ISSN-L 2664-9969; E-ISSN 2706-5448

UDC 655.226(5)
DOI: 10.15587/2706-5448.2025.337277

Sviatoslav Kavyn

DEVELOPMENT OF A MODEL OF RASTER POWER-LINEAR CONVERSION OF DIGITAL IMAGES OF LIGHT TONES

The object of research is the technological process of raster conversion of digital images based on power-linear transformation at the stage of preparation for printing.

The problem in the processes of prepress preparation is the lack of functionality in available computer image processing programs to construct the characteristics of the raster conversion, which are the main carrier of information about the image. Accordingly, this limits the capabilities of the reproduction process and leads to a loss of image quality on the print.

The work used the method of mathematical modeling, the theory of digital image conversion, and object-oriented programming. To solve the problems set, typical variants of power-linear transformation of digital images of different tonalities were constructed. In the process of the study, algorithms for raster transformation of different lineatures were developed, which are the main carrier of information about the image. Simulators for simulation modeling, analysis, and synthesis of power-linear transformation were built, ensuring high-quality tone reproduction of images of different lineatures.

A mathematical model of raster conversion of typical variants of power-linear conversion of digital images for light tones has been developed and new rasterization algorithms have been proposed. Based on them, a structural diagram of a simulator of raster power-linear conversion of images of light tones has been developed in the MATLAB:Simulink package, with which it is possible to calculate and construct gradation characteristics, rasterization characteristics and analyze their properties.

The proposed model of algorithms for raster power-linear conversion of digital images eliminates posterization of images in dark areas, which is an advantage of the developed new raster conversion algorithms using power-linear transformation.

The results of the conducted studies of raster tone reproduction can be recommended to operators and technologists for use in pre-printing processes at the stage of raster conversion of digital images.

Keywords: *power-linear conversion, raster tone reproduction, simulator, gradation characteristics, raster conversion characteristics.*

Received: 23.05.2025
Received in revised form: 12.07.2025
Accepted: 02.08.2025
Published: 29.08.2025

How to cite

Kavyn, S. (2025). Development of a model of raster power-linear conversion of digital images of light tones. Technology Audit and Production Reserves, 4 (2 (84)), 60–64. https://doi.org/10.15587/2706-5448.2025.337277

1. Introduction

There are various methods and modern algorithms of raster conversion, in particular frequency-modulated, hybrid rasters, various variants of stochastic rasterization, rasters of individual companies, which ensure the quality of printed publications [1, 2]. They increase the quality of images under the condition of strict standardization of technological processes, materials, equipment, as well as the presence of an automated system of zonal ink supply for a given circulation, which significantly limits the use of the latest rasters [3, 4].

Modern raster conversion of digital images is carried out using a raster processor (RIP), in which it is possible to specify a square, round or oval shape of raster elements and their linework. Let's note that the given shapes and especially the square shape of the elements greatly darken the image and the phenomenon of posterization occurs – visually noticeable transitions from one level to another in dark areas of the image [5, 6]. In computer publishing systems, available computer graphics programs and raster processors do not provide a program for constructing raster transformation characteristics, which are the main carrier of information about the tone of the image. Therefore, the operator is unable to evaluate the results of raster transformation, which are necessary for the manufacture of printing plates. Incorrectly selected or specified raster transformation characteristics lead to a loss of image quality on the printout. There is little information in available sources on the quantitative assessment of the properties of rasterization algorithms, which limits the possibilities of the reproduction process. Therefore, the development and analysis of new rasterization algorithms based on power-linear transformation of digital images for light tones is an urgent task. When preparing images for printing, its scanned version almost always requires correction, including tone correction. Scanned images are mostly too dark and, accordingly, with unclear tone separation [7, 8]. Today, the main method of image correction is the traditional power (gamma) transformation, which is generally expressed as [9, 10]

$$L_{out} = L_{in}^{r}, \qquad (1)$$

where L_{in} and L_{out} – the gradation characteristics of the input and rasterized images, r is the power exponent. If the power exponent is set within $1 \le r \le 3$, the image transformation darkens, while at $0.3 \le r \le 1$ it brightens. In sources [11, 12] it is noted that at $r \le 0.4$ and $r \ge 1.4$ the power transformation causes posterization (the appearance of visually noticeable transitions from one level to another in dark areas of the image).

In works [13, 14], general information about the technology of raster transformation, raster tone transmission and coordination of tone reproduction ranges is given. Depending on the selected rasterization algorithm, in general terms it is described by the expression

$$S = F\left(L_{out}\right), \tag{2}$$

where S – the relative area of raster elements, $F(\circ)$ is a function that depends on the selected raster transformation algorithm, the shape of the raster elements, etc.

