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RESEARCH INTO THE PROCESS OF PRINTING DIGITAL PHOTOGRAPHS WITH VARIOUS PROCESSING METHODS

The presented work analyzed current approaches to improving digital photography technologies. A test form and methodology for determining the stability of color reproduction in photo printing were proposed. The influence of technological parameters of the digital photo processing process on the quality of photo printing was studied. General recommendations for stabilizing the color reproduction of digital photographs in photo printing were suggested.

Keywords: digital photography; photo printing; colour difference; image processing; quality of imprints; patent research; ICC-profile; artificial intelligence.

Introduction

In recent years, the volume of digital photographs created in the world has been growing rapidly. In particular, according to various studies [1–3], the volume of digital photographs created in 2025 is approximately 2 trillion, with an average of about 5 million new digital photographs created per day. Also, most photographs are usually created using smartphones, which accounts for up to 94 % of the total number of photographs [1]. This trend is associated with the greater accessibility and convenience of digital photography technologies when using smartphones, which has allowed the introduction of innovative technologies for creating HDR photographs (from 'High Dynamic Range') with an extended dynamic range, noise removal algorithms and photo processing based on artificial intelligence technologies [3].

Also, some of the digital photographs are reproduced using photo printing technologies. In particular, according to Epson [4], about 2 % of the total number of photographs are reproduced by users using digital photo printing on photo paper, for example, for a family photo album. Therefore, today, digital photography technologies continue to be constantly improved, both in terms of approaches to correcting the visual quality of photographs and in terms of photo printing technologies.

ISSN 2077-7264. Tekhnolohiia i tekhnika drukarstva. 2026. # 1(91)

ISSN 2077-7264. Технологія і техніка друкарства. 2026. № 1(91)

However, despite the constant improvement of digital photography technologies, there is a certain problem with the stability of the quality of their reproduction by means of digital photo printing. This is due to the use of a large range of consumables, in particular different types of photo paper, for which the use of various color ICC photo printing profiles is provided. Also, the stability of photo printing can be significantly affected by the applied methods of processing digital photos, which often lead to deviations in color reproduction and a general decrease in quality.

Therefore, the study of the impact of technological processes of processing and preparing digital photographs is quite relevant and will allow us to identify rational approaches to increasing the stability of photo printing. Also, one should take into account the constant development of digital technologies, which necessitates the implementation of constant research to adapt the existing photo printing process to the emergence of new technologies for preparing digital photographs, in particular the use of artificial intelligence technologies for tone and color correction of images.

Methods

Given the wide popularity and accessibility of digital photography technologies, existing thematic and related research concerns such areas as methods for improving the quality of digital photography [5–9], methods for color stabilization using ICC profiles [10, 11], and methods for preparing and printing digital photography [12–15].

In particular, a review of the possibilities of preparing photographs with an extended dynamic range [5], which are intended for posting on web resources, is widespread. Given the variety of photographic equipment and, as a result, the presence of some distortions on most unprocessed digital photographs, there is a large proportion of research devoted specifically to methods of tonal and color correction of digital photographs [6–9]. Including existing research [8] concerns the use of artificial intelligence technologies for photo correction.

Also, given the availability of photo printing equipment, which is quite popular for printing photo albums and other printed products, there are studies [10–15] aimed at optimizing the preparation of digital photographs for the printing process while ensuring acceptable color reproduction quality. However, as noted in the study [11], the ac-tual quality of a large number of printed products can significantly exceed the acceptable deviations, which indicates some complexity of reproducing photographs using standard approaches to quality control.

To determine the general trends in the development of digital photography, a patent search [16] was conducted with a 10-year retrospective starting from 2015 and ending in 2025. In total, about 400 patents were selected and analyzed in individual areas of development (Fig. 1–3).

The dynamics of patent issuance over the years (Fig. 1) indicates the steady development of digital photography technologies. In particular, since 2021, there has been a significant increase in the volume of developments dedicated to methods of preparing photographs for printing.

