# Journal of Print and Media Technology Research

## Scientific contributions

# Journal of Print and Media Technology Research

### A PEER-REVIEWED QUARTERLY

**A mission statement**

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

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

By regularly publishing peer-reviewed, high quality research articles, position papers, surveys, and case studies as well as review articles and topical communications, the journal is promoting original research, international collaboration, and the exchange of ideas and know-how. It also provides a multidisciplinary discussion on research issues within the field and on the effects of new scientific and technical developments on society, industry, and the individual. Thus, it intends to serve the entire research community as well as the global graphic arts and media industry.

The journal is covering fundamental and applied aspects of at least, but not limited to, the following topics:

**Printing technology and related processes**
- Conventional and special printing
- Packaging
- Fuel cells and other printed functionality
- Printing on biomaterials
- Textile and fabric printing
- Printed decorations
- Materials science
- Process control

**Premedia technology and processes**
- Colour reproduction and colour management
- Image and reproduction quality
- Image carriers (physical and virtual)
- Workflow and management

**Emerging media and future trends**
- Media industry developments
- Developing media communications value systems
- Online and mobile media development
- Cross-media publishing

**Social impact**
- Media in a sustainable society
- Environmental issues and sustainability
- Consumer perception and media use
- Social trends and their impact on media

**Submissions to the Journal**

Submissions are invited at any time and, if meeting the criteria for publication, will be rapidly submitted to peer-review and carefully evaluated, selected and edited. Once accepted and edited, the papers will be published as soon as possible.

✉ Contact the Editorial office: journal@iarigai.org

# Journal of Print and Media Technology Research

# Contents

# A letter from the Editor

*Gorazd Golob*
Editor-in-Chief
E-mail: gorazd.golob@jpmtr.org
journal@iarigai.org

The first issue of the Journal in 2019 is comprised of five papers, with a total of 86 pages, more than average in the previous year. The trend is positive.

Again, topics from a broad border area appear, that at the same time indicate research trends in the field of print and media, which for a long time is not only traditional printing of books and booklets, newspapers, and magazines.

The first original scientific paper published in the present issue covers the field of printing of the nucleic acid. It is from the research area that can be considered conditionally as the field of bio-printing, however, it is interesting also because of the selected methods for evaluation of the results of the experiment, based on the fluorescence measurement method that is probably not well known to established and more traditionally oriented researchers in our field. The second paper presents the research results of an improved method for the production of a printing form for pad-printing, which enables the use of this printing technique for the printing of electronic devices.

Two review papers follow. The first deals with low-cost chipless RFID tags, which some years ago promised a revolution in the labelling of products in retail sales, it, however, did not happen due to too high tag price. With the development of technology presented in the paper, it is becoming increasingly topical. Another review paper deals with augmented reality and print media, which is bringing additional functionality to the print media and hence new opportunities in the future.

The last paper deals with movie genres, their characterization, and recognisability. Despite some dilemmas regarding the scope, it has been accepted as an interesting example of media coverage, including movie and video.

Our editor Markéta Držková again prepared Topicalities section with an overview of news in the field, new literature and interesting events. The presented patents on printing inks, granted to inventors and assignees in 2018, are covering traditional and digital printing techniques, and are dedicated also to speciality and security print products, printed electronics and sensors. The news from Enfocus and Ghent Workgroup gives an overview on the latest activities in pre-press. The detailed presentation of UK's Centre for Process Innovation shows state of the art research capabilities in the field of printed electronics with a detailed introduction of research labs and advanced commercial printing equipment for prototype and small scale production.

In the Bookshelf the latest editions are listed, covering typography and design, graphic communication business and library technologies, printed electronics, sensors, 3D printing, and even some history, including the transcription and translation of the oldest Spanish printing manual from the end of 17th Century.

Academic dissertations presented are from UK and German universities. The first one was defended at the University of Sheffield by Preeyanuch Voravickositt, who studied users' needs, experience and e-book collection management in Thai academic libraries. Guohua Hu's research was from the field of graphene and related 2D materials, nanoengineering and functional printing; the thesis on printable 2D material optoelectronics and photonics was defended at the University of Cambridge. Stephan Pröller defended his thesis on morphology of printed organic solar cells at the Technical University of Munich.

A number of conferences, congresses, trade shows and other events organized worldwide for a next few months show a significant interest of the industry, academic and research institutions for intensive communication and opportunities for the exchange of knowledge, technologies, presentation of their work and interests. Most of the presented events have a long tradition, some are a result of merging and transformation of previously well-known traditional events into more attractive and up to date conferences and trade shows. This is also an opportunity for ambitious new organizers and attendees.

The Journal is currently in good condition, with an appropriate number of submitted papers for publication, currently in review and editing process for next issues. However, we are expecting your valuable research results and interesting submissions, giving us the opportunity to further improve the quality and the status of the Journal in the dedicated research fields and on the lists of indexed journals. The Call for papers is constantly open. Also, your information on interesting events, new books or academic publications from the fields covered by the Journal will be taken into consideration by the associate editor Markéta Držková (marketa.drzkova@jpmtr.org).

Ljubljana, March 2019

# A test system for the printing of functional nucleic acids onto different carriers and verification of its functionality by DNA dyes

Jacqueline Stamm[1], Dieter Spiehl[1], Jeannine Jaeger[2], Florian Groher[2], Tobias Meckel[3], Beatrix Suess[2] and Edgar Dörsam[1]

[1] Institute of Printing Science and Technology,
 Technische Universität Darmstadt,
 Magdalenenstraße 2, 64289 Darmstadt
[2] Department of biology, synthetic genetic circuits,
 Technische Universität Darmstadt,
 Schnittspahnstraße 10, 64287 Darmstadt
[3] Macromolecular and Paper Chemistry,
 Technische Universität Darmstadt,
 Alarich-Weiss-Straße 8, 64287 Darmstadt

stamm@idd.tu-darmstadt.de
spiehl@idd.tu-darmstadt.de
jaeger.jea@bio.tu-darmstadt.de
groher@bio.tu-darmstadt.de
meckel@cellulose.tu-darmstadt.de
bsuess@bio.tu-darmstadt.de
doersam@idd.tu-darmstadt.de

## Abstract

The creation of inkjet printed biosensors belongs to rising applications of functional printing. One of their many uses is the detection of antibiotic residues in milk or meat from food-producing animals, which have been excessively treated. For example, they are treated with the fluoroquinolone ciprofloxacin (CFX), which we want to detect with an aptamer-based fluorescence biosensor, printed onto a carrier material. For that purpose, inkjet printing and several carrier materials are analyzed in their ability to obtain the functionality of nucleic acids. The printing process is analyzed by characterizing DNA and buffer solutions and by comparing printed with unprinted DNA using an agarose-gel test. The carrier materials are preselected by analyzing the auto-fluorescence excitation and emission spectra of ten different materials out of which three with the lowest intensity at the CFX excitation and emission peaks are chosen. After printing with DNA onto these materials, the fluorescence induced with DNA dyes is measured. The experiments show that nucleic acids can be inkjet printed without damage and that many foils and papers commonly used in the laboratory show auto fluorescence when excited in the UV-spectrum. Other properties of the carrier materials are important as well. Here a selection containing the paper Whatman Grade 1, the foil Hostaphan GUV 4600 and the nitrocellulose HF 120 are compared in their ability to sustain the functionality of nucleic acids printed onto them. Although, we were able to select a suitable material for future experiments of printing a CFX-biosensor, there are still open questions concerning the interactions between nucleic acids and different carrier materials.

Keywords: inkjet, aptamers, fluorescence, ciprofloxacin, biosensor

## 1. Introduction and background

In printing technology and research, the focus is shifting from graphic arts to functional printing. For example, printed circuits (Pankalla, et al., 2013), antennas (Mohassieb, et al., 2017) or gravure printed organic light emitting diodes (Raupp, et al., 2017) or transistors (Spiehl, et al., 2015) are current areas of research and some of them are already applied in production of goods. Another application are printed biosensors, which find use in the fields of health (Song Xu and Fan, 2006), food safety (Alocilja and Radke, 2003), environment protec-

tion (Justino, Duarte and Rocha-Santos, 2017) or even homeland security (Joshi, et. al., 2006). A biosensor is a device consisting of three parts: the bioreceptor, which binds to the target molecule; the transducer, which transforms the interaction into a measurable signal; and the signal processor, which displays the result in a user-friendly way (Kivirand, Kagan and Rinken, 2013). Concrete examples for biosensor application are the detection of pathogens to monitor and contain the spread of serious illnesses (Ecker, et al., 2008), determination of blood glucose levels for diabetics (Wang, 2001), controlling the usage of dangerous insecticides

(Bachmann and Schmid, 1999), which are also linked to the death of bees (Brandt, et al., 2016) or the detection of toxins, pesticides and antibiotic residues in foods (Mello and Kubota, 2002). In this paper special interest is given to the antibiotic residues in food-producing animals.

Antimicrobial drugs are used on food-producing animals for therapeutic, prophylactic or growth promoting purposes. They include disinfectants, antiseptics and antibiotics. It is an almost inevitable consequence that bacteria constantly exposed to antibiotics become resistant and the antibiotics ineffective. Since 1990 the resistance and particularly multiple resistance to several antibiotics has increased drastically in developed countries leading to numerous outbreaks of serious diseases (Threlfall, et al., 2000). In fact, antibiotic resistance is known to be one of the main public health problems (Novais, et al., 2010). Most antibiotics used are sulfonamides (20 %) or fluoroquinolones (19 %), followed by aminoglycosides (15 %), phenicols (15 %), β-lactams (15 %), tetracyclines (8 %) and oxazolidinones (8 %) (Cháfer-Pericás, Maquieira and Puchades, 2010). One example is the fluoroquinolone ciprofloxacin (CFX), which is used to treat a wide variety of bacterial infections on animals and humans (Groher and Suess, 2016; Groher, et al., 2018; Jaeger, et al., 2019).

Currently established methods of detecting antibiotics can be divided into two groups. Most frequently used are confirmatory methods, generally involving mass spectrometry. They are, however, time consuming, expensive and require specific equipment as well as training. Second are screening methods such as microbiological assays and immunoassays. While microbiological assays lack specificity and require long incubation times, immunoassays require the *in vivo* production of antibodies and are restricted in possible targets to antigens. The development of other screening methods is increasing considerably, with biosensors taking up about 8 % of all used methods (Cháfer-Pericás, Maquieira and Puchades, 2010). The possibility for a new biosensor method has arisen twenty years ago with the development of synthetic aptamers.

We have developed a CFX-binding ribonucleic acid aptamer (RNA-aptamer). Aptamers are approx. 25–100 nucleotide-long deoxyribonucleic acid aptamer (DNA) or RNA that bind specifically to molecular targets. They possess a complex three-dimensional structure, which entwines around its specific target, its ligand, upon binding (Garst, Edwards and Batey, 2011). Other interactions are also involved in recognizing the target molecule (Edwards, Klein and Ferré-D'Amaré, 2007). Additionally, aptamers can be denatured reversibly. This means that changing the surrounding conditions will only cause aptamers to temporarily unfold, while – upon returning to the original binding conditions – they are able to

regain their functionality (McKeague and DeRosa, 2012). The in vitro procedure of generating aptamers enables a great control over the binding conditions and the target selection. They can be generated de-novo for a specific ligand via a procedure called systematic evolution of ligands by exponential enrichment (SELEX). Usually 6 to 20 cycles of this procedure are needed (Ellington and Szostak, 1990).

Our motivation is the creation of a printed aptamer-based biosensor for the detection of CFX. There are mainly four components to consider when developing a printed biosensor: the ink formulation, the printing process, the carrier material and the readout. The ink formulation has to include the bioreceptor, namely the CFX-binding aptamer, as-well as the transducer, which produces the signal. In this case the transducer is already included, because the autofluorescence of CFX is reduced automatically after binding with its aptamer. For other antibiotics an element, which transforms the binding process into a signal, would have to be included.

In this paper, the focus is on analyzing general printing experiments of nucleic acids. For this purpose, a model system is used instead of the aptamer. The aptamer is time-consuming in production and will be printed after the investigations described in this work. The bioreceptor consists of a printed nucleic acid and the transducer is a special dye, applied afterwards. If the nucleic acid is still functional the dye is able to insert itself into the sequence and an increase in fluorescence can be detected. The requirements for the printing process are the delivery of small quantities of functional material in the liquid phase into well-defined locations. We will confirm, that inkjet printing is suitable for this job in 3.1, although each printhead has only a narrow viscosity range and exercises a high mechanical shear onto the used ink. Finally, a carrier material has to be found, which can store and protect the printed aptamers, without inhibiting its functionality or interfering with the produced signal and altering the readout.

In the presented tests, experience is gathered in handling and printing nucleic acids as well as their behavior on different carrier materials on the example of DNA. Parts of this work were already presented at the 45th International iarigai Conference in Warsaw (Stamm, et al., 2018). The end goal is to transfer the gained knowledge into the printing of RNA-aptamer biosensors.

## 2. Materials and methods

All materials and methods used for creating, characterizing and evaluating the DNA biosensor model system are introduced in the following sections. First, the DNA ink is presented, as well as the DNA dyes, followed by

J. Stamm, D. Spiehl, J. Jaeger et al. – J. Print Media Technol. Res. 8(2019)1, 7–17

9

the ink characterization. Then a suitable printing process and carrier materials are chosen. Finally, the different equipment used for fluorescence detection and their application areas are explained.

## 2.1 DNA and DNA dyes

Deoxyribonucleic acid is a pair of polynucleotide biopolymer strands that form a so-called double helix, while ribonucleic acid is a single strand of said polymer. The DNA dyes are used to make DNA visible. They intercalate in the DNA, meaning they insert themselves between the bases and increase their fluorescence after excitation. This principle is used as model detector system in this work, for the detection of DNA printed onto a carrier. The experiments mentioned and shown here use Hoechst 33342 (Thermo Fisher Scientific, Waltham, MA, USA), because of its similar fluorescence excitation and emission spectra to CFX (Figure 1); and YOYO-1 iodide (Thermo Fisher Scientific, Waltham, MA, USA), because of its significantly higher intensity increase after intercalating (Figure 2). The excitation and emission spectra are shown at the end of this section while introducing the fluorescence measuring equipment.

There are three different kinds of DNA we use for different experiments: DNA with low relative molecular mass ($M_r$ = 1.3 to 7.9 million g/mol), DNA V11 and a plasmid solution. Their properties and usages are listed in Table 1. The DNA low $M_r$ is chosen because its molecular mass is comparable to that of the CFX aptamer. The difference in molecular structure has no great impact on the macroscopic fluid properties. When doing the DNA staining, the DNA V11 is used because of its comparable structure. Eventually the plasmid with its high molecular mass and circular structure is used for testing of potential damaging during printing, because it is even more sensitive to damage than the CFX aptamer. All of them are stored and used in buffer solution, which consists of water from the Milli-Q processing plant, 40 mM of the chemical buffer agent HEPES, 125 mM potassium chloride and 5 mM magnesium chloride.

## 2.2 Fluid characterization

Nucleic acids, stored in their buffer, form the ink that needs to be printed to create a biosensor. But different printing processes call for different ink properties.

Usually the restricting properties are the viscosity and the surface tension, which requires the knowledge of the density as well.

The viscosity can be determined using the rotational rheometer Panalytical Kinexus lab+ by Malvern. The fluid is inserted into a gap between a plate and a variable cone, called the geometry. The geometry with 60 mm diameter and 1° inclination is suitable for low viscous fluids and is used in the following characterization. By rotating the cone with increasing speed ($10\ s^{-1}$ to $1\,000\ s^{-1}$ was used), the shear rate onto the fluid is increased and the resulting shear stress is measured. The viscosity is then found by the slope of a linear fit to shear stress over shear rate.

The surface tension can be measured with the tensiometer DSA 100 from Krüss. Droplets are created either hanging from the syringe (pendant) or set down onto a surface (sessile) and their shape is analyzed regarding their curve and contact angle respectively. The general surface tensions are measured via pendant drops, whereas their polar and disperse ratios via sessile drops onto a known material, here Teflon.

Finally, the density can be determined with a pycnometer. The glass flask has a well-defined filling capacity and is used by measuring the weight of an unknown substance in reference to a substance with known density, here water.

## 2.3 Printing methods and carrier materials

The established printing processes can be divided into conventional printing, which requires a printing plate, and non-impact printing (Kipphan, 2001). Considering the requirements of transferring small amounts of nucleic acids in a clean environment, one option of each group seems most promising: gravure and inkjet printing. In both methods, it is possible to have all machine parts coming into contact with the ink made from inert materials like polytetrafluoroethylene (PTFE), polyproylene (PP), chromium, stainless steel or silicone.

We will focus on inkjet printing because of its more variable dispensing options when doing a development process in the lab.

*Table 1: The used DNA solutions with their properties and applications; all of them are stored in buffer solution and used in their liquid state*

| Name | Properties | Usage |
|---|---|---|
| DNA low $M_r$ | Salmon sperm, low priced | Analyzing fluid properties |
| DNA V11 | R10K6_V11 as DNA | Functional tests |
| Plasmid | Circular DNA | Shear force stress test |

*Table 2: The materials initially chosen as possible carriers to print on,*
*listed with the manufacturer and material general name*

| Specific name | Manufacturer | Material | Thickness |
|---|---|---|---|
| Hostaphan GN 4600 | Mitsubishi Polyester Film | Polyethylene therephthalate (PET) | 125 µm |
| Hostaphan GUV 4600 | Mitsubishi Polyester Film | Polyethylene therephthalate (PET) | 50 µm |
| Melinex 339 | DuPont Teijin Films | Polyethylene therephthalate (PET) | 250 µm |
| Melinex Q65FA | DuPont Teijin Films | Polyethylene naphthalate (PEN) | 125 µm |
| SyntiTec 3900 | Sihl Direct | Polypropylene (PP) | 180 µm |
| SFT 40 T | Taghleef Industries | Biaxially oriented polypropylene (BoPP) | 40 µm |
| Rotilabo 601 | Carl Roth | Paper | 160 µm |
| Whatman Grade 1 | GE Healthcare | Paper | 180 µm |
| Amersham Hybond RPN2020N | GE Healthcare | Nylon membrane | 160 µm |
| HF 120 | Millipore | Nitrocellulose | 230 µm |

The used inkjet printer Autodrop from Microdrop Technologies is equipped with piezo-based drop-on-demand single nozzle printheads. They consist of glass nozzles with different available orifice diameters in the range of 30 µm to 100 µm. Prior to printing the ink is filtrated using a polyethersulfone (PES) filter, with a pore size of 0.2 µm. Afterwards the nozzle and inflow need to be cleaned. Long purging cycles, that pass several milliliters of water or sodium hydroxide, ensure that no molecules remain in the flow that could clog the nozzle after drying out.

Ten different carrier materials were initially chosen from the categories paper, plastic and combinations of both. Their names are listed in Table 2 together with the manufacturer and material general name. In the text carrier materials are called by their specific name.

## 2.4 The readout

Two devices are used for fluorescence detection. For fluid measurements the microplate reader CLARIOstar by BMG LABTECH is chosen, as it allows for precise recordings of both excitation and emission spectra measured in reflection. However, the device records the spectral properties of each sample on a single point, making it suitable for measurements of homogeneous

fluids but not for potentially inhomogeneous solid samples. For inhomogeneous solid samples a space-resolved imaging method is needed given by the imager Fusion FX Edge from Vilber. The imager has set illuminations for excitation and filter for emission, which need to be chosen according to the inspected substance. Another limitation is the fixed position of the illumination and detection elements. The detected intensities are captured by a camera from above, while the LEDs, which emit in the visible spectrum, are also placed above and enable measurements in reflection mode. But the UVB illumination is placed below and only permits measurements in transmission. Based on the CFX spectra obtained by the microplate reader and the DNA dye spectra taken from the Thermo Fisher website (Hoechst, n.d.; YOYO-1, n.d.), the optimal combination of light source and emission filter is chosen to achieve the best sensitivity. The CFX and Hoechst 33342 are best excited by the UVB transillumination, which emits light with a peak at 312 nm. Its range lies mostly between 280 nm and 360 nm, but reaches up into the visible range. A cut is set at 400 nm by an additionally integrated filter. The best suited emission filter for CFX and Hoechst 33342 detection is filter F440, with a range of 470–590 nm (Figure 1). The fluorescence of CFX is measured in solution in the microplate reader, and the fluorescence of Hoechst 33342 is taken from Hoechst (n.d.). The CFX data
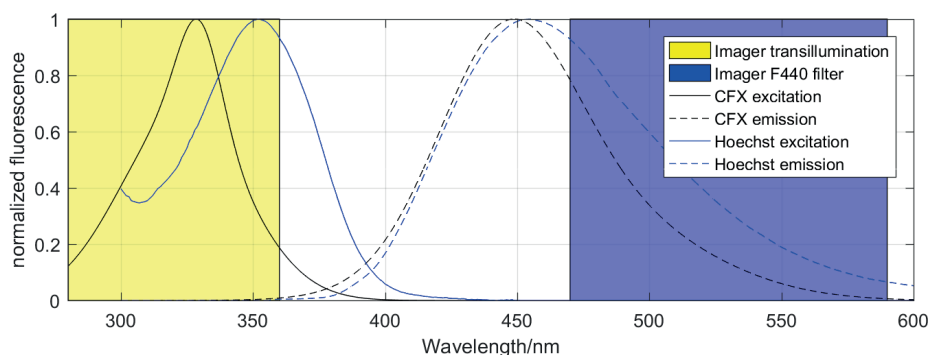


*Figure 1: Excitation and emission spectra of the DNA dye Hoechst 33342 in comparison to CFX and the best fitting imager illumination and emission filter; the normalized fluorescence intensities are given over the wavelengths in nm*
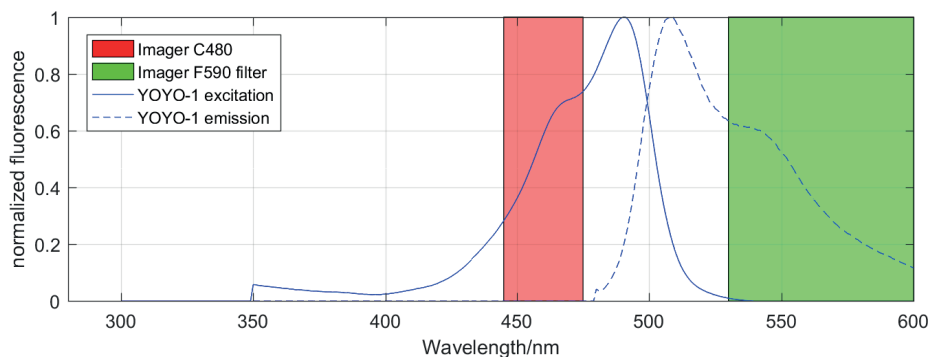
*Figure 2: Excitation and emission spectra of the DNA dye YOYO-1 and the best fitting imager illumination and emission filter; the normalized fluorescence intensities are given over the wavelengths in nm*

is extrapolated below 320 nm with a two term Gaussian fit. For the excitation of YOYO-1 the epi-illumination with an LED with 460 nm ± 15 nm (approx.) is used, which illuminates the sample from above. For the detection of YOYO-1 the filter F-590 fits best, which passes through 530–600 nm wavelengths (Figure 2). Spectral data were taken from YOYO-1 (n.d.).

## 3. Results and discussion

Two kinds of experiments are carried out. One concerning the maintenance of functionality during the printing process itself and one on sustaining the functionality on the carrier material. Both rely on fluorescence measurements.

### 3.1 Inkjet printing of nucleic acids

We need to verify that the used inkjet printer and its piezo-electric printhead are suitable for printing nucleic acids that are stored in their buffer solution. There are two main challenges to consider: ink printability and preservation of functionality. Each printhead has a range of ink surface tension and viscosity that have to be met to realize drop creation. In graphic arts insufficient properties can be compensated with additives. The surface tension can be lowered by adding surfactants like Triton X-100 or by adding solvents with lower surface tension like dimethyl sulfoxide. The viscosity can be raised by adding high viscous solvents like glycerol or

ethylene glycol or polymers like sodium carboxymethyl cellulose, polyvinyl alcohol, or polyethylene glycol. But in functional printing the additive's effect on the functional material would have to be analyzed first. Usually inkjet printers operate in a region of 20 mN/m to 70 mN/m for the surface tension and 0.3 mPa·s to 100 mPa·s for the viscosity. For the used orifice diameter of 70 μm in the inkjet printer Autodrop, the viscosity should be between 0.4 mPa·s and 20 mPa·s. A surface tension range is not stated, but is expected to be at the upper end for general inkjet printers, because of the rather big drop volume of approx. 260 pl. The drop spacing can be varied to create different volume per area concentrations. The driving voltage of the printhead is set to 68 V, the pulse length is 24 μs and the frequency is 100 Hz.

The functionality of aptamers can be reduced in several ways during the printing process. First, the high mechanical shear of the piezo-electric printhead may rip the molecules apart. Second, nucleic acids are usually stored cool but in an inkjet printhead temperatures can rise during printing. Both, the printability and preservation of functionality, will be analyzed in the following.

First the DNA with low $M_r$ and single fold concentrated buffer are characterized in comparison to water. The density is determined with a pycnometer, the surface tension is measured with a tensiometer and the viscosity is determined using a rotational rheometer. Density and surface tension are measured at 23 °C, the viscosity at 25 °C. The results are shown in Table 3.

*Table 3: Fluid characterization of water, buffer and DNA low $M_r$ in buffer, concerning the density, surface tension (ST) and viscosity; the densitiy of water is taken from literature as a reference*

|  | Water | Buffer | Buffer + DNA low $M_r$ |
|---|---|---|---|
| Density in g/ml | 0.997541 | 1.00 ± 0.02 | 1.01 ± 0.02 |
| ST in mN/m | 70 ± 5 | 68 ± 4 | 70 ± 4 |
| ST disperse | 30 ± 5 | 28 ± 4 | 33 ± 5 |
| ST polar | 40 ± 8 | 40 ± 6 | 36 ± 6 |
| Viscosity in mPa·s | 0.90 ± 0.01 | 0.92 ± 0.01 | 0.93 ± 0.01 |

Within their measurement errors all fluids have the same properties and lie within the stated range of the used inkjet printhead. It is assumed that all printing techniques suitable for water should also work with nucleic acid solutions and first printing tests show no problems.

Whether the molecules are damaged during inkjet printing, is tested with a plasmid solution. One part (reference sample) of the solution is kept at the Biology department, another is transported and stored, and the last part is printed. The printing was done over several minutes at a constant position into a test tube to collect 200 µl. An agarose-gel assay test shows the size distribution of the added molecules by applying a voltage. The positions of the travelled molecules are made visible with dyes. The smaller the molecule is, the further it travels in the gel, compared to molecules with the same charge. The size of the band for a particular size gives a qualitative information about the amount of that molecule in the added solution. Figure 3 shows no difference in the molecular sizes of all three solutions. It is concluded, that the shear stress and heat from inkjet printing do not tear plasmid molecules apart and it is assumed, that it will not damage similar molecules such as aptamers. This is also suggested by other works on inkjet printing of DNA micro-arrays (Goldmann and Gonzales, 2000), fabricating microfluidic paper-based analytical devices (Yamada, et al., 2015), and depositing nucleic acids to fabricate DNA chips (Okamoto, Suzuki and Yamamoto, 2000).
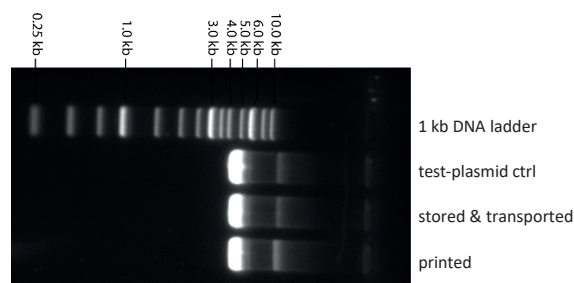


*Figure 3: Plasmid test with 1 % agarose-gel, where the stored, transported and printed solutions can be seen in comparisson to a DNA ladder, which is used as a reference; per lane, 500 ng are applied*

## 3.2  Functionality of nucleic acids printed onto carrier material

After verifying the printing process, the carrier material has to be chosen. We consider two aspects. First, the material properties should not interfere with the detection. Mainly this concerns the autofluorescence of the potential carrier material. Additionally, the carrier materials have to interact in a way that the nucleic acids are well stored and protected, but not hindered to bind. This can only be determined by testing.

### 3.2.1  Fluorescence of carrier materials

As we need to detect fluorescence for CFX or DNA dyes with a comparable fluorescence, the autofluorescence of the material has to be as low as possible in the same region. To determine which carrier material has the lowest auto-fluorescence in the range of the illumination and detection wavelength of CFX, all materials listed in Table 2 are examined at the maximum excitation and emission wavelength of CFX by an illumination at 328 nm and a detection at 450 nm, respectively. The measurements are carried out with punched-out pieces of the materials placed in a microplate and the fluorescence intensities measured in relative fluorescence units (RFU) by the plate reader are shown in Figure 4 in logarithmic scale to illustrate the broad range in intensities. It is not standard practice to analyze solid samples with a microplate reader, but the resulting order is confirmed by the imager measurements.

Especially certain plastics but also paper, because of its lignin content, show a high fluorescence. The intensity seems to correlate with their thicknesses as seen by the three PET foils Hostaphan GUV 4600, GN 4600 and Melinex 339.

Three different carrier materials with least fluorescence are selected for further experiments: the nitrocellulose HF 120, the PET Hostaphan GUV 4600 and the paper Whatman Grade 1. The PET foil was chosen over the BoPP foil SFT 40 T, because the latter is only produced in unpractically thin films.

Other works on depositing biological inks use nitrocellulose and nylon membrane (Goldmann and Gonzales, 2000) or filter paper and chromatography paper (Yamada, et al., 2015). There, the paper materials are stated to be composed of pure cellulose without additives such as brighteners, which might interfere with fluorescence-based detection, but the already mentioned lignin in paper has an autofluorescence, too. The filter paper Whatman Grade 1 is made of cotton fibers, which have a low lignin content when compared to other cellulose sources (Ververis, et. al., 2004).

### 3.2.2  Fluorescence of printed DNA and DNA dyes

Hoechst 33342 has the most similar fluorescence spectrum to CFX and seems promising to function as an alternative system for doing pre-tests for printing of aptamers and detection of CFX. Measurements in solution using the microplate reader, averaged over three measurements, show the characteristic rise and saturation of fluorescence when increasing the DNA concentration while holding the amount of 178 nM Hoechst 33342 constant (Figure 5).
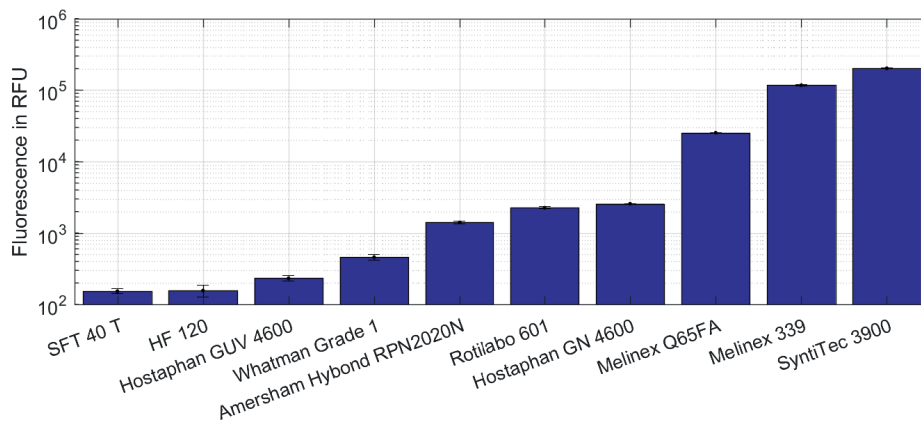
*Figure 4: Fluorescence of the different carrier materials at CFX excitation (328 nm) and emission maxima (450 nm) taken with the microplate reader and shown in logarithmic scale*
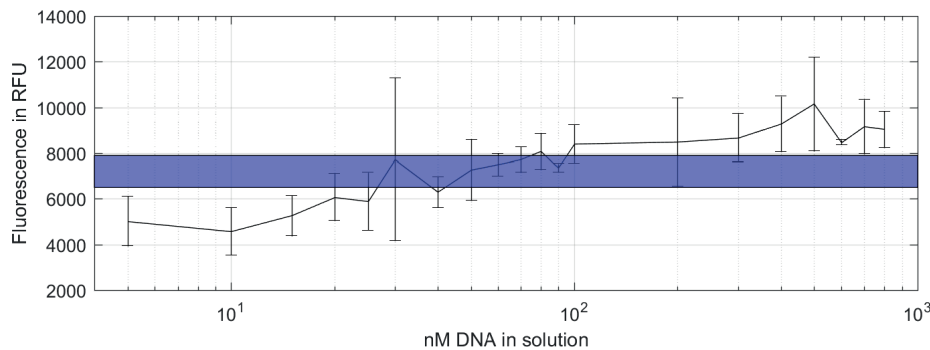


*Figure 5: Fluorescence of different DNA V11 concentrations mixed with a constant amount of 178 nM Hoechst 33342 dye; the intensity of the dye alone is indicated by the blue bar*

The problem is the relatively high fluorescence of the DNA dye alone when no DNA is present, which lies at $7\,200 \pm 700$ RFU and correlates with the intensity achieved by adding 30–90 nM DNA. All lower DNA concentrations added, actually yield a smaller fluorescence. The fluorescence intensity of Hoechst 33342 bound to DNA is not even twice the intensity of the unbound one, which was not expected, as the literature claims a twentyfold increase after binding. This is probably the case because DNA dyes are usually used with gel assays or inside cells, where the DNA concentration is a lot higher than in the tested solutions in the range of 1 nM to 1 μM. Furthermore, gels or assays are washed after staining to have only the dyed DNA left for detection.

Nonetheless the experiment is conducted with Hoechst 33342, since different DNA concentrations can be distinguished by fluorescence. A solution containing 10 μM DNA is printed onto the three selected carrier materials and left to dry, using the parameters in Table 4. Onto the same spots 5 μl solutions of different Hoechst 33342 concentrations, namely 10 nM, 100 nM, 1 μM, and 10 μM, are pipetted and the fluorescence is measured with the imager in the wet state (Figure 6).

*Table 4: Inkjet printing parameters for four 0.5 cm × 0.5 cm squares with increasing DNA concentration, printed with a drop volume of 260 pl from a 10 μM DNA solution*

| Drop spacing | Grid size/ drops | Amount of DNA solution printed | |
|---|---|---|---|
| 1.180 mm | 6 × 6 | 0.2 ml/m² | 0.01 μl |
| 0.354 mm | 20 × 20 | 2.0 ml/m² | 0.10 μl |
| 0.114 mm | 62 × 62 | 20.0 ml/m² | 1.00 μl |
| 0.036 mm | 196 × 196 | 20.0 ml/m² | 10.00 μl |

*Table 5: The molar ratios between DNA and dye, where the DNA solution is concentrated by using varying amounts of a 10 μM solution; the dye is always used in 5 μl quantities, but of varying molar concentrations*

| Dye \ DNA | 0.01 μl | 0.1 μl | 1 μl | 10 μl |
|---|---|---|---|---|
| 10 μM | 0.002 | 0.02 | 0.20 | 2 |
| 1 μM | 0.020 | 0.20 | 2.00 | 20 |
| 100 nM | 0.200 | 2.00 | 20.00 | 200 |
| 10 nM | 2.000 | 20.00 | 200.00 | 2000 |
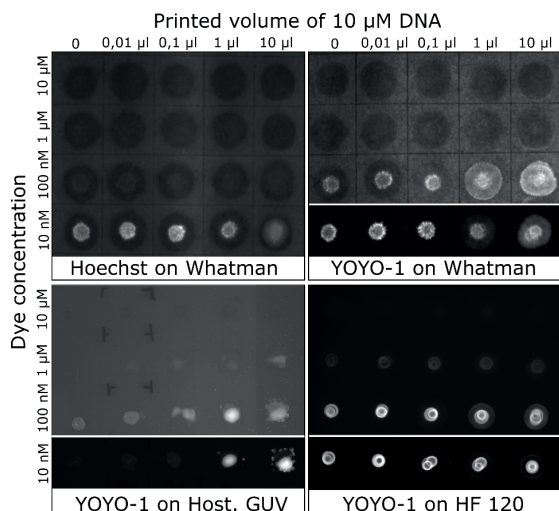
*Figure 6: Different DNA volumes printed onto different carrier materials, abbreviated with Whatman (Whatman Grade 1), Host. GUV (Hostaphan GUV 4600); Hoechst stands for the dye Hoechst 33342*

The dyes, varying in concentration, are added onto the dried DNA spots. All shown sub-pictures are taken with different exposure times to avoid over- and underexposure. All measurements are done when the spots are still wet after adding the dye. This yields 16 measurements for each carrier material with varying molar ratios between DNA and dye. The values lie between 0.002 and 2 000 and are shown in Table 5.

Unfortunately, all materials containing foils filter out the UVB transillumination, leaving only the paper as possible carrier. The intensity evaluation of Figure 6 is done by comparing area integrated densities and is shown in Figure 7. For each data set the integrated densities are processed by subtracting the dye fluorescence without DNA and normalizing to the highest fluorescence of that set. On Whatman Grade 1 the integrated intensity of the wet area increases between zero, 0.01 and 0.1 µl DNA solution, but falls to its initial value at 1 and 10 µl DNA. The only difference between low and high DNA concentration is that the fluorescence of the latter is spread more evenly instead of accumulating in the middle, see top left in Figure 6.