If the original image L_{out} was corrected based on the power (gamma) transformation, then posterization occurs in the raster transformed image accordingly. Therefore, the study of the properties of the raster power-linear transformation is a relevant task. Hence, *the aim of research* is to develop models of typical variants of the power-linear transformation of digital images and to perform their rasterization. Based on these models, to build a structural diagram of the model of the raster transformation simulator and analyze its properties.

2. Materials and Methods

The object of research is the technological process of raster transformation of digital images based on the power-linear transformation at the stage of preparation for printing.

In the process of conducting research on raster tone reproduction at the stage of pre-press correction using quantitative indicators of image properties, the following scientific methods were used:

– *mathematical modeling methods* for building mathematical models of typical variants of power-linear transformation of digital images of different tonalities for the purpose of analyzing and synthesizing pre-press correction of images;
– *the theory of digital image conversion* for correcting images of different tonalities and developing algorithms for raster transformation of different lineatures, which are the main carrier of image information in order to expand the functionality of pre-press image processing;
– *object-oriented programming* for developing simulators for simulating raster power-linear transformation of digital images in order to ensure high-quality tone reproduction of images of different lineatures.

The modeling was carried out in the MATLAB software environment using the Simulink interactive package. Operational blocks and software tools from the Simulink library were used for modeling. Mathematical function blocks are used to calculate the gradation characteristics, optical density and contrast sensitivity of the raster power-linear transformation of digital images for light tones. The Curves software tool is used to correct the images. The description of the functioning of the simulator of the raster power-linear transformation of digital images of different tones is presented based on the operators of the MATLAB application: Simulink.

3. Results and Discussion

The functional capabilities of the power gamma transformation can be expanded by modifying it by introducing an additional linear component, resulting in a power-linear transformation of images. Three typical variants of power-linear transformation of light tone images were developed for the study:

$$L_1 = (2L_0 - L_0^2)\cdot 255, \tag{3}$$

$$L_2 = (2L_0 - L_0^{1,6})\cdot 255, \tag{4}$$

$$L_3 = (2L_0 - L_0^{1,3})\cdot 255, \text{ if } 0 \le L_0 \le 1 \text{ and } 0 \le L_i \le 255, \tag{5}$$

where L_0 – the linear scale.

Let's perform rasterization of typical options for power-linear transformation of digital images of light tones

$$S_i = \frac{1}{255}\cdot\left(1 - L_i\right), \tag{6}$$

where S_i – the relative area of raster elements.

After substituting typical options, let's obtain:

$$S_0 = 1 - L_0, \tag{7}$$

$$S_1 = 1 - \left(\frac{1}{255}\cdot L_1\right), \tag{8}$$

$$S_2 = 1 - \left(\frac{1}{255}\cdot L_2\right), \tag{9}$$

$$S_3 = 1 - \left(\frac{1}{255}\cdot L_3\right), \text{ if } 0 \le L_i \le 255 \text{ and } 1 \le S_i \le 0, \tag{10}$$

where for comparison, it is possible to perform raster transformation of the linear scale L_0.

To analyze the properties of raster transformation of images, let's determine the difference between the rasterization characteristics and the linear one, which quantitatively assesses the perception of a raster image by the human visual system [15]

$$E_i = S_i - S_0, \tag{11}$$

where S_i – the relative area of the raster transformation of typical options for power-linear transformation, S_0 – the area of the linear transformation.

Based on the above and expressions (3)–(11), a structural diagram of the simulator model of the raster power-linear transformation of images of light tones was developed in the MATLAB:Simulink package, which is shown in Fig. 1.

The Ramp block generates a linear scale L_0, which is scaled by the Gain block and is fed in parallel to the inputs of the functional blocks of mathematical functions $F_{cn} - F_{cn2}$. The dialog windows of the blocks contain a program for calculating the gradation characteristics L_1, L_2, L_3, of the power-linear transformation of digital images. The obtained values of the gradation characteristics are visualized by the Step block and are fed in parallel to the inputs of the mathematical function blocks $F_{cn3} - F_{cn6}$. The dialog windows of the blocks contain a program for calculating the relative areas of raster elements S_0, S_1, S_2, S_3. The obtained values of the relative areas of raster elements are visualized by the Scope1 block, scaled by the Gain block and fed to the input of the quantization block Quantizer, after which they are visualized by the Scope3 block. To determine the differences E_i between the rasterization characteristics and the linear one, the summation blocks Add are used, the first inputs of which are fed with the relative area S_0, and the second inputs are fed with the relative areas S_1, S_2, of the raster power-linear transformation. As a result, the outputs of the blocks produce the differences E_1, E_2, E_3 of the raster transformation characteristics, which are visualized by the Scope2 block.