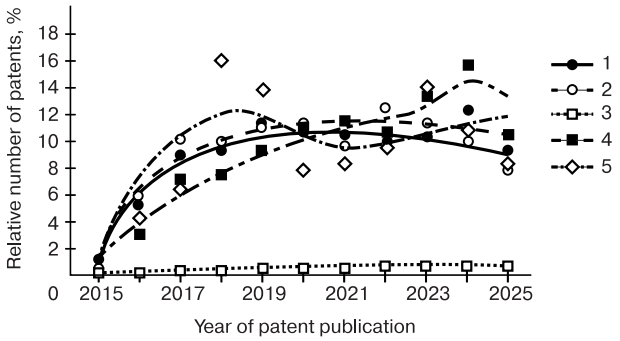

Fig. 1. Dynamics of patent issuance in individual areas: 1 — color reproduction by photo printing; 2 — methods of photo processing; 3 — application of ICC profiles; 4 — methods of preparing photographs for printing; 5 — digital photo studio technologies

Also, the general distribution of issued patent applications in percentage terms by different areas was established (Fig. 2). The largest number of patents over the past 10 years are developments related to the use of ICC profiles (45 %) and methods of photo processing (39 %). This may be due to the fact that these developments are universal and can be applied in addition to digital photography, also to the processing of information for the printing process of image reproduction. The smallest number of patents concerns digital photo studio technologies (3 %).

Also, an analysis of issued patents by country was carried out (Fig. 3), which revealed a trend towards the largest number of issued patents in the field of photo printing in Japan and the USA. This can be explained by the large number of existing manufacturers of photographic equipment in these countries.

Therefore, existing research and development have allowed us to establish a stable trend in the development of digital photography technologies, especially in the areas of processing and preparing digital photographs for the photo printing process.

Therefore, the purpose of the work is to study the influence of technological parameters of the digital photography processing process on the quality of photo printing

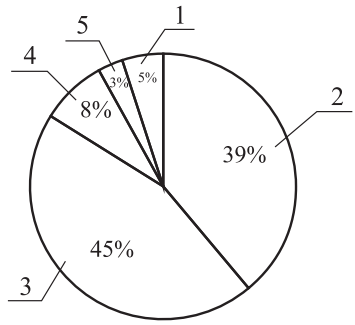

Fig. 2. Distribution of patents issued in percentage by individual areas: 1 — color reproduction by photo printing; 2 — methods of photo processing; 3 — application of ICC profiles; 4 — methods of preparing photos for printing; 5 — digital photo studio technologies

ISSN 2077-7264. Tekhnolohiia i tekhnika drukarstva. 2026. # 1(91)

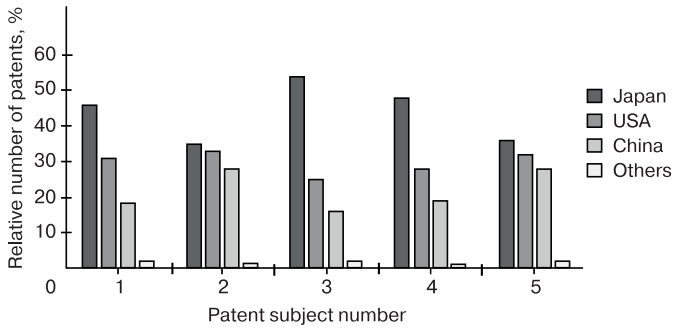

Fig. 3. Distribution of issued patents by country: 1 — color reproduction by photo printing; 2 — methods of photo processing; 3 — application of ICC profiles; 4 — methods of preparing photos for printing; 5 — digital photo studio technologies

and to determine recommendations for stabilizing the color reproduction of portrait photographs.

Results and Discussion

Research of the stability of color reproduction of digital photographs by photo printing were carried out using a specially designed A5 format test form with the following control elements: CMYK color plates, RGB color plates, flesh tones, gray tones, CMYK shades (at 20 %, 40 %, 60 %, 80 % and 100 %) and a test portrait photograph processed by various correction methods (Fig. 4).

