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Study of Inkjet Print Quality Using Colourimetry and Principal Components Analysis

Uporaba kolorimetrije in analize glavnih komponent (PCA) za določanje kakovosti odtisov narejenih s kapljičnim tiskalnikom

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Abstract

In the research, quality of prints made with inkjet printer Canon ImagePROGRAF W8400 using two different papers, matt coated and glossy photo paper, was determined. In addition, the impact of Wasatch softRIP settings – draft and high – on print quality was investigated. Software package Profile Maker 5.0.8 was employed for the creation of ICC colour profiles for both printing quality settings and both papers. For quality assessment of ICC profiles, a test chart with colour patches located within printer colour gamut was made by the open source program ArgyllCMS. Test chart was printed with different colour profiles and then measured. Quality of prints was assessed by means of colour difference equation ΔE^*_{ab} and multivariate statistical tool principal component analysis.
The results have shown that the RIP settings have no influence on print quality when glossy photo paper was used as a substrate. Final prints made on matt coated paper are of acceptable quality, although they possess a slightly smaller colour gamut when compared to the prints made on glossy photo paper. This is a consequence of different paper structure, however matt paper can accept larger amount of ink than glossy but also gives less saturated prints.

Keywords: printing quality, colour reproduction, inkjet printing, printer profiling, principal components analysis

Izvleček

V prispevku je raziskana kakovost odtisov narejenih s kapljičnim tiskalnikom Canon ImagePROGRAF W8400 na dveh različnih papirjih in sicer na motno in sijajno premazanem foto papirju. Pri tem je na Wasatch softRIP-u raziskan vpliv nastavitev kakovosti tiskanja – nizka in visoka – na samo kakovost odtisa. Za izdelavo ICC barvnih profilov pri obeh kakovostih tiskanja in pri obeh papirjih je bil uporabljen programski paket Profile Maker 5.0.8. Za določanje kakovosti ICC profilov je bila v odprtokodnem programu Argyll izdelana testna tablica z barvnimi polji, ki so se nahajala znotraj območja barvnega obsega tiskalnika. Testna tablica je bila natisnjena z uporabo različnih barvnih profilov in potem izmerjena. Kakovost odtisov je bila določena s pomočjo enačbe za barvne razlike ΔE^*_{ab} *in analize glavnih komponent.*

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Rezultati so pokazali, da v primeru uporabe sijajno premazanega foto papirja, nastavitve na RIP-u nimajo vpliva na samo kakovost odtisa. Kakovost končnih odtisov narejenih na motno premazanem papirju je sprejemljiva, čeprav imajo ti odtisi nekoliko manjši barvni obseg v primerjavi z odtisi narejenimi na sijajno premazanem papirju. To je posledica različne strukture papirja, saj lahko motno premazan papir sprejme večjo količino tiskarske barve od sijajno premazanega papirja, vendar so barve na končnem odtisu nekoliko manj nasičene.

Ključne besede: kakovost tiskanja, barvna reprodukcija, kapljični tisk, profiliranje tiskalnika, analiza glavnih komponent

1 Introduction

Creation of an inkjet printer profile is a frequently investigated colour management topic in printing on paper and textile substrates. In one typical research [1] linearization and characterization of three printers for paper and textiles, two inkjet and one electrophotographic ("laser") printer, were implemented. It was demonstrated that an accurate creation of colour profiles ensured high quality of prints and successful hard proof on both laser and inkjet printers. Zhang et al. studied creation of colour profiles that are based on independent polynomial colour transforms between XYZ and RBYK (red, blue, yellow and black) without the use of commercial software [2].

In the case of printers where the number of inks exceeds three, some mapping problems can occur. Many types of ink are optimized for achieving maximal colour gamut and in some cases black ink may not be used for reproducing pictorial images, many prints exhibit poor colour constancy. For such a purpose an algorithm for multi-ink printing was developed in which the mapping problems were overcome by selecting ink combinations with the best colour constancy between illuminants F11 and D50. The new algorithm improved colour constancy significantly [3]. In several studies quality evaluation of gamut mapping algorithms was performed [4], while the in others also some new algorithms were developed [5].

The use of ink-jet printers increased substantially with the rise of desktop publishing, especially due to the demand for high quality colour prints [6]. First generation Canon printers were very loud. With the second generation, smaller format laser printers intended for business applications were introduced. Third generation was characterized by improved speed and print quality [7].

The aim of our research was to assess quality of prints made with the Canon ImagePROGRAF W8400 inkjet printer using two different paper substrates. At the same time on Wasatch softRIP (RIP – Raster Image Processor), settings of printing quality, draft and high, were also investigated.