The blocks of mathematical functions of the simulator are configured for typical variants of the power-linear transformation and the corresponding programs and parameters are set. The results of modeling the gradation characteristics of typical variants of the power-linear transformation of digital images for light tones are presented in Fig. 2.

A linear gradation characteristic L_0 is presented below for comparison. Gradation characteristics are convex curves and at the beginning of the range have sufficient steepness, which gradually decreases, so that midtones and light details of the image are well reproduced. Gradation characteristics L_2, L_3 located above, have a slightly greater steepness at the beginning of the range, but not too large, so posterization of the power-linear transformation does not occur.

ISSN-L 2664-9969; E-ISSN 2706-5448

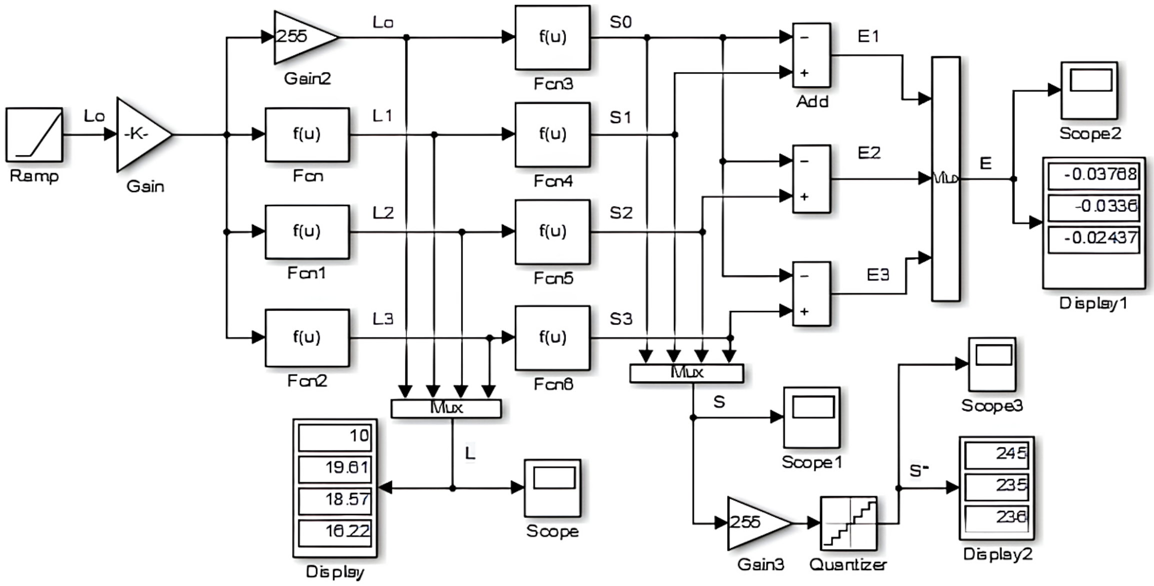

Fig. 1. Structural diagram of the model of the simulator of raster power-linear transformation of images

The results of modeling the raster power-linear transformation of images for light tones are presented in Fig. 3.