Portrait photography was chosen for the study as the most common among the genres. Among the applied methods of digital photography correction were black and white filter (Fig. 4, item 1), auto-correction in Photoshop (Fig. 4, item 2), photo correction method using artificial intelligence based on ChatGPT (Fig. 4, item 3), Camera Raw filter (Fig. 4, item 4), 'Sepia' filter of Adobe Photoshop (Fig. 4, item 5) and image without correction (Fig. 4, item 6). Measurement of color characteristics was carried out for samples with color correction and without correction (Fig. 4, items 2–4 and item 6), other samples were evaluated visually (Fig. 4, items 1 and 5).

The study used different digital printing media (Epson L805 and Canon imagePress V700), different types of photo paper (matte, semi-gloss, glossy and high-gloss), as well as different standard photo printing profiles (varieties of ICC profiles).

To assess the quality, measurements of color coordinates in the CIE Lab system were used at five points of the tested test element with calculation of the arithmetic mean and subsequent calculation of color distortions (ΔE_{00}) according to the requirements of ISO 12647 [17]. Comparison of the studied different photo printing samples with respect to color reproduction stability was carried out by calculating the interquartile range (from English Interquartile Range, ΔE_{IQR}). Moreover, the smaller the interquartile range (ΔE_{IQR}), the more accurate the total reproduction of the studied colors will be according to ISO 12647. Also, graphical dependencies were constructed based on

ISSN 2077-7264. Технологія і техніка друкарства. 2026. № 1(91)

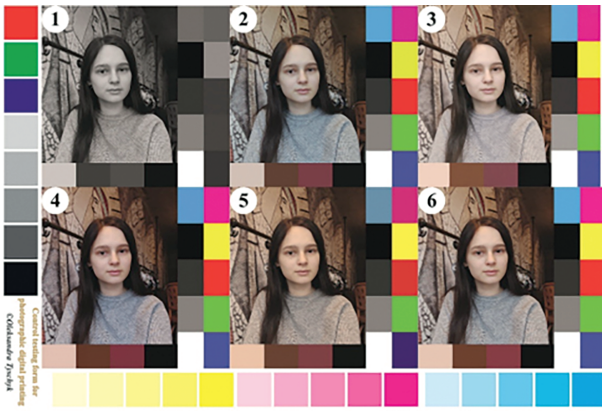

Fig. 4. A5 (10×15 cm) test form for checking the stability of color reproduction of photo printing

statistical analysis of color distortion data (ΔE_{00}): median (ΔE_{median}), maximum (ΔE_{max}), minimum value (ΔE_{min}), first quartile (ΔE_{Q1}), third quartile (ΔE_{Q3}) and interquartile range [18].

In particular, the influence of color profiles on the stability of color reproduction of unprocessed photographs in photo printing using the Canon imagePress V700 printer on glossy paper and various color profiles was analyzed: Japan Color 2011 Coated, GRACoL2013 CRPC6 (EFI), PSO Coated FOGRA51 (EFI), PSO Uncoated FOGRA52 (EFI) and printing with a standard ICC profile (None). Color measurements were performed five times for each color with averaging of color coordinates, the results are given in Table.

Analysis of the calculated level of average color distortion (ΔE_{00}) for photo imprints with different ICC profiles (Fig. 5) allowed us to

