

Realization Lines with Inkjet Head KM1024iLHE-30 and Additional Applying Metalized Foil

Igor Majnarić, Marko Morić*, Marko Kadija, Krunoslav Hajdek

Abstract: The Inkjet printing technology has found widespread application across diverse industries, particularly in graphic and textile printing. The crucial role of the Inkjet head in achieving precise prints cannot be overstated. The selection of the inkjet head significantly influences the homogeneity of the printed surface and the realization of screen elements. Furthermore, the inkjet printing principle's potential for adhesion of metalized foils through a digital foiling process necessitates a detailed investigation into the influence of commercial piezo Inkjet heads. In this study, we present a method for testing the efficiency of achieving four-sized metalized gold foil printing lines on standard mat-coated cardboard printing substrates, both in the machine direction and cross direction. The experiment involves the gradual variation of the amount of UV-cured Inkjet varnish. Utilizing three different thicknesses of UV-cured varnish (21 μm , 36 μm , and 51 μm) in conjunction with modular piezo inkjet heads KM1024 iLHE-30 and print speeds according to varnish thickness (0,300 m/s, 0,24 m/s and 0,182 m/s). Research demonstrates that a 21 μm layer thickness of UV varnish combined with cross-direction movement ensures optimal production of digital metalized foil lines. Additionally, our results confirm the superior potential of a larger varnish application for line reproduction and enhanced contrast.

Keywords: digital foil lamination; line quality; piezo inkjet head; UV cured varnish

1 INTRODUCTION

Inkjet technology has a wide range of applications in printing various media products. These machines use non-impact printing technology, where liquid ink or dye droplets are directly distributed onto the printing surface. The dominant technology among inkjet printers is Piezo Inkjet, which generates droplets on demand through the mechanical displacement of a dynamic piezoceramic element causing pressure and the ejection of ink droplets.

Today, piezo Inkjet machines are used in office and business printing, commercial printing, decorative printing, packaging printing, printing of electronic components, and printing on textile materials. In the field of decorative printing, there has been a significant increase in the use of Inkjet printing for bonding metalized foils through digital foil transfer technology.

Additionally, Inkjet technology has the potential to be used in various non-traditional printing applications such as film formation, 3D modeling, painting, functional material coating, granulation, biotechnology, and medicine. To ensure quality printing on various substrates, the distribution of the liquid ink must be strictly controlled. Therefore, there are many commercial piezo inkjet heads available on the market, designed to generate the exact volume of a liquid drop in a time interval of a few microseconds.

2 THEORETICAL PART

During a visit to DRUPA 2024, it was observed that the most modern Inkjet machines are dominated by four global manufacturers of high-quality piezo Inkjet heads. These leading manufacturers and series include Kyocera (KJ4A and KJ4B series), Ricoh (TH and MH series), FujiFilm (Skyfire, Samba, StarFire, Sapphire, Polaris, Emerald, Galaxy, and Nova series), and Konica Minolta (Shear 3 cycles, Shear independent and Bend models).

2.1 Kyocera Inkjet Heads

The KJ4A series (models KJ4A-0300, KJ4A-RH, KJ4A-AA, KJ4A-TA) is designed for ink with relatively high viscosity, like UV curable ink. This series is best suited for various print media applications, such as overprint, labels, and others. Two resolutions are available (300 \times 600 dpi and 600 \times 600 dpi) with a jetting frequency of 20 to 30 kHz and the size of dynamically changing droplets in the volume range from 3 pl to 17 pl. This provides two print speeds of 50,8 m/min and 76,2 m/min.

The KJ4B series (models KJ4B-EX600-RC, KJ4B-EX1200-RC, KJ4B-EX600, KJ4B-1200, KJ4B-0300, KJ4B-YH, KJ4B-QA) is designed for high-speed printing with water-based ink. This series delivers excellent productivity not only in single-pass applications such as transaction printing, document printing, and security printing using MICR ink, but also in multi-pass applications, including textile printing. Three resolutions are available in this series: 300 \times 600 dpi, 600 \times 600 dpi, and 1200 \times 1200 dpi. This means operating with a 30, 40, 64 kHz jetting frequency and the size of dynamically changing droplets in the volume range from 2 pl to 16 pl. Two printing speeds are possible: 76,2 m/min and 101,6 m/min. Machines can implement water-based ink with stable recirculation technology by choosing an Inkjet head printing option. [6]

2.2 Ricoh Inkjet Heads

The Japanese company Ricoh is one of the world's largest manufacturers of piezo inkjet heads, which have found applications in all sectors of printing and coating. To make this possible, there are three factory designs of Ricoh Inkjet heads that achieve droplet volumes ranging from 2,5 pl to 90 pl: TH series (2 models), MH series (9 models), and GH series (one model).

2.2.1 Ricoh TH Series

This series of MEMS Inkjet heads consists of the following models: Ricoh TH5241 and Ricoh TH6310F.

Their common feature is a thin-film piezoelectric transducer with bend mode, possibly using all types of Inkjet inks. Therefore, they are intended for different applications. One Ricoh TH5241 head contains 1280 nozzles arranged in a 4 x 320 configuration. This configuration enables printing in multi-drop technology with droplet sizes from 3 to 12 pl and three configurations: 4 inks at once in a resolution of 300 dpi (for each CMYK color one line), spot colors at a resolution of 600 dpi (2 lines for each ink) and one color at a resolution of 600 dpi (4 lines for one color). The model TH6310F features 600 dpi printing with two heads joined together in one standard housing (1600 nozzles = 8 rows × 100 nozzles × 2 heads). This configuration enables a greater printing distance compared to the printing surface, which is used for printing on materials such as textiles, labels, and corrugated cardboard. The droplet volumes of 3 pl to 12 pl and 7 pl to 35 pl achieved by these models are significant as they determine the resolution and quality of the printed material. Ink jetting is 80 kHz at 5 pl binary driving or 40 kHz at 5 pl, 10 pl 18 pl multi-drop driving. It also achieves the high productivity of 100 m/min print speed at 600 dpi.