Hence, the DNA dye YOYO-1 is chosen as an alternative to Hoechst 33342 because of the fact that it is stated to have an enormously larger difference in fluorescence between the bound and unbound state. Due to the dif-
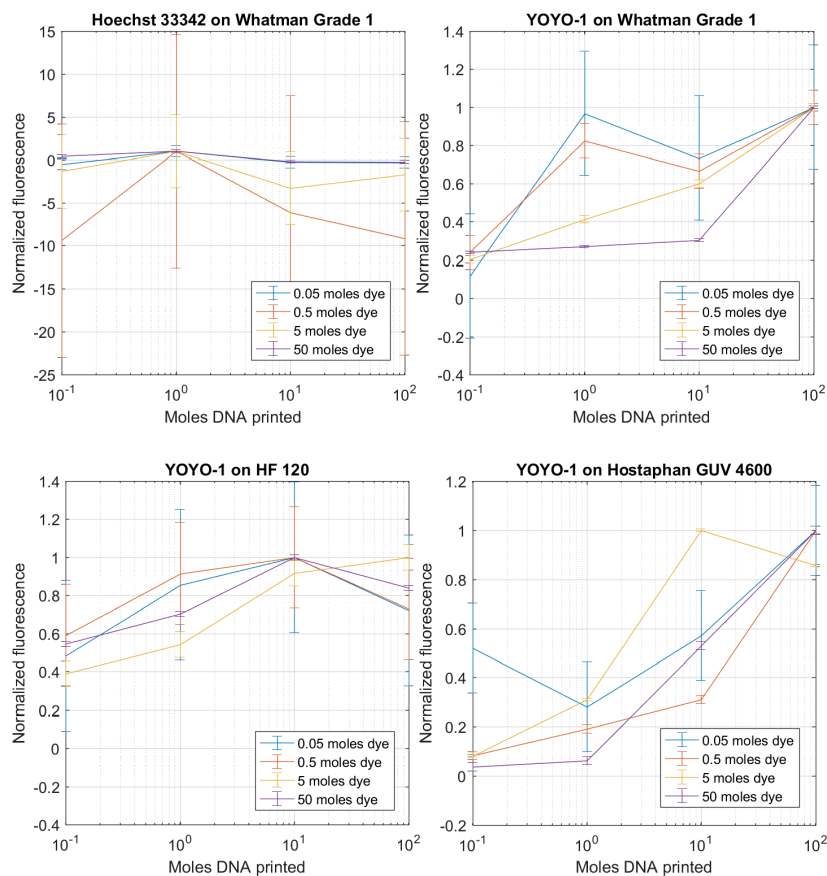


*Figure 7: The intensity evaluation of Figure 6 with the fluorescence intensities of each data series normalized by setting the highest intensity to 1; straight lines are added in between single data points as guide for the eyes*

ferent excitation wavelength, a different illumination can be chosen. As this illuminates from the top side, all three carrier materials can be used for this test.

The best results (Figure 6) are obtained with YOYO-1 on Whatman Grade 1 and Hostaphan GUV 4600. The fluorescence intensity (Figure 7) increases mostly for bigger DNA amounts. They are distinguishable from each other by their fluorescence while using all but the lowest dye concentration, however, the foil is impractical and not suited as carrier material for a biosensor. The wet spots are not well located, but spread unpredictably and are prone to running off the sample. On the nitrocellulose HF 120 a less steep increase in fluorescence is visible, but with a decrease towards the highest DNA concentration.

One important result of interactions between the printed nucleic acids and their carrier materials is their immobilization potential. The ink should not undergo global motion after adsorption and stay at the printed location, but it has to be able to undergo recognition and signaling chemistry (Carrasquilla, et al., 2015). One aspect that influences the immobilization is the protein binding capacity, which is assumed to be the highest for the nitrocellulose and the smallest for the foil. It is observed, that the general spreading of the printed fluid is the greatest on Whatman Grade. This is why it was suspected, that less of the DNA would be available for intercalation. But these factors prove to be less significant than the optimal immobilization potential of the filter paper.

A work on detecting viruses in dried serums, compares Whatman Grade 1, nylon membrane and nitrocellulose membrane as possible carrier materials and comes also to the conclusion, that Whatman Grade 1 provides the most efficient immobilization (Wang, Giambrone and Smith, 2002). The distribution of the DNA over the PET foil (Hostaphan GUV 4600) is nonuniform due to the creation of big droplets on its surface during printing and developing nonuniform contact lines during drying. Another aspect which should have an influence on the immobilization and thus the function of molecules on the substrates and especially on inhomogeneity of

the fluorescence is the surface energy and its distribution over the substrate. This should be measured and compared to the obtained results.

## 4. Conclusions

On our way to printing a functional biosensor with aptamers we were able to answer a few questions. Inkjet printing is a suitable method for transferring variable amounts and concentrations of nucleic acid solutions without damaging the molecules. The work with fluorescence substances which require excitation in the central UVB sector identified several problems to consider in the future. The CFX and Hoechst 33342 are both excited in a wavelength range that is provided by a UVB, rather than a UVA light source, which is filtered out by most materials containing foils. The transmittance of the carrier materials for the wavelength required to excite the fluorescent compound has to be considered or an illumination from the top must be possible in the imaging unit.

It was shown that DNA solutions can be left to dry on suitable carrier materials and still display their usual response to DNA dyes after renaturation, but on each material the amount of dye and DNA needed differed. For Hoechst 33342 no fitting settings were found, maybe the amounts of DNA and dye need to be higher. The YOYO-1 dye showed the greatest increase in fluorescence on the filter paper Whatman Grade 1 and the foil Hostaphan GUV 4600, with a steeper increase for higher dye concentrations. As the foil induces handling issues, the filter paper will be used in future experiments on printing an aptamer-based CFX biosensor. Future studies need to examine more material properties which play a role in immobilizing and maintaining the functionality of nucleic acids, like the surface energy. Another problem is building a detector system based on minimal fluorescence changes. Even after finding good conditions, the detected intensity was often hard or impossible to distinguish from the auto fluorescence of the DNA dye. An ideal detector system should produce a much better contrast between positive and negative probes.

## References

Alocilja, E.C. and Radke, S.M., 2003. Market analysis of biosensors for food safety. *Biosensors and Bioelectronics,* 18(5–6), pp. 841–846. http://dx.doi.org/10.1016/S0956-5663(03)00009-5.

Bachmann, T.T. and Schmid, R.D., 1999. A disposable multielectrode biosensor for rapid simultaneous detection of the insecticides paraoxon and carbofuran at high resolution. *Analytica Chimica Acta,* 401(1–2), pp. 95–103. https://doi.org/10.1016/S0003-2670(99)00513-9.

Brandt, A., Gorenflo, A., Siede, R., Meixner, M. and Büchler, R., 2016. The neonicotinoids thiacloprid, imidacloprid, and clothianidin affect the immunocompetence of honey bees (Apis mellifera L.). *Journal of Insect Physiology*, 86, pp. 40–47. https://doi.org/10.1016/j.jinsphys.2016.01.001.

Carrasquilla, C., Little, J.R.L., Li, Y. and Brennan, J.D., 2015. Patterned paper sensors printed with long-chain DNA aptamers. *Chemistry,* 21(20), pp. 7369–7373. https://doi.org/10.1002/chem.201500949.

Cháfer-Pericás, C., Maquieira, Á. and Puchades, R., 2010. Fast screening methods to detect antibiotic residues in food samples. *TrAC Trends in Analytical Chemistry*, 29(9), pp. 1038–1049. https://doi.org/10.1016/j.trac.2010.06.004.

Ecker, D.J., Sampath, R., Massire, C., Blyn, L.B., Hall, T.A., Eshoo, M.W. and Hofstadler, S.A., 2008. Ibis T5000: a universal biosensor approach for microbiology. *Nature Reviews Microbiology*, 6, pp. 553–558. https://doi.org/10.1038/nrmicro1918.

Edwards, T.E., Klein, D.J. and Ferré-D'Amaré, A.R., 2007. Riboswitches: small-molecule recognition by gene regulatory RNAs. *Current Opinion in Structural Biology*, 17(3), pp. 273–279. https://doi.org/10.1016/j.sbi.2007.05.004.

Ellington, A.D. and Szostak, J.W., 1990. In vitro selection of RNA molecules that bind specific ligands. *Nature*, 346, pp. 818–822. https://doi.org/10.1038/346818a0.

Garst, A.D., Edwards, A.L. and Batey, R.T., 2011. Riboswitches: structures and mechanisms. *Cold Spring Harbor Perspectives in Biology*, 3:a003533. https://doi.org/10.1101/cshperspect.a003533.

Goldmann, T. and Gonzalez, J.S., 2000. DNA-printing: utilization of a standard inkjet printer for the transfer of nucleic acids to solid supports. *Journal of Biochemical and Biophysical Methods*, 42(3), pp. 105–110. https://doi.org/10.1016/S0165-022X(99)00049-4.

Groher, F., Bofill-Bosch, C., Schneider, C., Braun, J., Jager, S., Geißler, K., Hamacher, K. and Suess, B., 2018. Riboswitching with ciprofloxacin — development and characterization of a novel RNA regulator. *Nucleic Acids Research*, 46(4), pp. 2121–2132. https://doi.org/10.1093/nar/gkx1319.

Groher, F. and Suess, B., 2016. In vitro selection of antibiotic-binding aptamers. *Methods*, 106, pp. 42–50. https://doi.org/10.1016/j.ymeth.2016.05.008.

Hoechst, n.d. *Hoechst 33342, Trihydrochloride, Trihydrate, 100 mg*. [online] Thermo Fisher Scientific Inc. Available at: <https://www.thermofisher.com/order/catalog/product/H1399> [Accessed 30 November 2018].

Jaeger, J., Groher, F., Stamm, J., Spiehl, D., Braun, j., Dörsam, E. and Suess, B., 2019. Characterization and inkjet printing of an RNA aptamer for paper-based biosensing of coprofloxacin. *Biosensors*, 9(1). https://doi.org/10.3390/bios9010007.

Joshi, K., Chen, W., Wang, J., Schöning, M. and Mulchandani, A., 2006. Biosensors for environmental monitoring and homeland security. In: J.M. van Emon, ed. *Immunoassay and other bioanalytical techniques*. Boca Raton: CRC Press. https://doi.org/10.1201/9781420020694.

Justino, C.I.L., Duarte, A.C. and Rocha-Santos, T.A.P., 2017. Recent progress in biosensors for environmental monitoring: a review. *Sensors*, 17(12):2918. https://doi.org/10.3390/s17122918.

Kipphan, H. ed., 2001. *Handbook of print media: technologies and production methods*. Berlin: Springer-Verlag.

Kivirand, K., Kagan, M. and Rinken, T., 2013. Calibrating biosensors in flow-through set-ups: studies with glucose optrodes. In: T. Rinken, ed. *State of the art in biosensors – general aspects*. IntechOpen. https://doi.org/10.5772/45127.

McKeague, M. and DeRosa, M.C., 2012. Challenges and opportunities for small molecule aptamer development. *Journal of Nucleic Acids*, 2012:748913. http://dx.doi.org/10.1155/2012/748913.

Mello, L.D. and Kubota, L.T., 2002. Review of the use of biosensors as analytical tools in the food and drink industries. *Food Chemistry*, 77(2), pp. 237–256. https://doi.org/10.1016/S0308-8146(02)00104-8.

Mohassieb, S.A., Kirah, K., Dörsam, E., Khalil, A.S.G. and El-Hennawy, H.M., 2017. Effect of silver nanoparticle ink drop spacing on the characteristics of coplanar waveguide monopole antennas printed on flexible substrates. *IET Microwaves, Antennas & Propagation*, 11(11), pp. 1572–1577. http://dx.doi.org/10.1049/iet-map.2017.0078.

Novais, Â., Comas, I., Baquero, F., Cantón, R., Coque, T.M., Moya, A., González-Candelas, F. and Galán, J.-C., 2010. Evolutionary trajectories of beta-lactamase CTX-M-1 cluster enzymes: predicting antibiotic resistance. *PLoS Pathogens*, 6(1):e1000735. https://doi.org/10.1371/journal.ppat.1000735.

Okamoto, T., Suzuki, T. and Yamamoto, N., 2000. Microarray fabrication with covalent attachment of DNA using bubble jet technology. *Nature Biotechnology*, 18, pp. 438–441. https://doi.org/10.1038/74507.

Pankalla, S., Ganesan, R., Spiehl, D., Sauer, H.M., Dörsam, E. and Glesner, M., 2013. Mass characterisation of organic transistors and Monte-Carlo circuit simulation. *Organic Electronics*, 14(2), pp. 676–681. http://dx.doi.org/10.1016/j.orgel.2012.11.033.

Raupp, S., Daume, D., Tekoglu, S., Merklein, L., Lemmer, U., Hernandez-Sosa, G., Sauer. H.M., Dörsam, E., Scharfer, P. and Schabel, W., 2017. Slot die coated and flexo printed highly efficient SMOLEDs. *Advanced Materials Technologies*, 2(2):1600230. https://doi.org/10.1002/admt.201600230.

Song, S., Xu, H. and Fan, C., 2006. Potential diagnostic applications of biosensors: current and future directions. *International Journal of Nanomedicine*, 1(4), pp. 433–440.

Spiehl, D., Häming, M., Sauer, H.M., Bonrad, K. and Dörsam, E., 2015. Engineering of flexo- and gravure-printed indium-zinc-oxide semiconductor layers for high-performance thin-film transistors. *IEEE Trans. Electron Devices*, 62(9), pp. 2871–2877. http://dx.doi.org/10.1109/ted.2015.2449665.

J. Stamm, D. Spiehl, J. Jaeger et al. – J. Print Media Technol. Res. 8(2019)1, 7–17

17

Stamm, J., Spiehl, D., Jaeger, J., Groher, F., Meckel, T., Suess, B. and Dörsam, E., 2018. DNA and DNA staining as a test system for the development of an aptamer-based biosensor for sensing of antibiotics. In: P. Gane, ed. *Advances in Printing and Media Technology: Proceedings of the 45th International Research Conference of iarigai*. Warsaw, Poland, October 2018. Darmstadt, Germany: International Association of Research Organizations for the Information, Media and Graphic Arts Industries, pp. 133–142.

Threlfall, E.J., Ward, L.R., Frost, J.A. and Willshaw, G.A., 2000. The emergence and spread of antibiotic resistance in food-borne bacteria. *International Journal of Food Microbiology*, 62(1–2), pp. 1–5. https://doi.org/10.1016/S0168-1605(00)00351-2.

Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P. and Santas, R., 2004. Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. *Industrial Crops and Products*, 19(3), pp. 245–254. https://doi.org/10.1016/j.indcrop.2003.10.006.

Wang, C.-Y.J., Giambrone, J.J. and Smith, B.F., 2002. Detection of duck hepatitis B virus DNA on filter paper by PCR and SYBR green dye-based quantitative PCR. *Journal of Clinical Microbiology*, 40(7), pp. 2584–2590. http://dx.doi.org/10.1128/JCM.40.7.2584-2590.2002.

Wang, J., 2001. Glucose biosensors: 40 years of advances and challenges. Electroanalysis, 13(12), pp. 983–988. https://doi.org/10.1002/1521-4109(200108)13:12<983::AID-ELAN983>3.0.CO;2-%23.

Yamada, K., Henares, T.G., Suzuki, K. and Citterio, D., 2015. Paper-based inkjet-printed microfluidic analytical devices. *Angewandte Chemie*, 54(18), pp. 5294–5310. https://doi.org/10.1002/anie.201411508.

YOYO-1, n.d. *YOYO™-1 Iodide (491/509) – 1 mM Solution in DMSO*. [online] Thermo Fisher Scientific Inc. Available at: <https://www.thermofisher.com/order/catalog/product/Y3601> [Accessed 30 November 2018].

# Assessing and improving edge roughness in pad-printing by using outlines in a one-step exposure process for the printing form

*Christina Bodenstein, Hans Martin Sauer, Felipe Fernandes and Edgar Dörsam*

Technische Universität Darmstadt,
Institute of Printing Science and Technology,
Magdalenenstr. 2, 64289 Darmstadt, Germany

bodenstein@idd.tu-darmstadt.de
sauer@idd.tu-darmstadt.de
doersam@idd.tu-darmstadt.de

### Abstract

We describe the specificities of the pad-printing form production. In printing experiments, we show the influence of different printing forms, in dependence on raster frequency and printing form material, on the printing quality of pad-printed patterns. A typical defect in pad-printing, the 'stamp effect', which occurs as a wavy contour, was determined and traced to the printing form production. By incorporating so-called outlines into the printing form, we were able to reproduce patterns with an edge roughness of less than 3 μm. We provide descriptions of the implementation of these outlines. To measure and analyze the edge roughness and edge defects we developed an image-based method to quantitatively assess the quality of edge patterns. With the use of outlines in the printing form, it seems feasible to use pad-printing for source and drain contact manufacturing on printed thin film transistors. Thus, the reproduction of electrically conductive, interdigital patterns for sources and drains having an electrode distance of less than 10 μm appears possible.

**Keywords:** stamp effect, wavy contour, Canny edge algorithm, raster, cliché

## 1. Introduction and background

Pad-printing is often used to print small, high-resolution patterns on curved surfaces. This technology is also known as indirect gravure printing technology since the printing pattern is engraved and the ink in it is picked up by a flexible subcarrier, the pad (Hakimi Tehrani, 2018). The pad is made of elastic, compressible silicone and can thus adapt to curved surfaces. This makes it feasible to print on dye-cast plastic bodies, pre-structured printed circuit boards, 3D-printed rapid prototypes and individually-shaped surfaces (as shown in Figure 1) in a most cost-efficient manner. Moreover, the silicone with low surface free energy permits complete transfer of ink from pad to substrate, leaving a perfectly clean pad for the next transfer sequence. In recent years, new technologies for producing printing forms, such as direct laser engraving, have become available. Alternative gravure patterns beyond the classical gravure cell raster are now possible, tailored to specific applications and printing inks, and these promise substantial progress in printing resolution and quality.



*a)*       *b)*
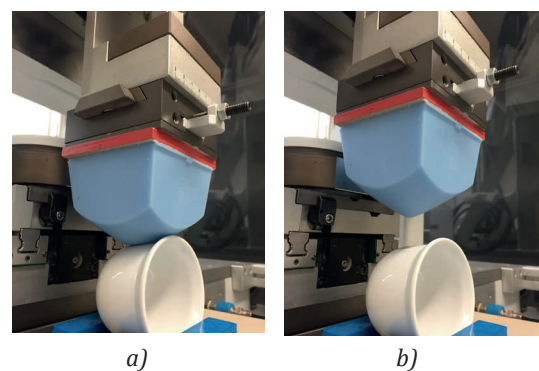
*Figure 1: Images of pad-printing on a cup, showing how the flexible pad clings to the shape of the object to transfer the ink (a), and after the transfer moves back upwards and returns to its original form (b)*

Particularly for printed electronics, pad-printing is becoming more widely used, with successful applications in solar cells (Hahne, et al., 2001; Krebs, 2009), microwave antennae (Xiong and Qu, 2011), sensor structures (Leppävuori, et al., 1994), UHF RFID (Merilampi,

et al., 2011), electrodes (Mooring, et al., 2005), electrolu-minescence (Lee, et al., 2010; Bodenstein, et al., 2018a) and source-drain structures (Willfahrt, 2007). Recently works on the pad-printing process itself (Al Aboud, et al., 2018; Hahne, 2001), the pad (Hakimi Tehrani, 2018), and the pad-printed image quality (Hübner and Till, 2007; Bodenstein, 2018; Bodenstein, et al., 2018b) have taken place. Especially in the field of printed electronics it is important to evaluate the printed patterns, since in this area functional materials with electrical properties are used. Instead of pigments or dyes that are responsible for coloring in a common printing ink, particles with electrical properties are used. When printing microstructures the edges play a significant role. Typical defects appearing in pad-printing have to be avoided, such as the 'stamp effect' as shown in Figure 2, without changing the electrical properties of the ink to guarantee stable conditions of the printed component.
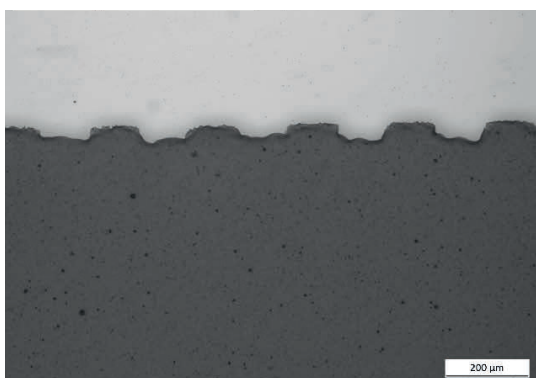


*Figure 2: Microscopic image of a typically appearing printing defect in pad-printing – 'stamp effect'*

These defects, which will be discussed in detail later, lead to a dysfunction of the component. Up to now evaluating printed edges was empiric in pad-printing. In this study, we introduce and demonstrate a method that reduces printing defects by evaluating and controlling the edge roughness of pad-printed images.

## 1.1 Pad-printing process

In indirect gravure printing technology, the printing layout is engraved as a raster of microscopic cells on a planar printing form or a cylinder. The size of these cells, usually a few tens of micrometres in width and depth, determines the amount of ink transferred to the surface of the substrate. The pad-printing process is shown in Figure 3. After the engraved cells are filled with ink and excess material is removed by blading, which is done by moving the printing form carrier (a), a soft silicone pad is pressed against the printing form (b). When the pad is lifted from the printing form, it takes the ink out of the cells (c), and after moving the printing form carrier back (d) deposits it on the surface of the substrate (e, f).
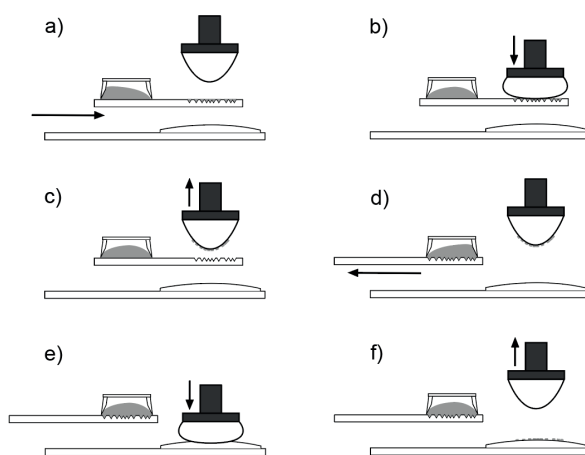


*Figure 3: Schematic of the pad-printing process*

## 1.2 Pad-printing form (cliché)

In literature pad-printing technology is rarely described as well as the production of the printing form, which is also called cliché. Pad-printing technology is still a niche technology which is often located in screen-printing companies due to its similar products. The materials that are mostly used for clichés are polymer and steel. The choice of the material depends on different requirements, such as the amount of print runs of each print job, the printing quality, chemical resistance and costs. Each material requires different image processing technologies, such as an UV exposure with an image film for polymer clichés (Section 1.4) or an etching process for steel material (Section 1.5).

Although pad-printing is an indirect gravure printing due to its principle that the ink is transferred from engraved cells, the mainly used printing form production process of polymer cliché itself is based on the same principle as it is in flexographic printing form production.

Even nowadays in 2018, in a digitalized world, printing form production using a film is still the most widely used process in pad-printing industry, as due to its simple and cost-effective process printing companies are fast in operating and self-sufficient from printing form producing companies.

## 1.3 Raster in pad-printing clichés

In printing technology colors are reproduced by printing several single dots (raster dots) with a specific distance with primary colors (CMYK) as described, e.g., in Nisato, Lupo and Ganz (2016). In pad-printing technology the raster has more widely spaced and variable raster components for various reasons. Especially when printing large scale areas, the remaining walls

in between the raster cells have a special importance, similar as in gravure printing technology:

1. In large scale areas the raster functions as a supporting structure. The walls that remain in between the raster cells prevent the blade from tilting into the indentations when blading the excess printing ink material (Figure 3a).
2. The ink would remain unsteady, changing thickness in the indentations. The walls hold back the printing ink homogeneously (Figure 4).
3. When the pad is moving downwards to take the ink out of the indentations, the pad is displacing the ink by its pressing force and rolling motion. The walls are bracing the pad so the pad cannot displace the ink and a homogeneous film can be realized (Figure 5).



*Figure 4: After the blading process the ink remains unsteady in the indentations without raster (a), with a raster the walls hold back the ink homogeneously (b)*
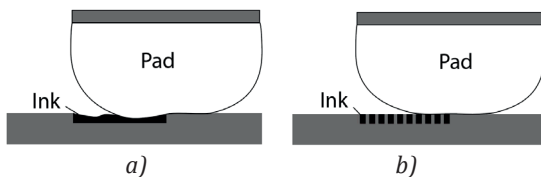


*Figure 5: Pad pressing on printing form without raster displaces the ink (a), whereas the walls of the raster brace the pad and the ink is not displaced (b)*

## 1.4 Production of photopolymer cliché

Hereafter, the 'engravure' process of a polymer cliché with a two-step exposure will be described first, as it is the most widely used material and process for pad-printing forms.

Figure 6 shows the structure of a photopolymer printing plate. A steel base plate (thickness of approx. 300 µm) acts as a stabilizer and carrier, which can be later fixed in the pad-printing machine by magnets. The base plate is connected to the polymer material (thickness of approx. 200 µm) by a bonding layer. A protective layer (thickness of approx. 50–100 µm) prevents mechanical damage and protects the polymer from dust and trapped air (Hahne, 2001).



*Figure 6: Photopolymer printing plate structure*

Figure 7 shows step by step the process of imaging of polymer pad-printing forms in a so-called 'two-step exposure'. With the help of an iron-doped metal halide lamps (burner) it is possible to render the photopolymer layer by a complete UV light pre-exposure in a first step (1). The photopolymer material cures from bottom to top and the cured layer thickness gains with longer exposure duration, which controls the depth of the (later developed) cells (Hahne, 2001). A shorter exposure leads to deeper raster cells.
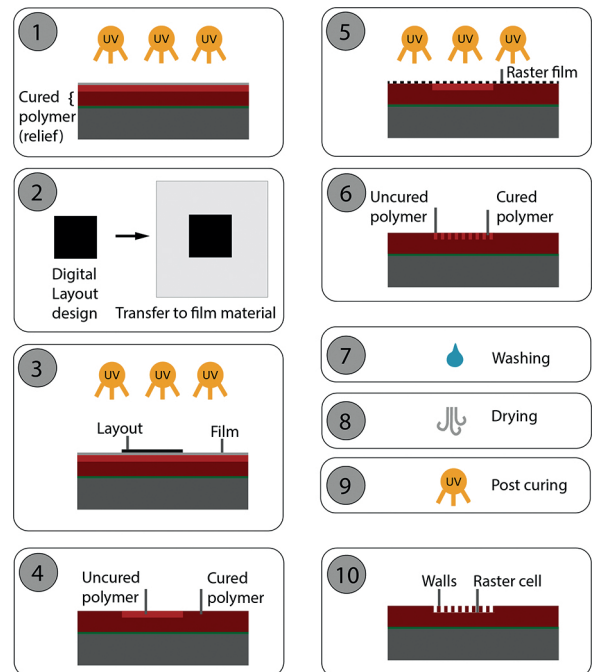


*Figure 7: Schematic of polymer pad-printing form production process for a two-step exposure*

The printing layout in general is designed with a software, for example Adobe Illustrator. As shown in Figure 7, the digital layout is then transferred to a film material (2). An inverted matted film positive is required with an optical density $D$ of the black parts of at least $D = 3.5$ and less than $D = 0.05$ for the transparent areas (Hahne, 2001). With a too low-density of the black parts UV light can pass through and leads to undesired polymerization. After the protective layer is removed from the photopolymer material, the imaged positive film is then placed on top of the light sensitive polymer material and the 1st exposure follows (3). After the exposure the uncovered areas are cured and the areas covered with the black parts of film are still light sensitive (4).

In the next step illustrated in Figure 7, a film that is fully covered with the desired raster dots at specified frequency and area coverage is applied to render the raster cells and the 2nd exposure step follows (5), where the UV light passes through the uncovered areas

*a) Schematic profile*



*b) Measured Profile*
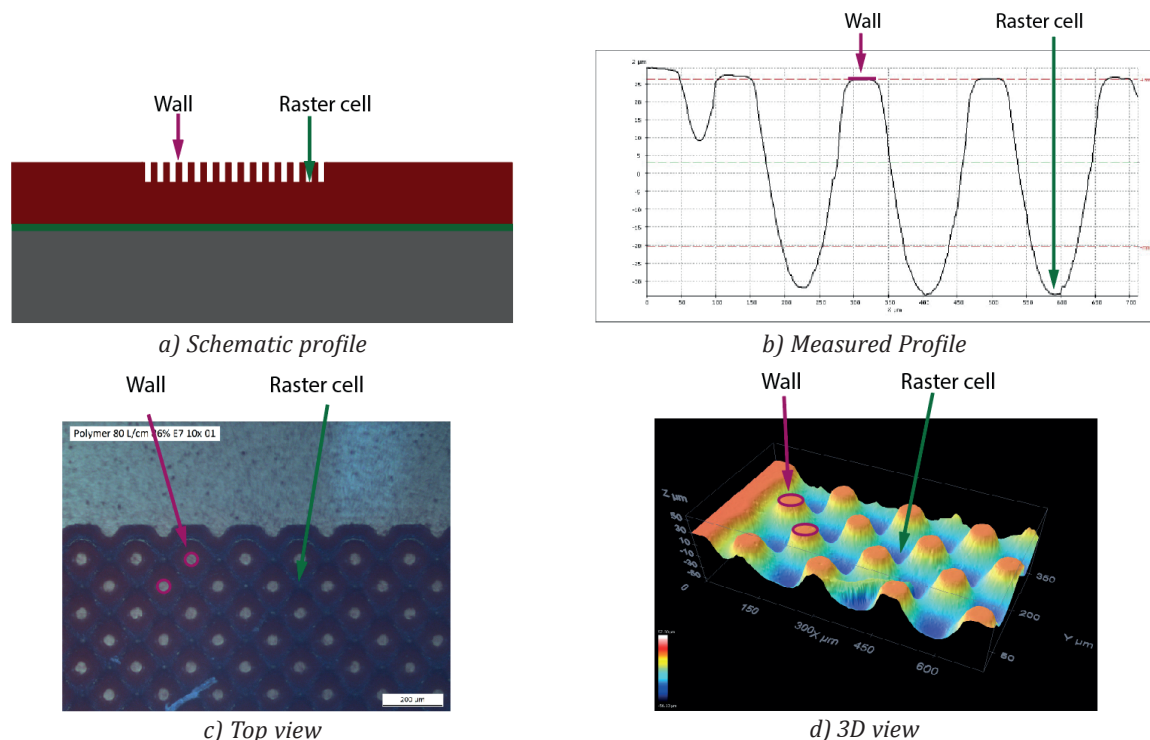


*c) Top view*



*d) 3D view*

*Figure 8: Schematic profile of a pad-printing form (a); the measured profile measured with Sensofar PLu neox (b); the top view taken with Leica DM4000M microscope (c); and the 3D view taken with a Sensofar PLu neox (d) of a pad-printing form with a raster frequency of 80 L/cm and an area coverage of 86 %*

and cures the walls (6). After that, the uncured areas need to be washed out with a plush brush by hand or a machine (7). In a drying process (8) the drying agent is evaporated and thus the final hardness of the plate is achieved. To stabilize the walls a post curing is needed (9). Afterwards the cliché is ready to print (10).

Figure 8 shows images of the cells of one finished polymer printing form with a raster frequency of 80 lines per centimeter (L/cm) and an area coverage of 86 %. In all four images the walls and the raster cells are marked. In the printing process the ink remains in the raster cells after the blading process (see Figure 3a), and the walls act as a support structure for the blade (see Section 1.3).

### 1.5 Production of steel strip cliché

Another commonly used material for pad-printing forms is strip of thin steel. The thickness of the flat steel material is 1 mm. This material can achieve longer service life (around 500 000 print runs) than photopolymer (around 20 000) due to higher abrasion resistance. The production compared to photopolymer cliché is more complex and requires special equipment as well as the corresponding disposal system for the produced waste (Lake, 2017). A thin photopolymer layer is coated onto the steel material. This layer is exposed with a film that carries the image information. The areas, that

are not cured are washed out. In the following etching process step the remaining areas, that carry the image information, are then etched into the material with iron(III)-chlorid. Afterwards the etching liquid need to be removed and the material cleaned (Hahne, 2001).

## 2. Materials and methods

### 2.1 Experiments

The pad-printing machine used in the experiments is based on the machine described by Hakimi Tehrani, Dörsam and Neumann (2016) and Hakimi Tehrani (2018). We modified it, by replacing the pneumatic drives of the gravure plate and pad holder by linear stepper drives. These drives were controlled via a National Instruments LabVIEW program. This allows for independent control of each motion of the printing process in distance and velocity, thus making this machine a unique research platform for process evaluation. To increase the versatility of our setup, we also installed force sensors. This enables independent control of each motion by setting forces instead of positions.

We used a chessboard printing pattern with 64 squares, each with an area of 4 mm × 4 mm (Figure 9). Each square is assigned a column (A–H) and row (1–8) iden-

tifier. In the printing process the position of the top of the pad to take out the ink is in the centre of the layout (in-between D4, E4, D5 and E5). In this study we only evaluate the printing tests of the upper edge of square C2, which is a square that is not in the inner parts (close to the pad centre) and not at the outer parts of the layout, as shown in Figure 9.
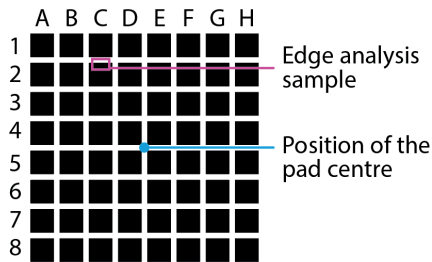


*Figure 9: Printing layout and field C2 as edge analysis sample with pad centre position*

We used printing forms made of polymer and steel with raster frequencies of 80, 100, and 120 L/cm and area coverage of 86 %. The printing plates are from ITW Morlock GmbH. We chose solvent-based printing ink from Marabu GmbH & Co. KG, type TPL 489 (black) due to its universal applicability on a big variety of materials. The ink is blended with a suggested amount of volume fraction of 20 % of solvent (TPV) to adjust the viscosity. The antistatic pad (TP082, blue, 12 Shore A with the dimensions of 67 mm height, 84 mm × 74 mm ground plate) is from Tampoprint AG and is shown in Figure 10; the substrate is a 125 μm PET Hostaphan GN 4600 foil from Pütz GmbH + Co. Folien KG. The velocities of all moving parts in printing machine, such as movement of the cliché table, as well as of the pad (see Figure 3), were set to 200 mm/s.
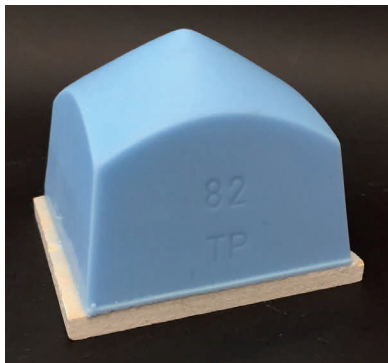


*Figure 10: Printing pad TP082 used in this study*

## 2.2 Edge recognition

To use an automatic edge-recognition software algorithm on printed patterns, one must precisely map a three-dimensional feature onto a continuous line, as shown in Figure 11. This results in a printed three-di-

mensional layer, with edges on top or in direct contact with the substrate. The critical edge which is used for edge evaluation in this work is specified in Figure 11.
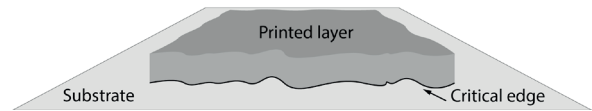


*Figure 11: Schematic of the three dimensions of a printed layer; the edge to be investigated is the contact line between the printed layer and the substrate (critical edge)*

After the printing process, it is likely that the edges are not perfectly even (Figure 11). On top of that printing defects are occurring. The most critical of these defects are those found at the edges: thin ink bridges that extend beyond the desired border. Without controlling these defects on conductive patterns, they lead to a short circuit between adjacent electrodes. Thus, in printed electronics, it is especially important to precisely evaluate the resolution of printed microstructures. To evaluate this critical edge, we take microscope images from the top view of the printed samples to map the three-dimensions onto a plane to detect the edge. To characterize height profiles, we adapted the roughness measures used in surface technology, as illustrated in Figure 12. Here, $y_i$ is the center line and $d_i$ is the distance from a peak to the center line. We applied this procedure to the top view of the border lines of the printed samples, which were measured by optical microscopy. By applying digital contrast amplification, thin ink bridges and residuals can be observed, regardless of the printed layer's local thickness.
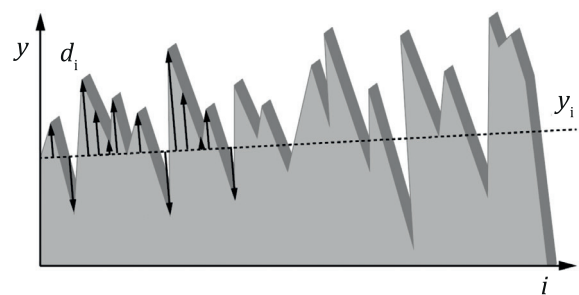


*Figure 12: Schematic of roughness measure for height profiles*

In this work, the edge roughness is defined as $R_m$, the average absolute distance between the desired border line and the actual border line. This is calculated via equation [1] and is used as an edge roughness and blurring measure.

$$R_m = \frac{1}{n-1} \sum_{i=1}^{n} |d_i - y(i)| \qquad [1]$$

With $n$ we denote the number of measuring points from $y_i$ to each $d_i$. A perfect edge sharpness is $R_m = 0$ µm. For $R_m > 0$ µm we talk about edge roughness. For the digitalized measurement analysis, we implemented an algorithm using Matlab software. The initial aim of the algorithm is to detect the straight center line $y_i$, i.e. the regression line, and the actual printed critical edge, for purposes of calculating $R_m$ as described in Equation [1]. Printed patterns were determined using a digital Leica microscope DM4000M camera image with a tenfold magnification objective lens. The pictures have the dimensions of $2592 \times 1944$ pixels (219.5 mm × 164.6 mm).



