Models of the Influence of Factors on the Process of Digital Inkjet Printing of Photographic Images

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Abstract

The article presents the results of the study of the factors influence on the printing process of a photo image, including the possible deformation of photopaper. The main factors influencing the printing process quality are established, the oriented graph of the influence and dependencies of these factors is constructed. The analysis of the graph is carried out by the ranking method, which takes into account direct and indirect influences and dependencies between the factors; their priority is calculated. It has been found that the most priority factors are the photopaper weight, the print resolution and the filling area with the following calculated weights: 85, 105, 80 units respectively. These factors have been used to analyse their impact on the inkjet printing process by fuzzy logic. Accordingly, a universal set and corresponding terms have been established in the form of linguistic variables for these factors. Based on the analysis results of the inkjet printing process, a fuzzy knowledge base with the condition "If-Then" has been formed, fuzzy logical equations have been constructed and one of the variants of the factors influence on the inkjet printing process of a photo image is calculated by the defuzzyfication operation according to the "centre of gravity" principle. The formed knowledge base has been verified with the help of the Fuzzy Logic Toolbox system of the Matlab technological calculation environment and the corresponding models have been constructed.

Keywords 1

Inkjet printing, Photopaper, Quality factors, Oriented graph, Fuzzy logic, Linguistic variable, Membership function

1. Introduction

The development of digital inkjet technologies has given a push not only to the development of printing processes, but it has also made it possible to print high-quality photos. The results of analytical studies show that the global photopaper market was valued at 1340.8 million in 2020 and is projected to reach US $ 1541.1 million by 2027, at a CAGR of 3.5% during the forecast period [1, 2], which indicates the further success of the application of inkjet digital technology for photo printing.

Manufacturers of photo printers, and not only, offer a wide range of photopaper on the market, which differs in both optical surface parameters (matte, gloss, high-gloss) and weight of 1 m^2, as well as physico-chemical structure of the surface (gel or micro-porous coating) [3, 4]. The leaders in manufacturing of ink and photopaper are the companies: Fujifilm, Kodak, Canon, China Lucky, ColorWay, Hewlett-Packard (HP), Epson, Brother, Polaroid, Shantou Xinxie Special Paper Technology, ILFORD Imaging Europe, Polaroid, Hahnemühle, FOMA BOHEMIA, ADOX Fotowerke.

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2. Literature Review

The peculiarity of photo images printing is the use of dyes and pigments water-based inks-jet [5, 6, 7, 8]. The presence of water in the ink ensures its environmental friendliness and applicability at home on the one hand, and on the other hand, it leads to paper deformation due to excessive moisture. Such specific features of the ink require the use of photo media. The analysis of the patents of leaders in the development of digital inkjet technologies has shown that such media (photopapers) are multilayer systems [9, 10]. They have one or two recording layers, a cellulose base protected by polymer coatings in most cases. The capillary structure is formed by a layer of silicon oxide, aluminium hydroxide and other white fine powders, their mixtures, and water absorption is provided by the presence of water-soluble polymers [11]. The greater the need to absorb water during printing is, the greater the thickness of the multilayer paper recording system is formed in the photopaper production process. Accordingly, the photopaper weight increases. Better colour reproduction, brightness, saturation, clear lines, the required optical image density and minimal deformation of the photopaper are achieved with such coatings on photopaper.

If the inkjet printing process is considered, it primarily depends on such factors as the print resolution, i.e. the capabilities of the photo printer and its printing heads. Most photo printers allow one to print with a maximum resolution of up to 5760 dpi and receive high quality photos accordingly. The minimum ink droplet volume is approximately 1.5 picoliter. As mentioned above, a significant role in obtaining a high-quality photo image is played by the surface type and the photopaper weight. There are guidelines for selecting the photopaper depending on the print resolution, because the more droplets are injected per inch of the image media, the more water it will absorb. Photopaper weighing 150 g/m^2 is recommended for photo images printing with the resolution of up to 2880 dpi. Thinner paper is easily deformed, torn, and it quickly fades. Consumables of larger weight – 300 g/m^2 – are needed for photos with the resolution of up to 5760 dpi [12, 13].

Thus, photopaper is a multilayer system whose task is to ensure the accuracy of a digital image reproduction and prevent its distortion during the operation, primarily to minimize its deformation during the application of water inks.