2.2.2 Ricoh MH Series

The MH series Inkjet heads operate on the principle of piston pulser with metallic diaphragm plate and are also known on the market as Gen 4 generation (Ricoch MH2420, Ricoh MH2620/2820, Ricoh MH2810F/2910F) and Gen 5 generation (Ricoch MH5220, Ricoh MH5320/5340, Ricoh MH5420/5440, Ricoh MH5421/5441, Ricoh MH5422/5442 and Ricoh MH5421F/5421MF).

The heads of the Gen 4 generation are characterized by variable drop volume droplet formation technology (the possibility of connecting three smaller drops into one larger one) with the durability of nozzles arranged in only two rows (2 x 192 nozzles in a line). This enables the heads to apply only one or two Inkjet inks with a 30 and 20 kHz jetting frequency. The Ricoh MH2420 model thus has a heater that regulates the color temperature up to 60° C, creating volume drops from 7 pl to 35 pl. The Ricoh MH2620/2820 model has a more robust ink heater (from 80° C), which enables the application of various Inkjet inks to generate larger droplets from 15 pl to 45 pl or 27 pl to 54 pl. Model MH2810F/2910F is a stainless steel print head that realizes the most significant Ricoh volume of released droplets from 27 pl to 50 pl and from 50 pl to 90 pl. With this characteristic (with appropriate heating), the possibility of applying highly pigmented Inkjet inks, which ensure the formation of a more extensive inks layer, has been realized.

Ricoh heads of the Gen 5 generation are characterized by their installation in Inkjet machines of high production and high reproduction quality. This means they can operate in binary droplet formation mode (volumes from 2,5 pl to 7 pl) and grayscale mode (volumes from 7 pl to 35 pl). The heads of this series have a native print resolution of 600 dpi and contain 1280 nozzles (arranged in a configuration of 4 x 150 nozzles).

With such a configuration, it is possible to print four inks at once (one line per color = 150 dpi), two spot inks (two lines per color = 300 dpi), and one ink (four lines per color = 600 dpi). The Ricoh MH5220 model is intended only for the use

of UV-curable inks. It prints a maximum of two colors during operation while generating the smallest droplet volumes from 2,5 pl to 9 pl. The Ricoh MH5320/5340 model has a stainless steel housing with built-in heaters, which makes it capable of working with most common Inkjet inks. With a high frequency of jetting (50 kHz) and a small volume of print dripping (from 5 pl to 15 pl), the head is suitable for easy connection in more comprehensive modules, enabling a color print of larger dimensions. The Ricoh MH5420/5440 model is used with all Inkjet inks and does not have a pronounced drip rate (max. 30 kHz). However, the head can generate high-quality images thanks to the grayscale mode that creates variable droplet sizes from 7 pl to 35 pl. The Ricoh MH5421/5441, Ricoh MH5422/5442, and Ricoh MH5421F/5421MF models have almost identical performance (volume 7 pl, 14 pl, and 21 pl) and are used in the most productive Inkjet machines. A slight difference is that water-based inks are applied (Ricoch MH5421/5441). It can recycle all types of Inkjet inks with a viscosity range of 6 pl to 11 mPa·s (MH5421F/5421MF) with greater precision in connecting to larger modules and making prints with enhanced non-wet-coating (Ricoch MH5422/5442).

2.2.3 Ricoh GH Series

The Ricoh GH series, represented by the Ricoh GH2220 head, operates on the piston pulser with a metallic diaphragm plate principle. This series is known for its excellent cost performance, making it a valuable asset for the sign graphic textile, coding, and marketing markets. The GH2220 head contains 384 nozzles that form droplets with a volume of 3 pl to 5 pl (binary mode) or 21±2 pl (grayscale mode) at a frequency of jetting 30 kHz. While the head does not have heaters, it is suitable for using water and solvent-based inks, making it a cost effective choice for various applications.

2.3 FUJIFILM Dimatix Inkjet Heads

Formerly known as Spectra Corporation, now operating as FUJIFILM Dimatix, Inc., we are a leading global supplier of drop-on-demand Inkjet printheads for commercial and industrial applications. With a robust portfolio of 37 types of piezo Inkjet heads, we stand out with our unique features and capabilities. Fujifilm printheads, divided into nine commercial series: Skyfire, Samba, Starfire, Sapphire, Polaris, Emerald, Galaxy, Nova, and S series, are a testament to our innovation and commitment to quality.

2.3.1 FujiFilm Skyfire Series

The SKYFIRE SF600 head currently represents this series with a native resolution of 600 dpi (1536 addressable nozzles jets in one module), which can form droplets from 5 pl to 25 pl (in binary and grayscale mode). Applying multi-pulse jetting technology with a frequency of 50 kHz, it is possible to achieve four printing speeds (66, 110, 130, and 264 m/min).

This speed directly corresponds with varying the printing resolution (600 × 1200 dpi, 600 × 720 dpi, 600 × 600 dpi, and 600 × 1200 dpi). This directly affects the ink laydown: 5,4 g/m², 10,8 g/m², 13 g/m², 21,7 g/m². As the head with Silicon

MEMs w/protective REDIJET coating that applies an additional heater with a thermistor, it is possible to print Aqueous, Solvent, and UV-curable inks. [8]

2.3.2 FujiFilm Samba Series

In the current fastest Inkjet machines, we usually find FujiFilm heads of the Samba G3L and Samba G5L. It is about silicon MEMs W heads with a native resolution of 1200 dpi (containing 2048 nozzles). Applying multi-pulse jetting technology with a frequency higher than 100 kHz, it is possible to achieve three printing speeds: 461 m/min (with a resolution of 1200×300 dpi), 230 m/min (with a resolution of 1200×600 dpi) and 115 m/min (with a resolution of 1200×1200 dpi). Applying binary and grayscale mode, Samba models achieve different volumes of formed droplets (Samba G3L from 2,4 to 10 pl; Samba G5L from 3,5 to 15 pl), ultimately affecting the achieved ink laydown. Thus, the more precise Samba G3L head will give smaller ink layers on paper substrates: 1 g/m² (resolution 1200×300 dpi), 2 g/m² (resolution 1200×600 dpi) and 4 g/m² (resolution 1200×300 dpi). Because of this, Samba heads can apply demanding latex Inkjet inks in addition to standard Aqueous, Solvent, and UV UV-curable inks (only Samba G3L heads).[9]

2.3.3 FujiFilm StarFire Series

The FujiFilm StarFire series is a testament to adaptability, offering the most significant number of construction variations. This characteristic has produced 23 Starfire models by application, divided into three groups (series A, series C, and series F). All StarFire heads of the SG 1024 series contain a metal plate with nozzles; a total number of 1024 print nozzles (8 lines \times 128 nozzles) achieve a native print resolution of 400 dpi or 200 dpi (if the same head applies two inks). The heads of the SG 600 series achieve a higher output resolution (600 dpi or 300 dpi if two inks are printed), which was completed by installing a metal plate with 1536 nozzles (12 print lines \times 128 nozzles). All models use binary and grayscale image generation methods and contain a system for dual ink recycling. This requires a viscosity of Inkjet inks in the 8 to 20 mPa·s range.