1) Original image



2) Grayscale image



3) Adjusting contrast



4) Reconstruction of the printed edge based on Canny edge detection (Canny, 1986)



5) Overlay of grayscale image and reconstructed edge



6) Determining straight edge line $y_i$



7) Grayscale image with detected edge and $y_i$
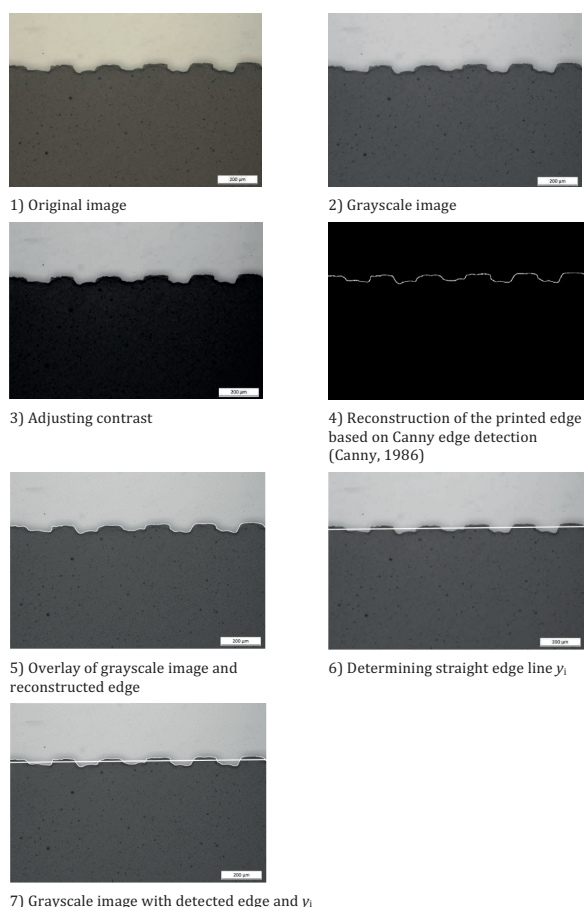
*Figure 13: Steps of image processing for determining straight edge line $y_i$ and average roughness $R_m$ at field C2 (see Figure 9)*

The algorithm we developed to analyze printed edges works as follows. As shown in Figure 13, the acquired RGB image (1) is converted to an 8 bit grayscale image (2), with gray levels between 0 (black) and 255 (white). The image contrast is adjusted such that 1 % of the data has a gray value of 0, whereas the top 1 % of the data has a gray value of 255. This yields a more robust edge distinction (3). The edge of the printed image is detected using a Canny edge algorithm

(Canny, 1986). Compared to other edge detection algorithms Canny delivers the best and most robust results (Mathworks, n.d.). Because the edge points obtained are not continuous, dilatation and erosion processes are performed (4) to reconstruct a continuous edge between the left and the right image border (5). The end points of the reconstructed edge are then connected by a straight line $y_i$ (6). The average absolute distance $R_m$ between $y_i$ and the detected edge is calculated with pixel-to-pixel resolution and a pixel distance of 0.5 µm (7). Note that this algorithm is well-defined even when there is a non-unique mapping of the center line to the border curve (e.g., for tilted or curved ink filaments) or when isolated ink residuals are situated close to the rim.

## 3. Results and discussion

By focusing the edges of pad-printed images we identified the so-called 'stamp effect', which is a typical defect occurring in pad-printing as it is also described by Hübner and Till (2007). By taking a closer look at the printing form in Figure 14, it can be clearly seen that this 'stamp' defect is related to the walls between the raster cells at the border of the ink transfer areas on the surface of the printing form. The raster is described in Section 1.3. The roughness measured on the printed patterns (Figure 14) is quite variable in the individual fields and ranges from 10 µm to 35 µm. A closer comparison with the gravure patterns of the printing form reveals that this type of defect is related to the relative gravure cells' row distance to the geometric border of the respective field on the printing form. These walls at the border are transferred in the printing process which can be seen in Figure 14b in the printing result with a wavy contour, the 'stamp effect'.



*a)*          *b)*
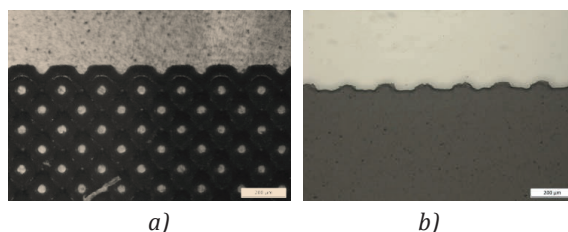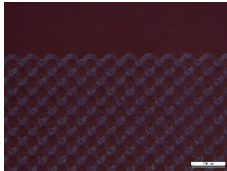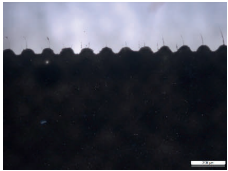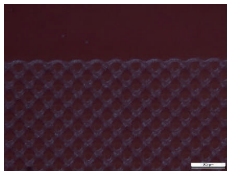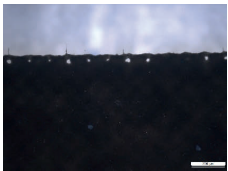
*Figure 14: Ten times lens magnification images of a printing form at the border of the pattern, imaged with a two-step exposure (a), and the resulting printed image with a 'stamp' defect (b)*

As shown in Table 1, it seems that the position of the raster walls at the edge is random. The position results from the desired layout and the fact that in the second exposure step a film fully covered with a raster is used. If rastered printing images with straight edges and without these 'stamp' defects are desired, so-called outlines should be used (Hahne, 2001; Kokot, 2013).

*Table 1: Ten times lens magnification images of a polymer printing forms (left column) with a raster frequency of 120 L/cm at random different areas of the edges of the pattern, the resulting printed image (right column) and the measured $R_\mathrm{m}$ by Equation [1]*

| Printing form | Printed image | $R_\mathrm{m}$ (µm) |
|---|---|---|
| | | 10.87 |
| | | 2.45 |

An outline is a contour in the digital layout which is aligning inward around the layout. The requirement for the line width is that it should be slightly larger than one raster wall to eliminate it from the edge. At the same time, the line width shouldn't be too large, so that the blade cannot tilt in these areas.

In our experiments the clichés with the coarsest resolution are those with a raster frequency of 80 L/cm. Those therefore have the largest raster walls. In there, one raster wall is not larger than 50 µm. A line width of 50 µm for the outline turned out to be sufficient for all three used raster frequencies. Contrary to what is shown in Figure 7, where one layout film and one raster film is needed, the raster specific for this layout is then already implemented in the digital layout combined with the outline (as shown in Figure 15, right) and transferred to the film material.
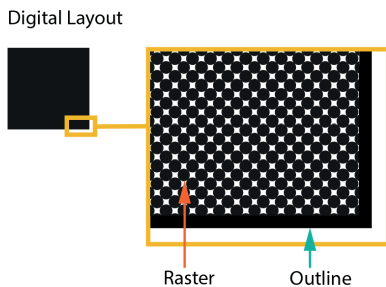


*Figure 15: Digital layout for the one-step exposure with implemented raster and outline*

Only one exposure step is sufficient, which we call 'one-step exposure' and will be explained later. Thus, in the printing form production (photopolymer or steel based), outlines eliminate the walls of the raster at the edges and reveal in a printed result (as shown in Figure 16b) with a straight edge.



a)                                b)
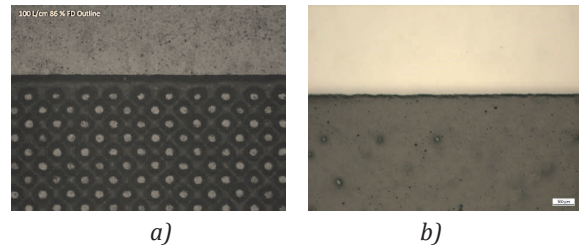
*Figure 16: Ten times lens magnification image of (a) printing form with outlines, and (b) printed result with a straight edge ($R_\mathrm{m}$ = 1.76 µm)*

The most commonly used process to produce printing forms, as described above in section 1.4, is a two-step exposure process, due to two films (one with the layout and one with the desired raster) that are necessary.

For implementing outlines, a 'one-step exposure' process is necessary. The difference between both processes is described below. In general, there are two possibilities to implement a raster in a printing form. Which of the variants is chosen depends on the requirements of the printing job.

A. Two-step exposure (most commonly used)
   The first exposure with the image layout is followed by a second exposure with the desired raster. Different raster films are available with different raster frequencies and area coverages. The advantage here is the easy processing and the flexibility if another raster frequency is needed.

B. One-step exposure
   The one-step exposure can be used if the raster is already integrated in the layout. The advantage in this process is first that only one exposure step is necessary, and second that so-called outlines can be implemented to print sharp edges. The disadvantage in this case is the comparatively more complex preparation of the data.

*Table 2: Results of the printing experiments with different printing form materials, different raster frequencies and the resulting edge roughness $R_\mathrm{m}$; all used printing forms in this table have outlines*

| Printing form material | Raster frequency (L/cm) | $R_\mathrm{m}$ (µm) |
|---|---|---|
| Polymer | 80 | 2.44  (± 1.02) |
| | 100 | 1.76  (± 0.95) |
| | 120 | 1.50  (± 0.28) |
| Steel | 80 | 1.74  (± 0.38) |
| | 100 | 1.83  (± 0.48) |
| | 120 | 1.55  (± 0.27) |
| | Average | 1.80  (± 0.31) |

Two-step exposure



One-step exposure (with outlines)
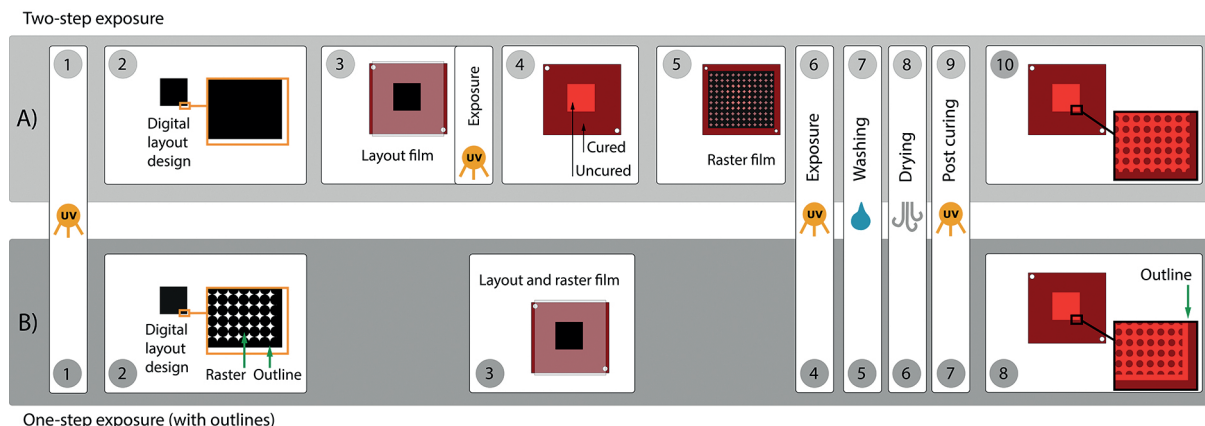
*Figure 17: Schematic showing the difference between the process of the two-step exposure (A)*
*and the one-step exposure (B)*

Figure 17 shows the differences between both processes employing the two-step (A) and one-step exposure (B) to produce a pad-printing form. The resulting printing forms from both processes (A) and (B) are the same with one significant difference that in (B) outlines are included, which enables printing of sharp edges. When we replaced the printing forms with those having outlines, we achieved an average edge roughness $R_m$ of $1.80 \pm 0.31$ µm. This represents an enormous improvement in edge quality (Table 2).

Out of the results we can see that the edge roughness is independent of printing form material and raster frequency. Raster frequency and area coverage, as well as the exposure and etching time determine the cell depth and thus also the theoretical ink volume (microPrint, 2012). The results obtained here also show that (if edge accuracies below 3 µm are desired) raster frequency and thus the ink volume has no influence on the edge roughness as long as the outlines are used.

## 4.  Conclusion

In this work, we consider the edge quality of pad-printed structures. With the help of Matlab software we created an algorithm to measure the edge roughness. With this algorithm we measured edge roughness's of more than 10 µm. We determined within each printing sample huge deviations of the measured roughness's at different areas of the sample due to strongly varying wavy contours of the edges. These wavy contours can be traced back to the cliché, where those so-called 'stamp effects' already occur. We identify the 'stamp effect' as a printing defect when focusing on the edge roughness. 'Stamp' defects are related to the structure of the printing area of the printing cliché. By providing an outline feature, 'stamp' defects can be avoided. To do this, the printing form must be exposed with a one-step exposure instead of the two-step exposure usually used. The raster and the outline must then be accordingly created in the layout. In the experiments we printed one layout with different printing forms (photopolymer and thin steel) and different raster frequencies, which has influence to the transferred ink volume and resolution. We expected to see an influence to the edge roughness with the algorithm we created. In experiments we used clichés with implemented outlines. It turned out that the raster frequency of the printing cliché and cliché material has no influence on the edge sharpness in our experimental setup. Summarizing, with regard to the printing results and the measured edge roughness, we can say that a value of less than 3 µm for the edge roughness can be achieved when using outlines, regardless of the printing plate material and raster frequency.

## References

Al Aboud, A., Dörsam, E., Hakimi Tehrani, A. and Spiehl, D., 2018. Using FEM simulation as a tool to develop pad printing. In: P. Gane, ed. *Advances in Printing and Media Technology: Proceedings of the 45th International Research Conference of iarigai*. Warsaw, Poland, October 2018. Darmstadt, Germany: iarigai, pp. 107–114.

Bodenstein, C., 2018. Einflüsse auf die Kantenqualität tampongedruckter Strukturen und deren Beurteilung für die Anwendung in der gedruckten Elektronik. In: *Open Seminar: Innovation Tampondruck 2018*. Bietigheim-Bissingen, Germany, 27–28 November 2018.

Bodenstein, C., Sauer, H.M., Hirmer, K. and Dörsam, E., 2018a. Influence of printing parameters in fully pad-printed electroluminescence panels on curved surfaces. In: *19th International Coating Science and Technology Symposium (ISCST)*. Long Beach, CA, USA, 16–19 September 2018.

Bodenstein, C., Sauer, H.M., Fernandes, F., Dörsam, E. and Warsitz, E., 2018b. Assessing the quality of pad-printed images by evaluating edge sharpness. In: P. Gane, ed. *Advances in Printing and Media Technology: Proceedings of the 45th International Research Conference of iarigai*. Warsaw, Poland, October 2018. Darmstadt, Germany: iarigai, pp. 97–106.

Canny, J., 1986. A computational approach to edge detection. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 8(6), pp. 679–698. https://doi.org/10.1109/TPAMI.1986.4767851.

Hahne, P., 2001. *Innovative Drucktechnologien: Siebdruck – Tampondruck*. Lübeck, Germany: Der Siebdruck, p. 94.

Hahne, P., Hirth, E., Reis, I.E., Schwichtenberg, K., Richtering, W., Horn, F.M. and Eggenweiler, U., 2001. Progress in thick-film pad printing technique for solar cells. *Solar Energy Materials and Solar Cells*, 65(1), pp. 399–407. https://doi.org/10.1016/S0927-0248(00)00119-7.

Hakimi Tehrani, A., 2018. *Automation improvement of indirect gravure printing with a focus on the mechanical characteristics of silicone rubber pads*. PhD Thesis. Technische Universität Darmstadt.

Hakimi Tehrani, A., Dörsam, E. and Neumann, J., 2016. Improving automation and process control of an indirect gravure (pad) printing machine. *Acta Polytechnica Hungarica,* 13(4), pp. 221–240.

Hübner, G. and Till, W., 2007. Rotogravure and pad printing of microstructures for electronic applications like oFETs. In: N. Enlund and M. Lovreček, eds. *Advances in Printing and Media Technology: Proceedings of the 34th International Research Conference of iarigai*. Grenoble, France, 9–11 September 2007. Zagreb, Croatia: Acta Graphica Publishers, pp. 297–305.

Kokot, J., 2013. *Drucken und Veredeln im Bogentiefdruck: Verpackungs- und Etikettendruck mit Verfahrenskombinationen*. Esslingen, Germany: Bibliothek des grafischen Wissens, p. 47.

Krebs, F.C., 2009. Pad printing as a film forming technique for polymer solar cells. *Solar Energy Materials and Solar Cells,* 93(4), pp. 484–490. https://doi.org/10.1016/j.solmat.2008.09.003.

Lake, M., 2017. *Oberflächentechnik in der Kunststoffverarbeitung: Vorbehandeln, Beschichten, Bedrucken, Funktionalisieren, Prüfen*. Munich, Germany: Carl Hanser Verlag, p. 302.

Lee, T.-M., Hur, S., Kim, J.-H. and Choi, H.-C., 2010. EL device pad-printed on a curved surface. *Journal of Micromechanics and Microengineering,* 20(1):015016. https://doi.org/10.1088/0960-1317/20/1/015016.

Leppävuori, S., Väänänen, J., Lahti, M., Remes, J. and Uusimäki, A., 1994. A novel thick-film technique, gravure offset printing, for the realization of fine-line sensor structures. *Sensors and Actuators A: Physical*, 42(1–3), pp. 593–596. https://doi.org/10.1016/0924-4247(94)80060-X.

Mathworks, n.d. *Edge Detection*. [online] Available at: <https://de.mathworks.com/help/images/edge-detection.html> [Accessed 10 January 2018].

Merilampi, S.L., Björninen, T., Ukkonen, L., Ruuskanen, P. and Sydänheimo, L., 2011. Characterization of UHF RFID tags fabricated directly on convex surfaces by pad printing. *The International Journal of Advanced Manufacturing Technology*, 53(5–8), pp. 577–591. https://doi.org/10.1007/s00170-010-2869-y.

microPrint, 2012. *The pad printing book*. [pdf] Schaffhausen, Switzerland: microPrint LC GmbH. Available at: <http://www.microprint.ch/pdf/The-pad-printing-book.pdf> [Accessed 06 December 2018], p. 43.

Mooring, L., Karousos, N.G., Livingstone, C., Davis, J., Wildgoose, G.G., Wilkins, S.J. and Compton, R.G., 2005. Evaluation of a novel pad printing technique for the fabrication of disposable electrode assemblies. *Sensors and Actuators B: Chemical*, 107(2), pp. 491–496. https://doi.org/10.1016/j.snb.2004.11.005.

Nisato, G., Lupo, D. and Ganz, S. eds., 2016. *Organic and Printed Electronics. Fundamentals and Applications*. Boca Raton, FL, USA: Pan Stanford Publishing, CRC Press, pp. 70–71.

Willfahrt, A., 2007. Examination of the printability of microstructures by means of pad printing for the realization of minimal structures for the use of conductive inks on PET-Substrate. In: *Printing Future Days 2007: Proceedings of the 2nd International Student Conference on Print and Media Technology*. Chemnitz, Germany, 5–8 November 2007. Berlin, Germany: Verlag für Wissenschaft und Forschung.

Xiong, Y. and Qu, Z., 2011. Antenna 3D pad printing solution evaluation. In: *International Symposium on Antennas and Propagation (APSURSI)*. Spokane, WA, USA, 3–8 July 2011. New York, NY, USA: IEEE, pp. 2773–2776. https://doi.org/10.1109/APS.2011.5997101.

S. Shrestha, R. Yerramilli and N.C. Karmakar – J. Print Media Technol. Res. 8(2019)1, 29–42

29

# Printing of low-cost chipless RFID tags

*Sika Shrestha, Ramprakash Yerramilli and Nemai Chandra Karmakar*

Department of Electrical and Computer System Engineering,
Monash University, Australia

sika.shrestha@monash.edu
ramprakash.yerramilli@monash.edu
nemai.karmakar@monash.edu

## Abstract

Chipless radio frequency identification (RFID) is a highly attractive and easy-to-operate technology allowing automated scanning of goods without any human intervention. It is a low-cost alternative to chip-based technology with few constraints. The flexibility to use low-cost printing techniques makes the chipless tags cost-effective to be useful as a competitive technology. In this paper, we review and compare the most common printing techniques for fabricating chipless RFID tags. Some of the issues encountered during printing of tags were identified and solutions to achieve better outcome were suggested. Most importantly, the advantages and limitations of the printing techniques were highlighted from a perspective of a vast amount of work done by various research teams worldwide. The review is an attempt to cover the basic aspects of conductive ink printing to fabricate functional chipless RFID tags. It is intended to guide researchers in tag printing using common printing techniques.

**Keywords:** inkjet printing, screen printing, flexographic printing, gravure printing, automatic identification and data capture technology

## 1. Introduction

Automatic identification and data capture (AIDC) technologies have been used to identify objects, collect the data and send the data into a computer system for further processing. The convergence of AIDC and network technologies is a predominant section of the Internet of things (IoT). The AIDC technology can collect and retrieve the data at every point of transaction and its integration with network entities can distribute the information for various applications in IoT. We can find several types of AIDC technologies such as barcodes, magnetic strips, smart cards, optical character recognition (OCR) and radio frequency identification (RFID). Barcode technology has become ubiquitous due to their high information density, low cost and direct printability over the items. The technology is considered as laborious as each item has to be scanned individually at the line of sight.

On the other hand, conventional RFID technology uses radio waves and can identify items held inside a case or hidden behind items in a shelf. It does not require line-of-sight communication with the tagged object and therefore requires minimal human participation between the data carrying device which, in most cases,

is a transponder (tag) and a separate interrogator (detector). The detector can count multiple objects quickly and identify them simultaneously. For these reasons, the technology has emerged as the most efficient wireless transmission and reception technique for data capture, authentication and automatic identification. However, the penetration of conventional RFID technology into the supply-chain market is limited by the cost associated mainly with the silicon (Si) chip. This can be easily understood from Figure 1, where the basic steps involved in the fabrication of a conventional RFID tag are shown.
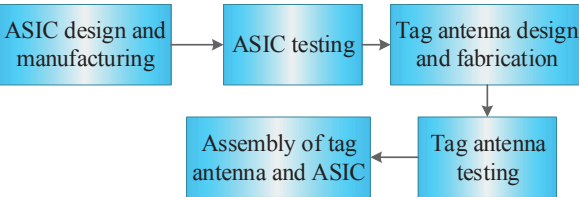


*Figure 1: Steps in RFID tag fabrication, adopted from Preradovic (2009)*

The fabrication process starts with the design and manufacturing of application-specific integrated circuit (ASIC). This integrated circuit (IC) is one of the

most important components in a conventional RFID tag detection system and contains the memory and tag data. The IC fabrication process generally includes a series of photolithographic and chemical processing steps such as photoresist deposition, removal, patterning, and tuning of the electrical properties (Shao, 2014).

Silicon chip based tags owe their high cost to its selection, processing, and assembly with other components such as batteries and antennas (Violino, 2004; Anee and Karmakar, 2012). Along with the advancement of wafer processing technology and consequent reduction in Si price, the size of an IC chip also shrunk making it more attractive for RFID applications. The discussion about the 5-cent RFID tag (Violino, 2004; Anee and Karmakar, 2012) concluded that advancement in IC chip technology will not be able to reduce the tag price below 5 cents to make it cost-effective for mass deployment for various reasons.

Chipless RFID technology is attractive for low-cost applications over Si-chip based tags due to the absence of the steps shown in Figure 1. The building blocks of a chipless RFID system are shown in Figure 2. The main function of a tag is to generate an identification code. The data encoding can be based on time, frequency and phase domain. Coding can also be done using hybrid domain and radar imaging. Since chipless tag does not have data processing capability, signal processing is entirely done in the reader electronics. A chipless tag reader, therefore, has a new set of design requirements and challenges compared to a chip-based tag reader.

A fully functional chipless tag reader requires an RF transceiver and a digital board with overall system integration. The reader interrogates the tag with an ultra-wide band (UWB) radiation envelope of constant amplitude. The tag returns a backscattering signal in the form of data stream known as the identification data (ID). A reader captures and processes the data to recognize and trace the tag ID. The middleware performs the signal processing for the detection of tag ID from the received signals with error correction and anti-collision algorithms (Anee and Karmakar, 2012).
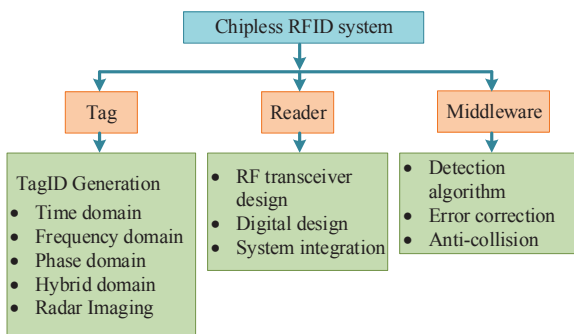
Printing of chipless tags using common printing processes is considered as an option to reduce the price of tags below a cent mark (Haak, 2018). Walmart deployed electronic article surveillance (EAS) 1-bit tags based on Si-chip technology in retail market. Walmart's requirement amounts to several million of tags per year. At a tag price of 5 to 10 cents, the cost for supply of several million tags for a retail application would not be cost-effective (Kosasi, Kom and Saragih, 2014; Vowels, 2006; Jewell, et al., 2015). To be cost-effective, the sale of low-priced goods at low-profit margins would require the tag price to be ≤ 1 cent. It has been predicted that 700 billion chipless tags will be sold in 2019, if the tag price falls below a cent. Market report from TechNavio (2017) mentioned that global chipless RFID market will grow at a compound annual growth rate (CAGR) of 27.43 % during the period 2017–2021. Inventory management involving tracking of products, assets, stored components and finished products has become an imperative asset of many companies and hence the demand for the supply of low-cost tags is in surge. The chance of counterfeiting of a polymer banknote issued by Reserve Bank of Australia and by governments in other countries, is an accepted threat to the banknote business incurring financial losses (Cowling, 2011). The printing of chipless tags is considered as an attractive proposition for banknote protection, if manufactured in large volumes, at a price of ≤ 1 cent per tag. Justification for the price of the tag is linked to the low-cost materials used in any printing industry compared to fabrication of tags using printed circuit boards (PCB) technology.

Research papers covering various aspects of chipless tag design (Huang and Su, 2017; Martinez and van der Weide, 2016; Noor, et al., 2016; Preradovic and Menicanin, 2016; Rance, et al., 2016), reader development (Karmakar, et al., 2013; Preradovic and Karmakar, 2010; Koswatta and Karmakar, 2012) and tag ID detection (Kalansuriya, et al., 2012; Kalansuriya and Karmakar, 2012; Anee and Karmakar, 2012) were sighted. The reading of tag identification data depends on the detectability of tag radar cross-section (RCS) response over the frequency range. In real-world scenario, the cluttering signals, the leakage of environmental reflections from the transmitter and the interference from surrounding tags attenuate the RCS response. It is, therefore, vitally important to look for improved signal detection electronics.

In this paper, we reviewed common tag printing techniques such as inkjet, screen, flexographic and gravure printing processes using conductive silver ink. Inkjet printing is a direct technique allowing printing of tags on any type of substrate. Screen printing is a well-established laboratory and industrial technique, while gravure and flexography are well-known high speed printing techniques for high volume production



Figure 2: Basics of a chipless RFID system

of tags. We cover the basics of the printing processes (Section 2), tag performance comparison reported in the literature (Section 3), tag performance study vs printing parameters (Section 4) and conclusions from this work (Section 5) in the rest of the review article.

## 2. Printing of chipless tags

The printing of chipless tags takes place through the deposition of conductive ink stripes on a substrate using a suitable design by any of the printing techniques mentioned above. The printed tags are sintered at suitable temperature to increase the electrical conductivity of the tracks. A schematic of the printing and sintering process is shown in Figure 3.
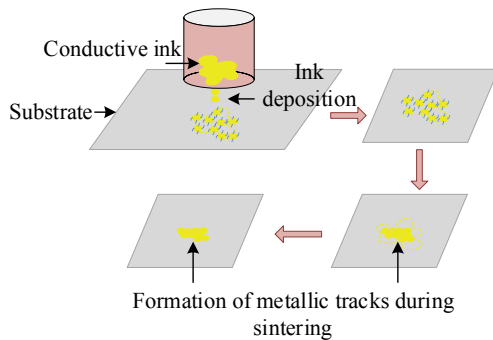


*Figure 3: Printing of conductive ink tracks by direct ink deposition and subsequent sintering, adopted from Shao (2014)*

### 2.1 Inkjet printing

The versatility of inkjet printing as a digital and non-impact printing process allows it to print directly from computer data onto virtually any substrate size. Inkjet printing requires very complex ink formulation. These formulations may be water or solvent-based. A few varieties of formulations might need to undergo hot-melt or UV-curing steps. The ink viscosities are around 0.01 Pa·s (Titkov, et al., 2015). The inkjet printing process is of two types: continuous inkjet and drop-on-demand (DoD). In the continuous ink jet process, the droplet generator is made of a reservoir storing ink under pressure which gets released when the generator is subjected to a vibration. The vibration increases the pressure inside the reservoir enabling a stream of fine droplets to eject from the nozzle. The droplets pass through a charged electrode and can be deflected in two different directions by means of two mutually perpendicular electric fields. The droplets which are not to be printed are deflected into a gutter and recycled while those going through the electric field, join to form a single printed line. The resolution is limited to only 60 lines per centimetre (Blayo and Pineaux, 2005), which is rather low for printed electronics.
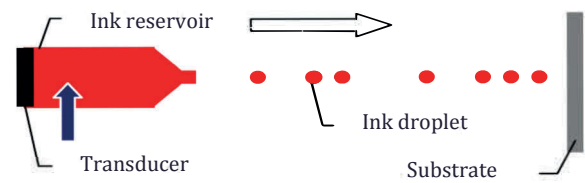


*Figure 4: The inkjet drop-on-demand process*
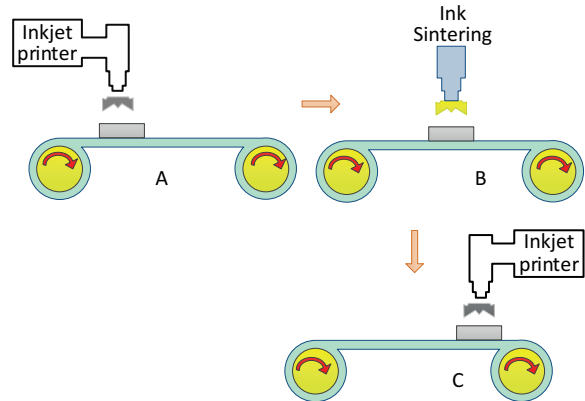


*Figure 5: Inkjet printing process showing: in step (A) ink droplet hitting the substrate at the beginning of the process, in step (B) sintering of the ink droplets after they hit the surface, and in step (C) second pass of inkjet printing (multi-layer printing), adopted from Shao (2014)*

In the DoD process (Figure 4), ink droplets coming out from the nozzle in the printer cartridge, sinter soon after hitting the substrate. The size of DoD droplets will be around 5 picolitres and much less at the time when they are ejected, but spreads into a diameter of 21 μm, soon after touching the substrate. Continuous lines of width of 21 μm will form after the individual droplets join together. It is common to have placement errors due to undesirable "satellite" droplets reaching specific substrate areas that should not get printed. The standard placement errors with state-of-the-art inkjet printers is approximately 10 μm at a distance of 1 mm from the print head (Cummins and Desmulliez, 2012). Edge effects are also possible, especially with thermal inkjet printers. This happens when the pressure in the reservoir increases, either due to the vibration of a piezo-element in the piezo-system or due to the blocking of the nozzle by dried ink bubbles formed due to the rapid evaporation of the solvent in the ink by the heating system.

Inkjet printing is economical in terms of ink usage as mostly, the required amount of ink is always printed. The design file is printed directly over the substrate by a print head containing conductive nanoparticle ink. Multilayer printing to build required thickness is accomplished by simply depositing a new layer on top of a cured layer (Figure 5C). Curing of ink takes place

by means of a substrate heater. A common issue in inkjet printing is clogged ink cartridges and this often requires flushing and cleaning of the cartridges to remove blockage.

## 2.2 Screen printing

In flat-bed screen printing, the ink is transferred to the substrate through a stencil containing the tag pattern. The stencil made of fabric is stretched on a frame to enable pressure to be applied to it by a squeegee (Figure 6). Conductive ink is deposited over the stencil by a spatula in an empty area below the design. In the next step, the ink is drawn across the tag pattern by the squeegee forcing it to go through the stencil. In the rotary screen printing process, the stencil will be cylindrical in shape. The ink is poured inside the cylinder and is forced by the squeegee also located within the cylinder, to get released to the substrate, during cylinder rotations.
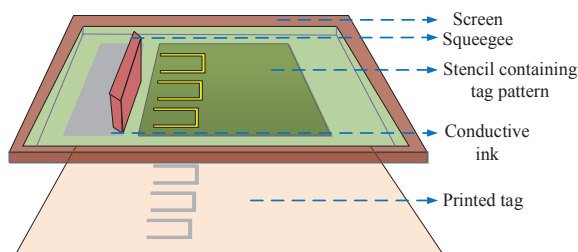


*Figure 6: Screen printing of RFID tags*

As a first step of the manual screen printing process, the frame will be held in a position above the substrate. In the second step, the ink is dragged along the screen by a squeegee using gentle hand pressure enabling it to flood the mesh openings. This is easily done by moving the squeegee upwards from the bottom of the screen at 45° angle. In the third step, the frame is set to sit exactly over the substrate. In this step, it will be necessary to flip the squeegee horizontally, collect the ink at one place, and get ready to drag it along the stencil and push downwards for printing to happen. In the fourth and final step, the ink is dragged along the stencil in a downward direction, beginning at the location where the squeegee was halted in the previous step (top of the screen), by applying increased hand pressure. This ensures release of the ink held in the mesh pores to the substrate placed beneath the screen.

The various parts of screen-printer and the overall printing process is shown in Figure 6. The mesh size, emulsion thickness, applied squeegee pressure and ink viscosity are optimized to obtain printing uniformity and reproducibility between runs. Screen-printing inks have viscosities in the range of 0.1 Pa·s to 10 Pa·s (Jewell, et al., 2015). It is possible to print thin to moderately thicker films, typically from 20 μm to 50 μm

(Merilampi, et al., 2010) in thickness using the viscous inks. Due to the flexibility to print variable thickness, screen printing has been in practice for micro-electronic printing. Drying of inks usually occurs through a thermal process whereby the solvent in the ink is evaporated by hot air blowers, IR heaters or radiant heat from UV lamps.

The screen-printing process has its limitations of resolution and speed. The maximum printable resolution remains usually at 30 lines per cm and print speed is limited to 12 m/min. In comparison, gravure and flexographic printing processes are fast with maximum print speeds exceeding 200 m/min. The print speed has a direct effect on the conductive film resistance. Increasing the print speed from 3 m/min to 12 m/min increases the resistance by 8 %. The uniformity and print tolerance are influenced by the print speed. An improvement of 21 % was observed in print uniformity by changing the speed from 3 m/min to 9 m/min. The printing tolerance was found to reach a fixed value of 10 % (Salam, et al., 2011) for print speeds ≥ 120 m/min. In laboratory phase trials, where a specific design needs to be printed to verify proof-of-concept, a print speed of 20 m/min is sufficient in any flexographic or gravure process.

## 2.3 Flexography printing
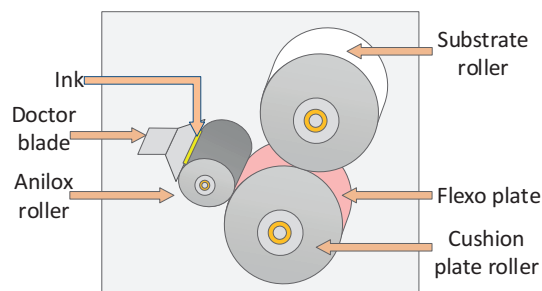


*Figure 7: Flexography printing process printing process for chipless RFID tag*

The basic process and the various parts of a flexographic printer are shown in Figure 7. The operating principle is described below.

The process allows printing on smooth and rough surfaces of plastic films and paper substrates, by a proper selection of a combination of resilient plates and low viscosity inks. The flexographic process consists of four components, namely (1) flexo plate, (2) anilox roller, (3) flexo plate cylinder, and (4) substrate roller. The flexographic image carrier uses a raised image attached to a cylinder. The flexo plate cylinder, covered with flexo plate made up of rubber, picks up ink from an anilox roller and delivers a smooth flow of ink to the substrate roller. The anilox roller surface contains mil-

S. Shrestha, R. Yerramilli and N.C. Karmakar – J. Print Media Technol. Res. 8(2019)1, 29–42

33

lions of cells to hold and carry fixed volumes of ink to the plate, during a print run. The number of cells vary from 80 to 1200 per inch. Ink is delivered to the plate in a controlled manner from the anilox roller and any excess ink is wiped off by a doctor blade (Figure 7). In this way, a thin layer of ink is transferred to the flexo plate, and then to the substrate backed by a substrate roller. The pressure between the anilox roller and the plate, and that between the plate and the substrate is mechanically controlled.

The inks used in Flexography printing can be solvent or water-based. Solvent-based inks dry fast under the application of heat by thermal heat blowers or by using an IR lamp heater. Ultraviolet curable inks can also be used. Printing can take place on absorbent and non-absorbent substrates. Standard flexographic presses can accommodate a wide range of cylinder repeat lengths to match customer requirements of print length.