Another factor that affects the photopaper deformation during printing is the image filling area. To determine the impact of this parameter, a survey has been conducted among owners of photo printers and companies specializing in the provision of photo printing services. The experts were offered a questionnaire where it was necessary to indicate how the image filling area from 40 to 100% affects the printing process quality in which the photopaper has no deformation. The answers have a fuzzy form, because it is indicated by the terms <high, medium, low>, which allowed the use of survey results for modelling by fuzzy logic. The examples of successful use of the fuzzy logic principles in the printing sphere are well known, namely for quantitative assessment of the flexographic printing quality [14], the analysis of digitization process of old books [15], forecasting the quality of classical printing processes [16].

At insignificant filling of photopaper there is a question of expediency of use of high weight photopaper, which is usually more expensive and accordingly, increases the photo cost.

This paper is devoted to constructing models to establish the factors priority and determine their optimal parameters for the inkjet printing process of photographs by using the fuzzy logic tool.

3. Methods, Results and Discussions

3.1. Analysis of Factors by Ranking Method

Identification of funding sources and other support, and thanks to individuals and groups that assisted At the first stage of our study, the factors priority is established by the ranking method [17]. The set of factors that determine the inkjet process quality is a set F=(f_1, f_2, f_3... f_n). The selected factors are denoted by mnemonic names for clarity:

f_1 – Photopaper Weight (PW);

f_2 – Print Resolution (PR);

f_3 – Surface Type (ST);

f_4 – Inkjet Type (IT);
f_5 – Filling Area (AR);
f_6 – Photopaper Deformation (PD).

The set of factors F and possible relationships between them are presented in the form of an oriented graph (Figure 1). The vertices of the graph indicate the presence of the set elements, and the arcs connect these vertices according to the established connections.

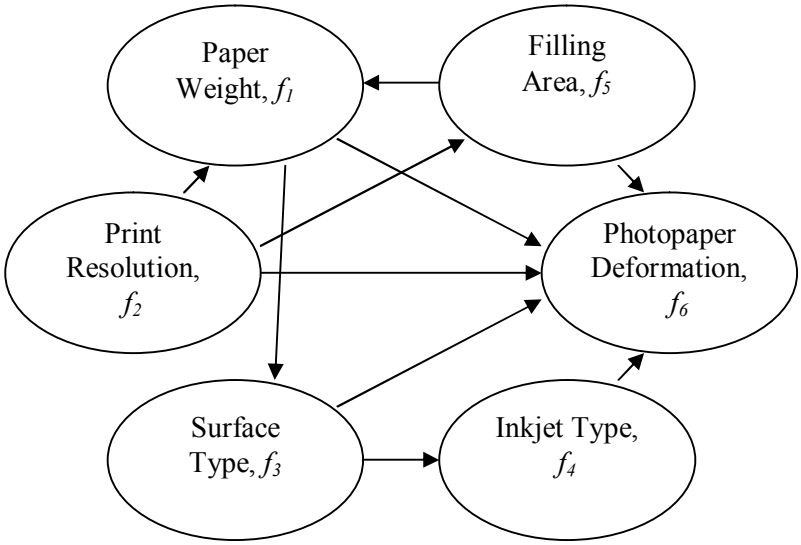


Figure 1: Oriented graph of factors of the inkjet printing process

The number of calculated influences and dependences for each of the factors is schematically shown in Figure 2. Based on the oriented graph (Figure 1), we construct for each of the factors hierarchical trees of their relationship with other factors (Figure 3).

The calculation of the total weight value and the rank for each factor, taking into account their direct and indirect influences and the integral dependency on other factors is as follows.

For our oriented graph, the following conditions are set:

1. Let k_{ij} – is a number of influences ($i = 1$ – direct and $i = 2$ – indirect) or dependencies ($i = 3$ – direct, $i = 4$ – indirect) for j-th factor ($j = 1,...,n$); w_i - is the weight of i-th type.

2. If a factor does not have one of the connection types, its corresponding value will be zero.

3. The conditional values for the weight coefficients of direct and indirect influences in conventional units are the following: $w_1 = 10$, $w_2 = 5$, $w_3 = -10$, $w_4 = -5$;

3. The total weight values are denoted by S_{ij}:

$$S_{ij} = k_{ij} w_i \ (i = 1,2,3,4;\ j = 1,...,n), \tag{1}$$

where n – is the number of the factor.

4. For the oriented graph (Fig. 1) in view of (1), the formula for calculating the total weight values for each factor is received:

$$S_{ij} = \sum_{i=1}^{4} \sum_{j=1}^{6} k_{ij} w_i \ , \tag{2}$$

5. The weight values are $S_{3j} < 0$ and $S_{4j} < 0$, because according to the given initial conditions $w_3 < 0$ and $w_4 < 0$.

