction using fractal dimensions, and intelligent approaches for the analysis of fractal features. The individual chapters deal with the analysis of Mandelbrot set fractal images based on machine learning, chaos-based image encryption, classifying images based on fractal features, evaluating image characteristics by the normalised fractal-based technique, fractal-based sequence learning, wavelets for anisotropic oscillations in nanomaterials, comparative analysis of approaches to optimise fractal image compression, and several example applications in medical imaging.

Editors: Soumya R. Nayak, Janmenjoy Nayak, Khan Muhammad, Yeliz Karaca

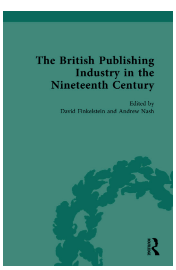
Publisher: Academic Press
1st ed., May 2024
ISBN: 978-0-443-18468-0
318 pages
Softcover
Available also as an eBook



The British Publishing Industry in the Nineteenth Century
Volume I: The Structure of the Industry
Volume II: Publishing and Technologies of Production
Volume III: Authors, Publishers and Copyright Law
Volume IV: Publishers, Markets, Readers

This four-volume work provides an in-depth insight into the transformation of the British publishing industry during the 19th century, as documented by contemporary sources showing how it was driven by the interplay of changes in many related areas, from evolving technology, production mechanisation and new modes of transport, communication and retail to reforms in education and copyright legislation, professionalisation, new business models, market internationalisation and increased demand for printed matter, all of which led to a mass reading public thanks to the growing affordability of books and periodicals, as well as their availability in libraries.

The first volume deals with the book trade operation and economic aspects, the government control through taxes and legal deposit requirements, and the situation in bookselling, including the discount question discussion. The second volume describes technologies and processes, from improved paper quality to monotype and linotype machines, and also presents printing offices and working practices. The third volume is dedicated to authors, publishers, agents, copyright law, and the society of authors. The fourth volume discusses the price of books and their circulation, popular publishing and reading, railway bookstalls, periodical markets, circulating libraries, the fiction market, and the impact of obscenity laws on the book trade.



Editors: David Finkelstein, Andrew Nash

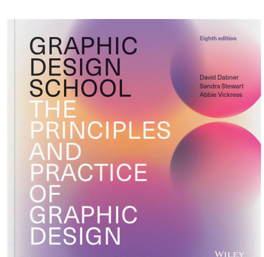
Publisher: Routledge
1st ed., March 2024
ISBN: 978-0-367-56522-0 (set)
1766 pages
Hardcover
Available also as an eBook

Graphic Design School
The Principles and Practice of Graphic Design

The structure of the 8th edition of this introductory book on graphic design remained unchanged, with the methods of how to approach design and basics of composition, typography and colour in the first part and selected software tools and advice on individual steps in designing common printed and digital media in the second part, but the content was updated with new images, examples and recommended reading.

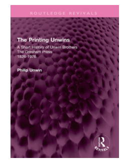
Authors: David Dabner, Sandra Stewart, Abbie Vickress

Publisher: Wiley
8th ed., December 2023
ISBN: 978-1-394-18566-5
208 pages
Softcover
Available also as an eBook



The Printing Unwins
A Short History of Unwin Brothers: The Gresham Press (1826–1976)

Author: Philip Unwin

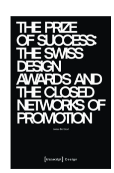


Publisher: Routledge
1st ed., October 2023
ISBN: 978-1032593623
195 pages
Hardcover
Also as an eBook

This book, first published in 1976 and now available as a part of the Routledge Revivals book series, presents the history of the Unwin family printing company over 150 years, from its founding by Jacob Unwin in London to the decades at new premises in Woking, including the last dozen years under new ownership. It shows the dedication to typography, printing and progress while reflecting the many economic, social and technological changes, also documented by illustrations with the equipment used in different periods, from the original composing room to Monotype keyboards and casters, perfectors and folding machines, up to a Compuscan machine for the optical character recognition, paper tape input keyboards and Linotron phototypesetting device.