Flexography process for microelectronic application was tested on indium tin oxide (ITO) coated polyethylene terephthalate (PET) films (Deganello, et al., 2012) and paper substrates (Kattumenu, 2008). Deganello and co-workers were able to print lines of 0.76 μm in thickness and 75 μm in width having a sheet resistance of 1.26 Ω/sq. Another research group studied flexography printing of silver inks on different types of paper substrates (Kattumenu, et al., 2009). A minimum sheet resistivity as low as 0.35 Ω/sq at 2 μm ink film thickness was reported.

Flexographic printing on low temperature co-fired ceramic (LTCC) substrates was tested by printing a mass fraction of 30 % of silver ink using roll-to-roll (R2R) print runs in 3 to 5 passes (Faddoul, et al., 2012). The printed lines on LTCC were sintered at 850 °C for 10 min under ambient air. They showed a resistivity of $2.8 \times 10^{-6}$ Ω·cm close to bulk silver resistivity and were 190 μm in width and 1.5 μm in thickness.

## 2.4 Gravure printing

Gravure printing is an established process for the manufacturing of high-quality images and is cost-effective. Best examples of some commercial products are wrapping paper, high-quality publications and Australian polymer banknote. Australian Research Council (ARC) funded two key R&D projects in 2009 and 2013 to develop multibit chipless RFID tags by gravure printing (Anee, et al., 2012) in collaboration with CCL Secure (formerly Securency International Pty Ltd.).

In gravure printing process (Figure 8), a large steel cylinder is electroplated with copper and engraved (or etched) to form microscopic cells on the cylinder surface by electromechanical means or laser engraving.

The engraved cylinder is electroplated with chrome to reduce its wear during production runs. Low-viscosity conductive printing ink is held in a tank beneath the rotating gravure cylinder. A roll of plastic film or paper travels between the grooved cylinder and an impression cylinder. A doctor blade is used to wipe off excess ink from the cylinder during printing runs. Printing takes place on the substrate when the ink is transferred by capillary action from the cells (or grooves) to the substrate. In this way an image of the tag design (on the cylinder) gets printed on the substrate. Gravure has the capability to print a continuous image, allowing it to be a versatile printing process.
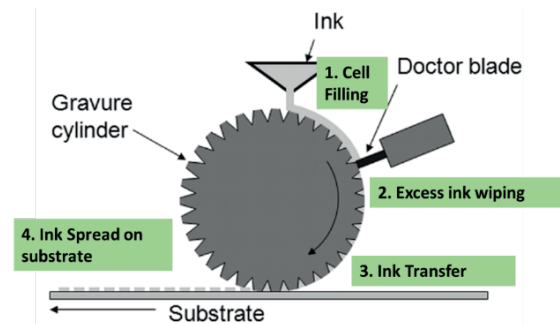


*Figure 8: Different stages of gravure printing process (Sung, de la Fuente Vornbrock and Subramanian, 2010)*

Gravure print quality is affected by substrate properties, ink characteristics and printer settings. Substrate properties include surface roughness of the plastic or paper, compressibility of the substrate between cylinders, porosity in the case of paper substrate, ink receptivity and wettability. Ink properties include ink chemistry, viscosity, solvent evaporation rate, drying temperature and time. Key printer setting parameters to achieve high print quality, are doctor blade angle and applied pressure, impression pressure, printing speed and flatness of the gravure cylinder across its diameter. The print quality is also affected by parameters such as, printing pressure, line width, printing direction and printing angle (Hrehorova, 2007).

Generally, gravure printing requires inks low in viscosity containing solvents that can evaporate quickly on the press during print runs. The press is generally fitted with heaters that blow hot air on the moving substrate. Low-viscosity inks are preferred over high-viscosity inks to obtain the best print quality. The shear rate was measured (Hrehorova, 2007) for water-based, solvent-based and UV-curable conductive inks. Typical viscosities of gravure conductive inks range from 0.05 Pa·s to 0.2 Pa·s (Hrehorova, et al., 2011). Inks containing a mass fraction of 75 % of silver can pose issues during printing. Kim and Sung (2015) examined the effect of using inks containing a mass fraction of 77 % of silver, having viscosity of 4 Pa·s, silver particle size between 1.4 μm and 1.5 μm and density of 3.25 g/cm³.

The researchers found that the printability decreased gradually with decrease in line width and the trend was predominant among the tilted lines. Increasing the tilt resulted in reduced printability for the fine line patterns. The electrical resistance of the lines was found to depend on the line width and print direction. As an example, the measured resistance of a line, 25 μm in width, at normal plane with no tilting, was found to be 35.5 Ω, across 1 mm length, compared to 190 Ω measured for a line of 10 μm in width of the same length.

Pudas, et al. (2005) research group chose gravure offset printing for printing conductive inks. They added an intermediate, compressible cylinder that is inked during its contact with the grooved cylinder and, subsequently, printing takes place on the flexible substrate. By using this approach, Pudas, et al. were able to print films in the thickness range from 8 μm to 12 μm. The effect of impression pressure was tested among the gravure configurations (Clark, 2010) while attempting to print lines of 40 μm in width. Direct printing without an intermediate offset cylinder produced the best fidelity of line width. Clark observed a line widening by 55 % for direct gravure and 145 % for offset gravure printing. Ink viscosity and print direction were also shown to influence line fidelity. The combination of higher ink viscosity and high impression pressure enabled printing of a line $50.7 \pm 4$ μm in width against a nominated line width of 30 μm. Lines printed parallel to the print direction showed better line fidelity than those printed perpendicular to the print direction.

## 3. Comparison of tag features

Features of tags printed by inkjet, screen, flexographic and gravure printing processes are collected from literature and compared as shown in Appendix A.

### 3.1 Printing comparison

#### 3.1.1 Inkjet printing

Inkjet printers were found to print lines with electrical conductivity comparable to tracks printed by other techniques due to the provision of overprinting capability. A 10-bit split ring resonator based tag was fabricated by inkjet printing (Herrojo, et al., 2017a) with all bits set to "1" to indicate the presence of functional resonators.

A humidity sensor based on a chipless RFID tag was fabricated and tested (Borgese, et al., 2017). The tags which were classified as frequency-selective surface (FSS) resonators, were printed by a piezoelectric printer using conductive ink on a cardboard backed by a metallic ground plane without the need for sintering.

A research group (Quddious, et al., 2016) fabricated a fully passive sensor operating in the 4–5 GHz band with capability to sense either humidity or gas through changes in conductivity. The integrated sensor electrode antenna is a combination of a loop and a dipole, and enabled wireless sensing using the frequency domain chipless RFID technique. The outer-dipole arm of the antenna was used for chipless identification in the 2–3 GHz band.

A research group of Khan, et al. (2015) reported the highest code density of 3.56 bits/cm$^2$ (28.5 bits) for a two-layer chipless RFID tag printed on Teslin paper using a Dimatix inkjet printer and silver nanoparticle ink (UT Dots). Tags were printed on one layer and the ground plane was printed on the other layer. By printing five single layers, each of 500 nm in thickness, over one another, they were able to form a thick layer, 2.5 μm in total thickness sufficient to eliminate any skin depth (1.6 μm) related effects which are mostly observed only at low frequencies and lower conductivities. The measured conductivity of the sintered tags was found to be $6.3 \times 10^6$ S/m. The tags had shown high values of quality factor ($Q$) > 100.

Vena, et al. (2013a) fabricated "near-transparent" chipless 3-bit RFID scatterer tags by using strip widths of 4 mm, 3 mm, and 2.5 mm, respectively, with a total of 6-bit encoding capacity. Using the flexible features available with the inkjet printer, they were able to print the chipless tag configuration in silver ink in the first step. In the second step, they were able to reconfigure the tags by printing an overlayer in organic ink with no need for further sintering. They devised a novel coding technique based on amplitude-shift keying linking it to the resistive properties of the organic ink. Another research group (Shao, et al., 2013) demonstrated the proof-of-concept for a novel "chipless RFID coplanar LC-resonator" based tag, printed on packaging paper for operation in the frequency range of 135 MHz to 330 MHz. Using a phase-position modulation (PPM) coding technique, they were able to obtain a 4.25-bit encoding capability within a compact area.

#### 3.1.2 Screen printing

Jeon and co-researchers (Jeon, et al., 2017) screen-printed chipless RFID tags based on dipole array structures onto plain paper using conductive ink. The tags encoded 3-bits of data by using spectral signature modulation over the frequency range 2.5–4 GHz. The tag functionality was analysed in terms of tag types, number of elements, reading range, and other parameters.

Researchers from Dresden University of Technology and Institute for Print and Media Technology, Chemnitz, Germany (Betancourt, et al., 2015) demonstrated tag

reading from a distance of 1.8 m using design methodologies of square-shaped chipless RFID tags based on FSS of plastic and paper. The application of such tags in an evacuation situation, for example in an event of a citizen's security and crisis, was explored.

The same researchers (Betancourt, et al., 2016) also reported on the design, development, fabrication and verification of octagon-shaped screen-printed tags. Besides morphological characterization and ID code verification, they undertook a complete study of the bending and folding effects on the tag. In this regard, a working tag with a bent curvature radius down to 16 mm was reported.

Continuing their work, Betancourt, et al. (2017) demonstrated a new working design of tags in the frequency range of 3–10 GHz. The design was based on genetic algorithm (GA) optimization technique. The tags were screen-printed with silver ink on low-cost substrates. They were able to operate a tag with 8-bit capacity by optimizing the frequency signature of the GA-based tags. The operated tag fits a frequency-shift keying-based coding methodology.

Nair and group (Nair, et al., 2014) fabricated a 3-bit chipless RFID tag by screen printing on a PET substrate. The proposed tag structure was formed by combining three dipoles-like structures. Microwave performance measurements were conducted in the frequency band of 2–5 GHz. Good agreement between simulation and measurement was reported for reading distance up to 1 m for 3 dBm transmitted power (dBm is a decibel referenced to the power of one milliwatt).

Blecha (2014) reported on the design, simulation and measurements of 4-bit binary-coded RFID tags fabricated by screen printing on PET foil. Different geometric dimensions and tag substrates were tested to study their influence on the resonance frequency and signal attenuation. Blecha found that resonance frequencies of particular resonance circuits depended on the length of planar resonance loops. He also found that the signal attenuation extent was dependent on the quality factor.

### 3.1.3 Flexographic printing

Flexographic printing is well known for its capability to print at high printing speeds of approximately 600 m/min. Printed line widths in the range of 50 μm to 100 μm and ink thicknesses up to 5 μm can be deposited at ease for any tag configuration. The technique is well suited for printing of chipless RFID tags requiring electrical conductivities in the range of $10^5$ S/m to $10^7$ S/m and read range distance of 1–3 m (Kattumenu, 2008). The key attraction for flexographic printing is the low production cost which could be ~0.003 USD

per tag, assuming the cost of silver ink to be 1500 USD per liter (2012 price) for bulk orders (Haffarzadeh and Zervos, 2012). As a R2R printing process, it makes possible to use various low-cost materials such as paper, cardboard, and polymer film.

The quality factor $Q$ provides the link between the frequency selectivity of a resonator and the dielectric losses due to the substrate; $Q$ should be as large as possible to maximize the coding capacity for frequency-encoded chipless tags. It is related to the losses in the dielectric, the resistance losses in the conductors arising due to low metal content in the inks, and the radiation losses, which become dominant for configurations based on multiple resonators (Kobe, et al., 2017).

Vena, et al. (2013b) using a frequency-shift coding technique tested five C-shaped resonators in the 2–8 GHz frequency range. They fabricated copper tags using a chemical etching process on a flame resistant (FR-4) fiberglass substrate and compared their performance with those printed using an inkjet catalyst on PET film.

The performance was also compared with silver tags printed by flexography on cardboard and glossy paper. The measured sheet resistance was 0.03 Ω/sq for copper tags compared to 0.67 Ω/sq for silver-based tags. The silver tags were not sintered but were only dried at ambient temperature. The R2R production technique enabled fabrication of a 19-bit chipless tag on paper substrate.

### 3.1.4 Gravure printing

Gravure offset printing method provides an economically viable method for large volume production of fine-line electrical conductors. Pudas, Hagberg and Leppävuori (2004), by using gravure offset printing process and Ag-filled polymer conductive ink, were able to print 150 μm and 300 μm wide lines, with measured sheet resistance of 0.03 Ω/sq and 0.02 Ω/sq, respectively, for 7–8 μm thick tracks matching conductivity requirement for fabrication of chipless tags.

In further work, Pudas, et al. (2005) printed conductive tracks, 4–7 μm in thickness, having sheet resistance ~0.05 Ω/sq, by engraving 20–60 μm deep grooves in a gravure cylinder. They found that thick layers can be printed using high impression pressure and low print speeds. Pudas research group compared the ink thickness for gravure printing and rotary screen-printing processes. They found that the screen-printing process can only print 3–9 μm thick lines. However, the yield touched 100 % for tracks > 350 μm in width. The measured sheet resistance of 0.61 Ω/sq was found to be high and unsuitable for tag fabrication. Pudas, et al. (2005) found improved results for inductors printed by gra-

vure offset process on PET films using polymer filled silver ink. These inductors showed 2–3 times higher losses ($Q > 10$) compared to reference capacitors made in copper metal. The losses were thought to be caused by rough line edges and are mainly associated with poorly conducting polymer-filled silver inks. It is difficult to completely burn out the polymer component in silver inks at sintering temperatures below 150 °C.

## 3.2 Sintering

Conductive inks can be sintered at different temperatures as shown by data in Column 4 of Appendix A. The product data for inks obtained from various suppliers, contain information relating to the sintering conditions for a range of substrates. The recommended temperature for thin sheets of biaxially-oriented polypropylene (BOPP), polyvinyl chloride (PVC) and paper is approximately 100 °C. For nylon and textile substrates, the safe temperature for sintering is < 70 °C. The PET and polyester films can be heated to 140–150 °C.

## 3.3 Tag reading, configuration, coding and signal losses

Studies on tag reading (Herrojo, et al., 2017b) based on the near-field coupling between a chain of printed and identical split-ring resonators (SRRs) acting as the tag and a reader were reported. Encoding was achieved by the presence or absence of SRRs at predefined (equidistant) positions in the chain, and tag identification was based on sequential bit reading. In a study of Jeon, et al. (2017) using a dipole array structure, the possibility of overcoming the limitations of ink conductivity to extend the read range to 2 m was reported.

In a publication by Betancourt, et al. (2015) tags were read for several rotation and tilt angles both inside and outside the anechoic chamber at a reading distance up to 1.8 m. In another publication (Vena, et al., 2013b) peak widening and overlapping of adjacent resonant modes was reported for a tag with a coding capacity of approximately 19.9 bits at a reading distance of 50 cm and 0 dBm transmitting power.

Demonstration of time domain tags based on uniform micro-strip line (UML) and linearly-tapered micro-strip line (LTML) configuration were reported (Shao, et al., 2010). The UML tags were found unreadable, but LTML tags were readable. A tag composed of three dual-rhombic loop resonators in a total size of 7 cm × 4 cm was successfully fabricated (Vena, et al., 2013a) and operated within the 3–6 GHz band.

Periodical-like structure based tags were fabricated and reported (Betancourt, et al., 2016) as an effective way to increase the read range distance to 3.5 m using a peak-based codification technique. A special printing method using a hybrid of analog and digital printing system was reported for printing of an unique antennae (Chopra, Kazmaier and Smith, 2009). The tag fabrication comprised printing of a RFID antenna pattern with disconnected wire segments as a first step, followed by a second step of printing aiming to interconnect the disconnected wire segments to the final RFID antenna.

Signal losses from a tag due to poor conductivity and methods to compensate losses, by printing large track widths of 4 mm, 3 mm and 2.5 mm were reported (Vena, et al., 2013a). The large track widths were found not feasible for designing compact-sized tags with high data bit density.

In some cases, substrate roughness can affect the tag performance (Shao, et al., 2013). These researchers were able to obtain an increase in electrical conductivity of the tracks by reducing the paper substrate roughness by overprinting.

## 4. Study of printing variables

Some of the key tag printing issues and available approaches to overcome them are summarized in Table 1.

Printing parameters that influence tag performance were reviewed in Anee, et al. (2012). Conductive inks (Oldenzijl, Gaitens and Dixon, 2010) can be water or solvent-based but must meet the occupational health and safety requirements. A study of the influence of ink conductivity on RF performance was reported (Islam and Karmakar, 2015) for a dual polarized chipless tag. They observed that low conductivity tracks resulted in an increase in resonant bandwidth, a decrease in the frequency depth notch and a shift in the resonant frequency.

Inks with low metal content also caused a loss of electromagnetic (EM) response. A decrease in electrical conductivity from $3 \times 10^6$ S/m to $3 \times 10^5$ S/m with a 3-dB loss in the EM response, has been reported (Vena, et al., 2013b).

The following selection criteria for conductive inks can be used as a guideline to fabricate printed RFID tags with reasonable microwave performance, according to Anee, et al. (2012):

- Electrical conductivity ≥ $10^6$ S/m to $10^7$ S/m
- Sheet resistance ≤ 5 mΩ/sq to 10 mΩ/sq
- Metal pigment content > 50 %
- Sintering temperature < 150 °C
- Sintering time 1 min to 30 min.

*Table 1: Some common printing issues and solutions*

| Issue | Solution |
|---|---|
| Ink spreads into the gaps between lines for thicker tags printed by screen, flexographic and gravure printing. | Use inkjet printing technique and overprint to increase thickness. |
| Tags printed by screen, flexo and gravure printing processes display low electrical conductivity. | Use low resolution flexography printing process to obtain higher electrical conductivity. Increase cylinder groove depth in gravure printing. Use low count mesh in screen printing. |
| Resin-based inks need sintering at 140 °C to obtain high electrical conductivity from printed tracks and therefore are unsuitable for certain substrates. | Use binder-free conductive printing inks that offer flexibility to sinter at low temperatures. Alternatively, use high-power laser cutting technique for cutting tag patterns from a metal foil. |
| Tags printed with conductive inks with ≤ 50 % metal content display low $Q$ factors. | Use inks with metal content ≥ 70 % to obtain high $Q$ factors. Alternatively, consider using metal foils if cost is not an issue. |
| Difficulty in replication to obtain higher RCS and long reading range. | Use high metal content inks, metal foils and additive printing techniques. |

The substrate dielectric permittivity and loss tangent has direct influence on the microwave performance of the printed tags. Increase in the resonant bandwidth, attenuation level and resonant frequency has been observed (Islam and Karmakar, 2015) on tags printed over substrates with low permittivity ($\varepsilon_r$). The loss tangent (tan $\delta$) representing the RF signal loss was found to depend on the substrate material. Islam and Karmakar also observed attenuation of frequency notch depth from 35 dBsm at tan $\delta$ = 0.002 to 10 dBsm at tan $\delta$ = 0.1 (dBsm is a decibel value referenced to a square meter). Poor print adhesion is often the result of incorrect ink sintering conditions. As a rule, ink with low surface tension will adhere better to any substrate with high surface energy. For this reason, substrates are plasma corona discharge treated before printing and it is a standard practice throughout the printing industry.

In Appendix B we listed few solvent-based screen printing inks. In Appendix C, we summarized key ink, printing and substrate related parameters and design considerations influencing the tag performance.

## 5. Conclusions

Printed tags have issues with tag detection mainly because of low electrical conductivity arising from low print thickness. It is possible to fabricate chipless RFID tags on any plastic or paper substrate by screen printing conductive inks in a simple setup at reduced cost. Inkjet printing is a popular technique and offers savings on ink usage, cost of substrate heating, and has the flexibility for overprinting to build up print thickness. Gravure and flexographic printing are suited for low-cost R2R manufacturing due to their ability to print at high speeds, up to 600 m/min. The performance of printed tags showing considerable spread of RCS response is directly associated with low track conductivity. The ink market is flooded with a variety of conductive inks and pastes to suit a variety of printing techniques and intended applications. In our knowledge, conductive inks that can dry at ≤ 70 °C on press and are suitable for high-speed gravure and flexographic printing process are not commercially available. For this reason, fully printed multibit chipless RFID tags at < 1 cent price per tag cannot be realized.

## References

Anee, R.-E-A. and Karmakar, N.C., 2012. Efficient collision detection method in chipless RFID systems. In: *7th International Conference on Electrical and Computer Engineering, ICECE 2012*. Dhaka, Bangladesh, 20–22 December, 2012. IEEE, pp. 830–833. https://doi.org/10.1109/ICECE.2012.6471679.

Anee, R.-E-A., Roy, S.M., Karmakar, N.C., Yerramilli, R. and Swiegers, G.F., 2012. Printing techniques and performance of chipless tag design on flexible low-cost thin-film substrates. In: N.V. Karmakar, ed. *Chipless and conventional radio frequency identification: systems for ubiquitous tagging.* Hershey, PA, USA: IGI Global. https://doi.org/10.4018/978-1-4666-1616-5.ch009.

Betancourt, D., Barahona, M., Haase, K., Schmidt, G., Hübler, A. and Elinger, F., 2017. Design of printed chipless-RFID tags with QR-code appearance based on genetic algorithm. *IEEE Transactions on Antennas and Propagation,* 65(5), pp. 2190–2195. https://doi.org/10.1109/TAP.2017.2684193.

Betancourt, D., Haase, K., Hübler, A. and Ellinger, F., 2016. Bending and folding effect study of flexible fully printed and late-stage codified octagonal chipless RFID tags. *IEEE Transactions on Antennas and Propagation,* 64(7), pp. 2815–2823. https://doi.org/10.1109/TAP.2016.2559522.

Betancourt, D., Nair, R., Haase, K., Schmidt, G., Bellmann, M., Höft, D., Hübler, A. and Ellinger, F., 2015. Square-shape fully printed chipless RFID tag and its applications in evacuation procedures. In: *9th European Conference on Antennas and Propagation (EuCAP)*. Lisbon, Portugal, 13–17 April 2015. IEEE.

Blayo, A. and Pineaux, B., 2005. Printing processes and their potential for RFID printing. In: *Proceedings of the 2005 joint conference on Smart objects and ambient inteligence: innovative context-aware services: usages and technologies*. Grenoble, France, 12–14 October 2014. New York, NY, USA: ACM, pp. 27–30. https://doi.org/10.1145/1107548.1107559.

Blecha, T., 2014. Screen printed chipless RFID tags. In: *Proceedings of the 2014 37th International Spring Seminar on Electronics Technology (ISSE)*. Dresden, Germany, 7–11 May 2014. IEEE, pp. 143–146. https://doi.org/10.1109/ISSE.2014.6887581.

Borgese, M., Dicandia, F.A., Costa, F., Genovesi, S. and Manara, G., 2017. An inkjet printed chipless RFID sensor for wireless humidity monitoring. *IEEE Sensors Journal,* 17(15), pp. 4699–4707. https://doi.org/10.1109/JSEN.2017.2712190.

Chopra, N., Kazmaier, P.M. and Smith, P.F., Xerox Corporation. 2009. Individually unique hybrid printed antennae for chipless RFID applications. E.U. Pat. EP 2 065 837 A1.

Clark, D.A., 2010. *Major trends in gravure printed electronics*. [pdf] California Polytechnic State University. Available at: <https://pdfs.semanticscholar.org/eaae/6771099cc878349abdb40f45909fc9ea1286.pdf> [Accessed June 2018].

Cowling, A., 2011. Recent trends in counterfeiting. *RBA Bulletin*, September, pp. 63–70.

Cummins, G. and Desmulliez, M.P.Y., 2012. Inkjet printing of conductive materials: a review. *Circuit world,* 38(4), pp. 193–213. https://doi.org/10.1108/03056121211280413.

Deganello, D., Cherry, J.A., Gethin, D.T. and Claypole, T.C., 2012. Impact of metered ink volume on reel-to-reel flexographic printed conductive networks for enhanced thin film conductivity. *Thin Solid Films,* 520(6), pp. 2233–2237. https://doi.org/10.1016/j.tsf.2011.08.050.

Faddoul, R., Reverdy-Bruas, N., Blayo, A., Haas, T. and Zeilmann, C., 2012. Optimisation of silver paste for flexography printing on LTCC substrate. *Microelectronics Reliability,* 52(7), pp. 1483–1491. https://doi.org/10.1016/j.microrel.2012.03.004.

Haak, D., 2018. *Will we get a one cent RFID tag?* [online] Available at: <https://www.linkedin.com/pulse/we-get-one-cent-rfid-tag-danny-haak/> [Accessed November 2018].

Haffarzadeh, K. and Zervos, H., 2012. *Conductive ink markets 2012–2018 silver & copper inks & pastes and beyond*. Boston, MA, USA: IDTechEX.

Herrojo, C., Mata-Contreras, J., Núñez, A., Paredes, F., Ramon, E. and Martín, F., 2017a. Near-field chipless-RFID system with high data capacity for security and authentication applications. *IEEE Transactions on Microwave Theory and Techniques,* 65(12), pp. 5298–5308. https://doi.org/10.1109/TMTT.2017.2768029.

Herrojo, C., Mata-Contreras, J., Paredes, F., Núñez, A., Ramon, E. and Martín, F., 2017b. Near-field chipless-RFID tags with sequential bit reading implemented in plastic substrates. *Journal of Magnetism and Magnetic Materials,* 459, pp. 322–327. https://doi.org/10.1016/j.jmmm.2017.10.005.

Hrehorova, E., 2007. *Materials and processes for printed electronics: evaluation of gravure printing in electronics manufacture*. PhD dissertation. Western Michigan University.

Hrehorova, E., Rebros, M., Pekarovicova, A., Bazuin, B., Ranganathan, A., Garner, S., Merz, G., Tosch, J. and Boudreau, R., 2011. Gravure printing of conductive inks on glass substrates for applications in printed electronics. *Journal of Display Technology*, 7(6), pp. 318–324.

Huang, H.-F. and Su, L., 2017. A compact dual-polarized chipless RFID tag by using nested concentric square loops. *IEEE Antennas and Wireless Propagation Letters,* 16, pp. 1036–1039. https://doi.org/10.1109/LAWP.2016.2618928.

Islam, M.A. and Karmakar, N.C., 2015. Real-World implementation challenges of a novel dual-polarized compact printable chipless RFID tag. *IEEE Transactions on Microwave Theory and Techniques,* 63(12), pp. 4581–4591. https://doi.org/10.1109/TMTT.2015.2495285.

Jeon, D., Kim, M.-S., Ryu, S.-J., Lee, D.-H. and Kim, J.-K., 2017. Fully printed chipless RFID tags using dipole array structures with enhanced reading ranges. *Journal of Electromagnetic Engineering And Science,* 17(3), pp. 159–164. http://dx.doi.org/10.5515/JKIEES.2017.17.3.159.

Jewell, E., Hamblyn, S., Claypole, T. and Gethin, D., 2015. Deposition of high conductivity low silver content materials by screen printing. *Coatings*, 5(2), pp. 172–185. https://doi.org/10.3390/coatings5020172.

Kalansuriya, P. and Karmakar, N., 2012. UWB-IR based detection for frequency-spectra based chipless RFID. In: *2012 IEEE/MTT_S International Microwave Symposium Digest.* Montreal, Canada, 17–22 June 2012. IEEE. http://dx.doi.org/10.1109/MWSYM.2012.6259704.

Kalansuriya, P., Karmakar, N.C. and Viterbo, E., 2012. On the detection of frequency-spectra-based chipless RFID using UWB impulsed interrogation. *IEEE Transactions on Microwave Theory and Techniques,* 60(12), pp. 4187–4197. http://dx.doi.org/10.1109/TMTT.2012.2222920.

Karmakar, N.C., Koswatta, R., Kalansuriya, P. and E-Azim, R., 2013. *Chipless RFID reader architecture.* Boston, MA, USA: Artech House.

Kattumenu, R., Rebros, M., Joyce, M., Fleming, P.D. and Neelgund, G., 2009. Effect of substrate properties on conductive traces printed with silver-based flexographic ink. *Nordic Pulp and Paper Research Journal,* 24(1), pp. 101–106. https://doi.org/10.3183/npprj-2009-24-01-p101-106.

Kattumenu, R.C., 2008. *Flexography printing of silver based conductive inks on packaging substrates*. PhD dissertation. Western Michigan Unversity.

Khan, M.M., Tahir, F.A., Farooqui, M.F., Shamim, A. and Cheema, H.M., 2015. 3.56 bits/cm$^2$ compact inkjet printed and application specific chipless RFID tag. *IEEE Antennas and Wireless Propagation Letters,* 15, pp. 1091–1112. https://doi.org/10.1109/LAWP.2015.2494864.

Kim, S. and Sung, H.J., 2015. Effect of printing parameters on gravure patterning with conductive silver ink. *Journal of Micromechanics and Microengineering*, 25(4): 045004. https://doi.org/10.1088/0960-1317/25/4/045004.

Kobe, O.B., Chuma, J., Jamisola Jr, R. and Chose, M. 2017. A review on quality factor enhanced on-chip microwave planar resonators. *Engineering Science and Technology*, 20(2), pp. 460–466. https://doi.org/10.1016/j.jestch.2016.09.024.

Kosasi, S., Kom, M. and Saragih, H., 2014. How RFID technology boosts Walmart's supply chain management. *International Journal of Information Technology and Business Management*, 24(1), pp. 29–37.

Koswatta, R.V. and Karmakar, N.C., 2012. A novel reader architecture based on UWB chirp signal interrogation for multiresonator-based chipless RFID tag reading. *IEEE Transactions on Microwave Theory and Techniques,* 60(9), pp. 2925–2933. https://doi.org/10.1109/TMTT.2012.2203929.

Martinez, M. and van der Weide, D., 2016. Compact single-layer depolarizing chipless RFID tag. *Microwave and Optical Technology Letters,* 58(8), pp. 1897–1900. https://doi.org/10.1002/mop.29944.

Merilampi, S.L., Bjorninen, T., Vuorimaki, A., Ukkonen, L., Ruuskanen, P. and Sydanheimo, L., 2010. The effect of conductive ink layer thickness on the functioning of printed UHF RFID antennas. *Proceedings of the IEEE,* 98(9), pp. 1610–1619. https://doi.org/10.1109/JPROC.2010.2050570.

Nair, R., Barahona, M., Betancourt, D., Schmidt, G., Bellmann, M., Höft, D., Plettemeier, D., Hubler, A. and Ellinger, F., 2014. A fully printed passive chipless RFID tag for low-cost mass production. In: *The 8th European Conference on Antennas and Propagation (EuCAP 2014)*. The Hague, Nederlands, 6–11 April 2014. IEEE, pp. 2950–2954. https://doi.org/10.1109/EuCAP.2014.6902446.

Noor, T., Habib, A., Amin, Y., Loo, J. and Tenhunen, H., 2016. High-density chipless RFID tag for temperature sensing. *Electronics Letters,* 52(8), pp. 620–622. https://doi.org/10.1049/el.2015.4488.

Oldenzijl, R., Gaitens, G. and Dixon, D., 2010. Conduct Radio Frequencies with Inks*.* In: C. Turcu, ed. *Radio Frequency Identification Fundamentals and Applications Design Methods and Solutions.* Rijeka, Croatia: InTech.

Preradovic, S., 2009. *Chipless RFID system for barcode replacement.* PhD thesis. Monash University.

Preradovic, S. and Karmakar, N.C., 2010. RFID readers–review and design. In: N.C. Karmakar, ed. *Handbook of smart antennas for RFID systems.* Hoboken, NJ, USA: Wiley. https://doi.org/10.1002/9780470872178.ch4.

Preradovic, S. and Menicanin, A., 2016. Printed 3-D stacked chipless RFID tag with spectral and polarization encoding capacity. In: *39th International Spring Seminar on Electronics Technology (ISSE)*. Pilsen, Czech Republic, 18–22 May 2016. IEEE, pp. 500–505. https://doi.org/10.1109/ISSE.2016.7563249.

Pudas, M., Hagberg, J. and Leppävuori, S., 2004. Gravure offset printing of polymer inks for conductors. *Progress in Organic Coatings,* 49(4), pp. 324–335. https://doi.org/10.1016/j.porgcoat.2003.09.013.

Pudas, M., Halonen, N., Granat, P. and Vähäkangas, J., 2005. Gravure printing of conductive particulate polymer inks on flexible substrates. *Progress in Organic Coatings,* 54(4), pp. 310–316. https://doi.org/10.1016/j.porgcoat.2005.07.008.

Quddious, A., Yang, S., Khan, M.M., Tahir, F.A., Shamim, A., Salama, K.N. and Cheema, H.M., 2016. Disposable, paper-based, inkjet-printed humidity and $H_2S$ gas sensor for passive sensing applications. *Sensors,* 16(12), 2073. https://doi.org/10.3390/s16122073.

Rance, O., Siragusa, R., Lemaître-Auger, P. and Perret, E., 2016. Toward RCS magnitude level coding for chipless RFID. *IEEE Transactions on Microwave Theory and Techniques*, 64(7), pp. 2315–2325. https://doi.org/10.1109/TMTT.2016.2562625.

Salam, B., Lai, W.L., Albert, L.C.W. and Keng, L.B., 2011. Low temperature processing of copper conductive ink for printed electronics applications. In: *2011 IEEE 13th Electronics Packaging Technology Conference*. Singapore, 7–9 December 2011. IEEE, pp. 251–255. https://doi.org/10.1109/EPTC.2011.6184426.

Shao, B., 2014. *Fully printed chipless RFID tags towards item-level tracking applications.* Doctoral thesis. KTH Royal Institute of Technology.

Shao, B., Amin, Y., Chen, Q., Liu, R. and Zheng, L.-R., 2013. Directly printed packaging-paper-based chipless RFID tag with coplanar LC resonator. *IEEE Antennas and Wireless Propagation Letters,* 12, pp. 325–328. https://doi.org/10.1109/LAWP.2013.2247556.

Shao, B., Chen, Q., Amin, Y., Mendoza David, S., Liu, R. and Zheng, L.-R., 2010. An ultra-low-cost RFID tag with 1.67 Gbps data rate by ink-jet printing on paper substrate. In: *2010 IEEE Asian Solid-State Circuits Conference*. Beijing, China, 8–10 November 2010. IEEE. https://doi.org/10.1109/ASSCC.2010.5716569.

Sung, D., de la Fuente Vornbrock and Subramanian, V., 2010. Scaling and optimization of gravure-printed silver nanoparticle lines for printed electronics. *IEEE Trasactions on Components and Packaging Technologies*, 33(1), pp. 105–114. https://doi.org/10.1109/TCAPT.2009.2021464.

TechNavio, 2017. *Global chipless RFID market 2017–2021*. [online] Available at: <https://www.researchandmarkets.com/research/4r759p/global_chipless> [Accessed June 2018].

Titkov, A.I., Bukhanets, O.G., Gadirov, R.M., Yukhin, Y.M. and Lyakhov, N.Z., 2015. Conductive inks for inkjet printing based on composition of nanoparticles and organic silver salt. *Inorganic Materials: Applied Research*, 6(4), pp. 375–381.

Vena, A., Babar, A.A., Sydänheimo, L., Tentzeris, M.M. and Ukkonen, L., 2013a. A novel near-transparent ASK-reconfigurable inkjet-printed chipless RFID tag. *IEEE Antennas and Wireless Propagation Letters,* 12, pp. 753–756. https://doi.org/10.1109/LAWP.2013.2270932.

Vena, A., Perret, E., Tedjini, S., Petot Tourtollet, G. E., Delattre, A., Garet, F. and Boutant, Y., 2013b. Design of chipless RFID tags printed on paper by flexography. *IEEE Transactions on Antennas and Propagation,* 61(12), pp. 5868–5877. https://doi.org/10.1109/TAP.2013.2281742

Violino, B., 2004. The 5-cent RFID tag. *RFID Journal* [online] 1 January. Available at: <https://www.rfidjournal.com/purchase-access?type=Article&id=748&r=%2Farticles%2Fview%3F748> [Accessed June 2018].

Vowels, S.A., 2006. A strategic case for RFID: an examination of Wal-Mart and its supply-chain. In: *Proceedings of the 2006 Southern Association for Information Systems*. Jacksonville, FL, USA, 8–9 December 2006. Citeseer, pp. 148–152.