6. To reduce the total weight values of the factor with the lowest priority to zero and the rest to a positive value, the formula (2) is transformed into the form:

$$S_{Fj} = \sum_{i=1}^{4} \sum_{j=1}^{6} k_{ij} w_i + \max\left|S_{3j}\right| + \max\left|S_{4j}\right| \tag{3}$$

To establish the number of influences and dependencies of factors, direct influences are determined for each of them, the number of which is fixed by coefficients k_{1j}. "Dependency ways"

are determined by obtaining the coefficients k_{3j}. The combined consideration of indirect influences or dependencies of the factor (i.e. the influence or dependency due to other factors) determines the coefficients k_{2j} and k_{4j}.

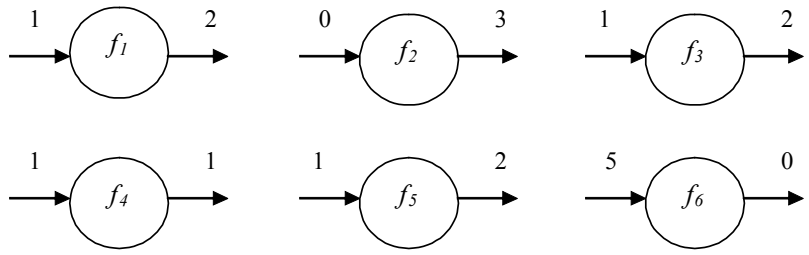


Figure 2: Number of influences and dependencies of factors

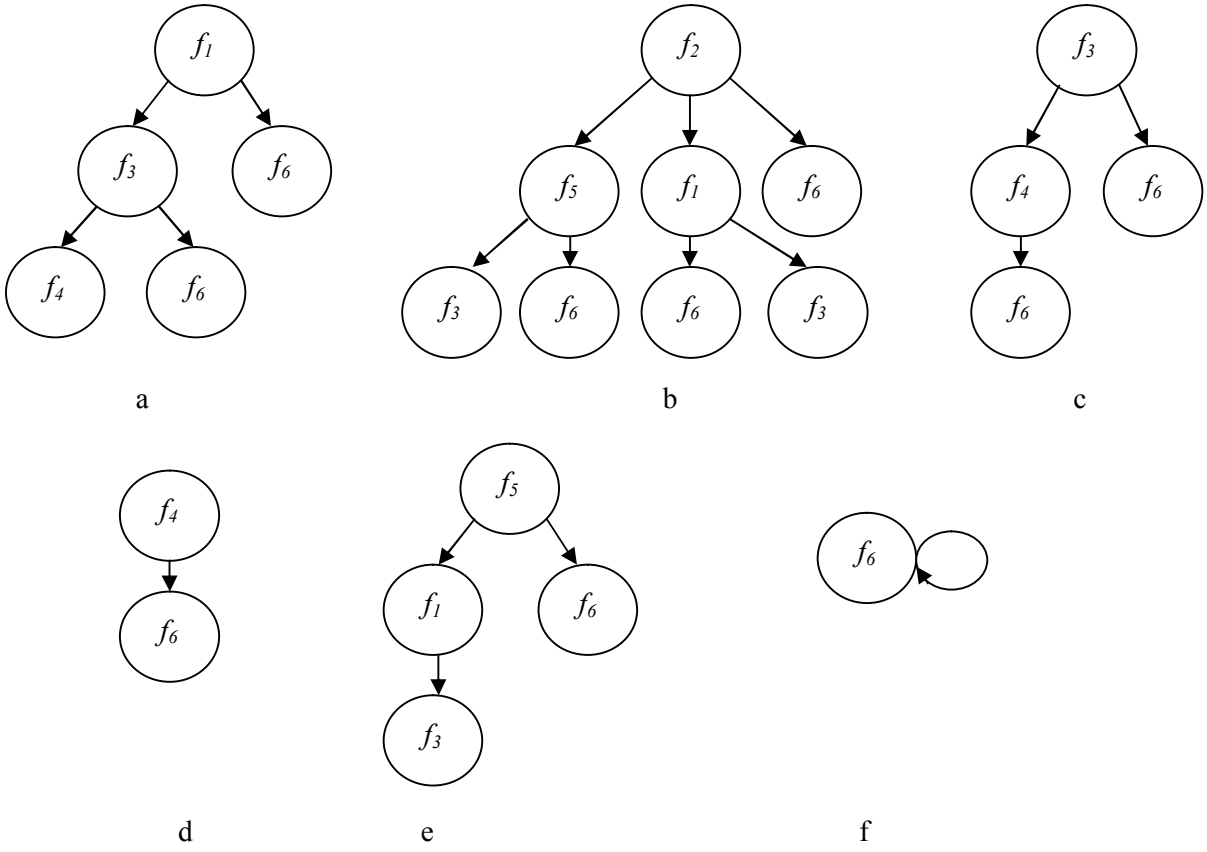


Figure 3: Direct and indirect influences of factors of the inkjet printing process (a – f)

According to the calculations, the table with the subsequent establishment of factors ranks is formed (Table 1).