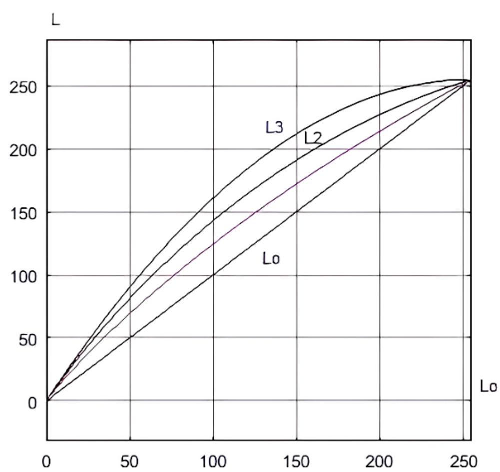

Fig. 2. Gradation characteristics of typical power-linear transformation options

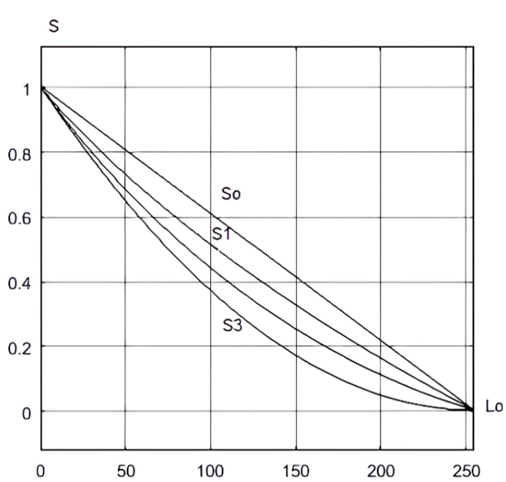

Fig. 3. Rasterization characteristics of typical power-linear transformation options

The initial values of the relative areas of raster elements are equal to unity, which corresponds to the black tone. For comparison, the linear rasterization characteristic S_0 is presented above. Rasterization characteristics are concave curves evenly stretched towards small areas, which corresponds to the light tones of images. At the beginning of the range, the steepness of the characteristics is relatively small, so there are no prerequisites for the occurrence of posterization. The steepness gradually decreases, which contributes to good resolution of image details in the middle range of tone transmission.

To analyze the properties of raster conversion of digital images, the differences in the characteristics of rasterization from linear were simulated, which are presented in Fig. 4.

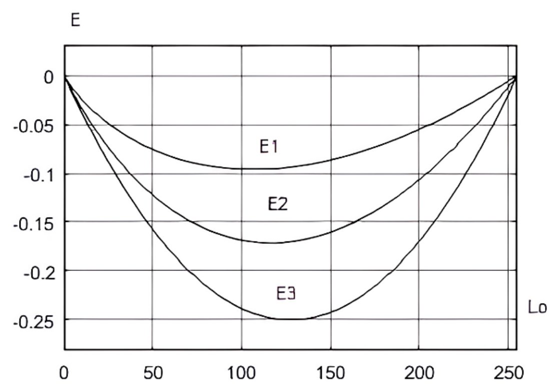

Fig. 4. Graphs of differences of the characteristics of the raster transformation from the linear

The graphs of the differences are almost symmetrical negative U-shaped curves. The minus sign indicates that the linear characteristic S_0 prevails over the characteristics of the rasterization S_1, S_2, S_3. Accordingly, the characteristics of the differences qualitatively and quantitatively assess the perception of the rasterized image by the human visual system.

To determine the presence of posterization of the raster power-linear transformation, its discretization was performed, the results of which are presented in Fig. 5.

The characteristics of the discretized raster transformation are stepped. The first discretes have a height of 255 black levels with a length of one level. The second discretes have a height of 254 levels with a length of two levels. The third discretes have a length of 253 levels with a length of two levels. The following discretes have similar parameters. Since the discretes have a length of two levels, the human visual system does not notice small changes in levels in dark areas of the image.

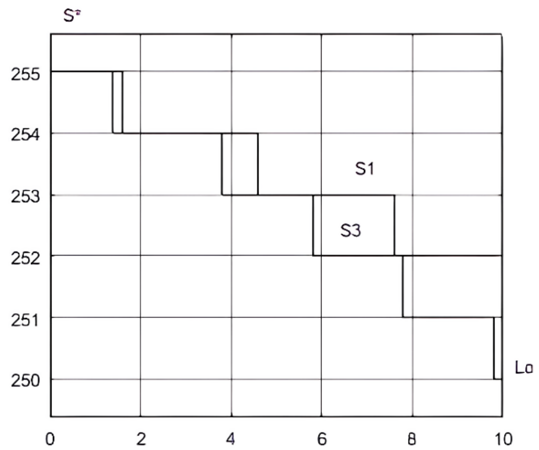

Fig. 5. Graphs of the discretized power-linear raster transformation

Comparing the results of the study of raster transformation of digital images based on the discretization of raster characteristics using the traditional power (gamma) transformation and the proposed power-linear transformation, it was established:

The size of the discretes of the discretized raster characteristics of the power transformation at the beginning of the range is significantly greater than the level of visual perception. In particular, the initial displacements of the discretes are: at the power index $r = 1.5$, the initial displacement of the discretes = 4 levels, at $r = 2$ – displacement = 12 levels, at $r = 3.0$ – displacement = 33 levels. This indicates the presence of posterization in the images and, accordingly, their distortion. In contrast, the discretes of the discretized raster characteristics of the power-linear transformation are much smaller. In particular, their range is within 1–3 levels. Since the human visual system does not notice the degree of length 3, the developed power-linear transformation eliminates posterization of raster images in dark areas. Accordingly, it is proven by mathematical modeling that the raster power-linear transformation eliminates posterization in dark areas of images, which is an advantage of the developed power-linear transformation over the traditional power-linear transformation.