The heads of the A series are characterized by different dripping frequencies (50 kHz, 30 kHz, 20 kHz), which also achieve different droplet sizes. Thus, Starfire A series models will achieve the following native droplet volumes: SG1024/XSA (6 pl), SG1024/SA (12 pl), SG1024/MA (30 pl), SG1024/LA (80 pl), SG1024/SA-2C (12 pl), SG1024/MA-2C (30 pl), SG1024/LA2Ci (80 pl), SG600/XSA (6 pl) SG600/SA (12 pl) and SG600/SA2C (12 pl). This ensures excellent application of most UV curable, organic solvents and aqueous inks.

The heads of the C series are also characterized by differently realized ink droplet sizes and their native dripping frequencies of 50 kHz, 30 kHz, and 20 kHz. Thus, Starfire C series models will achieve the following native droplet volumes: SG1024/XSC (6 pl), SG1024/SC (12 pl), SG1024/MC (30 pl), SG1024/LC (80 pl), SG1024/MCHF (30 pl), SG1024/LCHF (80 pl), SG1024/AQMH (30 pl), SG1024/AQMH (80 pl), SG600/XSC (6 pl), SG600/SC (12

pl) and SG600/MC2C (30 pl). This ensures an excellent application of oil and solvent-based ceramic inks.

Our f series heads are designed for unique applications in sand casting and metal sintering. These heads are specifically engineered to apply aggressive fluids, preventing clogging of nozzles and ensuring a more extensive ink layer (laydown 50 g/m²). To achieve this, our StarFire F series models produce larger droplets, with native volumes of 30 pl (SG1024/M3F head) and 80 pl (SG1024/L3F head).

2.3.4 FujiFilm Polaris Series

The Fuji Inkjet head series consists of three models: Polaris PQ-512/85 AAA, Polaris PQ-512/35 AAA, and Polaris PQ-512/15 AAA. All three Printheads have 512 independent nozzles arranged in multiple rows at 200 dots-per-inch spacing for single-color operation or 100 dots-per-inch spacing for two-color operation. The printhead is designed for binary jetting using an 80 pl drop size (PQ-512/85 AAA), 35 pl (Polaris PQ-512/35 AAA), and 15 pl native drop size (PQ-512/15 AAA). The nominal drop velocity for jetting fluids is 8 m/s thanks to two electrical connectors, which contain 8 serial data lines that support fire frequencies over 20 kHz, 30 kHz, and 40 kHz. Using VersaDrop jetting technology, the printhead is capable of adjustable binary operation at drop sizes up to 150 pl with a frequency of 10 kHz (PQ-512/85 AAA), 60 pl with a frequency of 18 kHz (Polaris PQ-512/35 AAA), and 30 pl with the frequency of 25 kHz (PQ-512/15 AAA). Polaris Printhead is compatible with a broad range of Inkjet inks (8 mPa·s to 20 mPa·s), including UV-curable, aggressive organic solvent and aqueous inks. [11]

2.3.5 FujiFilm Sapphire Series

Unlike the previously mentioned Inkjet heads, the MEMS Sapphire series has a slightly lower printing resolution (100 dpi), i.e., the number of addressable jets nozzles per module is 256. The series consists of three models: Sapphire QS-256/80 AAA, Sapphire QS-256/30 AAA, and Sapphire QS-256-10 AAA. The printheads are designed for grayscale jetting using a 10 pl, 14 pl, 30 pl, or 80 pl native drop size. As with the Polaris series, the nominal drop velocity for jetting inks is achieved with 8 m/s, which enables ink viscosity from 8 mPa·s to 20 mPa·s. Printhead operational temperature can be up to 90 °C. This allows for applying a broad range of printing inks, including UV curable and aqueous inks and associated maintenance fluids. [12]

2.3.6 FujiFilm Emerald Series

The Emerald QE family of printheads uses field-proven materials and a robust design to deliver a long service life. Although the printing characteristics are similar to the Sapphire series (printing resolution 100 dpi and number of addressable jets per module 256), the difference is evident in the metal nozzle plate technology. The series consists of two models: Emerald QE-256/30 AAA and Emerald QE-256/80 AAA. Their difference is in the precision of the formed droplet, which in the QE-256/30 AAA model is 30 pl with a

jetting frequency of 33 kHz, while in the QE-256/80 AAA model, it is 80 pl with a jetting frequency of 20 kHz. [13]

2.3.7 FujiFilm Galaxy Series

Galaxy series is a high-performance printhead designed for various industrial and commercial printing and hot melt printing applications at up to 450 dpi resolutions. The series consists of two models that use hot melt colors (Galaxy PH 256/80 HM and Galaxy PH 256/30 HM). In comparison, two models are designed to use classic Inkjet inks (Galaxy PH 256/30 AAA, Galaxy JA 256/80 AAA). The primary characteristic of these heads is the inclusion of 256 nozzles whose diameters are: 52 μm (Galaxy PH 256/80 HM), 42 μm (Galaxy PH 256/30), 36 μm (Galaxy PH 256/30 AAA), 52 μm (Galaxy JA 256 /80 AAA). In this way, with a jetting frequency of 12 kHz and 20 kHz, the size of the droplets was 80 pl and 28 pl. Unlike other versions, the Galaxy JA 256/80 AAA is a compact Inkjet jetting assembly designed specifically for applications that require multiple printheads. [14]