S. Shrestha, R. Yerramilli and N.C. Karmakar – J. Print Media Technol. Res. 8(2019)1, 29–42

41

## Appendix A

Comparison of chipless RFID conductive silver tag features produced by inkjet, screen, flexography and gravure printing techniques

| Substrate type | Printer make | Sintering temperature (°C) | Printed Ag thickness (µm) | Sheet resistance (Ω/sq) | Conduct. (S/m) | Tag geometry | Freq. range (GHz)/ No. of bits | Literature reference |
|---|---|---|---|---|---|---|---|---|
| **Inkjet printing** | | | | | | | | |
| PET | Ceradrop CeraPrinter | Room temperature dried | 3.3–3.5 | 0.04 | $7.3 \times 10^6$ | Split ring resonator | 3–6/10 | Herrojo, et al., 2017a |
| Paper | Brother printer | Not sintered | – | – | – | Three concentric loops | 2–8/3 | Borgese, et al., 2017 |
| Photo paper | Dimatix printer | 120 | 2 | 0.08 | $6.0 \times 10^6$ | Antenna and balloon | 2–3/1 | Quddious, et al., 2016 |
| Paper | Dimatix printer | 120 | 2.5 | 0.06 | $6.3 \times 10^6$ | Nested loop resonator | 3–9/28.5 | Khan, et al., 2015 |
| Polyimide | Dimatix printer | 150 | 2 | 0.08 | $6.3 \times 10^6$ | Dual-rhombic loop resonator | 3–6/3 | (Vena, et al., 2013a) |
| Packaging paper (four types) | Dimatix printer | 150 | – | – | – | LC resonator | 0.1–0.4/ 4.25 | Shao, et al., 2013 |
| **Screen printing** | | | | | | | | |
| Plain paper | Standard screen printer | 150 | 5–10 | 0.02 | $5.0 \times 10^6$ to $10^7$ | Dipole array structure | 2.5–4/3 | Jeon, et al., 2017 |
| PET | Semiauto printer | 120–140 | 4.3 | 0.11 | $2.0 \times 10^4$ | Frequency domain QR like appearance | 3–10/8 | Betancourt, et al., 2017 |
| 135 g/m$^2$ paper, PET | Semiauto printer | 120–140 | 4.4 (paper) 4.3 (PET) | 0.11 | $2.0 \times 10^4$ | Octagonal shaped tags | 3–10/5 | Betancourt, et al., 2017 |
| 135 g/m$^2$ paper, PET | Semiauto printer | 120–140 | 4.4 (paper) 4.3 (PET) | 0.11 | $2.0 \times 10^4$ | Metallic square rings | 2–5/4 | Betancourt, et al., 2017 |
| PET | Standard printer | – | – | 0.08 | – | Spiral resonator | 1.5–2.5/4 | Blecha, 2014 |
| PET | Semiauto Printer | 130 | 10 | 0.07 | $1.4 \times 10^6$ | Dipole Structure | 2–5/3 | Nair, et al., 2014 |
| **Flexography printing** | | | | | | | | |
| Cardboard, glossy paper | Standard printer | Room temperatur | 5 | 0.03 | $3.0 \times 10^5$ | C-like & loop resonator | 2–8/5 | Vena, et al., 2013b |
| **Gravure printing** | | | | | | | | |
| PET, Melinex, paper | IGT printer | 70–120 | 10 | 0.05 | $2.0 \times 10^5$ | 35 mm dia inductor coil | 0.915 (inductor) | Pudas, et al., 2005 |

## Appendix B

List of conductive inks used in screen printing

| Ink name | Sheet resistance | Conductivity (S/m) | Metal content (%) | Viscosity | Processing temperature |
|---|---|---|---|---|---|
| NovaCentrix [HPS-021] | 2.6 mΩ/sq (at 1 mil[*]) | $1.50 \times 10^7$ | 65 | > 1 Pa·s | 150 °C / 30 min |
| NovaCentrix [PSI-219] | < 40 mΩ/sq (at 3 μm DFT[**]) | $8.33 \times 10^6$ | 44 ± 2 | 5–10 Pa·s at 10 s$^{-1}$ | 15–90 s, 140 °C, > 2 min at 80 °C |
| Creative Materials [118-09A] | 0.019 Ω/sq/mil | $2.07 \times 10^6$ | 85 | – | 80° C / 4 h; 100 °C / 1 h; 125 °C / 20 min |
| Advanced nano products [DGP-No] | 0.01–0.05 Ω/sq/mil | – | 70–80 | 50–150 Pa·s | 120–150 °C |
| Ink-Tec [TEC-PA-010] | – | – | > 70 | 7–7.5 Pa·s | 140 °C (5 min) 120–170 °C (2–5 min) |

[*]mil – 0.001 inch (25.4 μm)
[**]DFT – Dry Film Thickness

## Appendix C

List of parameters influencing the tag performance

| Ink-related parameters | Ink metal content | High metal content based inks are preferable to obtain tracks with high electrical conductivity. |
|---|---|---|
| | Sintering condition | Low sintering temperatures are preferred for low melting point substrates. Sintering temperature can be elevated for high melting point substrates. |
| | Ink viscosity | Ink viscosity should be appropriate for the chosen printing technique. Viscosity is to be checked and adjusted before printing. |
| **Printing parameters** | Impression pressure (flexography, gravure and screen printing) Printing speed (flexography and gravure printing) | Impression pressure has to be adequate to obtain uniform and best printing quality. Excessive pressures may damage the substrate. Has direct impact on amount of ink transfer to the substrate. Low speeds transfer more ink to the substrate, and high speeds less ink. Uniform prints are obtained at high speeds (> 60 m/min). |
| **Substrate parameters** | Dielectric permittivity | Frequency shift occurs due to difference in dielectric permittivity of substrates. The calculation of resonant frequency can be performed via equation given in Islam and Karmakar (2015). |
| | Loss tangent | Low values are preferred. |
| | Substrate height | Affects specific tag configurations that need a ground plane. |
| | Melting point | Higher melting point substrates are preferred for effective sintering of printed ink. |
| | Surface energy | Ink with lower surface tension than the substrate surface energy is preferred for best adhesion to the substrate. |
| **Design considerations** | Line width (LW) and line slot width (LS) | Printing techniques have their own limitations of printable line width: LW 60 μm / LS 20 μm for inkjet printing, LW 30 μm / LS 300 μm for gravure printing, LW 30 μm / LS 30 μm for flexography printing, and LW 60 μm / LS 60 μm for screen printing. Advisable is to ensure that electrical conductivity of the printed lines is in the optimum range for tag detection. |

# The application of augmented reality in print media

*Merkourios Margaritopoulos and Elissavet Georgiadou*

Hellenic Open University – School of Applied Arts,
Thessaloniki, Greece

mermar@ekdd.gr
elisag@otenet.gr

## Abstract

Augmented reality is a growing research field aiming to enhance the elements of the real world by overlaying additional virtual information. The paper presents augmented reality as an efficient tool of renovating the traditional print media. It includes an introduction to its concept, covering its fundamental principles and technologies, and focuses on its application in print media. It examines the 'augmented print media' in terms of the related technologies and reports on distinguished examples of augmented newspapers, magazines, books and packaging products. Finally, the paper attempts to point out the role of augmented reality in redefining the position of print media in the digital world. It studies the differences between print and digital media and proves the contribution of augmented reality in upgrading print media to modern communication media.

**Keywords:** augmented print media, smart mobile devices, fiducial markers, computer vision, virtual information

## 1. Introduction

Augmented reality (AR) refers to a live view of physical real-world environment whose elements are merged with augmented computer-generated images, creating a mixed reality. The augmentation is typically done in real time and in semantic context with environmental elements. By using the latest AR techniques and technologies, the information about the surrounding real world becomes interactive and digitally usable (Carmigniani and Furht, 2011). Augmented reality aims at simplifying the user's life by bringing virtual information not only to his/her immediate surroundings, but also to any indirect view of the real-world environment, such as live-video stream (Furht 2011, p. vii). Augmented reality is not considered to be restricted to a particular type of display technologies, such as head-mounted display (HMD) or limited to the sense of sight. It can potentially apply to all senses, augmenting smell, touch and hearing as well. Augmented reality can also be used to augment or substitute users' missing senses by sensory substitution, such as augmenting the sight of blind users or users with poor vision using audio cues, or augmenting hearing for deaf users using visual cues (Carmigniani and Furht, 2011).

Augmented reality is an innovation that will almost certainly turn out to be as powerful and broadly applicable as was the Internet itself. This is the eventual, self-evident conclusion reached when anyone, upon achieving a basic level of comprehension, spends a few moments considering the limitless potential that AR promises. Augmented reality is a medium that allows the user to interact with digital data in a visual and spatial manner that is utterly seamless with his/her environment and everyday life (Mullins and Dempsey, 2013, p. xv).

Augmented reality has already many functional applications in a wide range of fields, including education, science, business and manufacturing, medicine, public safety and military, art, advertising and entertainment. The application of AR in the print and publishing sector is a relatively new idea gaining attention by increasing its penetration speed into the field with technologies and products being established in rapid rates. One can say that it is a corollary of situations in which the necessary content to adequately cover a subject is too big to fit into the limited space of a printed medium. For example, AR in the form of QR codes can be applied to a flyer to create a web link between the flyer and a web page with additional digital content. Nevertheless, the importance of AR is not limited into saving print space by 'condensing' large amounts of information into the small space of a printed surface, but it is extended by augmenting the user's sensory perception offered by interactive digital media that complement and enhance the printed media.

The paper presents a brief introduction to the concept and technologies of AR and describes the principles of its application to print media for which selective examples are given, to point out the role of AR in redefining the position of print media in the digital world. It examines the differences between print and digital media in order to prove the contribution of AR in upgrading print media to modern communication media.

## 2. Definitions and technologies of augmented reality

An AR system is a system that creates a view of a real scene by incorporating computer-generated virtual objects, including those with full three-dimensional properties, into the scene. As the user of such a system moves about the real scene, the virtual objects appear as if they exist in the scene. Ideally, the virtual objects should interact with the user and real objects in the scene in a natural manner. In all application domains AR enhances the user's performance and his/her perception of the world. The goal is to create a system such that the user cannot tell the difference between the real world and the virtual augmentation of it. To the user of this ultimate system it would appear that he/she is working in a single real environment (Vallino, 1998).

Several definitions for AR have been proposed by researchers. Milgram, et al. (1994) argue that AR is defined by two approaches: a broad approach and a restricted one. In the broad approach, AR refers to augmenting natural feedback to the operator with simulated cues. In the restricted approach, the technology aspect is emphasized defining AR as a form of virtual reality (VR) where the participant's head-mounted display is transparent, allowing a clear view of the real world. Klopfer (2008) proposed a broad definition for AR, suggesting that this term could be applied to any technology that blends real and virtual information in a meaningful way. Moreover, Klopfer and Sheldon (2010) define AR as a means able to provide users technology-mediated immersive experiences in which real and virtual worlds are blended, while Dunleavy, Dede and Mitchell (2009) state that in an AR environment, users' interactions and engagement are augmented. In a more structured, feature-based definition, Ronald Azuma defines an AR system as any system that has the three following features (Azuma, 1997):
1. combines real and virtual,
2. is interactive in real time and
3. is registered in 3D.

Azuma (1997) also referred to AR applications that require removing real objects from the environment, in addition to adding virtual objects. Such removal of objects from the real world corresponds to covering the object with virtual information that matches the background, to give the user the impression that the object is not there.

Augmented reality has its origin in VR. Virtual reality creates a virtual world that users can interact with. This virtual world is designed in such a way that users find it difficult to tell the difference from what is real and what is not. Both VR and AR are similar in the goal of immersing the user, though both systems do this in different ways. With AR, users continue to be in touch with the real world, while interacting with virtual objects around them. With VR, the user is isolated from the real world while immersed in a world that is completely artificial.

Although the terms are not identical, many people use 'mixed reality' interchangeably with AR. There is no consensus on the exact relation between the two. In some cases, AR is given a more relaxed definition as a technology that only overlays digital information on real-world elements, while mixed reality is additionally awarded with the ability of the user to interact with and manipulate both physical and virtual items and environments, using next-generation sensing and imaging technologies (Intel, 2018). In other cases, mixed reality is considered to be a broader interpretation that consists of anything of both the physical world and the digital world. The specific constraint of registration is relaxed. The registration and interaction features are appointed to AR. In this sense, all AR applications are mixed reality, but not all mixed reality applications are AR (Craig, 2013, p. 30). On top of these three terms, extended reality (XR) is an umbrella category referring to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables (Parrish, 2018).

An AR application needs to ensure that always two functions take place. Craig (2013, p. 39) defined that these functions are:

1. The determination of the current state of the physical world and the current state of the virtual world.
2. The display of the virtual world in registration with the real world in a manner that will cause the participant(s) to sense the virtual world elements as part of his or her physical world.

Figure 1 shows an example of a common AR system and the data which is acquired, computed, and presented. To register the virtual monster, the AR system derives tracking information from the video input. After rendering the registered 3D structure, its overlay allows to generate the impression of a virtual figure standing on a real-world paper card (Kalkofen, et al., 2011).

*Figure 1: Data flow in a common augmented reality system (Kalkofen, et al., 2011)*

There are three major components in an AR system to support the above functions. The three core components include (Craig, 2013, p. 40):

1. Sensor(s), to determine the state of the physical world where the application is deployed. Types of sensors range from the ones that exploit inertial methods (gyroscopes, accelerometers) or the electromagnetic spectrum (GPS, RFID, Bluetooth, etc.) to those that make use of cameras and computer vision methods.

2. A processor, that coordinates and analyzes sensor inputs, stores and retrieves data, carries out the tasks of the AR application program, and generates the appropriate signals to display. Computing systems for AR can range in complexity from simple handheld devices such as smartphones and tablets to laptops, desktop computers, and workstation class machines all the way through powerful distributed systems. In some cases, a handheld computer is in communication with a high-performabce server that might be located at a distance (Craig, 2013, p. 51). Furthermore, the necessary software to develop and consume AR

applications falls into one (or more) of three categories: Software Development Kits (tools for creating stand-alone AR applications), Browsers that allow for the discovery and consumption of AR content and Content Management Systems that offer a simple interface for the non-technical user to create and publish content to an AR browser (Kilby, et al., 2012).

3. A display suitable for creating the impression that the virtual world and the real world are coexistent and the effect on the participant's senses that he/she senses the combination of the physical and the virtual world. Examples of displays used by AR applications are head-mounted displays (HMDs), computer monitors, tablet and smartphone screens, as well as video projectors displaying virtual content on the surface of physical objects.

These core components of an AR system work closely together to create an augmented digital experience. A challenging application field for putting AR on the stand to provide digital interaction to static, in nature, communication media is print media.

## 3. Augmented reality in print media

In today's digital era, the modernized printing and publishing sector is trying to adjust its production by using unified workflows and adopting digital content, along with the traditional products of printing. The final product of this process is differentiated as printed or digital, only at the phase of publishing – the so-called 'cross-media publishing model' (Veglis, 2008). However, in recent years, the application of AR technology in print media makes the discrimination of a published end-product as exclusively printed or digital, invalid and obsolete.
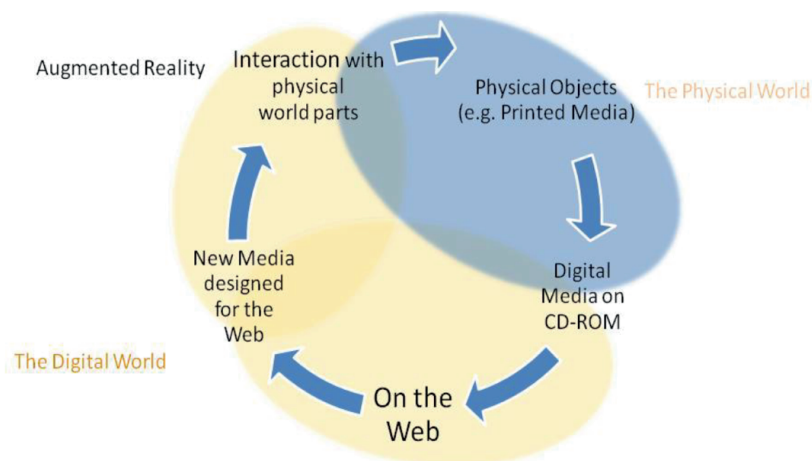


*Figure 2: Relationships between the digital and the physical world (Perey, 2011b)*

The field of AR applications in the print and publishing sector has its origin in a vision in which any printed material, from a poster, a sign or a package to a printed page in a newspaper, magazine or book, can provide its reader more value than what the original material was designed to convey. When combined with a camera, algorithms that detect the content of the page, and platforms that retrieve associated digital data, printed surfaces will provide value beyond what is possible with either print only or digital only content (Perey, 2011a).

In Figure 2 the way traditional print media relate to AR and new media is shown. The strength of AR lies in the ability of the technology to seamlessly close the gap between the digital and the real world. Augmented reality has the potential not only to allow a less dramatic transition to digital media, but also the creation of completely new editorial products with novel and original features (Inglobe Technologies Srl, 2011). Figure 2 shows the relations between the digital world on the one hand and the physical world on the other. Print media are entities belonging to the physical world. Digital media having a physical substance (e.g. a storage medium like a CD or a hard drive) belong to the intersection of the physical and digital world. Web sites and new media designed exclusively for the web belong to the digital world. Augmented reality, which uses the new web media, belongs to the digital world and intersects the physical world in its interaction with the physical entities (e.g. printed media).

An AR process in a print medium makes use of visual recognition as a method to determine the state of the physical world and takes place in three consecutive steps (adapted from Perey, 2011a):

1. The creation of the digital content to be associated with the content of the print medium.
2. The visual recognition of the printed content to trigger the digital augmentation.

3. The display of and interaction with the digital content in such a way that it is in complete 3D registration with the print medium.

The trigger for the digital augmentation in an AR process is significantly easier to be implemented in a print medium rather than in a 3D object, since the third dimension of a 3D object multiplies the object's visual features involved in the recognition process, in comparison with a simple 2D object displayed on a print medium.

Figure 3 shows a diagram depicting the workflow of making AR with print media. After the specification of the interactivity and performance of the digital augmentation, an associated digital medium the user will interact with must be created and the specific 'active' area of the surface of the print medium must be recognized and identified, based on feature extraction and communication with a database residing locally within the application or in a remote server, to trigger the display of the digital content.

The flow of processes involved by Perey (2011b):

1. The user of the AR application points at the specific 'active' area of the print medium.
2. On the other side, the AR application detects the active area of the print medium.
3. The AR application extracts the features of the print medium and sends them to a local database or a remote server for comparison and recognition, which triggers the next step.
4. The AR application receives the digital object and tracks the camera's position and orientation, in reference to the print medium in real time.
5. The AR application displays/renders the digital object in registration with the print medium.
6. The user of the AR application accepts the digital object and interacts.
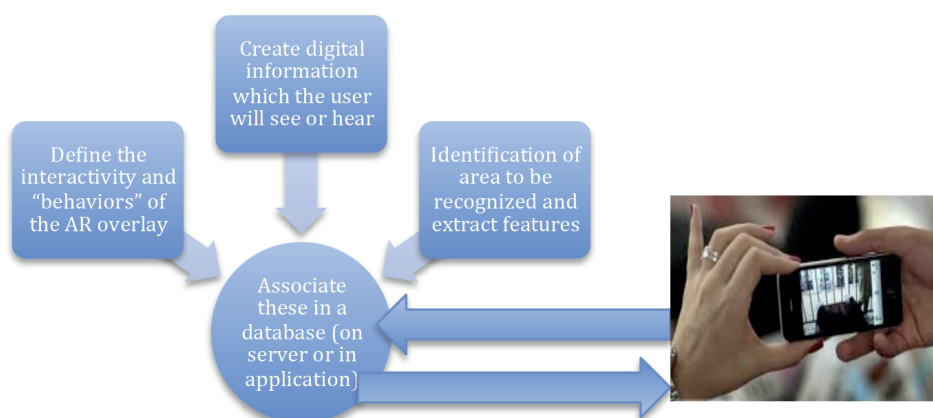


*Figure 3: Workflow diagram of making augmented reality with print media (Perey, 2011b)*

Tracking of the camera's position and orientation is not done using location-based services, since a print medium is mobile. For this reason, as noted before, computer vision techniques are utilized, either by exploiting artificial fiducial markers, e.g. QR codes, placed on the print medium (marker-based AR), or by directly recognizing and identifying its content itself (markerless AR) (Carmigniani and Furth, 2011).

Augmented reality applications for print products including posters, newspapers, magazines, commercial catalogs, business cards, books, flyers and products of packaging are growing in number, technological originality and entrepreneurial innovation. The examples are numerous and new are added every day, as the AR technology advances. However, next, selected examples of such applications are presented, in order to portray the field.

In June 2010, UK publisher Carlton Publisher released 'Dinosaurs Alive!' a book for children with AR capabilities triggered when a computer with a web camera is used (Figure 4). The book contains a CD with the necessary software by Total Immersion that needs to be installed into the computer. As the child reads the book, printed suggestions guide him/her to place the book in front of the computer's web camera. Then the printed dinosaur comes to life in 3D in the computer's screen and the child can interact with the live 3D models using the keyboard to instruct them to perform several movements. The technology works by embedding a series of markers into a page of the book. Software on the computer recognizes the markers when the page is scanned with the camera. These identifying features exploit sharp contrast and corners towards the edges of a page where folding isn't likely to obscure a reading, making the system more robust and quicker to respond than previous versions. As Russell Porter, the company's design director, notes in the New Scientist magazine (Ceurstemont, 2013) "*…once a code is captured, the software only needs to recognize about 10 per cent of those points and still works beautifully.*"



*Figure 4: 'Dinosaurs Alive!' augmented reality book*

The 44-page book 'Between Page and Screen' was created to combine the physical format of a printed book with Adobe Flash, telling a virtual love story via a webcam (Figure 5). The publisher's relevant online-catalog web page provides the following product description (Siglio, 2012): "*Coupling the physicality of the printed page with the electric liquidity of the computer screen, Between Page and Screen chronicles a love affair between the characters P and S while taking the reader into a wondrous, augmented reality. The book has no words, only inscrutable black and white geometric patterns that – when seen by a computer webcam – conjure the written word. Reflected on screen, the reader sees himself with open book in hand, language springing alive and shape-shifting with each turn of the page. The story unfolds through a playful and cryptic exchange of letters between P and S as they struggle to define their turbulent relationship. Rich with innuendo, anagrams, etymological and sonic affinities between words, Between Page and Screen takes an almost ecstatic pleasure in language and the act of reading.*"



*Figure 5: 'Between Page and Screen' augmented reality book*

Ireland's Metro Herald five editions published between 19 to 30 September in 2011 were marketed as the 'World's first fully augmented AR newspaper.' The newspaper implemented the mobile AR technology of Blippar which triggers the digital augmentation using markerless computer vision in a smartphone application (Figure 6). The AR features included video content for print advertisements, crossword puzzles, polls and promotional contests (O'Connell, 2011).
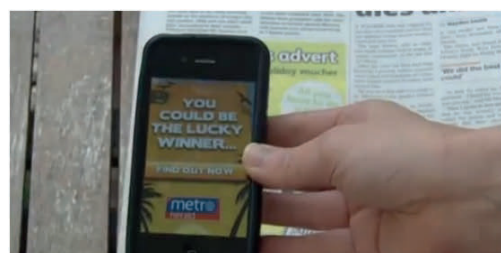


*Figure 6: The augmented reality promotional contest of 'Irish Metro Herald'*

In 2012, 'Metro' newspaper of Sweden implemented AR functionality that allowed readers to use a smart-phone's camera for online interaction with the contents of the physical newspaper. The application was based on the PointCloud Browser product from Swedish company 13th Lab. 'Metro' adopted an innovative approach by enhancing print articles with social-media features and interactive polls, current weather information, integration with Facebook pages allowing likes, comments, and sharing (Figure 7), bonus music content, video stories to supplement the print news story and images and interactive art gallery (Greg, 2012).



Figure 7: Facebook features in Swedish 'Metro'

In December 2009 the magazine 'Esquire' created an AR-enabled special issue (Figure 8).



Figure 8: Cover page of augmented reality issue of 'Esquire'

The AR features which were triggered by printed markers recognized by a webcam were included on the cover and on selected pages. To interact with the AR content, readers could point the webcam at the AR-enhanced printed pages and, through the custom software application, receive the digital content. The

AR features included interactions with a 3D version of the actor Robert Downey, Jr. for the film Sherlock Holmes (Curcurito, 2009). The reader could tilt the magazine toward the webcam, and the already walking, talking Downey would climb on top of it to sing a little song. If the reader pulled it toward him/herself, the actor would stand under a cloud of letters from the cover. Furthermore, if he/she turned it any which way, mini-Downey's introduction to the issue (and a trailer for Sherlock Holmes) would turn with him/her (Bell, 2009). Figure 9 shows a reader interacting with the AR features of the magazine.



Figure 9: Interaction with augmented reality features of 'Esquire' (Curcurito, 2009)

The magazine and newspapers described above as examples of print media with AR capabilities, represent pioneering efforts of the printed press to engage into this field of innovation, with limited editions. Since then, numerous other attempts have been undertaken with the most recent and noteworthy being the newspaper coverage of the winter Olympic Games in PyeongChang, South Korea from the New York Times and the Washington Post. The newspapers provided an AR presentation that enabled video, animation and even interactive content that practically jumped off the page. It seems that, for the printed press, AR is best used in special coverage, at least in the near future. Due to the time and cost it takes to prepare the AR content, the use cases are limited to key moments. As Todd Richmond, director at University of Southern California's Mixed Reality Lab notes "…the technology is still more at the proof-of-concept stage than for daily usage… we're still in the infancy of the medium" (Suciu, 2018).

In 2013, the leading retailer IKEA published a printed catalog with AR features to deal with the problem that 14 percent of its customers ended up taking home furniture which turned out to be the wrong size for its

intended location. Even with the most precise measurements, trying to imagine exactly how that stunning new sofa will look in a living room is not an easy task. Thanks to AR, customers of the Swedish home furnishings giant can now try out select products in their homes with the help of a printed catalog, a mobile app and a smartphone or tablet (Ridden, 2013).

To use the new service, customers need to download the IKEA Catalog App for iOS or Android. After launching the app, a smartphone or tablet camera is used to zone in on an orange cross to the bottom right of selected product pages. Then, an icon will appear on the device display, which gives users access to the AR mode. The app then instructs the user to close the printed version of the catalog and place it in the spot where the customer intends to put the new furniture. The approximate dimensions of the virtual furniture are based on the size of this physical, real-world IKEA catalog. The camera wakes up again and a product outline appears in the frame. This can be rotated, repositioned and manipulated so that it looks just right, before confirming the selection from a scrollable list. Finally, a virtual version of the new sofa, desk or bookcase with the room in the background is shown onscreen, as in Figure 10.
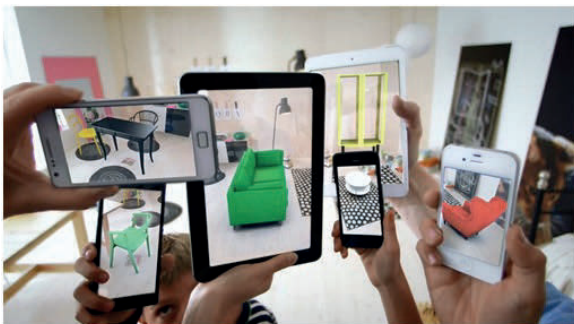


*Figure 10: Using the IKEA augmented reality catalog (Ridden, 2013)*

Seeing lifelike versions of Ikea's products in rooms lets shoppers make a 'reliable buying' decision, said Michael Valdsgaard, leader of digital transformation at Inter Ikea, the holding company for Ikea. Valdsgaard described potential uplift in sales from AR as a 'dream scenario' for Ikea, which is targeting € 5 billion ($ 5.9 billion) in online sales by 2020, up from the € 1.4 billion ($ 1.6 billion) it generated in 2016 (Joseph, 2017). This amount represents a 28 % jump in online sales which accounted for about 5 % of the total (Ringstrom, 2017).

In 2010, Metaio, a company developing AR solutions, created the 'Digital Box' for Lego, the Danish toy manufacturer, to provide consumers with a 3D image of what the toy would look like once assembled. The idea was to hold up a box of Lego to a kiosk that consisted of a webcam, a screen and Metaio's AR technology (Figure 11). Combining 3D animation with a live video feed, the assembled toy would project on screen on top of the box the consumer would hold. It would then be possible to view the finished toy on screen from all angles. According to Lego, purchase decisions in a store are mostly driven by customers' excitement about a product. With toys like Lego, it can take hours of construction to see what the finished product really looks like. The digital box, Metaio argues, gives consumers – in this case, kids – a detailed idea of the toy when it's assembled, thus sparking interest (Manninen, 2010). In terms of financial results, sales of LEGO Group in 2011 rose by 17 % to $ 3.495 billion (from $ 2.847 billion in 2010) (Trangbæk, 2012).
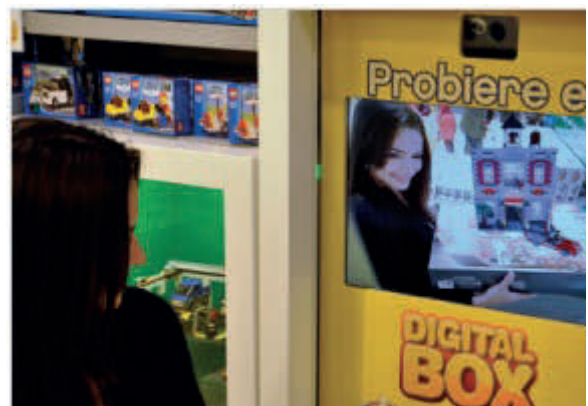


*Figure 11: LEGO's 'Digital Box' (Manninen, 2010)*

In 2011, Heinz food company ran a promotion campaign which was based on the use of AR-featured packaging. Users of a free app for Apple and Android smartphones and tablets, created by the AR technology specialist Blippar, could 'unlock' a pop-out recipe booklet when the camera was placed over the product's packaging, with the recipes featuring 'Heinz Tomato Ketchup' (Figure 12). The recipes could then be downloaded as a PDF, or the user could click through to video recipes on the product's Facebook page. The trial of the app formed part of the company's 'secret ingredient' campaign, which aimed to inspire people to use the tomato ketchup as a cooking ingredient (Macleod, 2011).

Augmented reality transformed the popular condiment into a product that managed to turn packaging into a fun user experience that got 170 thousand people engaged with the brand in a new and exciting way. The campaign boosted Heinz's digital marketing as it added another channel consumers can use to interact with the brand. The campaign came as part of Heinz' increased investment in digital marketing from 3 % to 20 %, and the Blippar campaign generated over 570 thousand blipps with 170 thousand unique global users blipping Heinz packaging around three times each (Digital Training Academy, 2014).
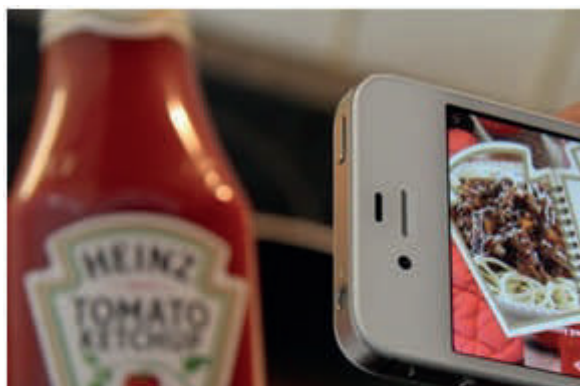
*Figure 12: 'Heinz Tomato Ketchup' augmented reality enabled recipe booklet*

## 4. Augmented reality and the future of print media in a digital world

The use of digital media in comparison to the use of paper as a means to store and convey information continues to draw the interest of the research community. Not, necessarily, in the form of a typical question 'which will prevail?' but more in terms of which performs better when used by a reader. A substantial body of literature comparing the reading of paper versus on-line documents can be found in the psychological, human factors, and ergonomics literature. Most of these studies focus on 'outcome' measures of reading, such as speed proof-reading accuracy and comprehension. Less effort has been devoted to investigating 'process' differences between reading on paper and reading on screen such as how readers look at text in terms of eye movements, how they manipulate it, and how they navigate through it (O'Hara and Sellen, 1997).

Undoubtedly, the technological breakthrough in the field of human-computer interaction underlines the major shift towards the adoption of digital equivalents instead of the traditional printed documents: the World Wide Web, hypertext and hypermedia applications, digital libraries, digital document reading devices. Some have predicted that such advances will make books obsolete, will radically alter the relationship between authors and readers and will change forever the concept of libraries as repositories of physical volumes of text and of publishers as producers and sellers of paper books (O'Hara and Sellen, 1997). The shift from print to digital is confirmed by market data. In a research conducted about the future of the European printing industry, a drop of 9.5 % for the printing market was estimated regarding the years 2005–2015. It is noted that while the issue of overcapacity and price competition impacts the sector as a whole, technology offers both a threat and an opportunity. Changes in customer behavior and a shift to the web are reducing demand for print (Vehmas, et al., 2011). However, the growth in digital printing adoption as well as steady growth in package printing markets has meant that overall revenues are now stabilising, and are expected to grow in real terms from a projected € 159.2 billion in 2016 to € 160 billion by 2021 (SmithersPira, n.d.).

The use of paper as a means to conduct administrational, scientific, commercial or any other type of processes dealing with information has been a controversial issue. At the one extreme, views about a so-called 'paperless office' have been expressed. As Arik Hesseldahl (2008) notes in his Bloomberg article 'The New Push to Get Rid of Paper' the term 'paperless office' entered the business lexicon in a BusinessWeek article titled 'The Office of the Future'. In the article, George Pake, the legendary head of the Xerox Palo Alto Research Center, foresaw that, by 1995, technology would let computer users summon on-screen documents 'by pressing a button' eliminating the need for much if not all the printed paper cluttering workspaces. Indeed, a very rough listing of the advantages offered by the digital functions of a paperless office designate the power of the arguments in favor of the digital media over the print media: easy access to documents, saving in time, saving in space, customer satisfaction, business processes made simple, more time to focus on business, increased levels of security in document access, more environmental friendly (in terms of deforestation to produce paper).

However, George Pake's vision for the paperless office was half-right. Today's offices are full of network-linked computers, loaded with software that lets users create, read, duplicate, and distribute digital documents. But the dream of a workplace where all that technology would eliminate the need for printed documents remains just that – a dream. The reality of day to day life shows that paper continues to be the preferred medium for much of our reading activity. This fact has been recognized and underlined by O'Hara and Sellen (1997) some 20 years ago, although screen technologies had vastly improved, wireless, mobile computing technology were widely available, and new navigational and input techniques significantly had improved the flexibility of interaction with digital documents at the time of their research. Despite the even more rapid breakthrough technological progress that followed up to the present days, paper still is dominant in our reading activities.

What paper does better than digital media is studied by Sellen and Harper (2002), in their book The Myth of the Paperless Office, where they point out four reading-related key affordances of paper. First, paper allows for quick and flexible navigation through a document with the size of a document being a rough indicator for the

amount of information stored in it and the readers always knowing where they are while flicking through the pages. A second affordance of paper for reading is the possibility of marking up a document while reading. Free-form annotations help readers to mark important text passages for easier re-reading and to structure their thoughts. Further, Sellen and Harper mention, that even though the information on paper is fixed, the paper documents still remain mobile. It is possible to read across more than one document at the same time by placing multiple documents next to each other and thereby defining a spatial order on a work space. Finally, paper supports the seamless interweaving of hybrid activities such as reading and writing. For instance, by placing a document next to a notebook we can take notes while reading the document (Signer, 2005).

Moreover, according to scientists (Sappi, 2014), print has more emotional pull for consumers than digital. A neuroscience study discovered that paper-based marketing – i.e., direct mail – leaves a 'deeper footprint' in the brain than digital – and that difference can even be pinpointed on functional MRI brain scans. The physical act of handling tangible material feels more 'real' to the brain. It produces brain responses that trigger emotional reactions, which get internalized in memory. In other words, the printed piece itself becomes part of the subliminal messaging. The brain associates the tactile quality of the piece with its perception of the brand.

However, it seems that these important advantages of paper are not always recognized. In many organizational settings, paper is seen as a problem. It is argued that there are three distinct problems with paper. The first is a symbolic problem whereby paper functions as a signifier of the past and, thus, as a symbol of the computer illiterates. The second problem is cost, especially for the storage and maintenance of large amounts of paper. Finally, the interactional problem is associated with restrictions in delivery, accessibility and modification of paper (Sellen and Harper, 2002, pp. 25–32).

The intrinsic incapacity of paper for interactivity is a consequence of its very nature. Paper is characterized by a unidirectional and linear communication circuit in which information is encoded and transmitted by a sender, who plays an active role in the communicative process, and is received by a receiver, who, on the other hand, plays a passive role. Information is transmitted as a product (newspaper, book, flyer, etc.) in a channel and then decoded by the recipient in such a way that he/she cannot respond in any way to the sender during the communication episode. In addition, the information transmitted is static, since the contents of the printed surface do not change over time, i.e. they do not have a dynamic (time) dimension (Inglobe Technologies Srl, 2011).

On the other hand, the worldwide spread of computers and networks (especially Internet) has triggered a radical change in the way information is created and used. This new technology enables a completely new way to communicate. New media, unlike traditional media, embody a bidirectional model of communication. According to this model, the sender and the recipient build, by means of interaction, a consensual domain of meaning. In such an interactive communication type, an essential characteristic of these kinds of media is that the participants play an active role which is enhanced by new 'social features'. Another important feature is their multimedia character, i.e. the possibility to integrate different types of content (text, audio, video, 3D, etc.) in one medium (Inglobe Technologies Srl, 2011).

As it was described in Sections 2 and 3, AR, as a new medium, was confirmed to have all what is required to provide print media with interactive and dynamic characteristics. First, it is rather apparent that the technological background and the widespread use of associated technological devices by large portions of the world population can already be taken for granted. As a print medium can always be at the hand of a reader to serve its purpose, such is the case with modern technological devices necessary to run AR applications and digitally augment print media. Today, smartphones and tablets equipped with all kinds of sensors, computing power and display capabilities can always be side by side to print media to perform digital augmentations and provide interactivity to paper. Up until 2012, desktop computer was the dominant online platform and the central hub for consumers' digital activities. With the proliferation of smartphones and tablets, however, mobile has become a dominant force (Pellow and McAbee, 2015). The statistics tell the story. For 2019, the number of smartphone users in the United States is estimated to reach 265.9 million (Statista, 2019), with the number of smartphone users worldwide projected to reach 2.87 billion by 2020 (Statista, 2015).

In a research conducted by hi-tech analysts of Juniper Research (2013), it is noted that the mobile AR market is set to increase dramatically from 60 million unique users in 2013, to nearly 200 million in 2018. The market will expand from the early adopting gaming segment and navigation-based utility to becoming an integral part of the consumer's ecosystem. Juniper Research (2013) forecasts AR to become a key future platform for communication and commerce, since it has a potential to engage a new generation of consumers in a unique manner, combining the personal nature of mobile devices with the Internet's wealth of accessible information. Augmented reality and virtual reality (mentioned with the umbrella term XR) is a mobile market that's gaining momentum as VR and AR markets may combine to create a $ 108 billion market by 2021 (Parrish, 2018).