The Prize of Success
The Swiss Design Awards and the Closed Networks of Promotion

Author: Jonas Berthod

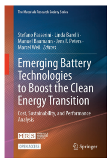


Publisher: Transcript
1st ed., May 2024
ISBN: 978-3837671919
256 pages, 96 images
Softcover
Also as an eBook

In this book, the author analyses the role of the Swiss Design Awards in graphic design promotion and the definition of "good" design. The text tracks their evolution and influence, as well as the interests and attitudes of various parties involved, and documents the networks formed around the awards in different periods, discussing the benefits and risks implied by closing the loop.

Emerging Battery Technologies to Boost the Clean Energy Transition
Cost, Sustainability, and Performance Analysis

Editors: Stefano Passerini, Linda Barelli, Manuel Baumann, Jens Peters, Marcel Weil



Publisher: Springer
1st ed., February 2024
ISBN: 978-3031483585
353 pages, 53 images
Hardcover
Also as an eBook

In this book, over 50 contributors provide an interdisciplinary view on the topic. The chapters in the first three parts address mobility and future trends, circular economy for batteries, system perspective for a clean energy transition, projected global demand for energy storage, other energy storage technologies, advantages and importance of batteries in the energy transition, segmentation of battery market and its outlook. Two parts focus on the performance and cost of present batteries, raw materials and recycling of lithium-ion batteries, and emerging battery chemistries for closed and open battery systems. The last part deals with prospective assessments of emerging batteries, methodological challenges, life-cycle assessments, techno-economics analyses, social implications and approaches, and a multicriteria decision analysis.

Smart Textiles from Natural Resources

Editor: Ibrahim H. Mondal

Publisher:
Woodhead Publishing
1st ed., April 2024
ISBN: 978-0443154713
926 pages, Softcover
Also as an eBook

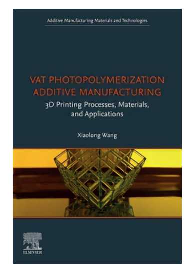
This extensive book covers various types of smart textiles, e.g. stimuli-responsive or electrically conducting, materials and technologies for their production, including printing, and their applications in different areas.

Vat Photopolymerization Additive Manufacturing
3D Printing Processes, Materials, and Applications

This book focuses on recent progress in 3D printing technologies based on vat photopolymerisation and their applications in various areas. Three chapters introduce the fundamental principles and components, the classification according to the type of light source and geometric configuration, the specifics of two-photon polymerisation and techniques using multiple beams, materials or wavelengths, including the strengths and weaknesses of the individual options, the photopolymerisation mechanism and composition of UV-curable resins, the relationship between structure and mechanical properties, and the possibility of optimising the process and output by controlling the involved interfaces. The following chapters deal with the manufacturing of various plastics, hydrogels, stimuli-responsive polymers, ceramics, electronics, metamaterials and bio-inspired structures, the advantages of surface functionalisation and relevant surface engineering methods, the impact of vat photopolymerisation 3D printing in the fields of engineering and bioengineering, and a brief outline of the trends and prospects.

Editor: Xiaolong Wang

Publisher: Elsevier
1st ed., April 2024
ISBN: 978-0-443-15487-4
518 pages
Softcover
Available also as an eBook

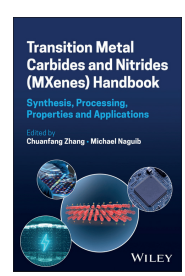


Transition Metal Carbides and Nitrides (MXenes) Handbook
Synthesis, Processing, Properties and Applications

With almost 80 contributors from across the globe, this handbook brings a comprehensive account of the MXene family of 2D materials. After the introduction, one part provides the guidelines on synthesising MXene precursors, use of fluorine, molten salt etching, intercalation of ions and molecules, and MXenes with multiple M elements. Further, it discusses MXene thermal and chemical stability, degradation mechanism, handling and storage, structural confirmation and morphological investigation, surface terminations, delamination and surface functionalisation. Finally, it deals with MXene dispersion stability, rheology and ink formulation for printing and wet coating, as well as 3D printing of MXenes and their assembling from liquid to solid. The following part focuses on the optical, optoelectronic and mechanical properties of MXenes and their prediction, while the last presents MXene applications in supercapacitor devices, batteries, electromagnetic interference shielding, electronics, sensors, environmental treatments and healthcare.