2.3.8 FujiFilm Nova Series

In the category of heads that contain one print line with 256 nozzles, FujiFilm heads of the Nova series are included. The FujiFilm Nova series consists of models PH 256/80 AAA and Nova JA 256/80 AAA intended for a broad range of industrial and commercial printing applications such as wide format graphics, addressing, and packaging. Although they form relatively large droplets (native size 75 pl with a frequency jetting of 20 kHz), connecting them makes it possible to achieve a print resolution of 450 dpi. With an operating temperature range of up to 90°C, applying liquids with a viscosity of 8 mPa·s to 20 mPa·s (aqueous ink, organic solvent ink, UV curable inks) is possible. [15]

2.3.9 FujiFilm S Series

Inkjet FujiFilm series S achieves the lowest reproduction quality. The reason for that is one line of 128 nozzles. This means that higher quality is achieved by combining several heads into one unit. The series consists of 3 models (SE-128 AA, SL-128 AA, SE-128 AA), which differ in the jetting speed and the formed droplets' size. The models of the SE mark thus achieve drops of size 30 pl (jetting frequency 40 kHz). The other two models form larger droplets and layers: SL droplets of 80 pl (jetting frequency with 30 kHz) and SM droplets of 50 pl with a jetting frequency of 20 kHz. This head type is used when working with liquids containing organic solvents and UV photoinitiators. [16]

2.4 Konica Minolta Inkjet heads

Konica Minolta Inkjet heads are engineered for precision, capable of generating droplets in three driving modes: Shear 3 cycles (Inkjet heads with 512 and 1024 nozzles), Shear independent (Inkjet heads with 512, 1024, and >1024 nozzles), and the band (Inkjet heads 800 and 1600 nozzles).

This precision allows for the formation of three categories of droplets: small (3,5 pl, 6 pl), medium (10 pl, 13 pl, 14 pl), and large (35 pl, 42 pl), with a grey scale (levels) range from 1 to 8.

The principle with the Shear 3-cycle head (models KM512MN, KM1024MNB, KM512LN, KM1024LNB, KM512SHX, M10245HB, KM1024MHB, KM1024LHB) applies exclusively to the input digital waveform signal. The installation of a heater is crucial as it enables the use of UV inks, while the construction without a heater (the first four heads) is only suitable for solvent inks.

The operating principle of Shear independent (KM512iLNB-30, KM1024iSHE, KM1024aSHE, KM1800iSHC-C, KM1024iMHE-D, KM1280MHH, KM1024iLHE-301, KM1024aLHG-RC, KM1024iSAE-C, KM512iMAB-C, KM1024iMAE-C) enables the installation of heaters in Inkjet heads. It enables us to work with all possible inks, as it can receive digital and analog input signals. It is possible to form different volumes of droplets that move in the volume range of 3,5 pl, 6 pl, 10 pl, 13 pl, 14 pl. Based on this, the heads have an output print resolution of 180 dpi, 360 dpi, 450 dpi, and 600 dpi. The "jetting frequency" refers to the rate at which droplets are ejected from the nozzles, and it is 27 kHz, 45 kHz, and 56 kHz for these heads.

Bend Inkjet heads (models KM800, KM1600) use an analog input signal to form multidrop droplets of size from 5 to 22 pl (jetting frequency 18,2 kHz). Heads of this type contain 800 and 1600 nozzles respectively, creating a print resolution of 360 dpi and 720 dpi. They are successfully applied with water-based inks and solvent inks.[17] All these KM heads (as well as the Inkjet head KM1024iLHE-30, which was used in this work) apply piezo crystal's shear movement principle.[18]

3 EXPERIMENTAL PART

In the experiment, we used only the highest quality materials, such as semigloss double-coated cardboard (grammage 300 g/m²), cated on final format dimensions SRA3+. For print quality evaluation, we used four vertical and four horizontal lines with defined widths ($W=1,40$ mm, $W2=1$ mm, $W3=0,6$ mm, and $W4=0,3$ mm. These lines are PDF Fogra line standard test charts used in the printing industry. In the first step, a high-quality reference print was created. The bitmapped vertical and horizontal lines were saved in PDF format (using Adobe Illustrator 2024), making it suitable for the RIP (Hikari KM IC602). This black and white reference imprint characterizes a high-quality print resolution of 1200 × 3600 dpi. For that occasion was used fine black Simitri powder toner and Japanese EP machine Konica Minolta Accurio Print C3080. [20]

The experimental samples were produced on an identical printing substrate. The key machine in the experiment the authors used was a commercial Jetvarnish 3DS film varnishing and printing machine. The main print engine features five Inkjet print heads type KM 1024 LHE-30 (positioned in the configuration of 3 + 2 heads). It also contains a modular UV light source with two LED lamps, which emit a wavelength of 395 nm. The first LED UV lamp has four modules (4×5 W power), while the second LED UV

lamp has one module of 12 W power. Using MGI UV Inkjet curing varnish, three different coating layers were printed (21 μm , 36 μm , and 51 μm). The JETVARNISH 3DS machine featured MGI JVTi 3.3.0.5 software, which adjusts the applied varnish layers. Data on the application of LED UV varnish were not obtained directly (through physical measurement) but indirectly (from the manufacturer's data on the system). The glossy varnish JV3DS contains photoinitiators, acrylic monomers and polymers, and various additives. The main ingredient is the polymer diphenyl (2,4,6-trimethyl benzoyl) and phosphine oxide (CH₃)₃C₆H₂COP(O)(C₆H₅)₂. [21]

Murata Gold-type foil was used to create the final gold lines. For this application, alongside the varnish application unit and UV curing, there is a metalized foil application unit. The length of the metalized gold foil was 400 m, meaning a maximum transfer of dimension 32 \times 45 cm foil could be achieved. The temperature was controlled in 6 independent zones, with the possibility of changing the foil temperature from 90 $^{\circ}\text{C}$ to 190 $^{\circ}\text{C}$. In our case, a constant heater temperature of 105 $^{\circ}\text{C}$ was used. MGI JVTi 3.3.0.5 was used to control the application of transparent JV3DS varnish. In contrast, an AIS scanner with 180 defined check positions was used to achieve the exact position of print elements. The varnish channel was created using the alpha channel generated by Adobe Photoshop CS6 25.7. [22]