Therefore, the developed model of raster power-linear transformation of digital images of light tones has significantly better characteristics compared to existing models of raster transformation. In particular, it makes it possible to significantly expand the functionality of raster correction in the process of image tone reproduction.

Based on the proposed model, a simulator of raster power-linear image transformation has been developed. The simulator makes it possible to form gradation characteristics and rasterization characteristics for light tones of images, as well as to determine the difference between rasterization characteristics and linear. This ensures the determination of optimal parameters for raster image correction.

In the course of the research and on the basis of the obtained modeling results, it was established that the presented model of raster power-linear transformation eliminates visually noticeable transitions in dark areas of images.

Practical significance. The obtained results of research on raster correction of tone reproduction and raster tone transmission are recommended for use by operators and technologists of computer publishing systems at the stage of preparing images for printing, in particular, in the process of raster conversion of digital images.

Research limitations. The main limitations of the study lie in the plane of several factors. The first is the need for appropriate software and hardware, which provides the ability to calculate optimal printing parameters in the process of raster conversion of digital images. The second is the availability of an appropriate information database that provides for the analysis of raster tone reproduction based on the construction of the appropriate raster characteristics.

Prospects for further research. The conducted research forms the basis for creating new approaches to expanding the functionality of the process of raster conversion of digital images, which makes it possible to eliminate negative influences in the process of adjusting raster tone reproduction and tone transmission. Accordingly, these are good prerequisites for the development of this area of research, in particular, with a projection on the introduction of the latest information technologies into the pre-printing process of digital image processing.

4. Conclusions

Currently, in computer publishing systems, available computer graphics programs do not provide a program for constructing gradation characteristics and rasterization characteristics. Incorrectly selected or specified characteristics lead to a loss of image quality in the printout. There is little data in available sources on the quantitative assessment of the properties of raster transformation algorithms, which limits the possibilities of the reproduction process.

Mathematical models of modern typical variants of power-linear transformation of digital images for light tones and a structural diagram of a raster transformation simulator model in the MATLAB:Simulink package based on functional blocks of mathematical functions F_{cn} have been developed. Based on the modeling results, it was established that at the beginning of the range, the steepness of the gradation characteristics is small, so posterization does not occur in dark areas of images. Rasterization characteristics are opposite to gradation characteristics and have initial values of the relative area of raster elements equal to unity, which corresponds to black tones. The steepness of the characteristics gradually decreases, so the details of the images in the initial and middle range of the tone transmission are well reproduced.

For a quantitative assessment of image reproduction, it is proposed to determine the difference between the rasterization characteristics and the linear one. The difference graphs are almost symmetric negative U-shaped curves. The minus sign indicates that the linear characteristic S_0 prevails over the rasterization characteristics S_1, S_2, S_3. The difference characteristics have an extremum, and their minimum values are $E_1 = -0.095$, $E_2 = -0.121$, $E_3 = -2.49$ units. Accordingly, the difference characteristics qualitatively and quantitatively assess the perception of the rasterized image by the human visual system.

To determine the presence of posterization of the raster power-linear transformation, its discretization was performed. The discretization characteristics are stepwise. The first discretes have a height of 255 black levels with a length of one level. The second discretes have a height of 254 levels with a length of two levels. The third discretes have a height of 253 levels and a length of two levels. The following discretes have similar parameters. Since the discretes have a length of no more than two levels, the human visual system does not notice small changes in levels in dark areas of the image. Thus, through mathematical modeling, it has been proven that the raster power-linear transformation eliminates image posterization in dark areas, which is an advantage of the developed power-linear transformation.

Conflict of interest

The author declares that he has no conflict of interest in connection with this research, including financial, personal, authorial or any other interest that could affect the study and its results presented in this article.

ISSN-L 2664-9969; E-ISSN 2706-5448

Financing

The research was conducted without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The author confirms that he did not use artificial intelligence technologies when creating this work.