Editors: Chuanfang Zhang, Michael Naguib

Publisher: Wiley
1st ed., June 2024
ISBN: 978-1-119-86949-8
784 pages
Hardcover
Available also as an eBook



Bookshelf

Academic dissertations

3D Printing and Stretchable Electronics

The research within this thesis focused on stretchable electronics comprising rigid module islands and their stretchable interconnections on deformable substrates, particularly the possibilities to improve their electrical performance and applicability by reducing the mechanical differences of the three main components. In order to achieve more robust systems, the work employed 3D printing and explored joining rigid module islands on a deformable substrate with different adhesives, designing protective structures, reinforcing screen-printed stretchable interconnections, and integrating carbon-based fibre cloth into composite matrices of electronics components.

After introducing the thesis and its aims, one chapter of the dissertation describes rigid, flexible, stretchable and textile substrates, module islands, their adhesion, bonding methods and the impact of stress concentration, rigid shaped copper foil interconnections, rigid and deformable printed interconnections, fibre-based interconnections and stretchable interconnections failure mechanisms. Also, it presents fused-filament fabrication for 3D printing of stretchable electronics, structure and stretchability of 3D-printed objects, as well as electronics and stretchable electronics prepared by this and other 3D-printing techniques. The following two chapters present and discuss the results. A nonstructural adhesive provided the best results when testing different non-conductive adhesives to fix common reinforced epoxy laminate and 3D-printed polylactic acid boards on thermoplastic polyurethane film. Further, the stress concentration around the rigid islands could be controlled by using suitable protective structures. Similarly, the support structures 3D-printed with thermoplastic polyurethane filament improved the stretchability of meander-shaped interconnections. Finally, it was shown that stretchable 3D-printed structures for wearable electronics could be produced by inserting permeable carbon fibre cloth plies inside a thermoplastic polyurethane matrix during 3D printing, and the use of these samples as a 3D-printed strain sensor was demonstrated.

Doctoral thesis – Summary

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Electrical Engineering

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Jukka Vanhala

Defended:
*28 March 2024, Tampere University,
Faculty of Information Technology
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Tampere, Finland*

Contact:
teemu.salo91@hotmail.fi

Further reading:
https://trepo.tuni.fi/handle/10024/154978

Advances in Additive Manufacturing of Organic Electrochemical Transistors

This work contributes to the progress in printed organic electrochemical transistors towards better performance and higher sustainability, facilitating their broader use in bioelectronic and logic circuit applications. In particular, the research comprised optimising printing strategies and device architectures, using novel channel materials and ink formulations, and integrating organic electrochemical transistors into all-printed sensor platforms.

Four chapters of the dissertation provide the background on relevant materials and printing technologies for additive manufacturing of organic electronics, especially organic electrochemical transistors, various aspects of these devices, and characterisation methods employed in the work. The text describes the structure and properties of organic semiconducting materials, charge transport in both polymeric and molecular organic semiconductors, and channel materials for organic electrochemical transistors, including the

Doctoral thesis – Summary

Author:
Anatolii Makhinia

Speciality field:
Organic Electronics

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Valerio Beni
Simone Fabiano
Daniel Simon*

Defended:
*24 May 2024, Linköping University,
Faculty of Science and Engineering
Norrköping, Sweden*

Contact:
anatolii.makhinia@ri.se

pgBTTT polymer, i.e. poly([4,4′-bis(2-(2-(2-methoxyethoxy)ethoxy)ethoxy)-2,2′-bithiophene-5,5′-diyl]-*alt*-[thieno[3,2-*b*]thiophene-2,5-diyl]). Among additive manufacturing technologies, screen printing, inkjet printing and aerosol-jet printing are presented, together with their advantages and limitations with respect to printed electronics. The chapter dedicated to organic electrochemical transistors introduces their history, working principle and mode of operation, performance metrics, device architectures, channel geometries, gate electrode materials and electrolytes. Also, it discusses the effect of solvent substitution on device performance and describes the example applications in logic circuits and ion-selective sensors. Finally, one chapter summarises the published studies. Combining the screen printing and aerosol-jet printing for the fabrication of organic electrochemical transistors enabled a significant decrease in the channel width and thus improved the switching response, demonstrated by the operational frequency of inverters beyond 100 Hz and self-oscillation frequency of the five-stage ring oscillator of about 60 Hz. By integrating transistors with other printed components, it was possible to develop two types of sensor platforms; one combined the transistor with a screen-printed piezoelectric sensor for monitoring electrophysiological signals, and the other integrated the transistor into a 3D-printed microfluidic circuit. The pgBTTT-based ink formulation with a biodegradable and non-toxic dihydrolevoglucosenone solvent was successfully used for a novel all-printed accumulation-mode vertically stacked organic electrochemical transistor.