Table 1 Calculated data of factor ranking

Factor number j	k_{1J}	k_{2J}	k_{3J}	k_{4J}	S_{1J}	S_{2J}	S_{3J}	S_{4J}	S_{FJ}	Factor rank r_j
PW, f_1	2	2	1	0	20	10	-10	0	85	2
PR, f_2	3	2	0	0	30	10	0	0	105	1
ST, f_3	2	1	1	2	20	5	-10	-10	70	4
IT, f_4	1	0	1	2	10	0	-10	-10	55	5
AR, f_5	2	1	1	0	20	5	-10	0	80	3
PD, f_6	0	0	5	3	0	0	-50	-15	0	6

As it can be seen from the table, $\max|S_{3j}| = 50$; $\max|S_{4j}| = 15$. The specified values are added in each of the rows to the sum of the values in the columns S_{1j} , S_{2j} S_{3j} , and S_{4j} . Finally, the resulting weight of the factor is obtained, which serves as a basis for establishing the factor rank, which is equivalent to the priority of its influence on the inkjet printing process. The maximum rank belongs to the factor with the highest weight value S_{Fj} . According to the obtained result, a multilevel model of the influence of the studied factors is constructed (Figure 4).

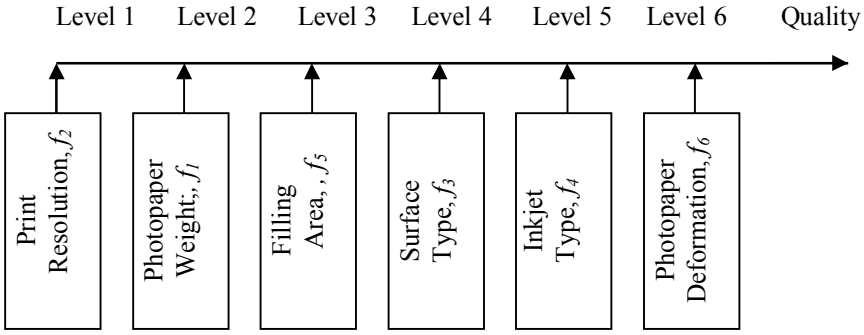


Figure 4: Multilevel model of factors influence on the photo inkjet printing quality

3.2. Construction of a model of factors influence on the basis of fuzzy logic

In general, fuzzy logic is the logic that operates with linguistic variables using rules that reflect the principles of human reasoning and are close to ordinary spoken language in their structure [18]. The concept of a linguistic variable was introduced in the work of Latfi Zadeh, who laid the foundations of fuzzy logic. The advantages of fuzzy logic systems make it possible to operate with fuzzy input data. The main stage of fuzzy logic is the fuzzyfication operation, i.e. the transformation of the original numerical data into a distribution that corresponds to the terms of the linguistic variable. In this case, each numerical value is described by one or more terms, and its degree of correspondence to the term is given as the degree of belonging to a fuzzy set [19].

The quality of the photo inkjet printing process Q depends on the priority factors presented as linguistic variables such as photopaper weight (PW), print resolution (PR) and image filling area (AR):

$$Q = f(PW, PR, AR) \quad (4)$$

These linguistic variables, which ensure the quality of the photo images printing process and assessment terms, are presented in Table 2.

Table 2 Linguistic variables of of factors influence on the photo inkjet printing quality

№	Variable	Universal set	Assessment terms
1	Photopaper Weight (PW), g/m^2	150-300	Low Medium Big
2	Print Resolution (PR), dpi	1440-5760	Low Satisfactory High
3	Filling Area (AR), %	40-100	Low Medium High

The logical scheme of the influence of priority factors of the process of inkjet printing of photographic images is shown in Figure 5.