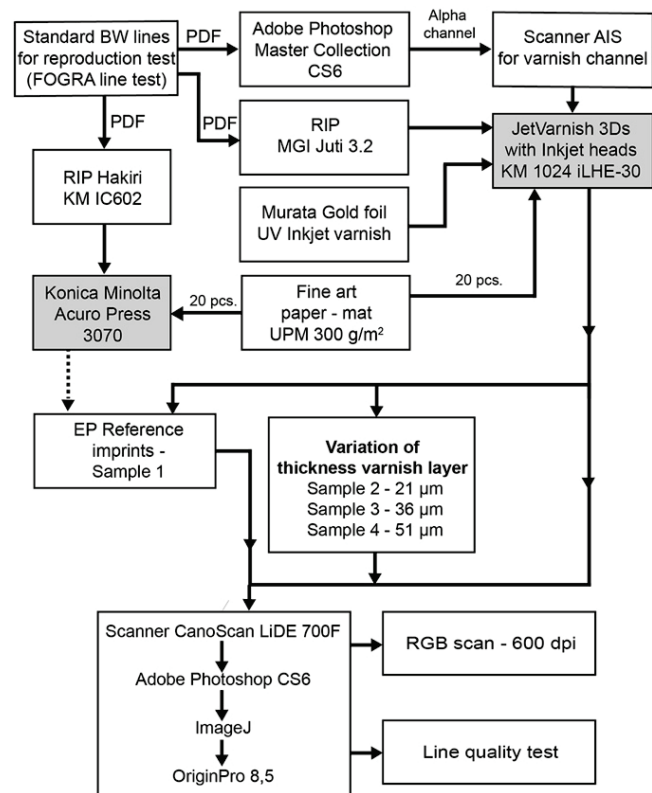


Figure 1 Chronological flow of the experiment [4]

Three different samples were printed, and the thickness of the varnish varied before contact with the metalized foil (21 μm , 36 μm , and 51 μm). After that for line image analysis, the all samples were scanned in a scanner Japan manufacture CanoScan LiDE 700F (RGB image in resolution

of 600 dpi and TIFF format). Before image analysis all line photos were meticulously prepared in Adobe Photoshop to the same TIFF grayscale format (size 9 \times 6 cm with an original resolution of 600 dpi). To ensure the thoroughness and accuracy of our analysis, the final results were obtained using the open-source program ImageJ version 1.5.3 with a carefully designed macro program to calculate line surface coverage.

```
run("HSB Stack");
run("Stack to Images");
selectWindow("Saturation"); close();
selectWindow("Hue");
close();
makeRectangle(9, 6, 456, 574);
makeRectangle(7, 0, 458, 580);
run("Plot Profile");
run("Select All");
```

Based on the detected black pixels, the grayscale profile and width of the line test were determined. The average results were processed and analyzed using OriginPro 8.5. Flow chart of the experiment is shown in Fig. 1 [4].

4 RESULTS AND DISCUSSION

Printed products used for information transfer may contain elements in horizontal and vertical lines (achromatic illustrations, tables, text, letters, etc.). In this research, we aim to enhance the quality of printed products by analyzing four golden lines created by the previous application of UV LED varnish. Figs. 2 and 3 show profiles of these experimental lines with widths of 1,40 mm, 1 mm, 0,6 mm, and 0,3 mm printed on a Konica Minolta AccurioPrint C3070L electrophotographic machine and JETVARNISH 3DS machine.

When compared to the meticulously precise reference BW print, generated by the ROS laser head, the gold print with a 21 μm varnish layer exhibits a reduction in line width. The mutual difference in line width is as follows: line 1 $\Delta W_{S1,S2} = 53,18 \mu\text{m}$; line 2 $\Delta W_{S1,S2} = 84,87 \mu\text{m}$; line 3 $\Delta W_{S1,S2} = 67,69 \mu\text{m}$; line 4 $\Delta W_{S1,S2} = 88,89 \mu\text{m}$. The line with the smallest width experiences the most significant deviation (reduced by 26%), while the widest line has the least deviation (reduced by 3,8%). The total width of all reproduced horizontal lines, created by applying a 21 μm varnish layer and accepting metallic foil, is reduced by $\Delta W_{\text{sum}} = 294,63 \mu\text{m}$ compared to the reference.

By analyzing the black horizontal lines of the reference Konica Minolta imprints, a characteristic trend is observed. The peripheral parts exhibit greater grayness ($Gr_{L1} = 91,53\%$, $Gr_{L2} = 89,57\%$, $Gr_{L3} = 90,40\%$, $Gr_{L4} = 88\%$) compared to the central part of the lines ($Gr_{L1} = 85\%$, $Gr_{L2} = 84,98\%$, $Gr_{L3} = 84,34\%$, $Gr_{L4} = 82,72\%$). Reduced line width correlates with a more pronounced decrease in edge grayness, offering key insights into their relationship.

