Mathematical Modeling of the Braille Font Formation for the Information and Communication Environment Creation for Blind People

Volodymyr Mayik [1], Nataliia Lotoshynska [2], Lyudmyla Mayik [1], Kseniya Bazylyuk[2] and Marian Khariv [3]

[1] *Ukrainian Academy of Printing, 19, Pid Holoskom St., Lviv, 79020, Ukraine*
[2] *Lviv Polytechnic National University, 12, Stepan Bandera St., Lviv, 79013, Ukraine*
[3] *Levenia Education and Rehabilitation Center, 71, Volodymyra Velykoho St., Lviv, 79000 Ukraine*

Abstract

The development of writing for people with visual impairments has a centuries-old history. Throughout the development of humankind, wise man worked on the problem of the writing creation for people with visual impairments. During this time, dozens of font versions were developed, but none of them could meet the needs of people with visual impairments and had limited application or theoretical interest only. However, with the invention of the six-point Braille font, this system of writing for people with visual impairments became a de facto international standard. One of the next challenging steps was the development and improvement of the Braille reproduction technologies, which could ensure high-quality tactile perception of relief-dotted images by people with visual impairments. Nowadays, a significant number of new and improved technologies have been developed to reproduce Braille. The main challenge of these technologies is to ensure the reproduction of Braille elements of the appropriate height for the high-quality perception by people with visual impairments. One of these ensuring methods is the stencil printing, which requires mathematical modeling of the printing processes impact on the reproduction of the Braille elements height.

Keywords

Modeling, analysis of regression, analysis of correlation, stencil printing, Braille font, element height, dry ink residue

1 Introduction

The global problem is to create an "information space" for the Braille font, which includes Braille publications, tactile signs, Braille inscriptions on labels and packaging products, information plates and mnemonics, marking of elevator buttons, door handles, etc. The analysis of scientific and technical sources confirms that the improvement of technological processes, materials, and equipment for the production of products for people with vision impairments was carried out during the entire period of use of the Braille system. The following basic technologies and their modifications are used to obtain relief dot images: congruous embossing (disadvantages: the relief dot has low mechanical strength; a decrease in the relief of the dot is observed when the air humidity in the room increases; editions of relief dot prints are heavy and bulky, their block is thick and friable; high cost of stamps and equipment, high labor intensity of equipment during printing); Braille printers (disadvantages – very high noise when printing, use for small editions, limited technological capabilities when reproducing multi-level relief images, limited range of materials for printing); laser engraving (disadvantages: the presence of combustion products;

ProfIT AI 2023: 3nd International Workshop of IT-professionals on Artificial Intelligence (ProfIT AI 2023), November 20–22, 2023, Waterloo, Canada
vol.mayik.2015@gmail.com (V. Mayik); natlot@ukr.net (N. Lotoshynska); ludmyla.maik@gmail.com (L. Mayik); k.bazylyuk@gmail.com (K. Bazylyuk); kharivm@ukr.net (M. Khariv)
0000-0002-6650-2703 (V. Mayik); 0000-0002-6618-0070 (N. Lotoshynska); 0000-0001-8552-0942 (L. Mayik); 0000-0002-6189-8446 (K. Bazylyuk); 0000-0002-5982-8983 (M. Khariv)

some materials form zones on the border of the engraved area, contaminated with the products of this material destruction: in some materials, during the processing, stresses are formed, which can lead to its destruction); the inkjet printing method (disadvantages: the operation of UV dryers leads to the release of ozone that is harmful to the body; higher cost compared to other types of ink; some materials emit an unpleasant smell under the influence of UV radiation; the relatively short service life of UV lamps; the need to use forced drying) ; vacuum forming (disadvantages: significant costs of manual labor; only small-batch products can be produced; difficulties in ensuring the uniformity of products; generation of a significant amount of waste; the need for additional mechanical processing of products; plastic is an artificial material and is not suitable for use by children; reproduction of small details clutters the image, and makes its perception harder).

During the creation of printed materials, label, packaging and other products for people with visual impairments, it is very important to achieve the appropriate height of the convex parts of the font to ensure their high-quality and accurate perception. In the printing industry, the stencil printing method is widely used, which has numerous advantages and allows, under certain conditions, to obtain thick image layers that can be perceived effectively by people with visual impairments [1-10].

The screen printing method has advantages in that it allows printing on various materials with any surface. It has high resistance of embossed details to mechanical impact when reading by people with vision problems. One of the most important technological parameters in the stencil printing process is the thickness of the copying layer of the stencil form, as well as the dry residue content of the printing ink, which is used in the printing process of the Braille texts for people with visual impairments. Research conducted by Ulano AG confirms the fact that, under certain conditions, the thickness of the paint layer depends on the thickness of the copy layer of the form, provided that it exceeds the thickness of the grid. It has been proven that if the line width exceeds 4 mm, the thickness of the paint depends solely on the characteristics of the grid material. But if the line width is less than 4 mm, then the thickness of the ink print will depend on the thickness of the form, taking into account the thickness of the copying layer or film [11]. The size of Braille font elements is in the interval from 1.4 to 1.6 mm, accordingly, the thickness of the form, in particular the copying layer, which exceeds the thickness of the grid, affects the thickness of the printing ink. These parameters were investigated during the simulation of the stencil printing process.