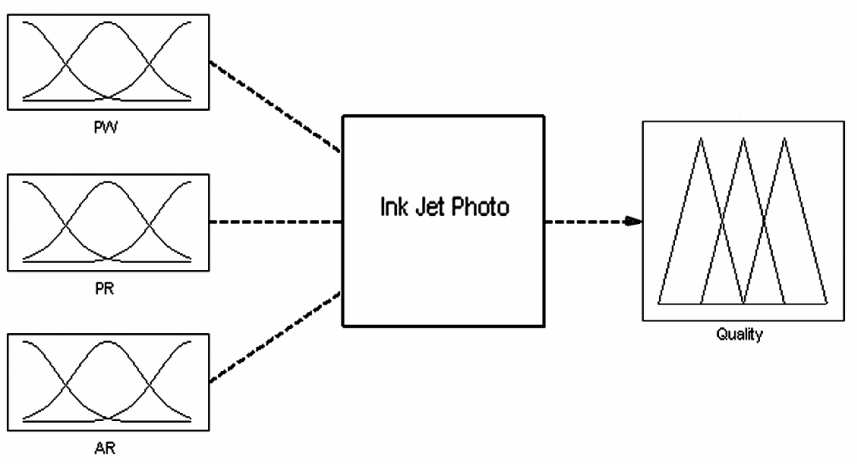


Figure 5: Logical scheme of the influence of priority factors of the process of photo inkjet printing quality

As a result, the expert knowledge base which corresponds to the inkjet photo printing process for the highest level can be presented as follows:

if (PW = Low) or (PW = Medium) or (PW = Big)
and (PR = Low) or (PR = Satisfactory) or (PR = High)
and (AR = Low) or (AR = Medium) or (AR = High)
then (Q = Low) or (Q = Medium) or (Q = High)

Based on technical recommendations and expert statements on the factors influence on the inkjet printing quality, in which the photopaper deformation will be minimal, the membership functions are constructed. Accordingly, the value of the variable "Photopaper Weight" is determined on the universal set: u_1= 150 g/m^2; u_2= 190 g/m^2; u_3= 230 g/m^2; u_4= 270 g/m^2; u_5= 300 g/m^2.

To linguistically assess this parameter, a set of fuzzy terms is used: T (x) = <Low, Medium, Big>. In accordance with these terms, the membership functions of the linguistic variable "Photopaper Weight" are obtained. The value of the variable in the form of fuzzy sets is as follows:

$$\text{Photopaper Weight is Low} = \left(\frac{1}{150};\frac{0,89}{190};\frac{0,78}{230};\frac{0,22}{270};\frac{0,11}{300}\right),\ \text{g/m}^2;$$

$$\text{Photopaper Weight is Medium} = \left(\frac{0,11}{150};\frac{0,78}{190};\frac{1}{230};\frac{0,78}{270};\frac{11}{300}\right),\ \text{g/m}^2;$$

$$\text{Photopaper Weight is Big} = \left(\frac{0,11}{150};\frac{0,22}{190};\frac{0,78}{230};\frac{0,89}{270};\frac{1}{300}\right),\ \text{g/m}^2.$$

For the linguistic variable "Print Resolution", the parameter is defined on the universal set: u_1= 1440 dpi; u_2= 2520 dpi; u_3= 3600 dpi; u_4= 4680 dpi; u_5= 5760 dpi. To assess the variable, a set of fuzzy terms is used: T (y) = <Low, Satisfactory, High>. Therefore, in relation to this parameter according to these terms, the value of this variable in the form of fuzzy sets is received as follows:

$$\text{Print Resolution is Low} = \left(\frac{1}{1440};\frac{0,88}{2520};\frac{0,55}{3600};\frac{0,33}{4680};\frac{0,11}{5760}\right),\ \text{dpi};$$

$$\text{Print Resolution is Satisfactory} = \left(\frac{0,11}{1440};\frac{0,55}{2520};\frac{1}{3600};\frac{0,55}{4680};\frac{0,11}{5760}\right),\ \text{dpi};$$

$$\text{Print Resolution is High} = \left(\frac{0,11}{1440};\frac{0,33}{2520};\frac{0,55}{3600};\frac{0,88}{4680};\frac{1}{5760}\right),\ \text{dpi}.$$

The linguistic variable "Filling Area", as another factor in the inkjet process quality, is defined on the universal set: u_1= 40 %; u_2= 55 %; u_3= 70 %; u_4= 85 %; u_5= 100 %. For linguistic assessment of the parameter, a set of fuzzy terms is used: T (z) = <Low, Medium, High>.