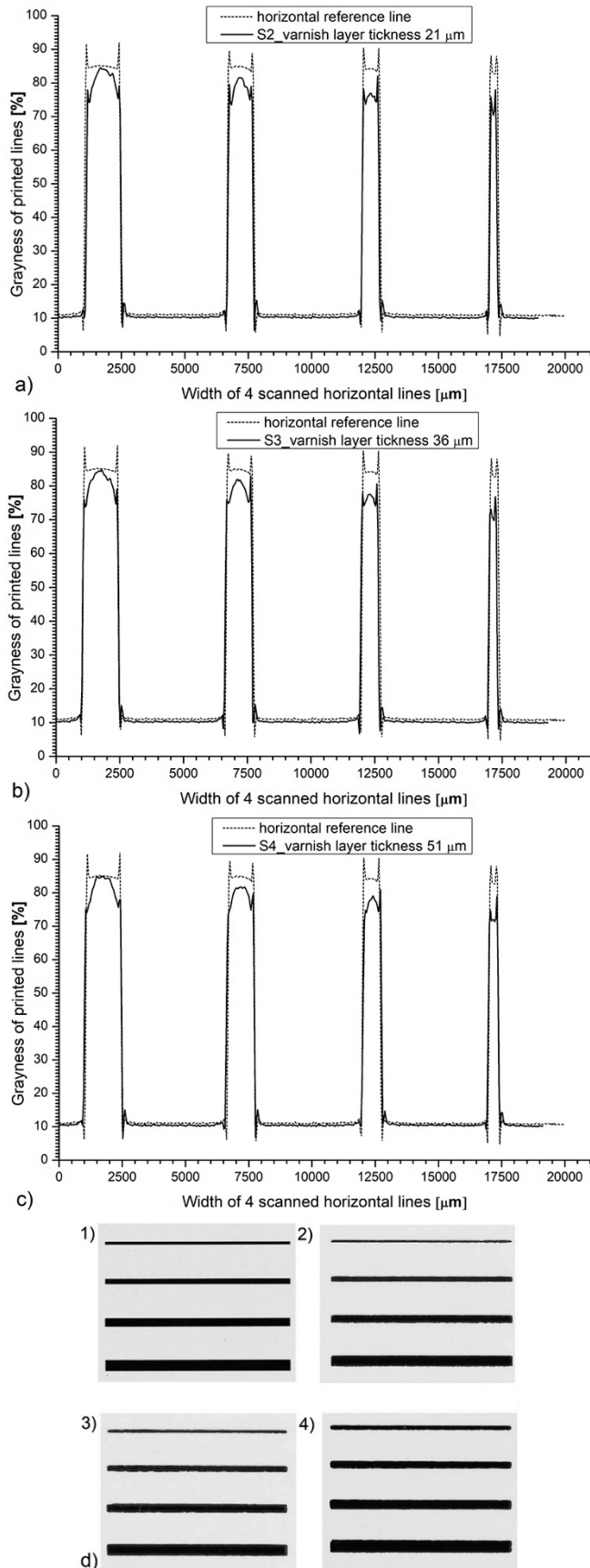


Figure 2 Reproductions of EP reference and four gold horizontal lines: a) varnish layer 21 μm ; b) varnish layer 36 μm ; c) varnish layer 51 μm ; d) enlarged samples used for image analysis (1 = ref; 2 = 21 μm ; 3 = 36 μm ; 4 = 51 μm).

The line profiles of sample 2 are uneven. With the wider lines (line 1 and line 2), grayness is most significant in the central part of the printed line, while the edges are of lower intensity. With lines of smaller widths (line 3 and line 4), grayness is more pronounced on the edge parts of the print, and the middle parts are less gray. By comparing the grayness of the gold lines with the reference, differences of samples were realized: $\Delta Gr_{L1} = 0,75\%$, $\Delta Gr_{L2} = 3,45\%$, $\Delta Gr_{L3} = 8,39\%$, $\Delta Gr_{L4} = 12,30\%$. Such amounts lead to the conclusion that the metal foil applied to the varnish reduces the possibility of reproducing gray tones. By lowering the wideness of the lines, the chance of reproducing gray decreases, which means there is also a decrease in information and reflection from the gold foil.

On all tested horizontal lines of the gold imprint (created with a layer of 36 μm), increased dimensions are realized compared to the electrophotographic reference. Their mutual difference amounts to line 1 $\Delta W_{S1_S3} = 111,3 \mu\text{m}$; line 2 $\Delta W_{S1_S3} = 73,64 \mu\text{m}$; line 3 $\Delta W_{S1_S3} = 87,14 \mu\text{m}$; line 4 $\Delta W_{S1_S3} = 47,73 \mu\text{m}$. Thus, of all the printed lines, the widest line will have the smallest deviations (increase of 8%), while the line of smaller width will have the most significant deviation (increase of 13%). With the reference, the total wideness of all reproduced horizontal lines (created by applying varnish with a thickness of 36 μm after subsequent bonding of the metallic foil) increases by $\Delta W_{\text{sum}} = 319,81 \mu\text{m}$. By reducing the wideness of the lines, the possibility of reproducing gray decreases slightly, but the reproduction is marginally better than with sample 2.

Profiles of horizontal lines on sample 3 are uneven. This is visible in wider lines (line 1, line 2, and line 3), where the grayness is most significant in the center of the printed lines, while the edges are porous and of lower intensity. In the case of the line of smaller width (line 4), the grayness is more pronounced on the edge parts of the print, while the middle parts of the print are of a lesser intensity of grayness. By comparing the average values of the lines of the reference imprint and the average values of the lines printed with foil (sample 3), the following deviations in gray were obtained: $\Delta Gr_{L1} = 0,91\%$, $\Delta Gr_{L2} = 3,43\%$, $\Delta Gr_{L3} = 5,37\%$, $\Delta Gr_{L4} = 10,31\%$.

Compared to the accurate reference, a gold imprint created with a set-up layer of 51 μm will drastically increase all four horizontal lines. Their mutual difference now amounts to line 1 $\Delta W_{S1_S4} = 225,63 \mu\text{m}$; line 2 $\Delta W_{S1_S4} = 186,39 \mu\text{m}$; line 3 $\Delta W_{S1_S4} = 226,67 \mu\text{m}$; line 4 $\Delta W_{S1_S4} = 225,52 \mu\text{m}$. Thus, regardless of the native width, the three printed horizontal lines will have an identical increment, which means their proportional increase ($L1 = 16\%$, $L3 = 32\%$, $L4 = 66\%$).

A characteristic deviation will be a line with a width of 1 mm, the increase of which is 18%. The total wideness of all reproduced horizontal lines (created by applying varnish with a thickness of 51 μm with the subsequent acceptance of metallic foil) increases by $\Delta W_{\text{sum}} = 864,21 \mu\text{m}$ compared to the reference.