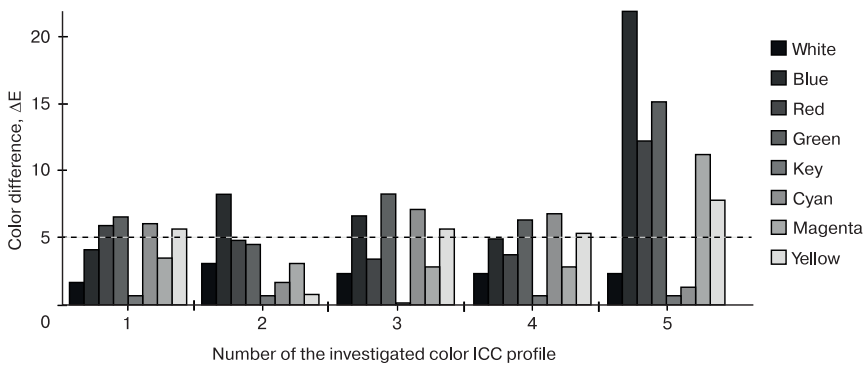

Fig. 5. Comparison of color reproduction quality of primary spot colors (CMYK + RGB) for photo imprints obtained using common ICC color profiles: 1 — Japan Color 2011 Coated, 2 — standard (None), 3 — GRACoL2013 CRPC6 (EFI), 4 — PSO Coated FOGRA51 (EFI) and 5 — PSO Uncoated FOGRA52 (EFI)

ISSN 2077-7264. Tekhnolohiia i tekhnika drukarstva. 2026. # 1(91)

Averaged measurements of color coordinates in the CIE Lab system for photo prints using different ICC profiles

Equipment	ICC-profile	The color under investigation	L	a	b	ΔE
Canon imagePress V700	Japan Color 2011 coated	White (material)	94,6	1,22	-4,15	1,65
		Blue	28,6	23,98	-44,89	4,1
		Red	45,55	59,83	30,63	5,9
		Green	54,12	-57,73	13,77	6,55
		Black	14,79	-0,29	0,03	0,66
		Cyan	60,12	-22,99	-45,45	6,04
		Magenta	46,35	72,22	-11,85	3,48
		Yellow	89,43	-14,1	85,98	5,64
		Key	16,87	-0,33	-0,45	0,66
	None	White (material)	95,25	1,48	-3,33	3,07
		Blue	24,55	31,62	-43,04	8,24
		Red	46,35	56,97	45,77	4,77
		Green	53	-63	28,45	4,5
		Black	16,56	-0,36	-0,39	0,66
		Cyan	56,85	-22,91	-48,08	1,67
		Magenta	45,54	73,08	-11,31	3,11
		Yellow	89,78	-15,24	92,48	0,8
		Key	17,25	-0,29	-0,47	0,66
	GRACoL 2013 CRPC6 (EFI)	White (material)	94,81	1,78	-4,09	2,33
		Blue	30,49	27,14	-43,11	6,67
		Red	46,88	57,46	36,9	3,44
		Green	56,97	-54,64	21,23	8,34
		Black	16	-0,31	-0,21	0
		Cyan	62,46	-22,98	-40,72	7,16
		Magenta	46,8	70,5	-10,73	2,8
		Yellow	88,49	-12,66	82,05	5,6
		Key	16,24	-0,34	-0,32	0
	PSO Coated FOGRA51 (EFI)	White (material)	94,65	1,57	-4,04	2,33
		Blue	29,09	25,75	-44,9	5
		Red	46,8	57,57	36,39	3,7
		Green	55,34	-58,01	22,22	6,3
		Black	14,87	-0,37	-0,22	0,66
		Cyan	62,68	-22,28	-42,91	6,82
		Magenta	45,82	72,55	-10,21	2,83
		Yellow	89,15	-13,26	83,67	5,35
		Key	14,64	-0,24	-0,18	0,66

ISSN 2077-7264. Технологія і техніка друкарства. 2026. № 1(91)