Different values of the variable "Filling Area" are presented in the form of fuzzy sets:

$$\text{Filling Area is Low} = \left(\frac{1}{40};\frac{0,89}{55};\frac{0,78}{70};\frac{0,22}{85};\frac{0,11}{100}\right),\ \%;$$

$$\text{Filling Area is Medium} = \left(\frac{0,11}{40};\frac{0,78}{55};\frac{1}{70};\frac{0,78}{85};\frac{11}{100}\right),\ \%;$$

$$\text{Filling High Area is High} = \left(\frac{0,11}{40};\frac{0,22}{55};\frac{0,78}{70};\frac{0,89}{85};\frac{1}{100}\right),\ \%.$$

A fuzzy knowledge base is formed on the selected quality parameters of the inkjet printing process:

1. For the photo inkjet printing quality term «Low»:

- If «Photopaper Weight» is «Low», «Print Resolution» is «High», «Filling Area» is «High», then Q is «Low»

or

- If «Photopaper Weight» is «Medium», «Print Resolution» is «Satisfactory», «Filling Area» is «High», then Q is «Low»

2. For the photo inkjet printing quality term «Medium»:

- If «Photopaper Weight» is «Medium», «Print Resolution» is «Satisfactory», «Filling Area» is «Medium», then Q is «Medium»

or

- If «Photopaper Weight» is «Low», «Print Resolution» is «Satisfactory», « Filling Area» is «Low», then Q is «Medium»

3. For the photo inkjet printing quality term «High»:

- If «Photopaper Weight» is «Big», «Print Resolution» is «High», «Filling Area» is «High», then Q is «High»

or

- If «Photopaper Weight» is «Big», «Print Resolution» is «Satisfactory», «Filling Area» is «Medium», then Q is «High».

According to the knowledge base, fuzzy logical equations are formed to ensure the quality of the inkjet printing process of photo images:

$$\begin{aligned}
\mu^{low}(Q) &= \mu^{low}(PW) \wedge \mu^{high}(PR) \wedge \mu^{high}(AR) \vee \mu^{med}(PW) \wedge \mu^{sat}(PR) \wedge \mu^{high}(AR); \\
\mu^{med}(Q) &= \mu^{med}(PW) \wedge \mu^{sat}(PR) \wedge \mu^{med}(AR) \vee \mu^{low}(PW) \wedge \mu^{sat}(PR) \wedge \mu^{low}(AR); \\
\mu^{high}(Q) &= \mu^{big}(PW) \wedge \mu^{high}(PR) \wedge \mu^{high}(AD) \vee \mu^{big}(PW) \wedge \mu^{sat}(PR) \wedge \mu^{med}(AR).
\end{aligned} \tag{5}$$

When substituting the degrees of belonging to the system of fuzzy logical equations, one of the options for calculating the quality of the printing process of a photo image is obtained:

$$\mu^{low} = 0,89 \wedge 0,33 \wedge 0,22 \vee 0,78 \wedge 0,55 \wedge 0,22 = 0,22$$

$$\mu^{med} = 0,78 \wedge 0,55 \wedge 0,78 \vee 0,89 \wedge 0,55 \wedge 0,89 = 0,55$$

$$\mu^{high} = 0,89 \wedge 0,88 \wedge 0,89 \vee 0,89 \wedge 0,55 \wedge 0,78 = 0,88$$

The notation $\wedge$ and $\vee$ are the operations of determining the minimum and maximum in logical equations.

Let one set the upper and lower limit of the inkjet printing process quality Q, namely: lower is 1%, upper is 100%.

After performing the defuzzyfication operation using the factors values, the numerical value of the quality parameter of the inkjet printing process is obtained. To do this, the formula according to the "centre of gravity" principle is used [19]:

$$Q = f(PW, PR, AR) = \frac{\sum_{i=1}^{m} u_i \cdot \mu(u_i)}{\sum_{i=1}^{m} \mu(u_i)} \quad (6)$$

Therefore, having performed the defuzzyfication operation, a quantitative parameter of the process quality is obtained:

$$Q = \frac{1 \cdot 0,22 + 50 \cdot 0,55 + 100 \cdot 0,88}{0,22 + 0,55 + 0,88} = 70,13\%$$

To test the knowledge base and construct a model of the influence of priority factors, a system for developing fuzzy control systems – Fuzzy Logic Toolbox system of the Matlab technological calculation environment and Mamdani principle is used [20]. For the defuzzyfication operation, the "centre of gravity" principle is used [18]. Figure 6 presents the constructed membership functions for three linguistic variables.