Moreover, Omaid Hiwaizi (2015) in the article 'How augmented reality can drive engagement and monetization for publishers' points out some key benefits for publishers by an augmented print medium:

- Expanding advertising space – Publishers are no longer confined to a limited print space; they are using AR to supplement, enhance and bring physical content to life via smart devices. Layering digital content on top of print pages solves an age old problem for publishers and advertisers alike: it creates new ad formats for brands and additional monetization opportunities for publishers. This technology allows for magazine readers to learn more about the products that interest them and scan the content to access information, including how and where to buy a product.
- Reforming the Print Model – AR techniques are not only reviving revenue streams for advertisers – they are transforming the print publishing business model. By activating digital content on top of pages, readers can flip through their favorite magazines as they always have, but with the added bonus of being empowered to immediately buy their favorite items from their smart devices. Augmented reality technology allows them to use a mobile device to scan the image and make the purchase seamlessly.
- Measuring Reader Behavior – While tracking user behavior and Return on Investment (ROI) for ads has previously been an elusive science, AR technology makes analyzing user behavior a simple process. By evaluating data received from these platforms, advertisers can better tailor their future campaigns, targeting demographics and user habits.

In the context of marketing, the ultimate goal of AR marketing is to achieve 'consumer engagement', a term used to describe the process of involving consumers in specific interactions and/or interactive experiences in order to build and enhance consumer relationships. Augmented reality, by entangling branded content within consumers' social and physical environments, offers marketers a dynamic way to interact with consumers and to insert branded content into consumers' conversations (Scholz and Smith, 2016).

The power of AR in advertising has been tested in a research experiment reported in The Drum magazine (Staff Writer, 2011). The experiment conducted by marketing communications consultancy Hidden Creative Ltd. to find the effectiveness of AR versus traditional sales confirms the potential for revenue of AR. One hundred parents were shown a marketing communication and a display advert for a child's toy, while another 100 parents were shown the child's toy as an

interactive AR experience. Each person was then asked if they would consider buying this toy for a child and how much they would consider paying for the toy. It was discovered that of those who saw the 2D printed advert, 45 % said they would consider buying the toy for a child, with estimates of the price leading to an average of £ 5.99. Of those who saw the AR experience, 74 % said they would consider buying it for a child, with the average estimated price being £ 7.99.

In a more recent study reported by Yaoyuneyong, et al. (2016), seven advertisement properties were measured – informativeness, entertainment, irritation, advertising value, time-effort, novelty, and ad effectiveness – in order to compare consumer response to three different ad formats: a traditional print ad, a quick response (QR) code print ad, and an AR print ad. Results showed that the AR print ad was preferred, yielding higher perceptions of informativeness, novelty and effectiveness, whereas the QR print ad resulted in higher irritation and the traditional print ad resulted in higher time-effort. The authors concluded that consumers prefer critical product and convenience information to be included on print ads, letting the ad serve its purpose with no need for an external device as an intermediary interface. Augmented reality or QR hypermedia can then serve as an extra feature, letting consumers gain access to added content and, ideally, ways to interact with the brand.

In accordance with the above research findings, it is obvious that, however powerful AR can be in its role as a connecting bridge between print and digital media, it should not create wrong impressions and pointless expectations. A print medium cannot gain any prospective for survival just by putting a QR code in a page or any other AR content. Bob Sacks, a veteran of the print and publishing sector in USA, speaks eloquently about this idea (Sacks, 2013): "*I support the use of AR in that it is a wonderful tool and can be a bonus for any printed product for either ads or editorial… Innovative use of AR can supplement a magazine's content, where print cannot. Of that, I am a big fan… It can actually deliver more timely information than print can…my argument is that augmented reality with its many uses is good…, but it is surely not going to be the savior of print. We will live or die upon our own sword.*"

With new AR technologies and other innovative techniques, which are beneficial from both monetization and reader/consumer engagement perspectives, print media is facing a critical turning point. Quoted from Hiwaizi (2015), "*The media that adopt new approaches, enabling readers to interact with content long after issue dates fade, are the ones that will emerge victorious in digital media's new era.*" Paper can preserve its position in the modern digital era. Not as a rival to digital

media, but as an ally. Paper cannot be totally replaced by digital media, but it can continue its evolutionary course within digital environments. Augmented reality can offer solutions so as the intrinsic capabilities of print media (i.e. the key affordances of paper mentioned by Sellen and Harper (2002), along with its emotional pull and deeper footprint in the brain, compared to digital media) be augmented and enhanced with new digital features. However, the survival and development of print media cannot be relied only on AR. It is up to print media to maintain high quality levels as pure printing products, first, and then allow AR to augment and enhance them. Augmented reality can bridge the gap between the traditional world of print media and the new digital world by harnessing the best from both in order to create a cohesive, tangible, dynamic and interactive communicational experience.

## 5. Conclusion

The world of print has experienced a shift in recent years as a result of the rapid growth of digital media. With AR, this shift can simply be a transition from traditional print to a new-age print industry. Augmented reality extends the sensory experience of a traditional printed product creating an emerging new world in the printing and publishing sector with great opportunities and potential. This article presented AR as an innovative and efficient tool of renovating and modernizing the traditional print media and re-identifying paper as an equivalent and privileged partner in the modern communication media. More specifically, after a general introduction into the research field of AR, covering the fundamental principles and the technologies it is based on, the article focused on its application in print media. It examined the new 'augmented print medium' in terms of the necessary processes and technologies to implement such systems and described distinguished applications in newspapers, magazines, commercial catalogs, books and products of packaging. Furthermore, the article underlined the role of AR in redefining the position of print media in the modern digital world. It studied the differences between print and digital media and proved that AR can upgrade print media into modern communication media seamlessly connected and integrated into the digital activities of the new era. However, it was made clear that AR cannot totally carry a print medium on its back, if the print medium itself does not comply with minimum quality standards as a pure printing product that provides the affordances a reader expects from paper.

## References

Azuma, R.T., 1997. A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, 6(4), pp. 355–385. https://doi.org/10.1162/pres.1997.6.4.355.

Bell, I., 2009. Esquire to showoff 3D augmented reality issue in December. *Digital Trends,* [online] Available at: <https://www.digitaltrends.com/home/esquire-to-showoff-3d-augmented-reality-issue-in-december/> [Accessed 1 October 2017].

Carmigniani, J. and Furht, B., 2011. Augmented reality: an overview. In: B. Furht, ed. *Handbook of augmented reality*. New York: Springer Science & Business Media, pp. 3–46.

Ceurstemont, S., 2013. Augmented reality brings dinosaurs and planets to life*. NewScientist,* [online] 11 June. Available at: <https://www.newscientist.com/article/dn23680-augmented-reality-brings-dinosaurs-and-planets-to-life/> [Accessed 10 October 2017].

Craig, A.B., 2013. *Understanding augmented reality: concepts and applications*. Waltham, MA, USA: Morgan Kaufmann, Elsevier.

Curcurito, D., 2009. Behind the Scenes of Augmented Esquire. *Esquire*, [online] 9 November. Available at: <http://www.esquire.com/news-politics/news/g371/augmented-reality-technology-110909/> [Accessed 1 October 2017].

Digital Training Academy, 2014. Heinz Tomato Ketchup augmented reality recipe book. *Digital marketing industry case study library,* [online] Available at: <http://www.digitaltrainingacademy.com/casestudies/2014/10/heinz_tomato_ketchup_augmented_reality_recipe_book.php> [Accessed 30 July 2018].

Dunleavy, M., Dede, C. and Mitchell, R., 2009. Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology*, 18(1), pp. 7–22. https://doi.org/10.1007/s10956-008-9119-1.

Furht, B., 2011. Preface. In: B. Furht, ed. *Handbook of augmented reality*. New York: Springer Science & Business Media, pp. vii–viii.

Greg, 2012. Pointcloud browser augments reality for metro newspapers & the whole Internet. *Arcticstartup*, [online] Available at: <http://arcticstartup.com/pointcloud-13th-labs/> [Accessed 5 October 2017].

Hesseldahl, A., 2008. The new push to get rid of paper. *Bloomberg,* [online] Available at: <https://www.bloomberg.com/news/articles/2008-05-27/the-new-push-to-get-rid-of-paperbusinessweek-business-news-stock-market-and-financial-advice> [Accessed 1 October 2017].

Hiwaizi, O., 2015. *How augmented reality can drive engagement and monetization for publishers.* [online] Available at: <https://www.linkedin.com/pulse/how-augmented-reality-can-drive-engagement-publishers-omaid-hiwaizi> [Accessed 28 October 2015].

Inglobe Technologies Srl, 2011. *Augmented reality and the future of printing and publising: opportunities and perspectives*. [online] Available at: <http//www.inglobetechnologies.com/docs/whitepapers/AR_printing_whitepaper_en.pdf> [Accessed 20 January 2019].

Intel, 2018*. Virtual reality vs. augmented reality vs. mixed reality: demystifying the virtual reality landscape.* [online] Available at: <https://www.intel.com/content/www/us/en/tech-tips-and-tricks/virtual-reality-vs-augmented-reality. html> [Accessed 25 November 2018].

Joseph, S., 2017. How Ikea is using augmented reality. *Digiday UK*, [online] Available at: <https://digiday.com/ marketing/ikea-using-augmented-reality/> [Accessed 30 July 2018].

Juniper Research, 2013. *Mobile augmented reality users to approach 200 million globally by 2018, finds Juniper Research*. [online] Available at: <https://www.juniperresearch.com/press-release/augmented-reality-pr1> [Accessed 8 April 2019].

Kalkofen, D., Sandor, C., White, S. and Schmalstieg, D., 2011. Visualization techniques for augmented reality. In: B. Furht, ed. *Handbook of augmented reality*. New York: Springer Science & Business Media, pp. 65–98.

Kilby, J., Gray, K., Elliott, K., Martin-Sanchez, F., Waycott, J. and Dave, B., 2012. Interface, information & interaction: an exploration of mobile augmented reality present and future. *IBES, The University of Melbourne,* [online] Available at: <http://networkedsociety.unimelb.edu.au/__data/assets/pdf_file/0009/1661319/Interface-information-interaction.pdf> [Accessed 20 January 2017].

Klopfer, E., 2008. *Augmented learning: research and design of mobile educational games*. Cambridge, MA: MIT Press.

Klopfer, E. and Sheldon, J., 2010. Augmenting your own reality: student authoring of science-based augmented reality games. *New directions for youth development*, 128, pp. 85–94. https://doi.org/10.1002/yd.378.

Macleod, I., 2011. Heinz launches augmented-reality trial for ketchup with Blippar. *The Drum,* [online] 27 October. Available at: <http://www.thedrum.com/news/2011/10/27/heinz-launches-ketchup-augmented-reality-trial-blippar> [Accessed 1 October 2017].

Manninen, J.P., 2010. *Metaio helps Lego market toys with augmented reality kiosks*. [online] Available at: <https:// venturebeat.com/2010/04/21/metaios-augmented-reality-for-lego/> [Accessed 1 October 2017].

Milgram, P., Takemura H., Utsumi, A. and Kishino, F., 1994. Augmented reality: a class of displays on the reality – virtuality continuum. In: H. Das, ed. *Proceedings of SPIE: Telemanipulator and Telepresence Technologies, Volume 2351.* Boston, MA, 31 October – 4 November 1994. Bellingham, Washington: SPIE, pp. 282–292.

Mullins, B. and Dempsey, G., 2013. Foreword. In: A.B. Craig, *Understanding augmented reality: concepts and applications*. Waltham, MA, USA: Morgan Kaufmann, Elsevier, pp. xv–xvi.

O'Connell, S., 2011. Digitally augmenting print ads for advertisers and readers. *The Irish Times,* [online] 29 September. Available at: <https://www.irishtimes.com/business/media-and-marketing/digitally-augmenting-print-ads-for-advertisers-and-readers-1.612069> [Accessed 1 October 2017].

O'Hara, K. and Sellen, A., 1997. A comparison of reading paper and on-line documents. In: *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*. Atlanta, Georgia, USA, 22–27 March 1997. New York, NY, USA: ACM, pp. 335–342.

Parrish, K., 2018. Qualcomm expected to reveal Snapdragon chip dedicated to VR, AR next month. *Digital Trends,* [online] Available at: <https://www.digitaltrends.com/computing/qualcomm-snapdragon-xr1-chip-for-extended-reality/> [Accessed 25 November 2018].

Pellow, B. and McAbee, R., 2015. *documobiFUSE: making print integral to the mobile experience*. [pdf] Available at: <http://web-cdn.documobi.com/whitepaper/InfoTrends%20Documobi%20Whitepaper%20docx.pdf> [Accessed 8 April 2019].

Perey, C., 2011a. Standards for AR with print: call for a new initiative. In: *International AR Standards Meeting.* Barcelona, Spain, 17–19 February 2011. [online] Available at: <http://www.perey.com/ARStandards/Perey-Standards_for_ expanding_AR_with_Print.pdf> [Accessed 20 January 2017].

Perey, C., 2011b. Print and publishing and the future of Augmented Reality. *Information Services & Use*, 31(1–2), pp. 31–38. https://doi.org/10.3233/ISU-2011-0625.

Ridden, P., 2013. IKEA catalog uses augmented reality to give a virtual preview of furniture in a room. *New Atlas*, [online] 14 August. Available at: <https://newatlas.com/ikea-augmented-reality-catalog-app/28703/> [Accessed 1 October 2017].

Ringstrom, A., 2017. Online sales jump encourages IKEA to think outside the box. *Reuters*, [online] 10 October. Available at: <https://www.reuters.com/article/us-ikea-group-sales/online-sales-jump-encourages-ikea-to-think-outside-the-box-idUSKBN1CF0GO> [Accessed 30 July 2018].

Sacks, B., 2013. Bosacks speaks out: defending print the right way. *Bosacks Precision Media Group*, [online] Available at: <http://www.bosacks.com/bosacks-speaks-out/bosacks-speaks-out-defending-print-the-right-way> [Accessed 8 October 2017].

Sappi, 2014. Print &. *Sappi Fine Paper North America*, [online] Available at: <https://cdn-s3.sappi.com/s3fs-public/ sappietc/Sappi_Print_And.pdf> [Accessed 20 January 2017].

Scholz, J. and Smith, A., 2016. Augmented reality: designing immersive experiences that maximize consumer engagement. *Business Horizons*, 59(2), pp. 149–161.

Sellen, A.J. and Harper, R.H.R., 2002. *The myth of the paperless office*. Cambridge, MA, USA: MIT press.

Siglio, 2012. An unlikely romance between digital and analogue: a love affair for the 21st century. *Siglio*, [online] Available at: <http://sigliopress.com/wp-content/uploads/2012/09/Siglio_BPS_Press-Release.pdf> [Accessed 10 October 2017].

Signer, B., 2005. *Fundamental concepts for interactive paper and cross-media information spaces*. PhD Dissertation. Swiss Federal Institute of Technology Zurich.

SmithersPira, n.d. *The Future of European Printing to 2021*. [online] Available at: <https://www.smitherspira.com/industry-market-reports/printing/the-future-of-european-printing-to-2021> [Accessed 2 January 2018].

Staff Writer, 2011. Consumers more likely to buy following augmented reality experience. *The Drum*, [online] 8 September. Available at: <http://www.thedrum.com/news/2011/09/08/consumers-more-likely-buy-following-augmented-reality-experience> [Accessed 8 October 2017].

Statista, 2015. Mobile phone internet user penetration worldwide from 2014 to 2019. *Statista*, [online] Available at: <https://www.statista.com/statistics/284202/mobile-phone-internet-user-penetration-worldwide/> [Accessed 8 April 2019].

Statista, 2019. Number of smartphone users in the United States from 2010 to 2022 (in millions)*. *Statista*, [online] Available at: <https://www.statista.com/statistics/201182/forecast-of-smartphone-users-in-the-us/> [Accessed 8 April 2019].

Suciu, P., 2018. Augmented reality is changing how newspapers (and readers) are seeing things. *Editor & Publisher*. [online] 9 April. Available at: <http://www.editorandpublisher.com/feature/augmented-reality-is-changing-how-newspapers-and-readers-are-seeing-things/> [Accessed 30 July 2018].

Trangbæk, R.R., 2012. *LEGO Group sales up by 17 % in 2011*. [online] Available at: <https://www.lego.com/en-us/aboutus/news-room/2012/march/annual-result-2011> [Accessed 30 July 2018].

Vallino, J.R., 1998. *Interactive augmented reality*. PhD dissertation. University of Rochester.

Veglis, A., 2008. Modeling cross media publishing. In: *Proceedings: The Third International Conference on Internet and Web Applications and Services, ICIW'08*. Athens, Greece, 8–13 June 20018. Los Alamitos, CA, USA: IEEE Computer Society, pp. 267–272.

Vehmas, K., Kariniemi, M., Linna, H., Jokiaho, K., and Torniainen, E., 2011. *Future of European Printing Industry*. Espoo, Finland: VTT Technical Research Centre of Finland.

Yaoyuneyong, G., Foster, J., Johnson, E. and Johnson D., 2016. Augmented reality marketing: consumer preferences and attitudes toward hypermedia print ads. *Journal of Interactive Advertising*, 16(1), pp. 16–30. https://doi.org/10.1080/15252019.2015.1125316.

R. Kompare, H. Gabrijelčič Tomc – J. Print Media Technol. Res. 8(2019)1, 57–69

57

# Analysis of movie genres experiencing when changing post-production stylistic elements of the media

*Rok Kompare and Helena Gabrijelčič Tomc*

University of Ljubljana, Faculty of Natural Sciences and Engineering,
Department of Textiles, Graphic Arts and Design

helena.gabrijelcic@ntf.uni-lj.si

## Abstract

In this paper, we have analyzed the changes in four stylistic elements that are present in almost every film and their influence on movie genres experiencing. In the theoretical part a review of studies that proposed different approaches for movie genres categorisation is presented. This is followed by the definition of film genres and investigation of the possibilities of set stylistic parameters and their impact on the film form. The experimental part includes the study how the stylistic elements influence the viewer's assessment, whether it is possible to determine the genre of the movie based on just one stylistic element and at least how many elements are necessary to determine the correct movie genre. Five movie genres that were analyzed are: action, drama, horror, comedy and science fiction, and the impact of stylistic elements as color correction, camera movement (added in post-production), visual effects and music/sound effects were studied. The observers' experience about movie genre produced with different stylistic forms was tested with the questionnaire. The results in terms of the number of observers' correct answers in relation with the recognition of proposed genres and influence of stylistic elements and their combination were statistically analyzed. Based on the statistical analysis it was found out that adding visual effects and music/sound can be sufficient for the correct genre determination. In addition, the research has proved that a combination of two stylistic elements, but only if at least one of them is a visual effect or music/sound, is also sufficient for the correct genre determination. The analysis of the test results revealed that more than half of the respondents correctly identified the genre if at least three parameters were included.

**Keywords:** color correction, camera movement, visual effects, music and sound, audience testing

## 1. Introduction

The whole concept of the movie production is very complex. Film form is built up with many stylistic and narrative elements and movie production captures everything from performance, scene setting, direction, shooting, light, computer processing, and sound as well as the setting, costumes, colors, etc. Each subcategory requires its own ordered system, i.e. form. If this system is not regulated, it can drastically influence the experiencing of movies. Viewers are also very demanding, which leaves directors, cameramen, actors and other members of the film project very little room for errors. The most basic division of films is the division by genres. The information about the movie genre is one of the most important characteristic to be found with a movie title (Kompare, 2017; Selbo, 2015). Automatic movie classification is required due to the huge amount of films downloaded online. It gives viewers

filtered and systematically classified results. Rasheed and Shah (2002) have therefore studied what is the easiest way to automatically sort films without human interaction. They noticed that directors often choose to insert the most important and interesting elements of the entire movie into the movie preview (trailer), so they focused on trailers in their research. Their study showed that a careful analysis of the trailers can lead to an appropriate classification. First, they divided trailers into action and non-action films (drama, horror, comedy, etc.) based on length and motion picture. With the help of calculations, they paid attention to individual pixels. They made two categories, in the first one there were static frames or those who moved "globally" (full frame). The second category included frames where the pixel points were moved "locally" (only at one end of the frame). They noticed that action films had more local movements compared to drama or horror. They also found that the transitions in the

action movies is changing significantly faster than in any other genre. Later on, they analyzed the brightness and therefore classified also non-action trailers. Their research showed that among the nineteen selected trailers, everything was well sorted out, except for one that displayed as a comedy, but was in fact a drama-genre trailer.

Huang, Shih and Hsu (2008) wanted to find a best way to automatically sort films by genres. They also got the idea that with the help of special sorting application, children could watch violent movies with the violent content being automatically eliminated. They decided to try to sort the film trailers into three main genres: action, drama (subgenres: comedy and romance) and thriller. Trailers were classified with the help of four parameters: the length of the shots, colors, light and the transitions between the frames. Movie trailers have been transformed into thumbnails. They thus received a long "film tape" of frames that was suitable for analysis. If the changes of frames were slow, the genre was determined as drama. But if the changes were quick (if they were made in less than 0.2 seconds), the movie genre was not determined as drama. In the next step, the non-dramas movies were analyzed based on a light. Forty-four films were analyzed: nine thrillers, ten actions and twenty-five dramas. With the help of the graphs, they noticed that actions had the fastest pace of changing frames as well as the light and colors were the most active in this genre. The results of the experiment showed that these parameters reached 73 % accuracy. They learned that including the analysis of sound or text in the movie could also improve the accuracy.

Austin, et al. (2010) wanted to characterize the differences of film genres with respect to two parameters: the influence of the tone quality (the performance of support vector machines) and the rhythm (rhythm features) of film score. Eighteen films were selected for the survey (twenty-five romantic films, twenty-five dramas, twenty-three horror films and twenty-five actions). All the films were instrumental, i.e. without vocals. For reference, they featured descriptions of film genres on the Internet Movie Database (IMDb) website, which is a data-base for all existing films. Each song was isolated and then analyzed using various computer programs and tools. They found that the tone quality was better parameter for sorting than rhythm. The authors have proved the differences in musical cues between more dynamic genres as action and horror and more emotional ones, drama and romance. Romantic films were the easiest to distinguish from action movies, while with film score it was the hardest to distinguish between drama and romantic films.

Nowadays, new movie genres are being developed that adapt to viewers and spread their horizons. The film archives also feature many works that cannot be marked with a specific genre or can also cover more genres together. However, there are criteria that allow the classification of films into basic film genres (Žitnik, 2015).

Jain and Jadon (2008; 2009) applied neural network in the process of classification of movie genres. The foundation of their methodology is based on audio-visual features that were computationally extracted from different samples. In the experiment, Windows platform and Java, C# and Matlab were used. Movie clips were spitted in audio and video signals and sampling of audio and shot segmentations were performed. They defined shot length, motion, color dominance and lighting key for visual features and time domain, pitch, frequency domain, coefficients for sound modelling (Mel-frequency cepstrum coefficient) and energy for audio features. The results have shown that their classifier was able to successfully recognize different film genres.

Authors Wang and Cheong (2006) discussed the challenges in the categorization of film genres in Hollywood movies and applied systematic approach combining Darwinian psychology (cognitive science, recognition of observers' emotions) and cinematographic (film grammar) aspects and complementary approach that links emotion categories and low-level input features. Their methodology included probabilistic audio inference scheme, movie genre classification and movie affective vector analysis and defined audio-visual cues and effectively identified movie categories.

For prediction of film genre also likability rating or content-based features can be used. Olney (2013) performed a research including six studies, i.e. likability-based topic model, the use of likability-based topics that were defined with the model and the prediction of human annotated film genres, predictions with content-based features, application of synopsis-based topic model and predicting with synopsis-based topics and the analysis of user-viewed topics (topics created without frequency information). The results presented that the likability rating is a valuable method for prediction of film genres, but only when the user has actually seen film (a significance of post-viewing method) and that the accuracy of the likability-based topics can predict human annotated genres with the percentage of 41 %. The third result was that the intuitive content-based features that were tested during the research have lower predictive value as likability-based models.

Shon, Kim and Yim (2012) presented a new method for classification of the movies with the employment of quantitative approaches. The authors implemented a distinct movie characteristic as perceived by the

R. Kompare, H. Gabrijelčič Tomc – J. Print Media Technol. Res. 8(2019)1, 57–69

59

audience that allow the researchers to define different movie types. The movie type indicators, as the authors introduce them, allow to define eight categories: eye-catching, commonplace, fun, feel-good, touching, serious, discomfort and different. The cluster analysis enabled the definition of nine movie types that share similar indicators. Considering the results of the comparison of their model and other established methodologies, the authors suggested that the application of their model could perform more accurate prediction, however, according Redfern (2014), the more valuable use in the film theory and practice remain questionable due to the context of the performance of the study.

The most recognizable film genres according to Dirks (2018) are: action, drama, musical film / musical, horror, comedy, crime, adventure, western, historical film and science fiction. The genre determines the sum and the simultaneous action of narrative and stylistic elements that together create a film form. The main stylistic parameters that create the film are: production design and photography, lighting, make up and costume design, performance and montage. In technical terms, the style of film is also shaped by the basic elements of film grammar: type and combination of plans, the type, length and frame content, and the transitions between frames (Munitić, 1977). Primary and secondary color correction and color grading strongly influence the feelings of viewers, according to the research of Hullfish (2008) and Pompe (2015). The movement of the camera, which is divided into the movement of the camera in production (twisting, tilting, zooming in and out, etc.) and the movement of the camera in post-production (which is not an actual phenomenon but an optical illusion) activates viewers and maintains their interest (Figgis, 2007). Effects that can be implemented in production and/or post-production are visual and special. Visual effects are imagery created, altered or enhanced for a moving media that cannot be accomplished during live-action shooting. They are often produced and added to the media in post-production. Special effects can be done while the scene has been shot and are in nowadays media production often intertwined used with visual effects (Fink and Ford Morie, 2010).

A review of the researches has shown that the field of categorization and evaluation of film genres is quite well researched. Different models (calculative and algorithmic) as well as categorical descriptive models based on the perception of the viewer, involvement and overall experience are used. However, the area of stylistic elements influencing the definition of the genre of the film remains a rather unexplored area. Genre contains a multitude of stylistic and narrative elements and therefore the isolation of the element and its separate analysis is risky. But this is the only way to study

selected combinations of stylistic elements integrated, which can bring new insights into this field and consequently helps us to understand the influence of stylistic elements. The purpose of this study was to explore and determine how many and which stylistic elements are necessary for the correct determination of the film genre. With this focus, one content-neutral frame was shot, where individual changes of the four stylistic elements were introduced. The aim of the research was to determine whether one stylistic element is enough to determine the genre. And if it is not, how many are necessary to determine the genre. Stylistic parameters that were analyzed were: color correction, camera motion, visual effects and sound or music. Based on the reviewed literature, the study suggested that from all four parameters, music and sound would provide the best results. Consequently, our research question was whether music and sound are the most effective stylistic elements in genre determination.

## 2. Materials and methods

In the research five genres of the film were analyzed: comedy, drama, action, science fiction and horror. We tested the communication-visualization aspect of the one frame and the experience of spectators. One frame included different settings and variations of selected stylistic elements. With the questionnaire we tested how many and which parameters were necessary for the correct genre determination. We also checked statistically significant differences between the analyzed genres with analysis of variance (ANOVA) to confirm or reject the importance of the differences between the groups of results. In Figure 1 experimental procedure is presented, including pre-production, production (shooting), post-production (definition of movie genres and implementation of stylistic parameters) and analysis in two phases that enabled the study and statistical evaluation of the influence of one parameter and the combination of two, three and four parameters on participants' experience.

In the experimental work we used the professional programs – Adobe Premiere Pro and Adobe After Effects. The hardware used was the iMac Computer (Processor: 4 GHz Intel Core i7, RAM: 16 GB 1867 MHz DDR3, Graphics: AMD Radeon R9 M395 2048 MB), and camera recording equipment used was: Canon 70D, lens: Samyang 35mm T1.5 Canon VDSLR, stand: standalone tripod Manfrotto 055 + 501HDV, microphone: Rode VideoMic Pro R Rycote suspension.

In the pre-production, we determined that the analysis of participants' experience would be done on one neutral shot (therefore the content would not affect the results). The shot was: (i) short – approximately
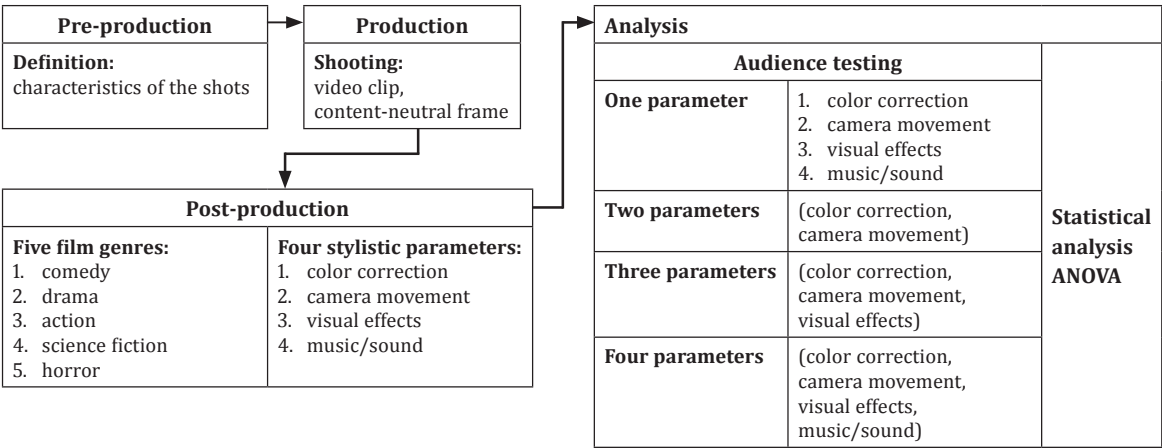
*Figure 1: Experimental procedure for the analysis of the influence of stylistic parameters on film genre*

ten seconds long (since it was necessary to watch it 35 times during testing), (ii) static – since it is easier to add visual effects and change the movement of the camera to the static frame without any special additional tracking tools, (iii) interesting for the viewer, and (iv) shot in cloudy weather (since it affects the colors and color correction the least).

In production, we shoot a bicycle rider who drove through the avenue and moved towards the camera. We got a neutral and moving frame where we had the opportunity to process five film genres we were researching, i.e. action, drama, horror, comedy and science fiction. In post-production, we changed four parameters in the shot and thus influenced the style of display: (i) color correction, (ii) camera movement, (iii) visual effects, and (iv) sound or music. By doing this, we created five different genres: action, drama, horror, comedy and science fiction, as presented. We used the settings that are used in video production as software recommendations and personal authors' experience to achieve certain effects.

## 2.1 Production

We shot the basic frame with a color profile "Technicolor CineStyle". This color profile provides a better dynamic range of captured content which allows greater artistic freedom in the color processing (Laforet, 2011). The color profile settings were: sharpness: 0, contrast: −4,

saturation: −2, and color tone: 0. The color correction settings for individual genres, including cinematic color grading preset based on Lookup Table (LUT), are presented in Table 1. We recorded the shot on a tripod, so there was no camera movement present in the production phase; it was added later in post-production as a movement of virtual camera. The virtual camera movement settings used for individual genres are presented in Table 2. The specific effects of the individual genres presented in Table 2 were determined according to the typical use in the film production. In the action frame we inserted the effect of fire and two explosions. We inserted rain into the drama frame to show the feeling of drama. In the case of a horror, a smoke effect was used, which mysteriously hides the contents of the frame itself. In a comedy frame we made a speech bubble and wrote: "Še daleč je do Portoroža …" (in English: "It is still far to Portorož…" – Portorož is a Slovenian seaside resort). The mentioned quote can be found in a popular Slovenian song. In the genre of science fiction, we created the effect of something that is impossible in the real world. We decided that the character on the bike would disappear due to some kind of laser hit. For the sound and music analysis we used already recorded musical and audio contents, also presented in Table 2.

Total of 35 shots (Figure 1) were prepared, comprising the shots for five different genres (action, comedy, drama, horror and science fiction) in variations of one of the four tested parameters, combination of two stylistic

*Table 1: Color correction settings for definition of different film genres*

| Movie genre | Exposure | Contrast | Whites | Blacks | Saturation | LUT |
|---|---|---|---|---|---|---|
| **Action** | 0 | 10 | 80 | −10 | 100 | Earthy |
| **Comedy** | 0 | 5 | 80 | −10 | 120 | Hilutite |
| **Drama** | 0 | 10 | 40 | −20 | 100 | Heulandite |
| **Horror** | −1 | 5 | 10 | −30 | 60 | IWLTBAP Aspen |
| **Science fiction** | −0.5 | 5 | 80 | −5 | 80 | IWLTBAP Aspen |

R. Kompare, H. Gabrijelčič Tomc – J. Print Media Technol. Res. 8(2019)1, 57–69

61

*Table 2: Color correction settings, camera movement settings and visual effects settings*
*for definition of different film genres*

| Movie genre | Camera movement | Visual effects | Music/sound effects |
|---|---|---|---|
| **Action** | Shaking | Explosions, fire and smoke | Intense music and explosion sounds |
| **Comedy** | Reverse | Speech bubble | Funny music |
| **Drama** | Zoom out | Rain | Gentle, neutral music and the sound of rain and birds |
| **Horror** | Zoom in | Smoke | Intense music with high-pitched tones and whisper sound |
| **Science fiction** | Up and down | Green laser and disappearance | Space music |

*Table 3: The original shot and the shots with color correction and visual effects*

| Original shot | Shot with basic color correction |
|---|---|
| | |

| Genre | Color correction | Visual effect |
|---|---|---|
| Action | | |
| Drama | | |
| Horror | | |
| Comedy | | |
| Science fiction | | |

parameters (color correction and camera movement), combination of three stylistic parameters (color correction, camera movement and visual effects) and combination of all four stylistic parameters (color correction, camera movement, visual effects and music/sound).

In Table 3 the original shot and the shots with color correction and visual effects are presented.

## 2.2 Audience testing

Testing the influence of stylistic elements (added in the post-production) on the perception of the film genre took place in test room under controlled viewing conditions (isolated dark room), where the test videos with various stylistic elements and their combinations were consecutively displayed on the calibrated projector BenqRC02. Distance from the participants to the projection was 4 m. Seventy participants, 21 to 26 years old took part in the testing (49 female and 21 male). The participants were students and the representatives of the so-called transition to adulthood, i.e. persons aged from 18 to 29 years (Arnett, 2013). In this life period most of the youth complete their education and training, which is the basis for their career and earnings. This is also a period when individuals overcome adolescent dependence, but do not yet take on responsibilities that are normative for adulthood and explore different possible paths in the field of relationships, careers, social and cultural interactions and views of the world (Kodrič, 2014, pp. 10–12). After viewing each short video, they had to define which film genre was – in their opinion – best suited to the presented parameters set. The video-clips with variations of the stylistic elements were shown in two phases. In the first phase the clips included only one element (color correction, camera movement, visual effect or sound and music) that defined the style; while in the second phase the clips including the combinations of selected two (color correction, camera move-

ment), three (color correction, camera movement, visual effect) and four (color correction, camera movement, visual effect and music/sound) elements were shown. The clips presenting selected film genres were randomly shown to the participants.

## 2.3 Statistical analysis

In the final phase of the research, the statistical analysis was performed to prove or decline the statistically significant differences between the results of the number of correct answers of the observers for the proposed genres. The analysis was carried out with ANOVA single factor for the different genres and different parameters and/or their combinations. In the analysis, only the number of the answers presenting the participants' experience that matched defined movie genres were statistically evaluated.

## 3. Results and discussion

The results are presented in Figures 2 to 8. In Figures from 2 to 5 test results for the individual elements (Figure 2: color correction, Figure 3: camera motion, Figure 4: visual effects and Figure 5: music/sound) are shown. In Figure 6 we can see the results for connecting two stylistic elements (color corrections and camera motion), in Figure 7 combination of three elements (color correction, camera motion and visual effects), and in Figure 8 the connection of all analyzed parameters (i.e. color correction, camera motion, visual effects and music/sound).