2 Modeling of the Braille elements forming process in the stencil printing

2.1. Research methods

Nowadays, IT Market offers high-quality applications with a perfect and multifunctional service of the corresponding tools among the software products for data analysis.

We used the STATISTICA software complex, developed by StatSoft, Inc. (USA) for processing and analyzing of the received experimental data. This software package is well known among experimenters, analysts, scientists, and other specialists who work with big data, carry out their systematization and modeling. The package is characterized with user-friendly interface, provides a wide range of analysis tools, from determining correlations, scatter diagrams, plotting distribution graphs to exploratory data analysis, neural networks, process analysis, and allows interactive visualization of results.

Methods of correlation and regression analysis are the most developed methods of mathematical statistics. They are used to study statistical connections, including identifying the form of the connection and determining its strength. The main goal in the application of correlation analysis is to identify an estimate of the strength of the connection between random variables (characteristics) that characterize a certain real process or object. It does not establish the causes of dependence between the studied characteristics, but only reveals the existence of the dependence itself, its strength and direction. Regression analysis examines the form of dependence (the model of connection expressed in the regression function) between independent variables.

2.2. Research results

The readability of prints with relief-dotted images for people with visual imparments in the stencil printing is influenced by the dry residue content (DRC), which in the stencil printing inks can be measured from 20-30 to 100%. While modeling the process of the stencil printing, the coefficients of spreading and absorption, which can coincide or be opposite, were taken into account. The investigation was conducted for stencil form material with a minimal copying layer and with an increase of 100 μm [11]. A regression analysis (Fig. 1) of the technological process that uses a stencil form was carried out. It was found that the dependence of the thickness of the dry paint layer on the impression (TDLP) on the thickness of the raw paint on the impression (TRIP) and the dry residue content ratio (KDRC) is linear, since the coefficient of determination R2 is 0.98, which is a high value (> 0,7).

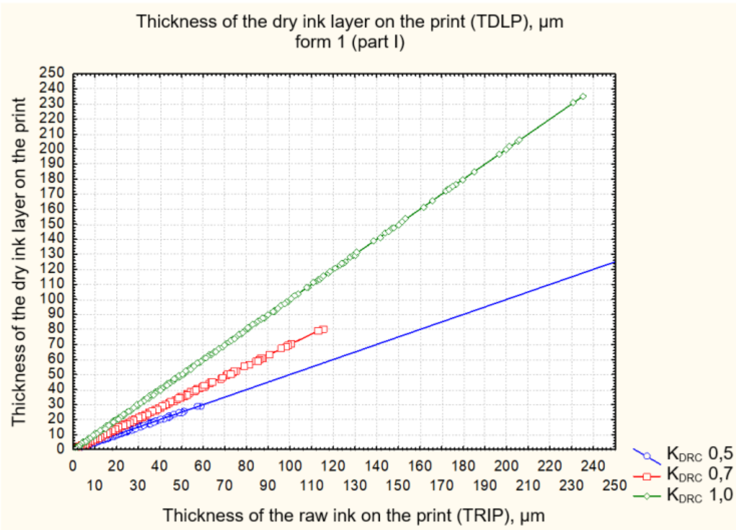

Figure 1: The regression dependence of TDLP from the technological parameters (TRIP, K_{DRC}), if the coefficients of spreading and absorption coincide

Formula (1) reflects the corresponding regression dependence and has the following calculation, as shown in Fig. 2:

$$TDLP_{form1}\ (part\ I) = -15{,}7227 + 0{,}8767\ TRIP + 19{,}0286 \cdot KDRC \pm 4{,}2314 \quad (1)$$

N=3096	Regression Summary for Dependent Variable: Thickness of the dry ink on the print (TDLP) R= ,98982657 R?= ,97975663 Adjusted R?= ,97974354 F=(2,3093)=74849E2, p<0,0000 Std.Error of estimate: 4,2314					
	Beta	Std.Err Of Beta	B	Std.Err Of B	t(3093)	p-level
Intercept			-15,7227	0,1348053	-45,1733	0,00
Thickness of raw ink on the print (TRIP), μm	0,944555	0,002749	0,533333	0,002552	343,5718	0,00
Coefficient of the dry residue content (KDRC)	0,109325	0,002749	19,0286	0,478518	39,7658	0,00

Figure 2: Image of the software Statistica for the regression coefficients determining

A correlation analysis of the interconnection (Fig. 3) between the technological process of using the stencil form and the minimal copying layer (part I) was carried out. The results show that there is a direct linear dependence between TDLP and TRIP, where the partial correlation coefficient r is 0.99. However, such a dependence was not found between TDLP and the coefficient of dry residue content, where the partial correlation coefficient r is 0.58. Prior to this, TRIP has a greater effect on TDLP (0.94), while the coefficient of dry residue content affects less (0,11).