Print quality was assessed using the colour difference equation ΔE^*_{ab} and a multivariate statistical method Principal components analysis (PCA). PCA is a linear transformation method aiming at converting original multivariate data into a lower dimensional space of new variables, so called principal components (PCs), where the most important information, such as relationships among original variables or (dis)similarities among samples, becomes more obvious [8]. This method was successfully used in a previous work done by the authors [9–12].

2 Materials and methods

2.1 Materials

Research was focused on the quality analysis of prints printed with the ink jet printer Canon IP W8400 and Wasatch SoftRIP. During the study, RIP printing quality settings – draft and high – were varied. Samples were printed on two different types of paper, matt coated (PEPEL HW MAT) and glossy photo paper (SIENA 200L). Their properties are shown in Table 1.

Table 1: Paper specification [13, 14].

Paper properties	matt coated paper	glossy photo paper
Grammage	202 g/m^2	140 g/m^2
Opacity	95%	96%
ISO Brightness	96%	105%

2.2 Printer linearization and characterization

Some manufactures of photo papers and other substrates offer generic colour profiles for their substrates to be used with certain printers. Using these generic profiles it is possible to achieve acceptable results, but the results generally will not be comparable to those made with profiles that we create on printer Canon IP W8400 [15]. So, in our study we have created our own colour profiles for each printing quality settings and each paper following a sequence of steps described below.

1. The first step included choosing of the paper type, and the number and type of the inks used in the research.

2. Next, the printer was adjusted to achieve the optimum repeatability and colour gamut following a sequence of substeps described below.

a. Defining individual ink limits

The linearization chart – chart that contains colour patches from 0 to 100% area coverage for individual CMYK inks – was created using the ProfileMaker Pro 5.0 Measure Tool (X-Rite) and printed with colour management settings turned off. After the printing, the spectral data were acquired using the spectrophotometer EyeOne (X-Rite), and the CIELAB and CIEL* C^*_{ab} h_{ab} values were calculated. The obtained CIELAB values were used to define the ink limit from the a^*, b^* diagram for CMY (C – cyan, M – magenta and Y – yellow) and from lightness L^* in dependence of the area coverage (%) for K (K – key – black ink).

An example of an a^*, b^* diagram for both papers is shown in Figure 1. From the figure it is evident that the printer with the same printing quality setting – draft or high – takes into consideration the type of paper being used.

In the case of matt paper, high quality setting defines larger amount of ink which results in a hue shift. In the case of glossy paper this phenomenon is less pronounced.

In the a^*, b^* diagram, the point (percent of the area coverage) where the chromaticity C^*_{ab} stops increasing and the colour hue h_{ab} starts changing was determined – this point defines the ink limit. In the end, the ink limit was set on Wasatch SoftRIP software.

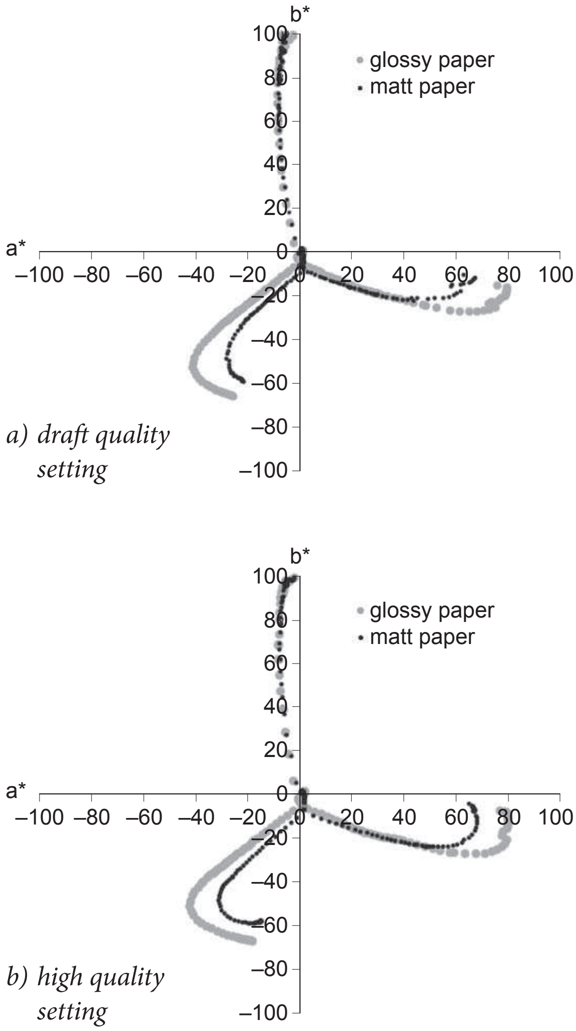


Figure 1: a^*, b^* diagram for CMY (C – cyan, M – magenta and Y – yellow) printed on both papers with a) draft quality settings and b) high quality setting.