The comments and assessment of the results of the participants in the test are based on the assumption that the authors have selected proper stylistic elements (based on the references presented in Sections 1 and 2) regarding the classification of the film genre.
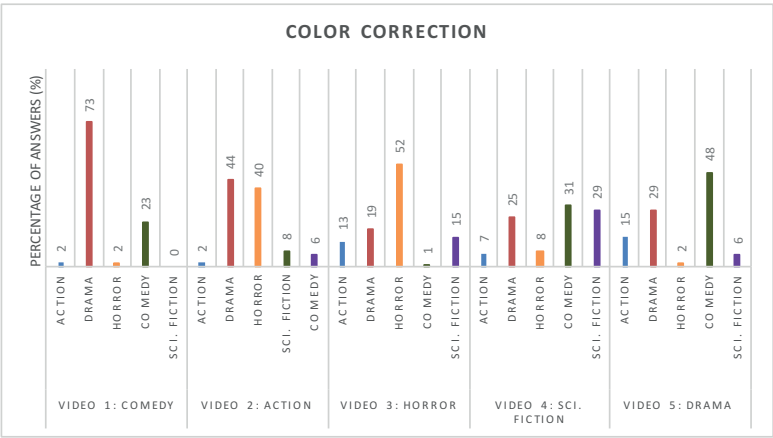


*Figure 2: Percentage of answers from participants for a defined genre: Video 1 – comedy, Video 2 – action, Video 3 – horror, Video 4 – science fiction, and Video 5 – drama, all post-processed with different color correction*

*Figure 3: Percentage of answers from participants for a defined genre: Video 1 – horror, Video 2 – action, Video 3 – drama, Video 4 – science fiction, and Video 5 – comedy, all post-processed with different camera movement*
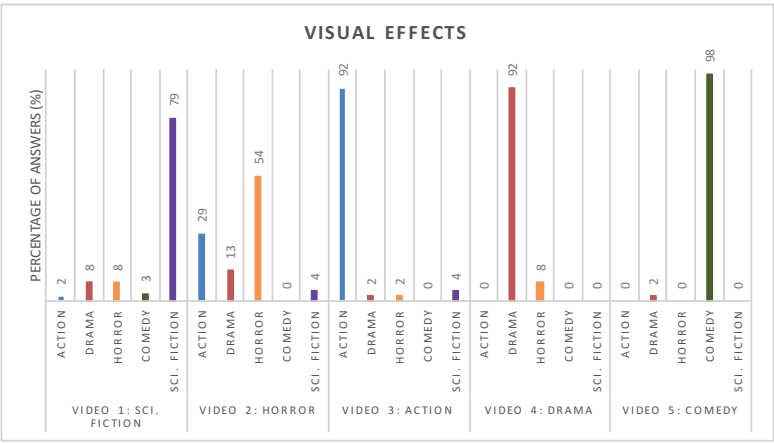


*Figure 4: Percentage of answers from participants for a defined genre: Video 1 – science fiction, Video 2 – horror, Video 3 – action, Video 4 – drama, and Video 5 – comedy, all post-processed with different visual effects*
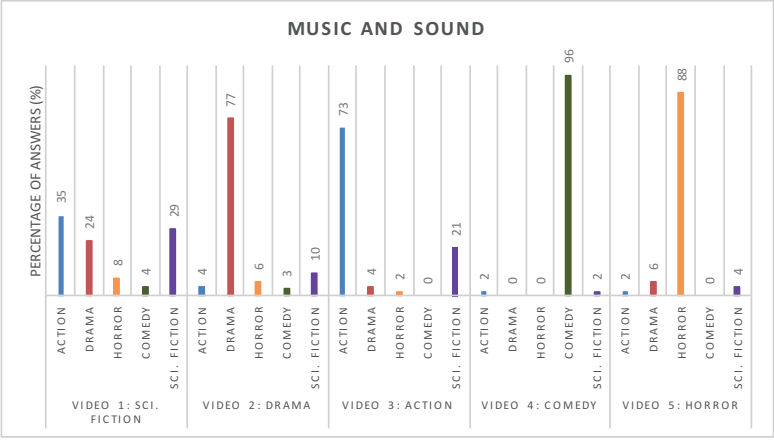


*Figure 5: Percentage of answers from participants for a defined genre: Video 1 – science fiction, Video 2 – drama, Video 3 – action, Video 4 – comedy, and Video 5 – horror, all post-processed with different music/sound*

From Figure 2 we can see that the most viewers (73 %) after watching Video 1 decided that the film genre was drama, but the correct answer (comedy) was given only by 23 %. Only 2 % of participants guessed the correct genre in Video 2 (action), while most of them opted for a genre of drama (44 %) and horror (40 %). After

watching Video 3 the slight majority of viewers chose the correct genre – horror (52 %). Green shades were therefore essential for the correct determination. In Video 4 we can see that blue color shades made viewers uncertain. They mainly decided between drama, comedy and science fiction, only 29 % of the viewers correctly determined the genre (science fiction), while comedy received the highest number (31 %). In Video 5, the correct answer was drama but the majority of viewers chose comedy (48 %). Based on these results we found out that it is almost impossible to determine the correct genre of the film just by using color correction. The majority of respondents correctly answered only for the horror film genre (52 %). This may be due to the similarity of the colors used in all videos.

In Figure 3 Video 1 shows the movement of the camera in the horror frame. We used the zoom-in effect but for most viewers (71 %) this was association for a drama. One possible explanation could be that zoom-in is also often used in drama genre and participants tended to correlate zoom-in and drama due to their previous experience. For Video 2, 38 % of viewers decided on the correct answer (action). However, 46 % of them opted for the wrong film genre – horror. It is interesting that a shaking camera presents a horror for most test subjects and not an action. In Video 3, we can see that most (61 %) viewers correctly determined drama by the zoom-out effect of the camera. For Video 4, more than half of the viewers opted for the wrong film genre – drama (53 %). The movement of the camera on the vertical correctly convinced only 21 % of viewers. For Video 5, half of the viewers decided on science fiction with the inverse movement of the camera. Only 38 % opted for the correct comedy genre. Therefore, less than half of people thought that inverse movement was funny and the other half thought it was supernatural.

We found that only Video 3 (zoom-out camera movement) convinced most of the participants, 61 %. For other videos, there were more correct answers in comparison to color correction, but it's still not enough to determine the correct film genre just by camera movement.

In Figure 4, Video 1, we presented a genre of science fiction with visual effects (disappearance of the character with the green laser hit); 79 % of viewers decided correctly. For Video 2, 54 % of people were convinced with the horror shot, 29 % opted for action, 13 % for drama and 4 % for science fiction. In Video 3, 92 % of viewers decided on the right answer (action genre with effects of explosion, shooting and fire). Due to the visual effect of rain, 92 % of viewers correctly decided that Video 4 was drama, but 8 % of the people chose a horror genre. For Video 5, we received the highest percentage in the correct answer (98 %), only 2% of people thought that

the text in the bubble could also appear in the drama. All other film genres did not receive any response.

In this part of the survey we discovered that viewers in all five videos voted correctly in more than 50 %. This shows that visual effects can already determine the genre of the movie, but not yet in full as we can see in the Video 2 where a third of the participants decided that they were watching an action instead of horror.

Figure 5 shows the results of the analysis of music and sound. The music in Video 1 was intended for the genre of science fiction with low-frequency tones. The audience decided for this correct genre with only 29 %. The majority of viewers (35 %) thought that this kind of music can also be used in action (35 %) and drama (24 %). In Video 2, which represents a drama, the audience listened to dramatic melody. Afterward, 77 % of them correctly identified the film genre, but all other genres also received some votes. In Video 3 we tried to show some tension by using the sound and rhythm of dynamic drums and create the action genre. Here 73 % of viewers correctly decided, but 21 % of responses was given to the science fiction. The most correct answers were for the Video 4, where we presented a comedy genre with light and fun music – 96 % of people voted correctly. For Video 5, 88 % of viewers correctly answered that high tones present a horror genre.

Therefore, in our experiment the audio parameter could not determine the film genre. The four videos received over 70 % correct answers, but the viewers were somewhat uncertain in Video 1.

In Figure 6, we tested the combination of two stylistic elements: color correction and camera motion. In the Video 1 we presented drama genre with natural colors and zoom-out effect of the camera. The genre was correctly determined by 65 % of people. All other film genres also received some answers. The blue shades and camera moving down in the Video 2 represented a genre of science fiction. However, most people voted for horror (38 %) and drama (35 %), the correct answer had only 19 %. For Video 3 we can see that the most people (60 %) correctly defined the genre.

The increased saturation of colors and inverse movement were enough to choose a comedy. However, science fiction again got some votes (34 %) probably due to the inverse movement. Green-blue color shades and zoom-in effect represented Video 4 as a horror genre. The correct genre was determined by 77 % of viewers. In Video 5, however, we can see that the stylistic elements that we used for the action (red shades and trembling movements) convinced only 41 % of people. As many as 33 % of them thought that such a color correction and the movement of the camera were in fact horror.
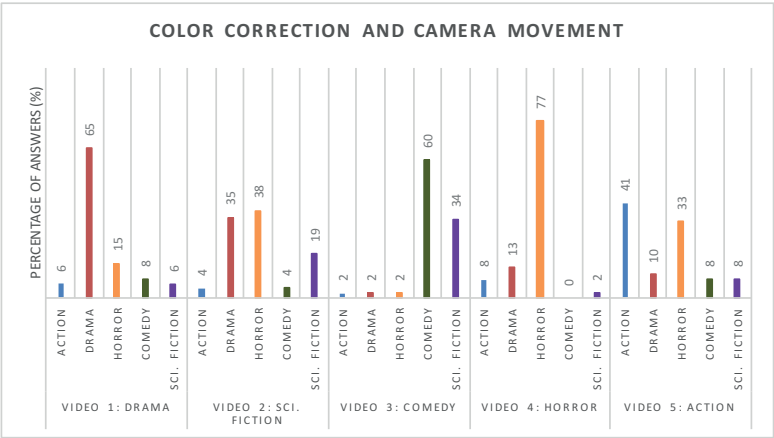
*Figure 6: Percentage of answers from participants for a defined genre: Video 1 – drama, Video 2 – science fiction, Video 3 – comedy, Video 4 – horror, and Video 5 – action, all post-processed with different settings of color correction and camera movement*
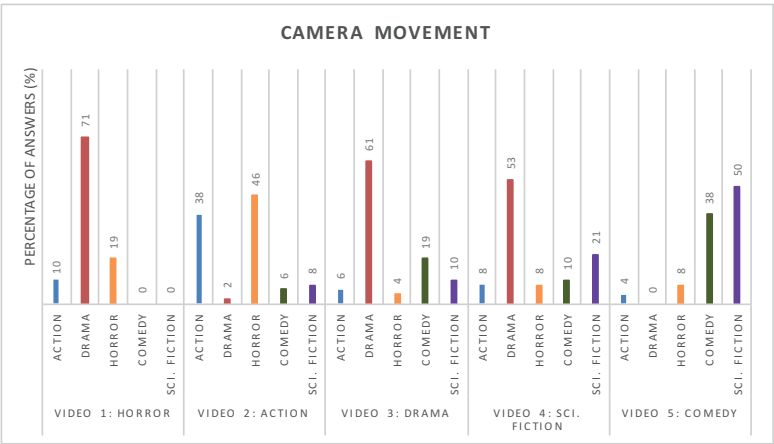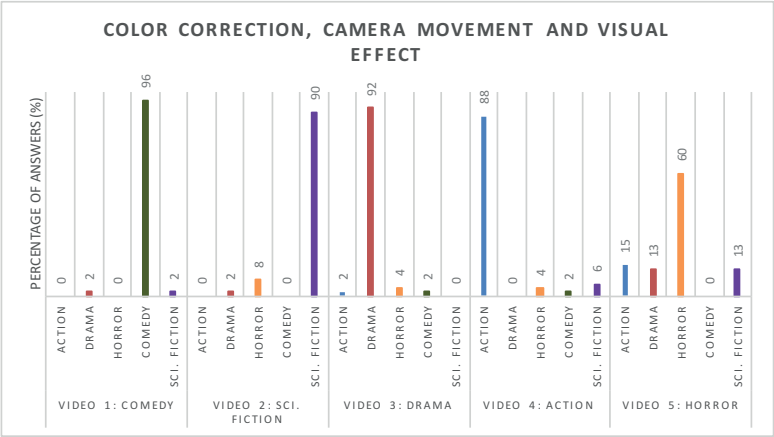


*Figure 7: Percentage of answers from participants for a defined genre: Video 1 – comedy, Video 2 – science fiction, Video 3 – drama, Video 4 – action, and Video 5 – horror, all post-processed with different settings of color correction, camera movement and visual effects*
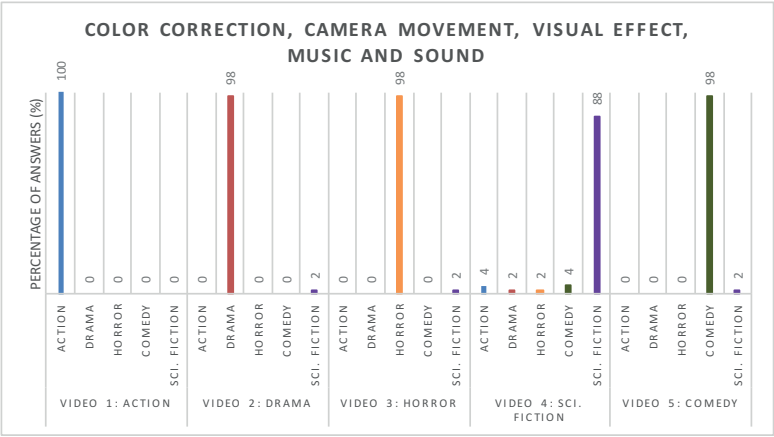


*Figure 8: Percentage of answers from participants for a defined genre: Video 1 – action, Video 2 – drama, Video 3 – horror, Video 4 – science fiction, and Video 5 – comedy, all post-processed with different settings of color correction, camera movement, visual effects and music/sound*

The combination of color correction and camera movement therefore produced mixed results. For three videos the correct answers exceeded 60 %, while in the Video 2 viewers were unable to determine the correct genre. Similarly, we found out that the correct answers for Video 5 did not exceed 50 %.

In Figure 7 we presented the results of the analysis of the combination of three parameters: color correction, camera movement and visual effects. For Video 1 comedy was presented with increased saturation of colors, inverse motion and a speech bubble. The genre was correctly determined by 96 % of viewers. Drama and science fiction have received 2 % each. Video 2 was a science fiction shot in which we added blue shades, camera moving down, green light and the disappearance of the biker. All these parameters convinced 90 % of the viewers. The horror received 8 % and the drama only 2 % of the votes. In Video 3, we can see that 92 % of viewers correctly chose the genre. The natural colors, zoom-out effect of the camera and the rain were enough to decide on the drama. The horror received 4 % votes, action and comedy 2 % each. For Video 4 the correct film genre – action was chosen by 88 % of people. They were convinced by red color shades and shaking camera with various explosions; 6 % gave their votes to science fiction, 4 % to horror and 2 % to comedy. In Video 5 we presented a horror shot. We added green-blue color shades, the zoom-in camera movement and a mist. All of these parameters convinced only 60 % of viewers. The action reached 15 %, drama and science fiction each 13 %.

Drama, comedy and science fiction have been correctly defined by more than 90 % of viewers using just three parameters. In Video 5 a visual effect – mist – was used which could have left some possibilities for other film genres than horror.

Figure 8 shows the results of the combination of four parameters: color correction, camera movement, visual effects, music/sound. For Video 1, we reached the maximum value. Red shades, the trembling movement of the camera, the explosions, the fire, and the tense melody, these are all parameters which helped the participants to determine the correct film genre – action. For Video 2, the drama reached 98 %. We used natural colors, camera distances, rain and soft melody; 2 % of the participants voted for science fiction. For the horror genre in Video 3 we got 98 % of the correct answers. We used green-blue shades, zoom-in effect of the camera and high tones; 2 % of the viewers voted for science fiction. In Video 4 we can see that 88 % of spectators decided for the correct answer – science fiction. Other film genres also received some votes here: action and comedy 4 %, drama and horror 2 %. In Video 5, with the increased saturation of colors, inverse movement,

speech bubble and cheerful music, 98 % of spectators correctly defined the comedy genre. Again, science fiction got 2 % of the votes, probably due to the inverse movement which could also be supernatural.

The results have shown that a combination of all four parameters enable the participants to experience a predefined movie genre with more than 88 % accuracy.

### 3.1 Statistical analysis

The results of ANOVA statistical analysis revealed that there is no statistically significant difference between mean values and variances of the results of percentage of correct answers according to different genres when one stylistic parameter is analyzed. The $F$-value was 0.639, $P$-value was 0.638 ($\alpha$-value 0.05) and $F_{\mathrm{crit}}$ was 2.689. That explains us that the observers have chosen very similarly the right (and wrong) answers for all the proposed clips including different genres and that the genres were very similarly definable when the tasks with different post-production stylistic effects and their combinations were tested.

On the contrary, the null hypothesis was rejected when the ANOVA was performed according to two or more analyzed parameters that were simultaneously introduced in the clips in post-production and their combinations. This showed that there were statistically significant deviations between the results of the correct genre's choice according to the introduced post-production parameters, so that the $F$-value was 10.608, $P$-value was $3.787 \times 10^{-6}$ ($\alpha$-value 0.05) and $F_{\mathrm{crit}}$ was 2.445.

Additional $t$-test calculations between the results presenting different pairs of parameters proved that the null hypothesis could be not rejected when the clips with single setting of color correction and camera movement were compared, as well as setting of visual effects and music/sound. That means that the results of correct answers have equal mean value, so that visual effect and music/sound gave to the viewers equal conditions for genre recognition and so did the color correction and camera movement. However, the observers have mainly answered correctly when they observed the videos with added visual effect or music/sound, meanwhile the results in our experiments demonstrated that when color correction and camera movement were tested alone (not in combination), they hardly represented the film genre (the numbers of correct answers for all the genres were low).

When the results presenting single stylistic parameters were statistically compared using $t$-test with the results presenting the combinations of two, three or four parameters it was discovered that the null hypoth-

esis can be rejected for all the tests, but not for the results of color corrections and camera movement (as a single or in combinations). Besides, the mean values of the results of visual effects and music/sound, when they were tested as single parameter in comparison with the combinations including one or both parameters were demonstrated to be statistically equal. These results additionally proved that, in our research, the parameters of visual effect and music/sound as single elements and also in all the combinations gave statistically the same stylistic imprint to the video clip for the successful definition of the genre.

## 4. Conclusions

The results of the analysis have shown that participants interpret various stylistic contents differently, namely, in our opinion a viewer decides based on his/her previous experiences, which were not tested in the research. In our study, only four parameters were studied, but in any case, the findings of film art add insight into the design of film genres and how individual parameters affect the viewer.

Movie genres are not of a static nature but an organic web of stylistic and narrative elements. The applied methodology for definition of the correlation of the stylistic elements is one possible solution of analysis, which was not performed before in the field.

The uniqueness of the research is that the selected parameters (color correction, camera motion, visual effects, music and sound) were displayed on the same frame. The viewer's interpretation was affected only by the stylistic elements. Here it has to be mentioned that the same testing condition could also result in bias results, due to the possible influence on the decisions of the participants that were exposed to the repetition of the same basic content and the possible conditioning of the experience with the previously seen material.

The audience that participated in the experience testing were the representatives of the specific life period, i.e. transition to adulthood. Consequently, it can be concluded that the results are representative only for the participants from 18 to 29 years. To understand the movie genres experiencing of different audience groups, the methodology should be applied on a wider age range. Besides, the analysis of the movie watching background could reveal interesting correlations between experiencing of movie genres and participants habits about movie consumption.

The research shows that the testers were correctly identified and that the participants experienced a defined movie genre (with at least 80 % of the value)

with all the four parameters of all five genres that were presented. It was also found that there are no statistically significant differences between the results of correctly determining different genres depending on introduced stylistic parameter when these are implemented separately.

Since the combination of color correction and movement of the camera yields mixed results, among which there are no statistically significant differences also in comparison with the results when these two parameters are considered individually, one cannot claim that the combination of only these two elements makes it possible to define a genre. In our opinion the reason for these results could be found in the fact that each viewer has his own perception and experience, what colors are suitable for which film genre, and how the camera should move to achieve a certain atmosphere.

The findings also revealed that the stylistic elements influence differently the participants' experience. Visual effects were found to be strongly influential and the participants could experience from 79 % to 98 % the determined movie genre of horror, drama, science fiction and comedy when only this element was set in the clip. According to the presented results it was discovered also that music and sound are not the most effective stylistic elements in genre determination. In our research it was found that visual effects can already determine the genre of the movie, yet not with so high percentage of participants experiencing the movie genre as when there is a combination of more stylistic elements. The research has proved that a combination of two stylistic elements, but only if at least one of them is a visual effect or music/sound, is also sufficient for the correct genre determination.

In the following analysis, it was found that there are no statistically proven differences between the results of the correct responses of analyzed images with the inclusion of visual effects and music/sound as independent parameters and/or all their combinations. Therefore, we can claim that in the case of our investigations these two parameters are independent and both individually and in combination they can determine the genre.

When we included three parameters in one frame: color correction, camera movement and visual effects, the results of the answers to determine the corresponding genre were already very high. This was possible in our case due to the presence of at least one of the parameters: a visual effect and/or music and sound. For all five videos, the values exceeded 60 %. In comedy, the value of the correct decisions reached up to 96 %. The spectators were no longer in the dilemma when all four parameters were included. For all five short clips, the value exceeded 88 %.

Practical use of the presented results is possible as recommendations for teaching and learning about the importance of stylistic elements in film production. The presented results can ease learning process and accelerate the exploration of the film's language to move to a more advanced level. In addition, it has been shown in the study that for automatic classifications it is necessary to consider the correlation of more stylistic elements, and not only individual ones. The findings of the research can therefore also be used to upgrade the systems for automatic categorization of film genres.

In the future, the research could be extended by testing all four parameters set on different frames, with different events, in a mixed version of the shots applied. Due to the controllability of the process in the presented research the choice of the parameters and their values for the definition of the genres were limited and were defined considering authors' experiences and software recommendations. In further researches there is also a potential for the study of different parameters for each stylistic element, the combination of different stylistic elements in the collaboration with narrative elements and their settings. Moreover, the analysis of the clips produced by different authors and the inclusion of story line in the shots could reveal wider observations on experiencing the stylistic elements in correlation with different authors' style and narrative.

## References

Arnett, J.J., 2013. Emerging adults and their parents: new results from a national study. *Developmental Psychologist*, [pdf] July. Available at: <https://www.apadivisions.org/division-7/publications/newsletters/developmental/2013/07/issue.pdf> [Accessed January 2019], pp. 32–34.

Austin, A., Moore, E., Gupta, U. and Chordia, P., 2010. Characterization of movie genre based on music score. In: *2010 IEEE International Conference of Acoustics Speech and Signal Processing*. Dallas, TX, USA, 14–19 March 2010. IEEE, pp. 421–424. https://doi.org/10.1109/ICASSP.2010.5495763.

Dirks, T., 2018. *Main Film Genres*. [online] AMC Filmsite. Available at: <http://www.filmsite.org/genres.html> [Accessed 5 March 2018].

Figgis, M., 2007. *Digital film-making*. London, UK: Faber & Faber.

Fink, M. and Ford Morie, J., 2010. Introduction. In: A.J. Okun and S. Zwerman, eds., 2010. *The VES handbook of visual effects: industry standard VFX practices and procedures*. Burlington, MA, USA: Focal Press.

Huang, H.-Y., Shih, W.-S. and Hsu, W-H., 2008. A film classifier based on low-level visual features. *Journal of Multimedia*, 3(3), pp. 26–33.

Hullfish, S., 2008. *The art and technique of digital color correction*. Oxford, UK: Focal Press, Elsevier.

Jain, S. and Jadon, R.S., 2008. Audio based movies characterization using neural network. *International Journal of Computer Science and Applications,* 1(2) pp. 87–90.

Jain, S.K. and Jadon R.S., 2009. Movies genres classifier using neural network. In: *2009 24th International Symposium on Computer and Information Sciences*. Guzelyurt, Cyprus, 14–16 September 2009. IEEE, pp. 575–580. https://doi.org/10.1109/ISCIS.2009.5291884.

Kodrič, M., 2014. *Psihološko osamosvajanje mladih na prehodu v odraslost v povezavi z navezanostjo na starše*. Master thesis. University of Ljubljana. (in English: *Psychological independence of young people on transition to adulthood in connection with attachment to parents*).

Kompare, R., 2017. *Analitična primerjava filmskih žanrov pri spremembi stilističnih elementov medija.* Master thesis. University of Ljubljana (in English: *Analytical comparision of movie genres when changing stylistic elements of the media*).

Laforet, V., 2011. *New Technicolor profile for Canon HDDSLRs*. [online] Available at: <http://blog.vincentlaforet.com/2011/04/29/technicolor-cinestyle-profile-available-for-canon-5dmkii/> [Accessed 26 January 2018].

Munitić, R., 1977. *Filmske zvrsti in žanri*. Ljubljana: DDU Univerzum. (in English: *Film form and genre*).

Olney, A.M., 2013. Predicting film genres with implicit ideals. *Frontiers in Psychology,* 3:565. https://doi.org/10.3389/fpsyg.2012.00565.

Pompe, A., 2015. Psihologija barv: Kako z barvo filmski ustvarjalci manipulirajo z našimi čustvi, *City magazine*, [online] 16 October. Available at: <http://citymagazine.si/clanek/psihologija-barv-kako-z-barvo-filmski-ustvarjalci-manipulirajo-z-nasimi-custvi/> [Accessed 12 February 2018]. (in English: Psychology of colors: how filmmakers manipulate our emotions by using color).

Rasheed, Z. and Shah, M., 2002. Movie genre classification by exploiting audio-visual features of previews. In: *Object recognition supported by user interaction for service robots: 16th International Conference on Pattern Recognition*. Quebec, Canada, 11–15 August 2002. IEEE, pp. 1086–1089. https://doi.org/10.1109/ICPR.2002.1048494.

Redfern, N., 2014. *Quantitative methods and the study of film: invited lecture*. [online] University of Glasgow. Available at: <https://nickredfern.files.wordpress.com/2014/05/nick-redfern-quantitative-methods-and-the-study-of-film.pdf> [Accessed 14 February 2018].

R. Kompare, H. Gabrijelčič Tomc – J. Print Media Technol. Res. 8(2019)1, 57–69

69

Selbo, J., 2015. *Film genre for the screenwriter*. New York : Routledge.

Shon, J.-H., Kim, Y.-G. and Yim, S.-J., 2012. Dissecting movie genres from an audience perspective: MTI movie classification method, *Working Paper No. 2012-008*. [online] KAIST Business School. Available at: <http://www.business. kaist.ac.kr/upload/paper/KCB-WP-2012-008.pdf> [Accessed 12 February 2018].

Wang, H. L. and Cheong, L.-F., 2006. Affective understanding in film. *IEEE Transactions on Circuits and Systems for Video Technology*, 16(6), pp. 689–704. https://doi.org/10.1109/TCSVT.2006.873781.

Žitnik, E., 2015. *Film*. [online] Arnes splet. Available at: <http://ezit.splet.arnes.si/2015/06/18/film>
[Accessed 4 March 2018].

# TOPICALITIES

*Edited by Markéta Držková*

## CONTENTS

# News & more

## Patents on printing inks granted in 2018

This review briefly presents a variety of inventions described in the patents published in 2018 and assigned with the general printing inks classification, starting with the assignees who are represented only once. Among the European patents, the solution of Sun Chemical Corporation in EP 2 424 943 B1 Reduction of misting in high speed offset printing is based on the measurement and proper choice of viscous modulus, phase angle and phase-angle slope of the printing composition within the intended range of printing operation temperatures. Teikoku Printing Inks patented the screen-printing ink allowing to print both fine patterns and wide-area solids simultaneously in a single step (EP 3 081 606 B1 Ink composition for high-quality and high-resolution screen printing, printed article obtained by screen printing with same, and method for producing said printed article). The patent EP 2 916 968 B1 Irreversibly magnetically induced images or patterns of Sicpa Holding provides an option for protection of security documents against counterfeit or illegal reproduction. Fujifilm Manufacturing Europe presented an ion-exchange membrane having a textured surface profile manufactured using a radiation-curable composition in EP 3 107 956 B1 Process for preparing membranes. There are also EP 2 401 335 B1 Coatings and printing ink compositions containing silylated polyether surfactants and articles made therefrom (Momentive Performance Materials), EP 2 720 865 B1 Printed polyester film based laminate, method of making and application thereof (Essel Propack), EP 2 775 976 B1 Aqueous medium-sensitive coating compositions for triggered release of active ingredients and visual indication for wetness (Kimberly-Clark), and EP 3 172 215 B1 Organic titanium derivative and process for the preparation thereof, ink containing the derivative and ceramic digital printing method that uses the ink (Graziano Vignali).

The U.S. patents include US 9,908,360 B2 Security feature and method for producing a security feature of Giesecke+Devrient Currency Technology, based on microcapsules with magnetic particles in a liquid medium, allowing to form a light-diffractive structure. Allnex Belgium in US 10,005,717 B2 Photo-reactive binder provides a solution for the preparation of inks, coatings and adhesives suitable for the food industry, and LG Bionano received a patent US 9,872,832 B2 Nanoemulsions having reversible continuous and dispersed phases, which can be used for printing, among others. The Sherwin-Williams Company patented a powder coating composition comprising acrylic resins having a differing hydroxyl value in US 9,890,289 B2 Low reflectance chemical agent resistant coating compositions. The acrylic resin is also used as a dispersant in a pigment ink described in US 9,957,399 B2 Aqueous ink, ink cartridge, and ink jet recording method (Canon). Further, AU 2015319542 B2 Inkjet recording method and inkjet recording medium of Nippon Paper Industries describes an ink-receiving layer to provide an offset printing-like feel. There is also the patent CA 2 797 833 C Method and apparatus for printing radiopaque indicia of Medical Components.

## HP Indigo

The two U.S. patents of HP Indigo, US 10,042,277 B2 and US 10,042,278 B2, are of the same name – Electrostatic ink compositions – and both describe

## Successful Enfocus partnerships and new PitStop features

Enfocus, a business unit of Esko, further spreads the partner collaborations. The recent integrations of Enfocus Switch with Avanti Slingshot, a Print MIS, and with tilia Griffin Pro, an application for the imposition of wide-format print jobs from Tilia Labs, were recognized as the Red Hot Technologies at PRINT 18 in Chicago.

The Enfocus PitStop 2019 release brings the possibility to selectively rasterise the overcomplicated vector objects otherwise causing bottlenecks in a workflow, the list-tree view for much easier object selection and the specific preflight profile for digital printers to optimise and report the amount of 'clicks' for each page, among others. Enfocus offers the pre-release webinars presenting in more detail the Rasterize Selection tool (9 April), Object Browser (16 April), and all new features (23 April).

## The specification for digital print and new webinar series from the Ghent Workgroup

Since March 2019, a new specification for the small-format digital print segment is available, as well as the corresponding application settings. The focus is on compliance with PDF/X-4 and avoiding problems such as white overprinting objects and colour shifts due to the wrong transparency blending colour space, while the rules on general overprint and image resolution are relaxed. This spring, the Ghent Workgroup also offers new webinars – What is PDF and PDF/X (11 April), Digital printing (18 April), PDF Creation & Workflow Strategies (7 May), Large format print (8 May), Packaging for brand owners (29 May), PDF 2.0 and PDF/X-6 (6 June), and How to setup color management for creatives and print buyers (13 June).

## Printable Electronics at the Centre for Process Innovation

The Centre for Process Innovation (CPI) is the UK's national technology and innovation centre. Its Printable Electronics Centre was launched ten years ago and at present it includes 1250 m$^2$ of Class 1000 and 100 Clean Room space, supported by a number of laboratories. A commercial-scale print facility is also available, situated in a non-clean room environment.

In the area of printing capabilities, the centre offers the prototyping line for the development and production of organic light emitting diodes and organic photovoltaics, roll-to-roll slot-die/screen-printing line, with options to incorporate other printing techniques such as reverse gravure, the combination roll-to-roll press Nilpeter MO-4/FA-4 that enables to print conductive ink tracks, and the Litrex industrial-scale inkjet printer with a print speed of up to 0.3 m/s. The semi-automatic flatbed screen printer DEK 248 can deposit inks and conductive adhesives; conductive adhesives can be dispensed also by the Europlacer iineo Pick & Place Component Attachment Tool.

Further, there is the experimental 3D printer Maker-Bot Replicator 2X with dual extrusion capabilities, the Dimatix Printer, the Optomec Aerosol Jet Printer, capable of printing a large range of materials, the advanced inkjet printing platform PiXDRO LP50 for a wide range of functional printing applications, and the Inkjet Flex for copper deposition on foil substrate in a two-stage print and plate process.

The list of equipment also includes the Netzsch MicroCer bead mill for grinding solid materials and making dispersions, the IGT F1 Proofer for the evaluation of inks at small scale, the KSV NIMA multi-vessel dip coater for coating medium to large samples up to 500 mm where up to ten samples can be coated simultaneously, MMM Group Venticell oven for adhesive curing, the digital cutting table Esko Kongsberg i-XE10, and the Trotec Speedy 300 CO$_2$ laser used in laser cutting and engraving.

compositions for magenta ink. The former is based on selected violet and red pigments, while the latter contains also the black pigment with a mass fraction of 0.01 to 0.5 % by total solids of the composition. The European patent EP 3 022 266 B1 Method of producing an electrostatic ink composition deals with the method based on spraying a lubricating liquid onto a surface of a precursor ink composition containing a relatively high amount of solids in order to decrease the propensity of the solids to aggregate over a given period. Another European patent of HP Indigo published in 2018 is EP 3 240 836 B1 Coating system, which describes a two-component solvent-borne system for forming a silicone polyurethane polymer coating of a liquid electrophotographic printer component to avoid ink sludge formation, with a polyol composition and a hardener comprising polyisocyanate.

## Ricoh Company

In the case of Ricoh, its three 2018 U.S. patents present the improvements related to inkjet printing on different media. The first one, US 10,011,728 B2 Ink, ink cartridge, inkjet recording apparatus, inkjet recording method, and recorded matter provides the water-based ink suitable for impermeable printing substrates. Besides water and colorant, the ink contains an acrylic resin as a dispersant polymer, urethane resin particles improving scratch resistance, and 3-methyl-3-methoxy-1-butanol. Similarly, the ink intended for forming high-quality images on plain paper is described in US 10,011,729 B2 Ink, method for producing ink, ink storage container, recording device, and recording method. It includes a quinacridone pigment and a hydrophobic organic solvent in a large amount. Finally, US 10,131,805 B2 Ink, ink stored container, inkjet recording apparatus, and printed matter provides an ink suitable also for coated papers thanks to the composition containing wax and properly chosen organic solvents, among others.

## Seiko Epson Corporation

The 2018 European patent of Epson, EP 2 874 470 B1 Ink for forming functional layer, method of manufacturing ink for forming functional layer, and method of manufacturing organic electro-luminescence element describes a solution to avoid defect pixels caused by the foreign substances present in the corresponding elements. The method of manufacturing the ink includes a filtration step in which the filter size is chosen according to the measured size and number of particles. In the U.S. patent, US 10,125,282 B2 Ink composition, Epson combines a hydrophobic solvent, a hydrophilic solvent, and an amphiphilic solvent (alcohol having eight or more carbon atoms) in order to further increase the choice of solvents adjusting the ink properties.

## Eastman Kodak Company

Both U.S. patents of Kodak published in 2018, i.e. US 10,132,031 B1 Foamed, opacifying elements with thermally transferred images and US 10,145,061 B1 Method for preparing thermally imaged opacifying elements, relate to elements that can be used as a light-blocking material for draperies decorated by thermal transfer printing. The patents describe the porous substrate comprising a dry foamed composition disposed on its internal surface so that the resulting stand-alone, self-lined draperies are impermeable to light and durable enough to withstand the temperatures required for thermal transfer printing operations. The approach avoids the use of a carbon black layer, reduces the effluence of noxious fumes during the transfer process and can be applied in a roll-to-roll manufacturing process. A single dry opacifying layer can also have antimicrobial and flame retardant properties.

Bookshelf – J. Print Media Technol. Res. 8(2019)1, 75–80

75

# Bookshelf

## Industrial Organic Pigments:
## Production, Crystal Structures, Properties, Applications

The first English edition of this comprehensive reference was published in 1993 as an updated version of the original German edition of 1987. Since then, also each following edition has been revised to include newly published data, available characterisation methods and commercial organic pigments introduced to the market. The aim always has been to provide readers with up-to-date information on synthesis, reaction mechanism, physical and chemical properties, test methods, and applications of all the organic pigments industrially produced worldwide. The current fourth edition is not an exception. It reflects the development of organic pigments during the 15 years since the third one, including the latest applications, three-dimensional X-ray analysis, current ecology and toxicology information, as well as the corresponding changes in legislation. It also considers the changes in terminology, such as from azo to hydrazone pigments.

The opening chapter introduces the definition of pigments and dyes, organic and inorganic pigments, and organic pigments classification, which is then reflected in the structure of the three following chapters. The first chapter also deals with the relationship between chemical structure and pigment properties (hue, tinctorial strength and fastness), physical characterisation of pigments, important application properties and concepts, particle size distribution and application properties of pigmented media, and finally with the areas of application for organic pigments. Here, the section on printing inks covers offset printing, gravure printing, solvent-based flexographic packaging printing, non-impact printing, and security printing.

The chapters presenting hydrazone pigments, polycyclic pigments and other pigments are now organised with more detail and, in addition to information on chemistry, manufacture, properties and application of individual types of pigments, provide also their crystal structures. Namely, the second chapter covers monohydrazone yellow and orange pigments, dihydrazone pigments, β-naphthol and naphthol red pigments, red hydrazone pigment lakes, benzimidazolone pigments, and dihydrazone condensation pigments, whereas the third one describes phthalocyanine and quinacridone pigments, vat dyes prepared as pigments, perylene and perinone pigments, diketopyrrolopyrrole pigments, indigo, thioindigo and thiazine indigo pigments, pigments derived from anthraquinone, dioxazine, quinophthalone, isoindolinone and isoindoline pigments. The fourth chapter on miscellaneous pigments includes triarylcarbonium pigments, metal complex pigments, organic/inorganic hybrid pigments, and the other pigments with either known or hitherto unpublished chemical structures. The last chapter is dedicated to legislation, ecology and toxicology issues, including food contact. The remaining part of the book before index provides the review of chemical structures and chemical reactions and the list of commercially available pigments.
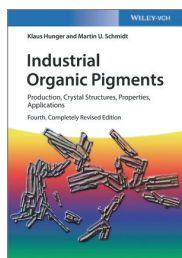
*Authors: Klaus Hunger, Martin U. Schmidt, Thomas Heber, Friedrich Reisinger, Stefan Wannemacher*

Publisher: Wiley-VCH
4th ed., January 2019
ISBN: 978-3-527-32608-2
804 pages
Hardcover

## Emerging Library Technologies: It's Not Just for Geeks

*Author: Ida A. Joiner*

Publisher: Chandos
Publishing
1$^{st}$ ed., August 2018
ISBN: 978-0081022535
206 pages, Softcover
Also as an eBook

This book from the established series covering topics that are of interest to librarians and other information professionals aims to support those "who want to learn, use, and help others with the latest, greatest, and hottest emerging technologies".
In particular, the author discusses artificial intelligence, robotics, drones, autonomous vehicles, big data, virtual and augmented reality, 3D printing, and wearable technologies. The two last chapters give advice on how to get stakeholder buy-in and how to keep abreast of emerging technologies.