End of table

Equipment	ICC-profile	The color under investigation	L	a	b	ΔE
Canon imagePress V700	PSO Uncoated FOGRA 52 (EFI)	White (material)	95,38	1,83	-4,35	2,33
		Blue	50,05	11,12	-30,96	22
		Red	53,28	50,2	18,14	12,35
		Green	61,57	-37,69	11,06	15,18
		Black	14,55	-0,35	0,17	0,66
		Cyan	66,43	-17,07	-37,45	1,3
		Magenta	55,92	55,59	-8,79	11,24
		Yellow	88,95	-12,03	67,54	7,83
		Key	13,92	-0,28	-0,13	0,66

establish that the difference in the level of distortion for different colors is not uniform and can reach a maximum level of up to $\Delta E_{00} = 7$. Only one photo imprint using the ICC profile PSO Uncoated FOGRA52 (EFI) shows a significantly higher level of color distortion up to $\Delta E_{00} = 22$, which is explained by its non-compliance with the type of paper used for photo printing. Since most profiles are adapted specifically for use on glossy, not matte photo paper.

To establish the stability of color reproduction for imprints obtained using different ICC profiles, the interquartile range index was calculated and analyzed (Fig. 6). The most stable in terms of color reproduction were imprints using ICC profiles: Japan Color 2011 Coated with an index $\Delta E_{IQR} = 2.9$, PSO Coated FOGRA51 (EFI) with an index $\Delta E_{IQR} = 2.9$ and the standard profile (None) with an index $\Delta E_{IQR} = 3.1$. Accordingly, much worse stability is observed for imprints using the

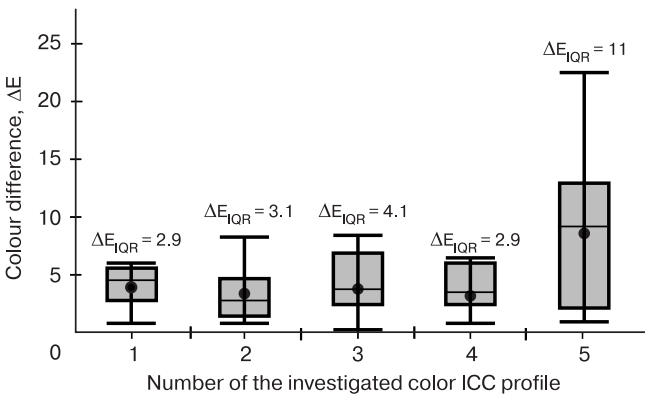

Fig. 6. Comparison of color reproduction stability by interquartile range (ΔE_{IQR}) for primary spot colors (CMYK + RGB) for photo imprints obtained using common ICC color profiles: 1 — Japan Color 2011 Coated, 2 — standard (None), 3 — GRACoL2013 CRPC6 (EFI), 4 — PSO Coated FOGRA51 (EFI) and 5 — PSO Uncoated FOGRA52 (EFI)

ISSN 2077-7264. Tekhnolohiia i tekhnika drukarstva. 2026. # 1(91)

ISSN 2077-7264. Технологія і техніка друкарства. 2026. № 1(91)

ICC profile PSO Uncoated FOGRA52 (EFI) with an index ΔE_{IQR} = 9.1.

During the analysis of the research results, the stability of tone reproduction was determined based on the interquartile range (ΔE_{IQR}) for the primary CMYK colors and gradations of 20 %, 40, 60, 80 % and 100 % when printing photos with a standard ICC printer profile on different types of photo paper: matte, semi-gloss, glossy and high-gloss. Analysis of the interquartile range (ΔE_{IQR}) revealed the most stable tone reproduction on high-gloss paper with an index of ΔE_{IQR} = = 1.4 (Fig. 7). The worst color reproduction stability is observed on matte photo paper with an index of ΔE_{IQR} = 3.7.

Also, to establish the influence of the applied method of processing digital photos on the quality of photo printing, the stability of color reproduction was analyzed by the interquartile range (ΔE_{IQR}) for the main spot colors (CMYK + RGB) on photo printing imprints with different types of photo paper. Digital photos were sequentially processed using the main color correction methods before photo printing (Fig. 8).