b. Linearization

Next, another linearization chart selected from the Wasatch SoftRIP software was printed and measured. After the measuring and final linearization process, the linearization chart was printed and measured once more to ensure that the linearization was performed appropriately.

c. Defining total ink limit

This substep included the printing of a chart with black patches printed with all four inks (area coverage 0-400%) and defining the colour patch where the ink was not bleeding. In general, this parameter is important when the test chart and the final ICC profile were elaborated.

3. In the next step, the test chart was made in the program ProfileMaker Pro 5.0.8 Measure Tool (X-Rite) and printed.

4. Finally, the printed test chart was measured using the spectrophotometer EyeOne (X-Rite) and the ICC colour profile was made using software ProfileMaker Pro 5.0.8 (X-Rite).

The total ink limits for matt coated and glossy photo papers were set to 200% and 135%, respectively. This is a consequence of different paper structure, however matt paper can accept larger amount of ink than glossy paper.
When total ink limit was defined, we noticed that some of the colour patches were wet, indicating that the total ink limit was not optimal. However, during the research, we found out that those colour patches were made of only two colours and that software Measure Tool for test chart creation uses such algorithms that do not take into consideration total ink limit with colour patches made of only two colours.

For the assessment of print quality another test chart with 832 colour patches that were within printer colour gamut was produced. Test chart with defined CMYK values was made in an open source program ArgyllCMS [16]. CMYK values were converted to CIELAB values using tools "xicclu" (xicclu –v –ff –ip profile name.icc <CMYK.txt> file name.txt) thus generating reference data.
Altogether 832 printed patches were measured by spectrophotometer EyeOne (X-Rite). For the calculations of CIEXYZ and CIELAB values from the spectral data, CIE 1964 Standard Colourimetric Observer (2°) and standard illuminant D50 were used.
Finally, colour differences were calculated between the reference data and measured CIELAB values from printed test chart.

3 Results and discussion

3.1 Analysis of print quality using color difference measurements

Figure 2 shows colour patches printed on matt coated paper and represented in a^*, b^* diagram. According to our expectations, colour gamut of the profile made for high print quality was larger than the one created for draft printing quality. Only in the magenta region the opposite was true.

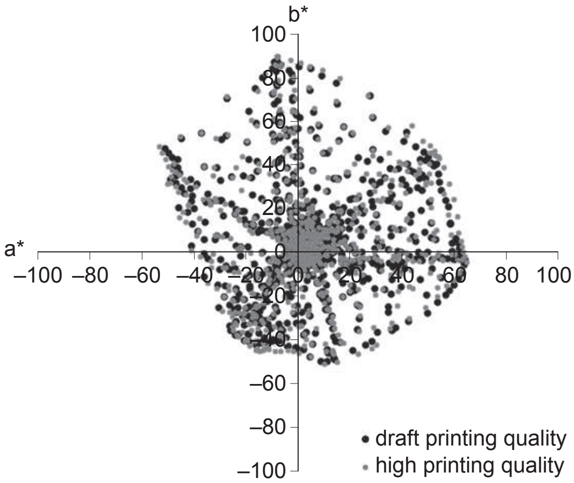


Figure 2: a^*, b^* diagram for colour patches printed with colour profiles made for draft and high quality settings and matt coated paper.

Prior to the analysis, each sample was categorized according to the magnitude of its ΔE^*_{ab} value into one of the four groups: 0 – 1 (colour difference undetectable with a human eye), 1 – 3 (small colour difference between two patches) [17], 3 – 6 (perceivable difference) or > 6 (large difference). In our case approximately 50% of colour patches belong to the second group (ΔE^*_{ab} 1 – 3), indicating small colour differences. For the majority of colour patches colour differences were lower than 6.

Table 2: Number of colour patches belonging to one of the four ΔE^*_{ab} groups (0 – 1, 1 – 3, 3 – 6, > 6) for matt coated paper.