Further reading:
DOI: 10.3384/9789180756167

Doctoral thesis – Summary

The Optimization of Sustainable Procedures for the Designing and Recycling of Pharmaceutical Cardboard Packaging

Author:
Mia Klemenčić

Speciality field:
Graphic Technology

Supervisors:
Ivana Bolanča Mirković
Nenad Bolf

Defended:
28 August 2024, University of Zagreb, Faculty of Graphic Arts
Zagreb, Croatia

Contact:
mia.klemencic@croatia.rit.edu

This thesis explored the possibilities of increasing the sustainability of pharmaceutical packaging by optimising its design in terms of better recyclability and circularity without deterioration in packaging quality. It involved analysing the processes of packaging manufacturing and recycling to identify the key factors affecting the relevant properties of recycled paper. The experimental work comprised preparing samples corresponding to the main stages of cardboard packaging production and the presence of lamination, their recycling with three different flotation methods, producing laboratory sheets of paper and flotation foam, and evaluating their optical properties and metal traces in samples. The research also dealt with a conceptual solution for a sustainable pharmaceutical product. The approach was based on defining the requirements and specifications and developing a calculation model for optimising the use of adhesive and lamination when considering different design concepts.

Two chapters of the dissertation provide an overview of paper production and properties in general, the use of additives, adhesives, coatings and multilayer structures with their impact on paper recycling, paper packaging, specific requirements in the case of food and pharmaceutical packaging, and other considerations related to the latter one. The following five discuss the concerns regarding heavy metals and other contaminants in food packaging materials, their migration and assessment, various stages and aspects of paper recycling, waste management, circular economy, sustainability, lifecycle assessment, eco-design and sustainable packaging, as well as current packaging trends, design optimisation and strategies for optimised use of adhesives and laminates in packaging. The remaining three chapters present methods, materials and obtained results. It was shown that understanding how the choice of materials affects recyclability helps to design a more sustainable product while achieving its required quality.

Further reading:
https://urn.nsk.hr/urn:nbn:hr:216:526006

Events

LOPEC 2025

Munich, Germany
25–27 February 2025

For the 2025 edition of this established event for flexible, organic and printed electronics, the topics of the plenary lectures include the benefits of integrating design principles with printed electronics, digital organic light-emitting diodes and displays in automotive exterior lighting, microscopic LED technology for flexible and stretchable displays, and different healthcare solutions, namely the printed electronics technology platform advancing diagnostic imaging, stretchable multifunctional platform with integrated microfluidics, photonics and electronics, and wearable devices based on hybrid printed electronics, sensors and artificial intelligence. The scientific lectures deal with power nanoelectronics, 3D kirigami lighting, organic artificial neurons, advancements in recyclable components, energy-saving production techniques and life-cycle extension strategies, printed sensors as part of a smart sensing skin for real-time monitoring of drones and planes, sensing platform for heavy metal ions monitoring, aerosol-jet printed MXene sensor arrays, high-precision capillary printing for microscale patterning of transparent conductive oxides, and more.

TAGA NextGen Conference

Boulder, Colorado USA
25–28 March 2025

The Technical Association of the Graphic Arts has become part of WhatTheyThink. In 2025, the annual conference, renamed to stress the increasing focus on students as the future of the graphic arts industry, traditionally covers a wide range of topics, from examining the variation in colour gamut volume estimation and determining the optimal range of scannability and verification of 2D barcodes to developing bio-based adhesives for bookbinding applications, up to studying the impact of commercial laundering on brand colour durability on printed textiles.