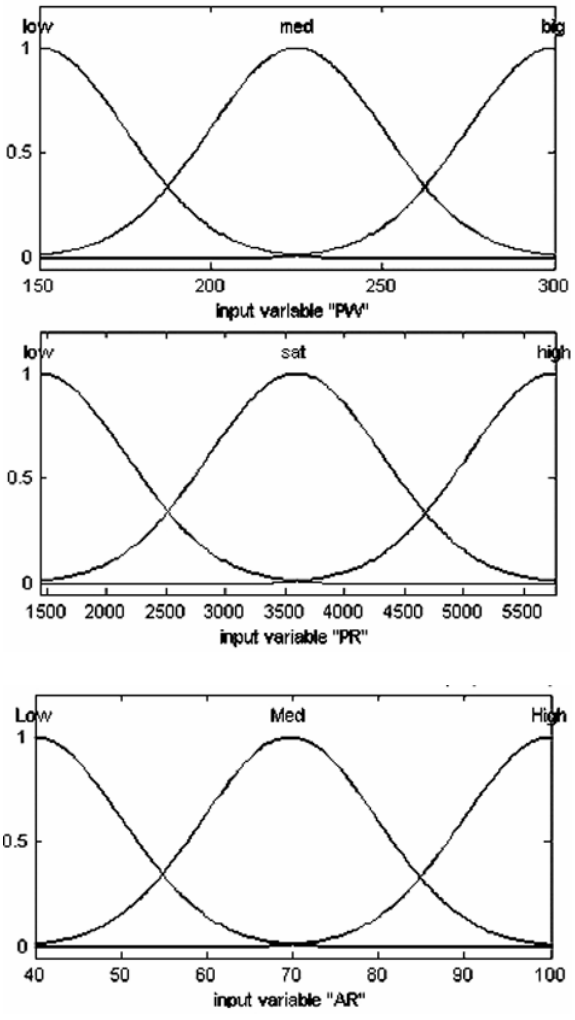
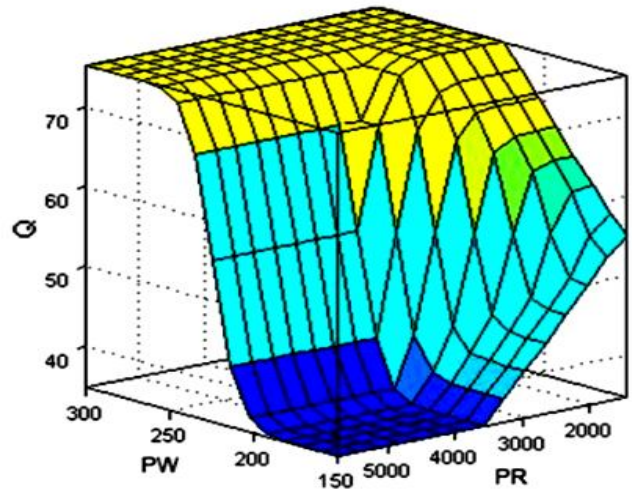


Figure 6: Membership functions of the linguistic variables: a – Photopaper Weight; b – Print Resolution; c – Filling Area



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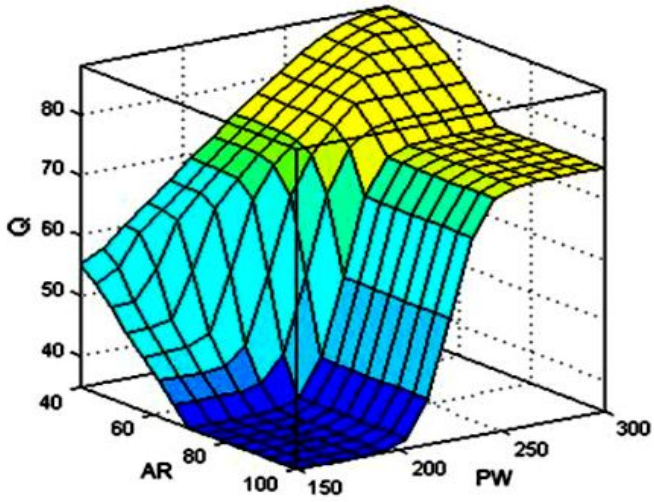

b

Figure 7: Model of influence of the factors on quality ink jet printing process: a – the influence of Photopaper Weight and Print Resolution; b – the influence of Filling Area and Photopaper Weight

The simulation results (Figure 7) show the adequacy of the developed knowledge base and the possibility of its use for forecasting assessment of the process quality when selecting the photopaper weight depending on the print resolution and the image filling area.

4. Conclusions

Thus, the quality factors of inkjet printing of photo images have been studied in the paper. By constructing an oriented graph of the influence and dependencies of factors and the ranking method, the factors priority has been established by giving them the appropriate weight value and constructing the appropriate model. The advantage of the ranking method used is that it takes into account not only direct influences and dependencies between factors, but also indirect ones, which allows to clearly establish their weight values, i.e. priority. Thus, the highest priority is given to the photopaper weight, the print resolution and the filling area with the following calculated weights: 85, 105, 80 units, respectively.