## Co-Creation: Reshaping Business and Society in the Era of Bottom-up Economics

*Editors: Tobias Redlich, Manuel Moritz, Jens P. Wulfsberg*

Publisher: Springer
1$^{st}$ ed., November 2018
ISBN: 978-3319977874
217 pages, 25 images
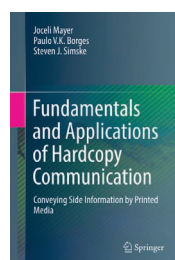Hardcover
Also as an eBook
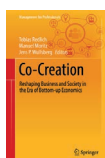
This book on value co-creation is contributed by many experts from various disciplines as the paradigm shift to more open and collaborative approaches can be observed across several industries. After the editorial introduction, the first part presents different examples and models of collaborative value creation that make use of open production sites, distributed manufacturing, blockchain technologies, online platforms, etc.
The second part on open source ecosystems explores software as well as hardware communities and also open source medical devices. Finally, the third part is focused on the legal challenges of co-creation.

## Fundamentals and Applications of Hardcopy Communication: Conveying Side Information by Printed Media

The authors of this book demonstrate various approaches to conveying additional information through printed media and explain how the content of a document can be modified using covert, semi-covert or overt techniques. They provide the fundamentals and discuss both basic and advanced techniques for modulation of side information into images, texts and barcodes in order to authenticate the content, mark copyrighted content, etc.

The book starts with the definition of the topic and presents typical applications of the hardcopy communication technology, as well as the challenges connected to its use and relationship with digital watermarking. The second chapter introduces an approach utilising hardcopy image communication and reviews the available techniques. Then it deals in more detail with robust authentication of documents after multiple passes and with hardcopy communication for inkjet channels. The next chapter dedicated to text watermarking first explores the effects of printing and scanning. The following sections present text watermarking via affine transformations, text luminance modulation and the related metrics, a practical authentication protocol, position-based coding, and colour modulation. The last chapter deals with the possibilities to add side information to print codes. Throughout the book, the authors discuss practical issues and provide the results of experiments done to validate the performance and robustness of the presented techniques and to compare competitive approaches.

*Authors: Joceli Mayer, Paulo V. K. Borges, Steven J. Simske*

Publisher: Springer
1$^{st}$ ed., February 2018
ISBN: 978-3-319-74082-9
134 pages, 77 images
Hardcover
Available also as an eBook

## Alonso Víctor de Paredes' Institution, and Origin of the Art of Printing, and General Rules for Compositors [Madrid: ca. 1680]

Pablo Alvarez has transcripted, translated and annotated the 96-page printing manual set and printed by Alonso Víctor de Paredes in Madrid around 1680, the earliest known printing manual published in Europe. In the first chapter, the manual reviews the origin of writing and printing. Each of the ten following chapters then describes individual tasks necessary to print a book – from various typesetting issues, such as the choice of type size and

*Author: Alonso Víctor de Paredes*

Publisher: The Legacy Press
1$^{st}$ ed., October 2018
ISBN: 978-1-940965-10-9
466 pages, 212 images
Hardcover

Bookshelf – J. Print Media Technol. Res. 8(2019)1, 75–80

77
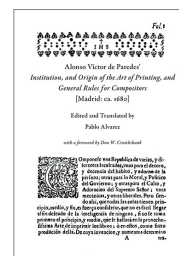
the rules of punctuation and other orthographic conventions, over imposition and casting off, up to the correction of proofs. In addition, the presented book features full reproductions of the two extant manual copies. Overall, it is a valuable source for learning about early printing in Europe.

## Typography Essentials:
## 100 Design Principles for Working with Type

This concise reference accompanied by inspiring design examples is popular as a comprehensive resource, which is easy to read and understand. It shows how type influences readers and what factors should be taken into consideration when choosing a font and working with type in order to convey the message in the best possible way. The revised and updated edition now includes new media, including mobile devices, interactive interfaces, etc. What remains unchanged is that the book is divided into four sections, each of which provides an explanation of 25 principles along with visuals showing different applications. It starts on a level of the letter and continues over the word and the paragraph to the page, altogether covering all practical aspects of designing with type. The important point to be learnt is that the rules can be efficiently broken only if they are known.

The first part shows how to work with letters and also with the space inside and outside the letters, why it is beneficial to consider the medium, time period, etc. The next part deals, for example, with hierarchy, using cases and mixing typefaces, while the third one with spacing, tracking, and leading. The fourth part then explores legibility, grid, margins, tables, etc.
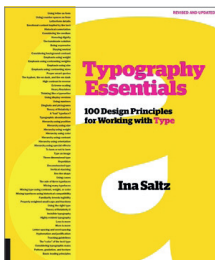
*Author: Ina Saltz*

Publisher: Rockport Publishers
2nd ed., January 2019
ISBN: 978-1-63159-647-6
208 pages, 300 images
Softcover

## International Yearbook Communication Design 2018/2019

The new yearbook from the series edited by Peter Zec for almost 25 years again features the selection of the latest communication-centred works and projects across different categories. The two volumes cover corporate and brand identity, packaging, annual reports, publishing and print media, posters, social responsibility, fair stands, spatial communication, retail design, film and animation, interface and user experience design, among others.

*Editor: Peter Zec*

Publisher: Red Dot Editions
1st ed., November 2018
ISBN: 978-3-89939-208-1
approx. 1 100 pages, 2 700 images
Hardcover

## Mike Bruno's History of Printing in the 20th Century

*Author: Michael H. Bruno*

Publisher: Graphic Communication Institute at Cal Poly
1st ed., 2017
ISBN: 978-0988673939
292 pages, Softcover

The unfinished autobiography of Michael Bruno, the co-founder and first president of the Technical Association of the Graphic Arts, could be published thanks to the efforts of Frank Romano and Cal Poly students in graphic communication.

## Never Use Futura

*Authors: Douglas Thomas, Ellen Lupton*

Publisher: Princeton Architectural Press
1st ed., October 2017
ISBN: 978-1616895723
208 pages, 172 images
Softcover

The readers of this book can learn more than just the history of Futura, one of the iconic and most used fonts.

## Browsers, Devices, and Fonts:
## A Designer's Guide to Fonts and How They Function on the Web

*Author: Gary Rozanc*

Publisher: CRC Press
1st ed., December 2018
ISBN: 978-1138612341
204 pages
Hardcover
Also as an eBook

The author demonstrates how designers can review their choices regarding typography, images and layout of a website or app through testing in different browsers, devices, and operating systems for supported features and performance. The book introduces the necessary basics of HTML (Hypertext Markup Language), CSS (Cascading Style Sheets), JavaScript and responsive design.

## Robotic Systems and Autonomous Platforms: Advances in Materials and Manufacturing

*Editors: Shawn M. Walsh, Michael S. Strano*

Publisher: Woodhead Publishing
1st ed., October 2018
ISBN: 978-0081022603
603 pages, Softcover
Also as an eBook

Contributed by more than 50 experts, this book reviews the advances that could enhance the capabilities of robotic and autonomous systems. The content is divided into six parts on actuation, mobility, control theory and algorithms, integration, energy, and novel robotics as material platforms. Additive manufacturing and 3D printing are among the enabling technologies – as the processes that give robots the means to make and remake robots in order to suit tasks. In the section on integration, one chapter details 3D-printed electronic materials and devices and another one deals with additive manufacturing of soft robots. Further advances can be achieved by the development and exploitation of 4D printing technology.

## 3D Printing and Biofabrication

*Editors: Aleksandr Ovsianikov, James Yoo, Vladimir Mironov*

Publisher: Springer
1st ed., May 2018
ISBN: 978-3319454436
558 pages, 164 images
Hardcover
Also as an eBook

The book with almost 80 contributors presents a thorough overview of this emerging and truly multidisciplinary field. While exploring different tissue engineering tasks, the first part describes additive manufacturing approaches based on a fabrication of structures that are subsequently seeded with cells, whereas the second part deals with processes where living cells are integrated into the fabrication process.

## Printing of Graphene and Related 2D Materials: Technology, Formulation and Applications

The authors from the Cambridge Graphene Centre review both the technological and economic implications of developments in the field of 2D materials and their utilisation. During the last 15 years, these materials received considerable research interest thanks to their many advantageous properties, which enable to develop new or at least significantly improved solutions in various applications. One of the main concerns is the transition from lab-scale demonstrators to mass-producible devices and systems. It requires sufficient production capability and suitable methods for further processing of 2D materials into desired components. Functional printing of inks containing 2D materials is one of the promising approaches to achieve rapid and low-cost mass production.

After a brief introduction of main concepts and the economic landscape of graphene and other 2D materials, two chapters present structures, properties, applications and production methods of 2D materials. The fourth chapter deals with 2D ink design, including the basic ink composition, viscosity and rheology considerations, the process of ink production, ink–substrate interactions and optimisation of ink formulation. The following chapter then goes through applicable printing technologies and the corresponding 2D ink formulations. The last chapter presents current applications of printed 2D materials in sensors, energy storage, membranes, and more.

*Authors: Leonard W. T. Ng, Guohua Hu, Richard C. T. Howe, Xiaoxi Zhu, Zongyin Yang, Chris Jones, Tawfique Hasan*

Publisher: Springer
1st ed., July 2018
ISBN: 978-3-319-91571-5
220 pages, 98 images
Hardcover
Available also as an eBook
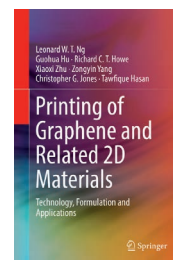
## Smart Sensors and MEMS: Intelligent Sensing Devices and Microsystems for Industrial Applications

This comprehensive reference covers a wide array of industrial applications for smart sensors and smart MEMS (microelectromechanical systems), including the chapter on MEMS print heads for industrial printing. It reflects their capabilities for direct patterning of micro- and nanodevices and circuits; the main focus is on the electrohydrodynamic (EHD) print head. The second edition features new chapters on magnetic sensors, micro-reaction chambers and temperature sensors.

*Editors: Stoyan Nihtianov, Antonio Luque*

Publisher: Woodhead Publishing
2nd ed., February 2018
ISBN: 978-0-08-102055-5
604 pages
Softcover
Available also as an eBook

Bookshelf – J. Print Media Technol. Res. 8(2019)1, 75–80

79
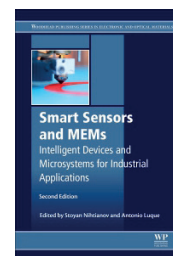
# Bookshelf

## Academic dissertations

### Understanding the Relationship Between Users' Reading Attitudes and Behaviours, and E-Book Collection Management in Thai Academic Libraries

The increasing popularity of e-books is naturally connected with a research interest in various aspects of their use, including the position of e-books in academic libraries. This thesis was focused on two gaps in the literature on e-books. The first concern was the possible relationship between academic library management of e-books and user perspectives on e-books because these areas mostly had been studied separately. Second, in order to gain insight into this topic in the context of developing countries, the study was conducted in academic libraries in Thailand. The two chapters after the introduction provide the literature review and the context of the study, including the details of Thai higher education, academic library structure and its digital transition. The fourth chapter presents the philosophical background of the study and the methods employed. It describes research setting, i.e. the participating academic libraries and number of university students, a mixed methods approach adopted in research design, and individual research phases – semi-structured interviews with academic librarians, a questionnaire survey to obtain quantitative information about library users' attitudes toward e-books and paper books, and photo-diary interviews to investigate their reading behaviour in depth. This chapter also clarifies how all the collected data were integrated and considers ethical issues. The next three chapters present the findings from the individual phases of the study, followed by the discussion and the concluding chapter. Based on the results, the key factors affecting the relationship between academic librarians and library users regarding e-books management and use are library organisational structure, budget constraint, attitudes of librarians and users toward each other, user reading habits, and educational system.

Doctoral thesis – Summary

Author:
*Preeyanuch Voravickositt*

Speciality field:
*Information Services Management*

Supervisors:
*Stephen Pinfield*
*Andrew Cox*

Defended:
*17 May 2017, University of Sheffield,
Information School
Sheffield, United Kingdom*

Contact:
*preeyanuch.vo@buu.ac.th*

### Printable 2d Material Optoelectronics and Photonics

The aim of this thesis was to develop functional inks of graphene and related 2D materials and explore them in printable applications. The main goal was to achieve a significant improvement in the formulation of inkjet-printable 2D material inks which would enable reproducible device fabrication, necessary for large-scale device printing. The research comprised the development of a polymer-stabilised alcohol-based ink formulation of graphene and a binder-free binary alcohol ink formulation of semiconducting transition metal dichalcogenides and black phosphorus, along with their applications. To expand the scope of 2D material printing toward even more efficient device fabrication, the work was also focused on ink formulation for high-speed printing utilising commercially available graphene nanoplatelets.

After a brief introduction, the dissertation reviews structures, properties and applications of common 2D materials studied, as well as the others that might be of interest. Next, it describes methods for solution processing of 2D materials, with an emphasis on the ultrasonic-assisted liquid phase exfoliation as the main solution processing technique used in the doctoral work, and methods relevant for characterisation of the exfoliated 2D materials.

Doctoral thesis – Summary

Author:
*Guohua Hu*

Speciality field:
*Graphene and Related 2D Materials
Nanoengineering and Functional
Printing*

Supervisor:
*Tawfique Hasan*

Defended:
*19 October 2017, University of
Cambridge, Department of Engineering
Cambridge, United Kingdom*

Contact:
*hgh5470@gmail.com*

The fourth chapter deals with ink systems and printing technologies, with more detail on inkjet printing principles and its use with 2D materials. Three chapters then present formulation of inkjet-printable inks enabling large-scale spatially uniform material depositions on untreated substrates and their practical applications. Graphene and 2D materials were produced by exfoliation in pure solvents and with stabilisers (surfactants or polymers). The produced graphene dispersion was used directly as the ink for the printing of the active layer in CMOS humidity sensors and in dye-sensitised solar cells with graphene counter-electrode. Exfoliated $MoS_2$, $WS_2$ and $MoSe_2$ flakes were formulated into inks for inkjet-printed saturable absorbers and photodetectors. In the case of black phosphorus, the author paid attention to the stability against oxidation, describing inkjet printing and passivation of black phosphorus in the manufacturing of saturable absorbers and photodetectors. The eighth chapter presents formulating functional inks of commercial graphene nanoplatelets for high-speed printing by a commercial flexographic press and their use as an additive for conductive inks and nanocomposites. The possibility of high-loading ink formulation of other 2D materials is also discussed. The concluding chapter summarises key accomplishments and points out that the ink formulation strategies can be transferred to other 2D materials.

Doctoral thesis – Summary

Author:
*Stephan Hubert Pröller*

Speciality field:
*Organic Photovoltaics*

Supervisor:
*Eva M. Herzig*

Defended:
*9 February 2018,
Technical University of Munich,
Munich School of Engineering
Munich, Germany*

Contact:
*stephan.proeller@ph.tum.de*

## Morphology Formation and Manipulation in Printed Organic Solar Cells

The research within this doctoral thesis was aimed towards large-scale organic solar cells as the organic photovoltaics is considered an important option for renewable energy supply. The understanding of the structure formation in organic solar cells is a key prerequisite for its control and thus for an improvement of the device performance. To study the relationship between structure and function in up-scalable printing techniques, a modular printing setup for organic thin films was developed and constructed so that it allowed automated sample processing and *in situ* X-ray scattering studies. The insight into the kinetics involved in the nanostructure formation then enabled to efficiently influence the morphology during processing. Similarly, the solidification process could be controlled.

The theoretical chapter after the introduction provides fundamentals on conductive polymers, their crystallisation and phase separation, organic solar cells, slot-die coating, and X-ray scattering. The next two chapters describe the methods employed for characterisation and sample preparation. The fifth chapter presents the design and construction of the experimental printing setup – the basic setup comprising the slot-die coater that can be transferred into a synchrotron beamline, the modification enabling application of an external electric field, and the atmospheric control chamber. The chapter on structure formation dynamics in printed films then presents *in situ* characterisation by grazing-incidence wide- and small-angle X-ray scattering methods exploring polymer crystallisation process and phase separation along with fullerene aggregation, respectively; solar cell performance is also discussed. On this basis, the structure evolution model is proposed. The following chapter explores the benefits of electrophoresis-assisted printing and shows the impact of electric field on the active layer, employing electronic and spectroscopic characterisation to study solar cell performance, absorption behaviour and mobility measurements, as well as morphological analysis of crystallinity, vertical material composition and lateral phase separation. The last chapter before the conclusion deals with the influence of the solvent-enriched atmosphere on film evolution.

# Events

## IMI Europe – Inkjet Ink Development Conference 2019

Hamburg, Germany
8–11 April 2019

This spring event organised by the IMI Europe starts with the Inkjet Academy and Inkjet Ink Characterisation courses on 8–9 April. The former covers the essential theory and goes through the introduction to inkjet, inkjet ink technologies, drop production, inkjet inks, drops in flight, inkjet ink materials and dispersions, system design issues, substrates and interactions, print and image quality, inkjet applications, and emerging technologies. The latter deals with the fundamental ink properties and ink behaviour along with the equipment and techniques for their analysis. It focuses on jetting and print quality analysis, optimising ink rheology for printing applications and surface tension measurements, complemented by the KRÜSS Laboratory Visit.

The Inkjet Ink Development Conference itself is held on 10–11 April. The topics include high-performance colorant dispersions, inkjet printing for packaging, food and pharmaceuticals (together with the related panel discussion on inkjet development in these applications), printhead waveforms, a new drop visualisation instrument, rheology of inkjet inks, modelling of drop dynamics, control of meniscus pressure, new photoinitiators and monomers for UV-curable formulations, drying technology considerations, choice of substrate and substrate wetting additives.

Two months later, the IMI Europe Inkjet Summer School 2019 takes place in Cambridge, UK on 10–14 June. It comprises a selection of six technical courses (1.5 days each), including the above-mentioned Inkjet Academy.

## Printed Electronics Europe 2019

Berlin, Germany
10–11 April 2019

The Printed Electronics keynotes for the 2019 edition of this established IDTechEx event comprise 'Real world smart packaging for pharmaceuticals' by Michael Petersen, 'Printed electronics: status of the industry 2019–2029' by Raghu Das, 'Opportunities for printed electronics in the smart home' Graham Anderson, and 'Introducing smart packaging in an FMCG company' by Jonas Vandercruys. The co-located tracks include the European editions of the 3D Printing, Electric Vehicles: Everything is Changing, Energy Storage Innovations, Graphene & 2D Materials, Internet of Things Applications, Sensors, and Wearable conferences, each also opened by four keynotes. All tracks of the conference programme then continue with sessions presenting commercial applications and opportunities in various markets, as well as innovations and advances in technology. Altogether, over 250 speakers are announced in the agenda. Traditionally, the two-day conferences are accompanied by the combined exhibition and framed by 25 masterclasses ranging from the introductory ones to those focused on individual applications, scheduled on 9 and 12 April.

## InPrint USA

Louisville, Kentucky, USA
9–11 April 2019

With the focus on industrial printing in packaging, decorative and functional applications, this event combines the exhibition of print technology with educational sessions, where each day is dedicated to one of these areas. The first keynote by Dawn Olson deals with the packaging and label business growth strategies, the second one by Kristen Dettoni explores décor market opportunities for print on demand, and the last one by Robert Malay is on the integration of conductive printing techniques for sensors and flexible electronics.

## Graphics Canada 2019

Toronto, Canada
11–13 April 2019

Besides several workshops, seminars and the Canadian Label & Package Printing Conference, this fair features the keynotes 'The transformation mandate' by Chris Bondy, 'Digital printing and inkjet trends and opportunities' by Frank Romano, and 'Leadership and entrepreneurship strategies for smaller firms' by Donald Rumball.

## SPIE Defense / Commercial Sensing 2019

Baltimore, Maryland, USA
16–18 April 2019

This event includes the sessions on 3D printing of functional materials and devices and on flexible electronics for the industrial Internet of Things, among others.

## WAN-IFRA Events

The events planned by WAN-IFRA for the second quarter of 2019 are framed by the two Digital Media events – the European edition held in Vienna, Austria (1–2 April) and the North American one taking place in New York City, New York, USA (24–25 June), including the ceremony of the European and North American Digital Media Awards, respectively.

The other events comprise the WAN-IFRA Academy workshop on relaunching websites and SEO (search engine optimisation) in Bangalore, India (4–5 April), Publish Asia in Singapore (7–9 May), the 71st edition of the World News Media Congress in Glasgow, United Kingdom (1–3 June) with World Digital Media Awards, followed by the Reader Revenue Study Tour (3–5 June) in Glasgow and London, and the German event beBETA 2019 on digital newspapers in Berlin, Germany (5–6 June).

## 3D Printing Event

Sittard-Geleen, Netherlands
16–17 April 2019

The programme of this event features the 3D Printing Materials Conference on 16 April and two conferences on 17 April, namely the 3D Printing Post Processing Conference and the Additive Manufacturing Integrated Factory Conference.
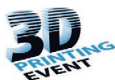
## INMA World Congress of News Media

New York City, New York, USA
13–17 May 2019

The 89th edition of this event organised by the International News Media Association (INMA) traditionally offers the study tour, media conference, several seminars, the INMA Global Media Awards, and also the Print Innovation Workshop discussing the possibilities of

## Forum & INFOFLEX 2019

New Orleans, Louisiana, USA
5–8 May 2019

The sessions prepared by the Flexographic Technical Association for this year's Forum start with the steps that need to be taken when corrugated converters are moving into the areas of multi-colour flexographic printing, followed by a round-table discussion on how flexography complies with brand owners expectations, and the presentations of new packaging functions enabled by the enhanced capabilities of flexographic presses, such as lenticular printing or product coding. The topics of the next three days include common print defects in flexography, press finger-printing and characterisation methods, as well as new screening and plate technologies. The last session then elucidates the judging process of the annual FTA Excellence in Flexography Awards competition and how the printers can improve the weak points of the submitted pieces. As usually, two afternoons are reserved for the INFOFLEX 2019 Exhibition showcasing flexographic, digital and hybrid technologies for the packaging printing and converting industry, and one Forum session is dedicated to student research and industry projects – in 2019 with presentations of research findings in plate relief modifications, prepress workflow and consumer preference of soft-touch coatings.

## 11th International Conference on Hybrid and Organic Photovoltaics

Rome, Italy
12–15 May 2019

The technical programme of this event is scheduled for three days and starts on 13 May. Each day, the plenary lectures are planned before the lunch break and the afternoon sessions with oral and poster presentations run in three tracks. The main focus is on the development, function and modelling of materials and devices for hybrid and organic solar cells, including the perovskite, quantum-dot and dye-sensitised ones, as well as on the integration of solar cells into devices for photoelectrochemical water splitting.

One of the invited talks, 'Step by step toward commercially available flexible perovskite modules,' reviews recent advancements in the development of a fully scalable inkjet printing process, presenting the ink formulations and specific post-processing treatments allowing fabrication of high-quality perovskite films and devices in ambient atmosphere. Among other contributions, the programme includes the findings on inkjet-printed perovskite nanowire films and the performances of printed sensitive photodetector, intensity-modulated photocurrent spectroscopy analysis of screen-printed $WO_3$ photoanodes for solar water-splitting cells, and demonstration of the proof-of-concept monolithic all-perovskite triple-junction solar cell, which opens new possibilities for large-scale, low-cost, printable perovskite multi-junction solar cells. There are also the studies presenting the inkjet-printed micron-thick triple-cation absorber layers with columnar crystals in perovskite solar cells, self-assembled 2D perovskite layers for efficient printable solar cells, digital printing of polymer solar cells based on non-fullerene acceptors, flash-evaporation printing technology incorporating a physical vapour deposition technique and a printing method, and more.

Events – J. Print Media Technol. Res. 8(2019)1, 81–84

83

## CPES2019

Quebec, Canada
16–17 May 2019

This Canada's conference and trade show presented by intelliFLEX, a not-for-profit industry alliance, is focused on flexible and hybrid electronics with the already existing or currently developed applications in various fields, such as smart packaging or aerospace defence. It provides different networking opportunities and a panel discussion on collaboration to further support the adoption and commercialisation of the innovative solutions and products. The topics announced for the fifth edition of the event include updates to flexible roadmaps, advances in components for inkjet materials printing, green electronics, wearable technology and smart textiles, heterogeneous integration of thin-film and nanoscale materials in flexible electronics manufacturing, utilisation of hybrid printed electronics in interactive smart retail displays, availability of track-and-trace technologies, vehicle-to-everything (V2X) communication opportunities, and also the importance of artificial intelligence for the Internet of Things, for example, the use of machine learning to protect the industrial IoT from cyber attacks.

## The Inkjet Conference USA

Chicago, Illinois, USA
22–23 May 2019
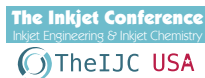
This year, The Inkjet Conference USA is held for the second time to complement the successful European event dedicated to engineering and chemistry topics relevant to the inkjet technology. TheIJC is now jointly organised by ESMA (European Specialist Manufacturers Association) and Digital Direct Technologies. The 2019 programme is planned in two parallel tracks on both conference days.

The speakers represent both the industry and research organisations. The presentations connected to the inkjet equipment and process control deal with various aspects influencing the print quality and related issues, such as the detection and compensation of defective nozzles, requirements for liquid pumps handling inks in inkjet systems, utilisation of the next-generation LED curing systems or NIR technology, ink and waveform performance optimisation, including the results of the experimental study using a novel device for characterising drop formation, drop–substrate interaction and waveform optimisation (presented also at the IMI Europe event in April, see above), and the development of a photopolymer-based additive printing process. The progress in the area of inkjet inks is reflected in contributions dealing with new materials and challenges in microscale liquid engineering, high-shear viscosity measurements, the use of high-performance colorant dispersions for aqueous inkjet applications, resin technology for inkjet in packaging, urethane acrylate composition for low-viscosity, energy-curable inkjet ink applications, and hybrid curing solutions. The programme features also the discussion on the quality of inkjet print in comparison to offset technology, colour management software for industrial printing, the possibilities to extend the colour gamut and improve the colour transition, as well as the applications in the production of complex shapes, medicines, and direct-to-container inkjet printing, among others.

personalisation, programmatic printing and the integration of online behaviour and print follow-up, as well as presenting how The New York Times is managing the process of innovating within print, with the three different examples of successful projects that go strictly to print subscribers, not online.

## Archiving

Lisbon, Portugal
14–17 May 2019

This event organised by the Society for Imaging Science and Technology offers an intensive program on the digitisation, preservation and access of 2D, 3D, and audiovisual materials, with numerous presentations, short courses, tours, and more. One of the keynotes for 2019 is 'The JPEG2000 suite of standards: capabilities and new opportunities' by David Taubman, discussing the efficient interactive browsing of large media, coding of imagery with rich colour information (e.g., hyperspectral content), and coding of radiometric and raw camera data, among others.

## FMTX 2019

Malmö, Sweden
28 May 2019

This Nordic event brings together two successful predecessors – 3D Printing Live show and Future Manufacturing Technologies Exhibition.

## Smithers Pira Events

The calendar features the 2019 editions of Specialty Papers Europe in Berlin, Germany (9–10 April), Global Food Contact in Lisbon, Portugal (14–16 May) and Digital Print for Packaging US (4–5 June) followed by Digital Textile Printing US (6–7 June), both in Orlando, Florida, USA.

## Graphitec 2019

Paris, France
4–6 June 2019

In 2019, the schedule of this French show for all stages of graphic arts production from content creation and prepress to finishing, in areas ranging from web-to-print and cross-media to packaging and labels, again lists the presentations discussing a variety of different topics. These include, for example, the impact of GDPR – the General Data Protection Regulation of the European Union – on the document management, business and human-resources activities and the social and entrepreneurial responsibility in the graphic arts industry on the one hand, and the added value of artificial intelligence for printing industry and Fogra standards 51–54 with the corresponding ICC profiles and their adoption on the other hand.

## CreativePro Week 2019

Seattle, Washington, USA
10–14 June 2019

This event features the Ps/Ai conference for designers using Adobe Photoshop and Illustrator, The InDesign Conference, the presentation design conference Click, and the 10th annual PePcon – the conference bridging print and digital publishing.

## 2019 IAS PPFIC
### 65th Annual Pulp, Paper and Forest Industries Technical Conference

Jacksonville, Florida, USA
23–28 June 2019

This long-established conference is focused mainly on the advances in electrical systems, maintenance and safety issues; however, one of the papers deals with the calculation of a degree of polymerisation in cellulose. The participants can register also for the tutorials, including the one on network security concerns and applications of the Internet of Things.

## ICC Color Experts' Day

Bressanone, Italy
24 May 2019

The focus of this Experts' Day organised by the International Color Consortium (ICC) is on colour management in printing on non-paper substrates using wide-format printing. The attendance is free, but places are limited.

Besides the fundamentals of ICC colour management and colour measurements, including the use of the M3 measurement condition, the presentations deal with the advanced colour management workflow for inkjet applications, challenges in n-colour printing, and the use of eciCMYK (FOGRA53) as the working colour space for wide-gamut output devices. Further, the schedule features colour management on variable substrates and for backlit applications with backlight off and on; several contributions are related to print on textiles, covering textile colour management, colour workflow challenges for dye-sublimation printing, measurement solutions for signage and digital textile printing, and measurement of 3D textile features. Other issues related to printing on non-paper substrates are also included – from the use of hybrid profiles for the cases when the colour of the substrate is involved with the colorants to the definition of the printer gamut, over RIP solutions for functional and decorative applications, up to measurement and profiling challenges for special materials, such as glass, ceramics, leather and laminates, and how the established measurement conditions need to be changed in the case of substrates with a higher level of sub-surface scattering.

## CIE 2019 29th Quadrennial Session

Washington, DC, USA
14–22 June 2019

This event of the International Commission on Illumination (CIE) combines the work on the development of CIE International Standards and Technical Reports at technical committee meetings, administrative meetings, and a three-day conference as an opportunity to share technical knowledge and present new research results. Each day begins with a plenary session and then the programme splits into three parallel tracks with paper sessions, poster presentations and workshops. The planned workshops include the joint one of CIE Division 1 and Division 8, the Optical Society (OSA) and the Society for Imaging Science and Technology (IS&T) on 'Colour imaging, perception, and reproduction: new directions in colour science and technology', two CIE Division 1 workshops – 'Research method for investigating light source colour rendition' and 'Modelling colour quality of light sources', and more. The four topical areas of the joint workshop are (i) Revision of human cone fundamentals and colour matching functions, (ii) Contributions of melanopsin to visual functions in humans, (iii) High-dynamic range imaging, and (iv) Virtual reality and augmented reality.

On 24 June, post-session technical tour to the National Institute of Standards and Technology (NIST) in Gaithersburg is organised, namely to the laboratories for vision science, photometry, radiometry and optical properties of materials with a number of interesting facilities – such as 2.5 m absolute integrating sphere for luminous flux scale and calibration.

# Call for papers

The Journal of Print and Media Technology Research is a peer-reviewed periodical, published quarterly by iarigai, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries.

JPMTR is listed in Emerging Sources Citation Index, Scopus, Index Copernicus International, PiraBase (by Smithers Pira), Paperbase (by Innventia and Centre Technique du Papier), NSD – Norwegian Register for Scientific Journals, Series and Publishers.

Authors are invited to prepare and submit complete, previously unpublished and original works, which are not under review in any other journals and/or conferences.

The journal will consider for publication papers on fundamental and applied aspects of at least, but not limited to, the following topics:

- ⊕ **Printing technology and related processes**
  Conventional and special printing; Packaging; Fuel cells, batteries, sensors and other printed functionality; Printing on biomaterials; Textile and fabric printing; Printed decorations; 3D printing; Material science; Process control

- ⊕ **Premedia technology and processes**
  Colour reproduction and colour management; Image and reproduction quality; Image carriers (physical and virtual); Workflow and management

- ⊕ **Emerging media and future trends**
  Media industry developments; Developing media communications value systems; Online and mobile media development; Cross-media publishing

- ⊕ **Social impact**
  Environmental issues and sustainability; Consumer perception and media use; Social trends and their impact on media

Submissions for the journal are accepted at any time. If meeting the general criteria and ethic standards of scientific publishing, they will be rapidly forwarded to peer-review by experts of relevant scientific competence, carefully evaluated, selected and edited. Once accepted and edited, the papers will be published as soon as possible.

There is no entry or publishing fee for authors. Authors of accepted contributions will be asked to sign a copyright transfer agreement.

Authors are asked to strictly follow the guidelines for preparation of a paper (see the abbreviated version on inside back cover of the journal).

Complete guidelines can be downloaded from: <http://www.iarigai.org/publications/journals/>
Papers not complying with the guidelines will be returned to authors for revision.

Submissions and queries should be directed to: journal@iarigai.org

## Vol. 8, 2019
## Prices and subscriptions

Since 2016, the journal is published in digital form.
A print version is available on-demand and at additional price.

Please, find below the prices charged for the Journal, as well as for a single paper.
Use the opportunity to benefit from the Subscriber's discount price.

By ordering a publication, or by subscription, a password will be provided to you for downloading.
The password protection of every issue is active during a period of six months.
After this period the publications will be available free of charge.

iarigai members will be given the download password for free.

### Regular prices

| | |
|---|---|
| Four issues, digital JPMTR (password protected) | 300 EUR |
| Single issue, digital JPMTR (password protected) | 100 EUR |
| Single paper from JPMTR (PDF file) | 20 EUR |
| Four issues, print JPMTR (on-demand) | 400 EUR |
| Single issue, print JPMTR (on-demand) | 100 EUR |

### Subscription prices

| | |
|---|---|
| Annual subscription, four issues, digital JPMTR (password protected) | 240 EUR |
| Annual subscription, four issues, print JPMTR (on-demand) | 400 EUR |

### Prices for iarigai members

| | |
|---|---|
| Four issues, digital JPMTR (password protected) | Free of charge |
| Single paper from JPMTR (PDF file) | Free of charge |
| Four issues, print JPMTR (on-demand) | 400 EUR |
| Single issue, print JPMTR (on-demand) | 100 EUR |

Place your order online at: <http://www.iarigai.org/publications/subscriptions-orders/>
Or send an e-mail order to: office@iarigai.org

## Guidelines for authors

Authors are encouraged to submit complete, original and previously un-published scientific or technical research works, which are not under reviews in any other journals and/or conferences. Significantly expand-ed 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>

If it is necessary to use an illustration, diagram, etc. from an earlier publication, it is the author's responsibility to ensure that permission to reproduce such an illustration, diagram, etc. is obtained from the copyright holder. If a figure is copied, adapted or redrawn, the original source must be acknowledged.

Submitting the contribution to JPMTR, the author(s) confirm that it has not been published previously, that it is not under consideration for publication elsewhere and – once accepted and published – it will not be published under the same title and in the same form, in English or in any other language. The published paper may, however, be republished as part of an academic thesis to be defended by the author. The publisher retains the right to publish the printed paper online in the electronic form and to distribute and market the Journal containing the respective paper without any limitations.

### 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.

**References:** The list of sources referred to in the text should be collected in alphabetical order on at the end of the paper. Make sure that you have provided sources for all important information extracted from other publications. References should be given only to documents which any reader can reasonably be expected to be able to find in the open literature or on the web, and the reference should be complete, so that it is possible for the reader to locate the source without difficulty. The number of cited works should not be excessive - do not give many similar examples.

Responsibility for the accuracy of bibliographic citations lies entirely with the authors. Please use exclusively the Harvard Referencing System. For more information consult the Guide to Harvard style of Referencing, 6th edition, 2019, used with consent of Anglia Ruskin University, available at: <https://libweb.anglia.ac.uk/referencing/files/Harvard_referencing_201718.pdf>

### C – Technical requirements for text processing

For technical requirement related to your submission, i.e. page layout, formatting of the text, as well of graphic objects (images, charts, tables etc.) please see detailed instructions at:
<http://www.iarigai.org/publications/journals/>

### D – Submission of the paper and further procedure

Before sending your paper, check once again that it corresponds to the requirements explicated above, with special regard to the ethical issues, structure of the paper as well as formatting.

Once completed, send your paper as an attachment to:
journal@iarigai.org

If necessary, compress the file before sending it. You will be acknowledged on the receipt within 48 hours, along with the code under which your submission will be processed.

The editors will check the manuscript and inform you whether it has to be updated regarding the structure and formatting. The corrected manuscript is expected within 15 days.

Your paper will be forwarded for anonymous evaluation by two experts of international reputation in your specific field. Their comments and remarks will be in due time disclosed to the author(s), with the request for changes, explanations or corrections (if any) as demanded by the referees.

After the updated version is approved by the reviewers, the Editorial Board will decide on the publishing of the paper. However, the Board retains the right to ask for a third independent opinion, or to definitely reject the contribution.

Printing and publishing of papers, once accepted by the Editorial Board, will be carried out at the earliest possible convenience.

The journal is publishing contributions
in the following fields of research

- ✥ Printing technology and related processes
- ✥ Premedia technology and processes
- ✥ Emerging media and future trends
- ✥ Social impacts

For details see the Mission statement inside

## JPMTR is listed in

- ✥ Emerging Sources Citation Index
- ✥ Scopus
- ✥ Index Copernicus International
- ✥ PiraBase (by Smithers Pira)
- ✥ Paperbase (by Innventia and
  Centre Technique du Papier)
- ✥ NSD – Norwegian Register for
  Scientific Journals, Series and Publishers

## Submissions and inquiries

journal@iarigai.org

## Subscriptions

office@iarigai.org

## More information at

www.iarigai.org/publications/journal