10th Conference on Information and Graphic Arts Technology

Ljubljana, Slovenia
29–30 May 2025

The anniversary edition of this event for the graphic communications industry offers three keynotes dealing with sustainable solutions in different applications and settings. Sustainability is also dealt with in other contributions, such as the one presenting paper bags made from annual plants or those discussing the printed packaging future and packaging waste regulation. Other topics include, for example, the bibliometric analysis of typography research, properties of mixed leuco-dye thermochromic systems, and colour reproduction on 3D printed flat and low-relief surfaces.

INGEDE Symposium 2025

Munich, Germany
25–26 February 2025

The focus of this event, held in a hybrid format, is on paper recycling, especially in terms of packaging. The topics cover various aspects, including properties and combinations of materials, waste treatment, value chain redesign and developments of technologies for papermaking, printing and recycling, as well as methods for measurement and characterisation. The keynote deals with the carbon footprint of printed products.

Packaging, Labelling and Printing Events by EasyFairs

Besides several Empack events, held in UK, Spain, The Netherlands, Portugal, and Germany from February to June 2025 and co-located with Packaging Innovations or other fairs, Paris Packaging Week is organised in France (28–29 January), Visualize Expo, formerly Sign & Print Expo, takes place in Gorinchem, The Netherlands (25–27 March), and Packaging Première and PCD are co-located in Milan, Italy (13–15 May).

FESPA Events

The series of events dedicated to speciality printing, sign-making and visual communications can be attended around the world again in 2025. After FESPA Middle East in Dubai, UAE (20–22 January) and FESPA Brasil in São Paulo (17–20 March), three events are co-located on 6–9 May in Berlin, Germany: FESPA Global Print Expo, including the ceremony of FESPA Awards 2025, Personalisation Experience and European Sign Expo.

Screen Print Innovations 2025

Essen, Germany
3–5 June 2025

This new ESMA trade show includes the Innovation Theatre forum with keynotes presenting the latest screen-printing applications, e.g. for smart textiles, next-generation antennas and security features, sustainable screen-printing inks based on polysaccharides, and also the value of the outcome-based approach to innovations.

FLEPS 2025
IEEE International Conference on Flexible, Printable Sensors and Systems

Singapore
22–25 June 2025

This edition offers plenary talks by Joshua Yang on memristive devices for neuromorphic computing, Ajay Virkar on nanoscale silver for flexible and transparent electronics, and Xiaodong Chen on materials chemistry in bio-interfaced electronics, parallel lecture sessions, workshops on the Internet-of-Things kit, laser-induced graphene and flexible electronics standards, and tutorials on soft and sensor systems.

High-Performance Graphics 2025

Copenhagen, Denmark
23–25 June 2025

In 2025, this graphics and imaging systems research event is co-located with EGSR, the 36th Eurographics Symposium on Rendering.

Droplets 2025

Liège, Belgium
1–3 July 2025

The 6th International Conference on Droplets features a dozen keynotes and six plenary talks, presenting spontaneous charging of sliding water drops, droplet microfluidics, dynamics of complex interfaces, and more.

Color Impact 2025

Rochester, New York, USA
16–18 June 2025

This event is dedicated to various facets of colour research, including colour naming, using and characterising, colour-vision deficiency, and special colourants. The keynote speakers are Dimitris Mylonas, presenting research on facilitating colour communication within and across languages, Cynthia Brewer, discussing the schemes matching the perceptual dimensions of colour with conceptual structures in geographic data, and Mark Fairchild, reviewing the evolution of specifying colour and directions towards future colorimetric systems. The main programme is preceded by the pre-conference workshops, offered on 15 June; in addition, short courses are scheduled for three afternoon sessions.

NANOTEXNOLOGY 2025

Thessaloniki, Greece
5–12 July 2025

The rich programme of this event again offers five working days filled with conference sessions on nanosciences and nanotechnologies, artificial intelligence, 3D (bio)printing, intelligent manufacturing and automation, and flexible organic electronics, accompanied by the exhibition and various networking opportunities, and complemented by summer schools scheduled for the weekend days. The announced plenary talks are 'Physics approaches to organic light source enhancements' by Donal Bradley and 'MXenes and assembled 2D nanosheets redefine what materials can do' by Yury Gogotsi.