According to the analysis of experimental data, the nature of the influence of digital photo processing methods on the quality of photo printing was established. In particular, an increase in color reproduction stability of up to 10 % was found when applying auto-correction to photos in Photoshop (Fig. 8, a), which is typical for most types of photo paper. The only exception is photo imprints on semi-glossy paper. A slight improvement in color reproduction stability is observed on photo imprints when applying the correction method based on artificial intelligence (Fig. 8, b). In contrast, the use of the Camera Raw filter for color correction leads to a slight decrease in color reproduction stability in photo printing (Fig. 8, c) compared to the control unprocessed photo (Fig. 8, d). This can be explained by the fact that the Camera Raw filter is used

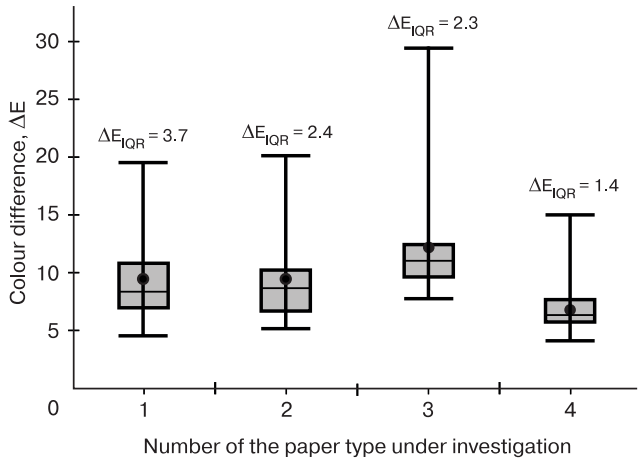

Fig. 7. Comparison of tone reproduction stability by interquartile range (ΔE_{IQR}) for analysis of basic colors (CMYK) for photo imprints obtained using different types of photo paper: 1 — matte, 2 — semi-gloss, 3 — glossy, 4 — high-gloss

with manual adjustment of correction parameters, which can slightly distort individual colors in the photo.

Conclusions

During the conducted analytical and patent research, stable trends towards further development of digital photography technologies were identified, in particular in photo processing methods and color stabilization methods using ICC profiles. Also, in the last 3–4 years, there has been significant scientific interest in improving methods of preparing photographs for photo printing.

The use of the developed test image of A5 format (Fig. 4) and the calculation of the interquartile range (ΔE_{IQR}) based on the data of measuring color differences (ΔE_{00}) of photo print imprints allowed us to establish the nature of the influence of technological parameters of the digital photo processing on the quality of photo imprint. In particular, a significant influence of the applied color ICC profile on the stability of color reproduction of the photo imprint was established. When using standard and adapted ICC profiles, which are intended for a certain type of photo paper, respectively,