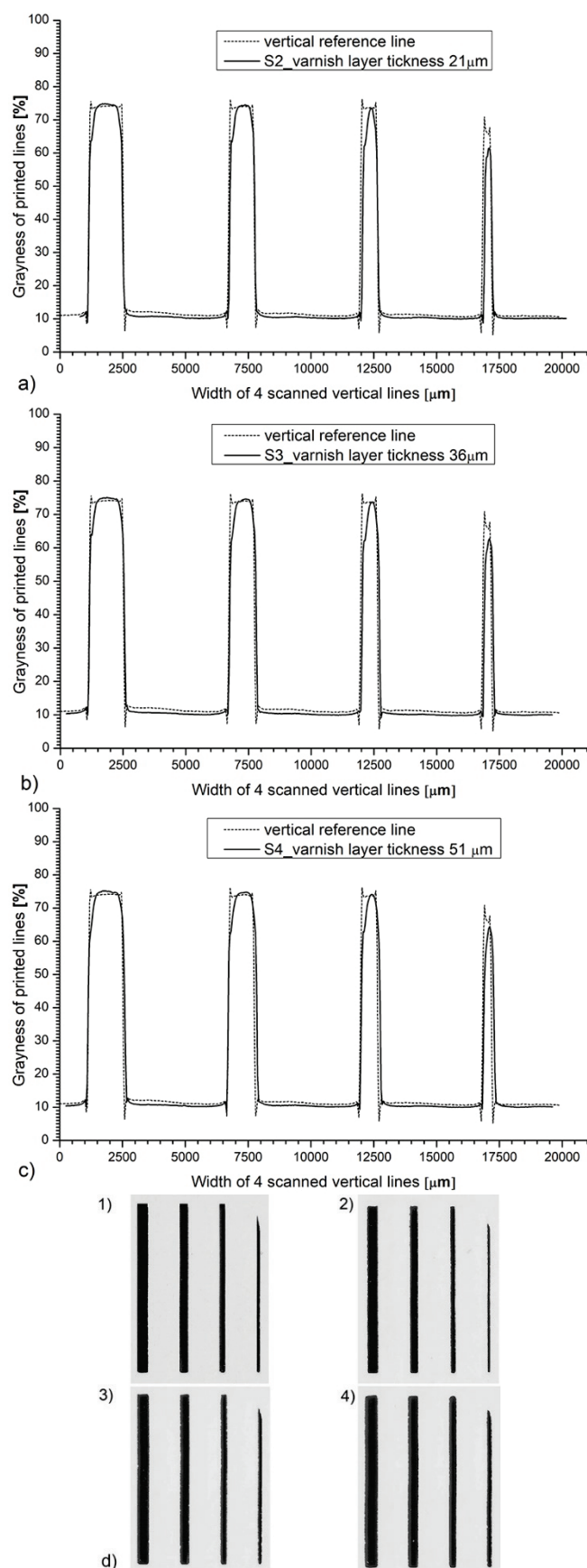


Figure 3 Reproductions of EP reference and four gold vertical lines: a) varnish layer 21 μm ; b) varnish layer 36 μm ; c) varnish layer 51 μm ; d) enlarged samples used for image analysis (1 = ref; 2 = 21 μm ; 3 = 36 μm ; 4 = 51 μm).

The horizontal line profiles of sample 4 are very uniform. The centers of the line element have a more significant oscillation of the gray value compared to the edge parts of the line. With a line of smaller width (line 4), the grayness of the center and edge parts is almost the same. By comparing the central values of the lines of the reference print and the central values of the lines of the printed lines of sample 4, the difference in grayness of the samples is reduced compared to the previous experimental samples. With line 1, the difference is negligible, while the others are still obvious: $\Delta Gr_{L1} = 0,04\%$, $\Delta Gr_{L2} = 1,70\%$, $\Delta Gr_{L3} = 2,96\%$, $\Delta Gr_{L4} = 7,19\%$. The results of this research confirm that with a more extensive application of varnish, a better possibility of reproducing the line and its more excellent contrast is realized.

When analyzing the reference vertical line and the line created by applying varnish with a thickness of 21 μm , a trend of decreasing wideness of the golden printed lines can be observed. Their mutual difference amounts to line 1 $\Delta W_{S1_S2} = 66,36 \mu\text{m}$; line 2 $\Delta W_{S1_S2} = 30,09 \mu\text{m}$; line 3 $\Delta W_{S1_S2} = 90,15 \mu\text{m}$; line 4 $\Delta W_{S1_S2} = 29,73 \mu\text{m}$.

This demonstrates the precision of the vertical line printing, with the three widest lines achieving a negative movement (reduction of line width 0,6 mm by 14%), while the line of smaller width will have positive deviations (increase of line wideness 0,3 mm by 14%). The reduction in the total wideness of all 4 sample lines amounts to $\Delta W_{\text{sum}} = 156,87 \mu\text{m}$. In relation to all horizontal lines ($\Delta W_{\text{avgr}} = 73,65 \mu\text{m}$), the vertical direction will give a smaller deviation in line reproduction ($\Delta W_{\text{avgr}} = 54,08 \mu\text{m}$). Therefore, the vertical direction with this drift will be slightly more precise.

By analyzing the vertical black lines of the reference print, it is also possible to observe the characteristic phenomenon that the edge parts are of greater grayness ($Gr_{L1} = 75,70\%$, $Gr_{L2} = 76,17\%$, $Gr_{L3} = 76,24\%$, $Gr_{L4} = 70,93\%$) concerning the central part of the lines ($Gr_{L1} = 74,20\%$, $Gr_{L2} = 74,07\%$, $Gr_{L3} = 73,70\%$, $Gr_{L4} = 65,61\%$). However, there is no significant grayness reduction here (except for line 4). The vertical lines' maximum grayness is smaller than the horizontal lines. This shows that the direction of printing (orientation of lines) affects the quality of line reproduction; that is, the laser head and the application of tones have different effects on the quality of line realization.

Profiles of vertical lines on sample 2 are regular, and there are no significant deviations, which is the case with profiles of horizontal lines. By comparing the average gray values of the lines of the reference print and the average gray values of sample 2, it is noticed that the gold foil is accepted on the varnish in almost the exact amounts. The exception is the thinnest line, where the grayness is reduced by $\Delta Gr_{L4} = 4,18\%$. A more significant reduction of deposition in the edge zone of the lines was also observed. Thus, the beginning of the line will be slightly less reproduced. By comparing horizontal and vertical lines, it was noticed that the vertical distribution of lines would give a better and higher quality golden line. This is partly caused by a configuration where the modular head is stationary and the substrate moves during printing. This precision is evident in the minimal deviation in the line reproduction.