As a result of the simulation process of the influence of priority factors, implemented using fuzzy logic, a matrix of knowledge and fuzzy logical equations are formed to calculate the membership functions of linguistic variables with the corresponding given terms. Their analysis using the "If-Then" condition and the defuzzyfication operation has allowed obtaining a quantitative assessment of

the quality of the inkjet printing process. In addition, with the help of Fuzzy Logic Toolbox system of the Matlab technological calculation environment, models of the influence of the print resolution, the photopaper weight and the image filling area have been constructed, which will allow to select the paper weight a priori depending on other factors to ensure sufficient quality of photo printing process.

5. References

[1] Global Photo Paper Market Overview, Size, Share and Trends 2021, 2021. URL: ttps://www.marketwatch.com/press-release/global-photo-paper-market-overview-size-share-and-trends-2021-2021-03-11?tesla=y.

[2] Papers for Inkjet Photo Printers. Guide to Photo Papers, 2020. URL: https://www.fomei.com/en/guide-to-photo-papers.

[3] M. Akihiro, Y. Masataka, 1998, Opaquing Recording Method For Transparent Recording Medium And Recording Medium, Patent JP H10244662A, Canon KK, Earliest priority: March 07, 1997, Earliest publication: September 14, 1998.

[4] Shibahara Yoshihiko, Yabuki Yoshiharu, Picture Recording Medium, Patent JP H11348408A (1999), Fuji Photo Film Co Ltd, Earliest priority: August 06, 1998, Earliest publication: December 21, 1999.

[5] I. Hirobumi, K. Hiromitsu, 2008, Water-Based Curable Ink For Ink Jet And Ink Jet-Recording Method JP2008184546A CANON KK, Earliest priority: January, 2007, Earliest publication: 14 August, 2008.

[6] O. Masakazu; C. Kosuke; M. Toshiyuk, 2019, "Pigment printing ink jet ink composition and pigment printing ink jet recording method", Patent CN110358360 (A), Seiko Epson Corp., Publ. October 22, 2019.

[7] Patent JP2010229251 (A), 2010, "Ink Composition For Ink Jet Printing And Printing Method", Seiko Epson Corp, October 14, 2010.

[8] Ink Composition, and Ink Jet Recording Method and Recorded Matter Using the Same, Patent US 2008047461 (A1), 2008, Seiko Epson Corp., Publ. February 28, 2008.

[9] Photo-media printing using an opaque backing layer, Patent GB2362852A (B), 2001, Hewlett Packard Co, Earliest priority: March 27, 2000, Earliest publication: November 13, 2001.

[10] E. L. Burch, Pierre-Alain Brugger, M. Staiger, Porous inkjet receiver layer with a binder gradient, Patent US 6872430, 2002, Hewlett-Packard Development Company, Filed: May 31, 2002.

[11] T. Joseph, M. Edward, Inkjet receiving media, Patent US 10858530, 2018, Eastman Kodak Company, Filed: August 21, 2018.

[12] Which photo paper is best for inkjet printers, 2013, URL: https://bz.g-m-i.net/2111-which-photo-paper-is-best-for-inkjet-printers.html.

[13] Which photo paper is best for inkjet printers: important criteria for choosing photo paper for an inkjet printer, URL: https://hundred-worries.com/en/advices/15445.

[14] V. Repeta, Yu. Kukura, 2016, "Quantitative Evaluation of Quality of Flexographic Prints by Means of Fuzzy Logic", Acta Graphica, 2016, № 1, pp. 39-46.

[15] O. Tsimer, V. Repeta, I. Myklushka, 2020, "Analysis of Quality Factors for for digitization Process of old Books", Journal of Graphic Engineering and Design, 2020, Vol. 11, № 2, pp. 5-8.

[16] V. Senkivskyy, I.Pikh, N. Senkivska et al, Forecasting assessment of printing process quality, ISDMCI 2020: Lecture Notes in Computational Intelligence and Decision Making, Springer, pp 467-479.

[17] V. Senkivskyy, I. Pich, O. Melnykov, 2013, "The method of ranking factors influencing the quality and manufacturing processes". Printing and Publishing, pp.61-62 (1-2), 33-41.

[18] L. Zadeh, 1970, "Decision-Making in Fuzzy Environment, Management Science", 1970, vol. 17, 4, pp. 141-160.

[19] A. Rotshteyn, 1999, "Intelligent identification technologies: fuzzy sets, neural networks, genetic algorithms", UNIVERSUM-Vinnytsya, 1999, 320 p.

[20] E. Mamdani, S. Assilian, 1975, "An experiment in linguistic synthesis with a fuzzy logic controller", International Journal of Man-Machine Studies, 1975, vol. 7, 1, pp. 1-13.