References

1. Kovalskiy, B., Semeniv, M., Shovgenyuk, M. (2016). Computer program for the image synthesis on impress for the new information and traditional technologies of color printing. *Science and Education a New Dimention: Natural and Technical Science, IV (10 (91)),* 72–78. Available at: https://seanewdim.com/wp-content/uploads/2021/03/Computer-program-for-the-image-synthesis-on-impress-for-the-new-information-and-traditional-technologies-of-color-printing-Kovalskiy-B.-Semeniv-M.-Shovgenyuk-M..pdf
2. Lutskiv, M. M. (2012). *Tsyfrovi tekhnolohii drukarstva.* Lviv: UAD, 488.
3. Durnyak, B., Lutskiv, M., Shepita, P., Karpyn, R., Savina, N. (2021). Determination of the Optical Density of Two-Parameter Tone Transfer for a Short Printing System of the Sixth Dimension. *Intelligent International Technologies & Systems of Information Security: CEUR Worhshop Proceedings, 2853,* 134–140. Available at: https://ceur-ws.org/Vol-2853/short11.pdf
4. Jähne, B. (2005). *Digital Image Processing.* Springer-Verlag. Berlin Heidelberg. Available at: https://aitskadapa.ac.in/e-books/CSE/DIGITAL%20IMAGE%20PROCESSING/Digital%20Image%20Processing%20(%20PDFDrive%20)%20(1).pdf
5. Gonnzalez, R., Woods, E. (2008). *Digstal image Processing.* Printice Hall, 954. Available at: https://dl.ebooksworld.ir/motoman/Digital.Image.Processing.3rd.Edition.www.EBooksWorld.ir.pdf
6. Kavyn, B. (2025). Development of a model for coloring raster elements of polynomial transformation of digital images. *Technology Audit and Production Reserves, 2 (2 (82)),* 27–31. https://doi.org/10.15587/2706-5448.2025.323533
7. Tkachenko, V., Hordieiev, A. (2022). Using Upsampling Technologies to Reproduce Low-Resolution Images. *Technology and Technique of Typography, 2 (76),* 66–73. https://doi.org/10.20535/2077-7264.2(76).2022.267428
8. Durnyak, B., Lutskiv, M., Shepita, P., Sheketa, V., Karpyn, R., Pasyeka, N.; Hu, Z., Dychka, I., Petoukhov, S., He, M. (Eds.) (2022). Analysis of Transfer of Modulated Ink Flows in a Short Printing System of Parallel Structure. *Advances in Computer Science for Engineering and Education.* Cham: Springer, 17–26. https://doi.org/10.1007/978-3-031-04812-8_2
9. Kavyn, S. (2025). Development of a model of power-linear conversion of digital images for dark tones. *Technology Audit and Production Reserves, 2 (2 (82)),* 32–36. https://doi.org/10.15587/2706-5448.2025.323535
10. Doros, M. (2010). *Przetwarzanie obrazow.* Warszawa: Wydawca translator S. C., 352.
11. Vorobel, R. A. (2012). *Loharyfmichna obrobka zobrazhen.* Kyiv: Naukovo-vyrobnyche pidpryiemstvo "Vydavnytstvo "Naukova dumka" NAN Ukrainy", 232.
12. Pashulia, P. L. (2011). *Standartyzatsiia, metrolohiia, vidpovidnist, yakist u poli-hrafii.* Lviv: UAD, 408.
13. Baranovskyi, I. V., Lutskiv, M. M., Fil, L. V. (2013). Construction and analysis of characteristics screening. *Naukovi zapysky, 4 (45),* 131–138. Available at: https://nz.uad.lviv.ua/media/4-45/20.pdf
14. Durnyak, B., Lutskiv, M., Shepita, P., Hunko, D., Savina, N. (2021). Formation of liner Characteristics of Normalized Roster Trans Formation for Rombic Elemtnts. *Intelligent Information Technologies & System of Information Security. CEUR Workshop Proceedings, 2853,* 127–133. Available at: https://ceur-ws.org/Vol-2853/short10.pdf
15. Mrozek, B., Mrozek, Z. (2018). *MATLAB: Simulink*. Gliwce: Wydawnictwo Helion. Available at: https://helion.pl/pobierz-fragment/matlab-i-simulink-poradnik-uzytkownika-wydanie-iv-bogumila-mrozek-zbigniew-mrozek,matsi4/pdf?srsltid=AfmBOoolF31xdXgjRysP1rpxUKRzV9Q0hvEDTJ5jgFW1Od2ScAhty5d

Sviatoslav Kavyn, *PhD Student, Department of Computer Technologies in Publishing and Printing Processes, Lviv Polytechnic National University, Lviv, Ukraine, e-mail: kavinsviatoslav@gmail.com, ORCID: https://orcid.org/0000-0002-6189-3848*