When analyzing the reference vertical line and the line created by applying varnish with a thickness of 36 μm , a trend of increasing the wideness of the golden printed lines can be observed. Their mutual difference amounts to line 1 $\Delta W_{S1_S3} = 116,57 \mu\text{m}$; line 2 $\Delta W_{S1_S3} = 119,25 \mu\text{m}$; line 3 $\Delta W_{S1_S3} = 59,37 \mu\text{m}$; line 4 $\Delta W_{S1_S3} = 185,68 \mu\text{m}$. Thus, of all the printed lines, the largest deviation will be the line of 0,3 mm (an increase of 86 %), and the smallest deviation of the lines will be 0,6 mm (an increase of 9%). The increase in the total wideness of all 4 sample lines amounts to $\Delta W_{\text{sum}} = 480,87, \mu\text{m}$. With all horizontal lines ($\Delta W_{\text{avg}} = 79,95 \mu\text{m}$), the vertical direction will give a more significant deviation in the reproduction of lines ($\Delta W_{\text{avg}} = 120,21 \mu\text{m}$) with an increase in varnish layer of 15 μm . Therefore, the vertical direction with this application will not be more precise in terms of dimensions.

The line profiles of sample 3 are regular, and there are no major deviations as in the horizontal line profiles. This means that the maximum amounts of grayness are in the area of the center of the line. By comparing the average value of the lines of the reference print and the average values of the lines printed with the foil of sample 3, a more pronounced deviation occurs only in line 4. The same anomaly is also observed in sample 3, where the amounts of grayness are slightly higher than the reference sample ($\Delta Gr_{L1} = 0,61\%$, $\Delta Gr_{L2} = 0,79\%$, $\Delta Gr_{L3} = 0,35\%$, $\Delta Gr_{L4} = 1,51\%$). This leads to the conclusion that the grayscale reproduction of the vertical lines of sample 4 is also almost identical to the reference sample.

The vertical line of sample 4 (with varnish coating thick 51 μm with the subsequent application of metallic foil) will achieve a significant increase in line thickness compared to the reference lines. Their mutual difference amounts to: line 1 $\Delta W_{S1_S4} = 337,2 \mu\text{m}$; line 2 $\Delta W_{S1_S4} = 224,88 \mu\text{m}$; line 3 $\Delta W_{S1_S4} = 191 \mu\text{m}$; line 4 $\Delta W_{S1_S4} = 307,21 \mu\text{m}$. This further demonstrates the precision of the vertical line printing, with the line of 0,3 mm (increase by 142%) having the largest deviation, and the line having the smallest deviation of 1 mm (increase by 22%). Compared to the reference sample, the total wideness (all 4 lines) increases by $\Delta W_{\text{sum}} = 1060,42 \mu\text{m}$. The mean value of the change in the wideness of the lines with an increase in varnish layer of 30 μm is $\Delta W_{\text{avg}} = 265,11 \mu\text{m}$. This alone continues the trend that the vertical direction is more imprecise (gives slightly larger line impressions).

The profiles of the vertical lines of sample 4 are regular, and there are no deviations like the profiles of the horizontal lines. This means the maximum amounts of gray are in the cent area of the vertical line printing element. By comparing the average values of the lines of the reference print and the average values of the lines of printed sample 4, there are no significant deviations in contrast ($\Delta Gr_{L1} = 0,79\%$, $\Delta Gr_{L2} = 0,89\%$, $\Delta Gr_{L3} = 0,69\%$, $\Delta Gr_{L4} = 0,78\%$). Namely, the possibility of reproducing gray is increasing, and the possibility of reproducing sample 4 is better than that of the reference sample.

This results shows that the varnish application is not optimal and need additional corection in printing file. An optimal metallized print on semigloss cardboard could be achieved by a targeted reduction of line thickness depending

on the height of the varnish application (the higher the varnish application, the lower the speed of the machine, which affects the spreading of the UV varnish).

5 CONCLUSION

The optimal experimental setup for the KM Inkjet head KM1024iLHE-30 involves applying a 21 μm UV drying varnish on paper. This setup is best for achieving accurate lines for protective printing and printing with strict metal conductors.

Increasing the varnish layer by 15 μm or 30 μm will significantly alter the dimensions of the realized lines, possibly distorting the image and text.

The quality of the realized lines is affected by the direction (verticals and horizontals) of line in original files. With minimal varnish application, vertical lines are more precise than horizontal ones. However, as the varnish layer increases, the width of the vertical lines increases more significantly than the horizontal lines. Increasing the varnish amount leads to growing increments, resulting in less precise line imprints in the cross direction than in the machine direction.

The line profile reflects the homogeneity of line reproduction. Increasing the varnish application achieves better uniformity of lines, with the central part being more contrasting than the peripheral part. Additionally, wider lines will exhibit more pronounced gray values.

Changing the printing direction will impact the realized grayness. Vertical lines (print-direction) produce more precise and homogeneous lines. Lines with a width of 0,3 mm will have the most significant oscillations in width, while a 1 mm line will have the least oscillations during printing.

To achieve optimal results, an Inkjet head with a smaller print nozzle and volume will be necessary. Further research will focus on testing of volume of applied UV varnish and adopting referent file to achieve better outcomes in realizing targeted printing elements. Therefore, it is planned to test the possibility of using a larger number of print heads and higher printing speeds.

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Authors' contacts:

Igor Majnarić, Full. Prof. PhD
University of Zagreb Faculty of Graphic Arts,
Getaldićeva 2, 10000 Zagreb, Croatia
Igor.majnarić@grf.unizg.hr

Marko Morić, Asst. PhD
(Corresponding author)
University North,
Trg Žarka Dolinara 1, 48000 Koprivnica, Croatia
mmoric@unin.hr

Marko Kadija, mag. ing. techn. graph.
Konica Minolta Croatia - Business Solutions, Ltd.,
Horvatova 82, 10000 Zagreb, Croatia
marko.kadija@konicaminolta.hr

Krunoslav Hajdek, Assoc. Prof. PhD
University North,
Trg Žarka Dolinara 1, 48000 Koprivnica, Croatia
khajdek@unin.hr