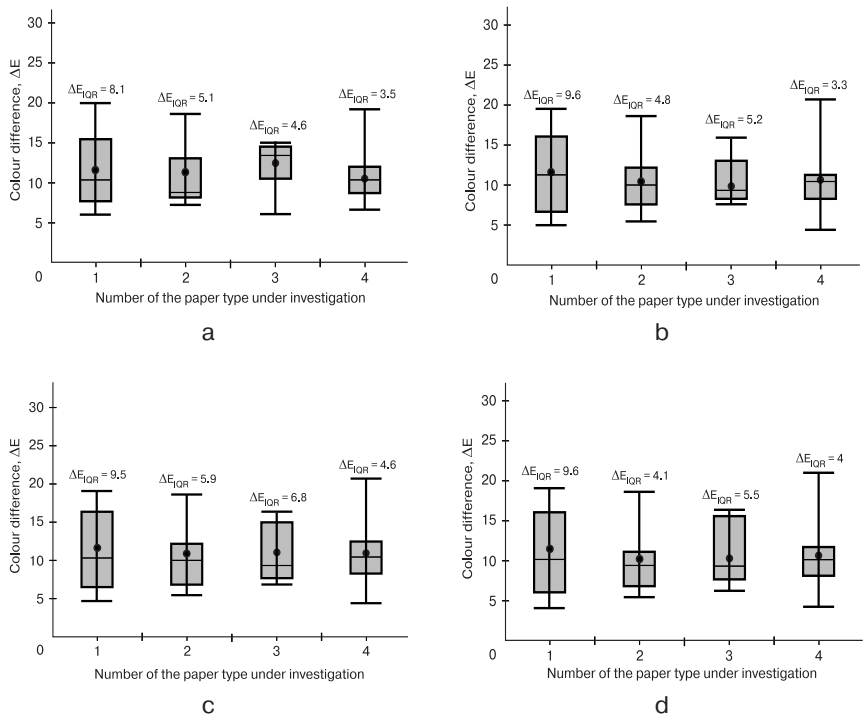

Fig. 8. Comparison of color reproduction stability by interquartile range (ΔE_{IQR}) for primary spot colors (CMYK + RGB) for photo imprints obtained using different types of photo paper: 1 — matte, 2 — semi-gloss, 3 — glossy, 4 — high-gloss, as well as different methods of photo color correction: a — auto-correction in Adobe Photoshop, b — photo correction method using artificial intelligence based on ChatGPT, c — Camera Raw filter, d — image without correction

ISSN 2077-7264. Tekhnolohiia i tekhnika drukarstva. 2026. # 1(91)

the stability of color reproduction can increase almost threefold (Fig. 5). Also, a more stable tone rendition was established when using high-gloss paper, compared to other types of photo paper (Fig. 7).

Analysis of digital photo processing methods for photo printing quality has established an increase in color reproduction stability of up to 10 % when using the standard auto-correction method in Adobe Photoshop. Other methods of photo color correction can improve the accuracy of reproduction of individual tone shades, but in general can slightly reduce the accuracy of color reproduction of individual tone shades.

Therefore, general recommendations for ensuring stable reproduction of photo imprints may include giving preference to the use of high-gloss paper, adapted ICC color profiles created based on calibration and profiling of the photo printing device, as well as the use of the standard auto-correction method in Adobe Photoshop.

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ISSN 2077-7264. Tekhnolohiia i tekhnika drukarstva. 2026. # 1(91)

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Дослідження процесу друку цифрових фотографій із різними методами опрацювання

В ході проведеного дослідження встановлено сталі тенденції до подальшого розвитку технологій цифрової фотографії, зокрема за методами обробки фотографії та методами стабілізації кольору із застосування ICC-профілів. Також, в останні 3–4 роки спостерігається значний науковий інтерес щодо удосконалення методів підготовки фотографій до фотодруку.

У роботі проаналізовано актуальні шляхи розвитку технологій цифрової фотографії. Запропоновано тестову форму та методику визначення стабільності кольоровідтворення при фотодруці.

Застосування розробленого тестового зображення формату А5 та розрахунок показника міжквартильного розмаху (ΔE_{IQR}) на основі даних вимірювання колірних відмінностей (ΔE_{00}) відбитків фотодруку дозволило встановити характер впливу технологічних параметрів процесу опрацювання цифрової фотографії на якість фотодруку. Зокрема, встановлено значний вплив застосованого колірного ICC-профілю на стабільність кольоровідтворення відбитку фотодруку.

Аналіз методів опрацювання цифрової фотографії на якість фотодруку встановив зростання стабільності кольоровідтворення до 10% при застосуванні стандартного методу автокорекції в програмі Adobe Photoshop. Інші методи колірної корекції фотографій можуть покращувати точність відтворення окремих відтінків тону, але в цілому можуть дещо знижувати точність кольоровідтворення окремих відтінків тону.

Загальні рекомендації забезпечення стабільного відтворення відбитків фотодруку у застосуванні високоглянцевого паперу, адаптованих колірних ICC-профілів створених на основі калібрування та профілювання пристрою фотодруку, а також застосування стандартного методу автокорекції в програмі Adobe Photoshop.

Ключові слова: цифрова фотографія; фотодрук; колірні відмінності; опрацювання графічної інформації; якість відбитків; патентний пошук; ICC-профілі; технології штучного інтелекту.

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