ΔE^*_{ab}	draft/high
0 – 1	135
1 – 3	457
3 – 6	221
> 6	3

Figure 3 shows colour patches printed on glossy photo paper and represented in a^*, b^* diagram. Colour gamut of profile made for draft printing quality is smaller in the entire a^*, b^* region when compared to the colour gamut of profile made for high printing quality.

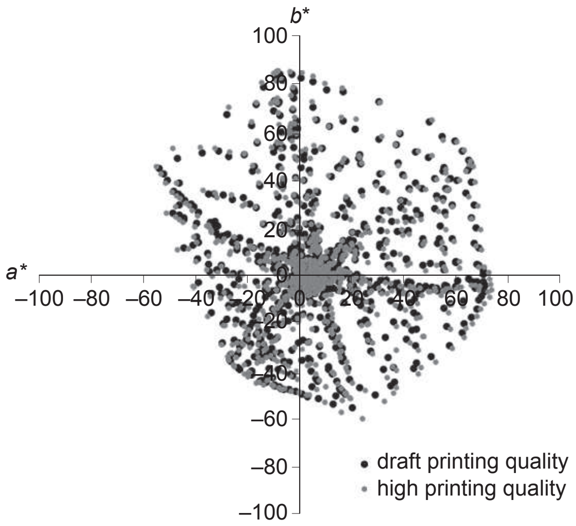


Figure 3: a^*, b^* diagram for colour patches printed with colour profiles made for draft and high quality settings and glossy photo paper.

Comparison of Figure 2 and 3 reveals that colour gamuts related to the patches printed with both draft- and high printing quality settings were larger when using glossy paper than matt coated paper. Those results are in accordance with those presented in Table 3.

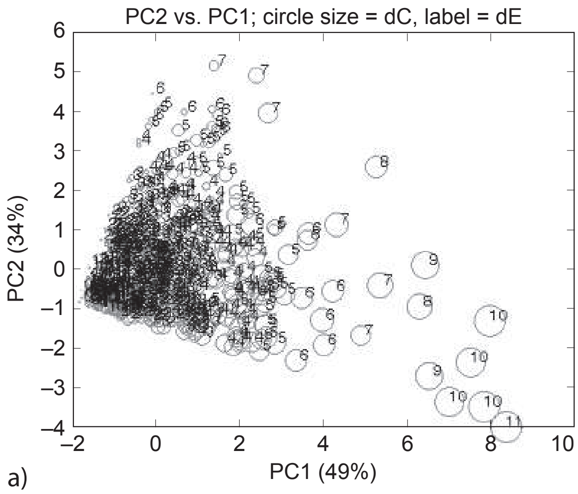
Table 3: Number of colour patches divided into groups of ΔE^*_{ab} (0 – 1, 1 – 3, 3 – 6, > 6) for glossy photo paper.

ΔE^*_{ab}	draft/high
0 – 1	92
1 – 3	616
3 – 6	121
> 6	3

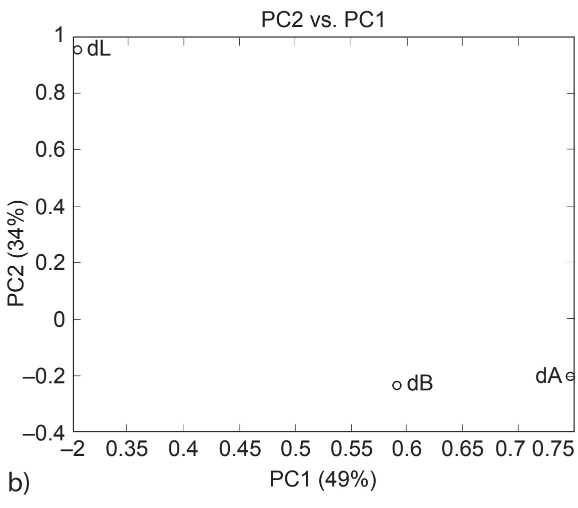
3.2 PCA results

PCA results are shown in Figures 4 and 5 for matt coated- and glossy photo paper, respectively. Figures 4a and 5a show locations of 832 samples – colour patches – while Figures 4b and 5b indicate positions of three variables – ΔL^*, Δa^* and Δb^* – in the PC1-PC2 coordinate system. In Figures 4a and 5a each circle, i.e. sample, is labeled by its ΔE^*_{ab} value (rounded to an integer) while its size corresponds to its ΔC^*_{ab} value. Regarding the prints on matt coated paper, as much as 83% (PC1: 49%, PC2: 34%) of original data variance can be accounted for by the first two PCs. Superposition of both corresponding diagrams (Figures 4a and 4b) reveals that colour patches located in the bottom-right part of Figure 4a are characterized by both large Δa^* and Δb^* values as well as large colour differences (ΔE^*_{ab}) between draft and high quality setting as indicated by big circles. Therefore, patches with biggest colour differences are those that also possess large chroma differences.