CIE 2025 Scientific Conference

Vienna, Austria
7–9 July 2025

The three-day conference is organised during the CIE Midterm Meeting, taking place on 4–11 July. The programme features, for example, the keynote on advances in artificial intelligence for the colour industry by Stephen Westland, the workshop 'Personal colour management for display devices and consumer products', and presentations dealing with the measurement accuracy in microscope-based reflectometry for thin film optical characterisation, mathematical framework for comparing photometric observers, corneal spectral sensitivities modelling, perceived white point of wide colour gamut display, validity of CIE colour matching functions for OLED-LCD mixed technology matches, broadband light source based on light-emitting diodes for radiometric calibrations in the UV region, and influence of level of details of 3D objects on realism in virtual reality.

In conjunction with the CIE event, ICC is holding a free-to-attend Expert Day on Individual Colour Matching Functions in Vienna on 8 July in the afternoon. Attendance is free, and remote participation is also possible. The announced presentations deal with individual differences of cone spectral sensitivities, possibilities to implement individual colour-matching functions in ICC.1 and ICC.2 profiles, display colour management and soft-proofing, transform the functions using a filter method, and more.

Guidelines for authors

Authors are encouraged to submit complete, original and previously unpublished scientific or technical research works, which are not under reviews in any other journals and/or conferences. Significantly expanded and updated versions of conference presentations may also be considered for publication. In addition, the Journal will publish reviews as well as opinions and reflections in a special section.

Submissions for the journal are accepted at any time. If meeting the general criteria and ethical standards of the scientific publication, they will be rapidly forwarded to peer-review by experts of high scientific competence, carefully evaluated, and considered for selection. Once accepted by the Editorial Board, the papers will be edited and published as soon as possible.

When preparing a manuscript for JPMTR, please strictly comply with the journal guidelines. The Editorial Board retains the right to reject without comment or explanation manuscripts that are not prepared in accordance with these guidelines and/or if the appropriate level required for scientific publishing cannot be attained.

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.

Only contributions submitted in English will be considered for publication. If English is not your native language, please arrange for the text to be reviewed by a technical editor with skills in English and scientific communications. Maintain a consistent style with regard to spelling (either UK or US English, but never both), punctuation, nomenclature, symbols etc. Make sure that you are using proper English scientific terms. Literal translations are often wrong. Terms that do not have a commonly known English translation should be explicitly defined in the manuscript. Acronyms and abbreviations used must also be explicitly defined. Generally, sentences should not be very long and their structure should be relatively simple, with the subject located close to its verb. Do not overuse passive constructions.

Do not copy substantial parts of your previous publications and do not submit the same manuscript to more than one journal at a time. Clearly distinguish your original results and ideas from those of other authors and from your earlier publications – provide citations whenever relevant.

For more details on ethics in scientific publication consult Guidelines, published by the Committee on Publication Ethics (COPE):
<https://publicationethics.org/resources/guidelines>

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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.

List of authors: I.e. all persons who contributed substantially to study planning, experimental work, data collection or interpretation of results and wrote or critically revised the manuscript and approved its final version. Enter full names (first and last), followed by the present address, as well as the E-mail addresses. Separately enter complete details of the corresponding author – full mailing address, telephone number, and E-mail. Editors will communicate only with the corresponding author.

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.

Discussion: Answer your research questions (stated at the end of the introduction) and compare your new results with published data, as objectively as possible. Discuss their limitations and highlight your main findings. At the end of Discussion or in a separate section, emphasize your major conclusions, pointing out scientific contribution and the practical significance of your study.

Conclusions: The main conclusions emerging from the study should be briefly presented or listed in this section, with the reference to the aims of the research and/or questions mentioned in the Introduction and elaborated in the Discussion.

Note: Some papers might require different structure of the scientific content. In such cases, however, it is necessary to clearly name and mark the appropriate sections, or to consult the editors. Sections from Introduction until the end of Conclusions must be numbered. Number the section titles consecutively as 1., 2., 3., ... while subsections should be hierarchically numbered as 2.1, 2.3, 3.4 etc. Only Arabic numerals will be accepted.

Acknowledgments: Place any acknowledgements at the end of your manuscript, after conclusions and before the list of literature references.

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