Similar observations can be made when comparing both glossy photo paper-related PCA diagrams (Figures 5a and 5b). PC1 and PC2 together account for 78% of data variability. An important difference to the matt paper prints, however, is evident: circles are noticeably smaller and ΔE^*_{ab} values lower, suggesting that both colour- and chroma differences between draft and high quality prints are in case of glossy paper substrate generally less pronounced.



a)



b)

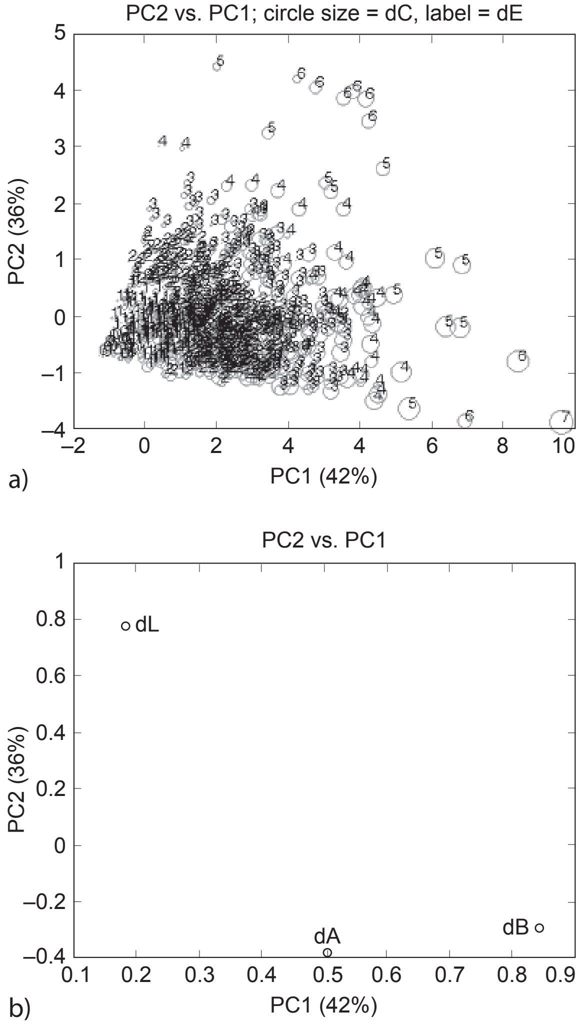


Figure 4: Position of colour patches (a) and variables (b) in PC1-PC2 coordinate system showing comparison between draft and high print quality for matt coated paper, da=Δa^*, dB=Δb^*, dL=ΔL^*.

Figure 5: Position of colour patches (a) and variables (b) in PC1-PC2 coordinate system showing comparison between draft and high print quality for glossy photo paper, da = Δa^*, dB = Δb^*, dL = ΔL^*.

Larger differences in colour (ΔE^*_{ab}) and chroma (ΔC^*_{ab}) that were found with matt coated paper are a consequence of a poorer (less accurate) printer profiling for this type of substrate. In the case of matt paper, as demonstrated with the PCA (Figure 4), largest colour differences – 8 to 11 – are associated with larger chroma (i.e. Δa^* and Δb^*) differences, while medium colour differences – 4 to 7 – are related to the lightness difference (ΔL^*). In the case of glossy paper, where the printer profiling was shown to be very good, this type of differentiation is less pronounced.

4 Conclusions

One of the main findings of our study was a high, nearly-optimum print quality when using glossy paper. Changes in the RIP printing quality settings (draft vs. high) produced only small differences in prints and when calculating colour differences so it can be concluded that the printing quality parameters, colourimetrically speaking, do not have any appreciable effect on prints printed on this type of substrate.

On the other hand, in case of matt paper colour gamut of the profile made for high print quality was larger than the one created for draft printing quality. The prints on matt coated paper possess a slightly smaller colour gamut when compared to the prints made on glossy photo paper. Quality of these prints was somewhat lower. Colours of the patches were found to be less saturated, there was a loss of saturation in darker tones, which is a consequence of the fact that the creation of the corresponding colour profiles was less accurate. Even though the profile creation procedure was the same for both substrate types, it seems that the printer settings when used with the matt coated paper have a significant effect on the device calibration and linearization and, consequently, on the profile generation.

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