Variable	Variables currently in the Equation; DV: Thickness of the dry ink on the print (TDLP)						
	Beta in	Partial Cor.	Semipart Cor.	Tolerance	R-square	T(3093)	p-level
Thickness of raw ink on the print (TRIP), µm	0,944555	0,987151	0,878059	0,865931	0,134069	343,5718	0,00
Coefficient of the dry residue content (KDRC)	0,109325	0,581635	0,101733	0,865931	0,134069	39,7658	0,00

Figure 3: Image of the software Statistica for the correlation coefficients determining

The next step, there was performed the regression analysis (Fig. 4) of the technological process with the usage of the stencil form and the minimal copying layer (part II). This analysis specifies the dependence of the thickness of the dry ink layer on the print (TDLP) from the thickness of the raw ink on the print (TRIP) and the coefficient of the dry residue content (KDRC) is linear, considering the fact that the coefficient of determination R2 = 0,96 is high (> 0,7).

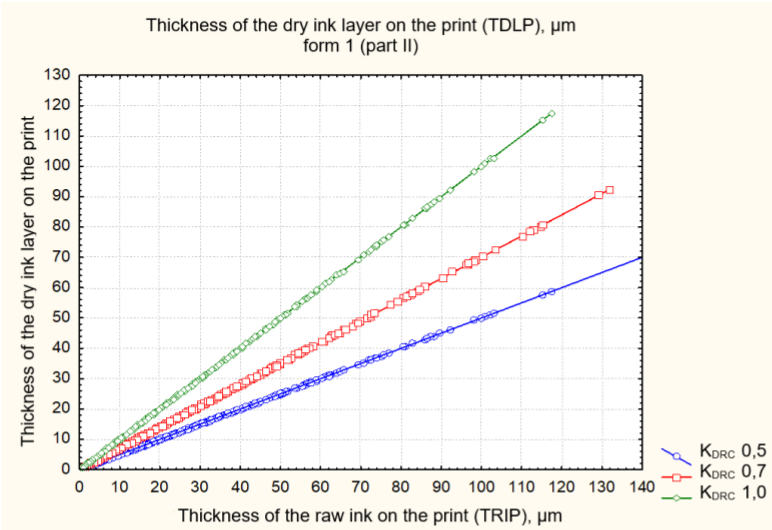

Figure 4: Regression dependence of TDLP on technological parameters (TRIP, K_{DRC}), provided that the spreading and absorption coefficients are opposite

In formula (2), the regression dependence will be presented as shown in Fig. 5:

$$TDLP_{form1}\ (part\ II) = -17{,}3411 + 0{,}75\ TRIP + 23{,}1215 \cdot KDRC \pm 3{,}9666 \qquad (2)$$

N=3096	Regression Summary for Dependent Variable: Thickness of the dry ink on the print (TDLP) R= ,97797166 R?= ,95642857 Adjusted R?= ,5640039 F=(2,3093)=33947, p<0,0000 Std.Error of estimate: 3,9666					
	Beta	Std.Err Of Beta	B	Std.Err Of B	t(3093)	p-level
Intercept			-17,3411	0,328827	-52,7362	0,00
Thickness of raw ink on the print (TRIP), µm	0,955619	0,003753	0,7500	0,002946	254,6090	0,00
Coefficient of the dry residue content (KDRC)	0,207897	0,003753	23,1215	0,417425	55,3907	0,00

Figure 5: Image of the software Statistica for the regression coefficients determining

Also, there was conducted the correlation analysis (Fig. 6) of the technological process with the usage of the stencil form and the minimal copying layer (part II). The result indicates that there is a direct dependence of TDLP from TRIP (the partial correlation coefficient r = 0,98) and the dry residue content coefficient (the partial correlation coefficient r = 0,70). In parallel, TDLP is more strongly influenced by TRIP (0,95) and less by the coefficient of dry residue content (0,21).

Variable	Variables currently in the Equation; DV: Thickness of the dry ink on the print (TDLP)						
	Beta in	Partial Cor.	Semipart Cor.	Tolerance	R-square	T(3093)	p-level
Thickness of raw ink on the print (TRIP), µm	0,955619	0,976965	0,955610	1,000000	-0,000000	254,6090	0,00
Coefficient of the dry residue content (KDRC)	0,207897	0,705678	0,207897	1,000000	-0,000000	55,3907	0,00

Figure 6: Image of the software Statistica for the correlation coefficients determining

The next move was carring out of the regression analysis (Fig. 7) with the usage of the stencil form (the copying layer exceeds the thickness of the grid by 100 μm (part I). This analysis shows that the dependence of the thickness of the dry ink layer on the print (TDLP) from the thickness of raw ink on the print (TRIP) and the coefficient of the dry residue content (KDRC) is linear, since the coefficient of determination R2 = 0,98 is high (> 0,7).

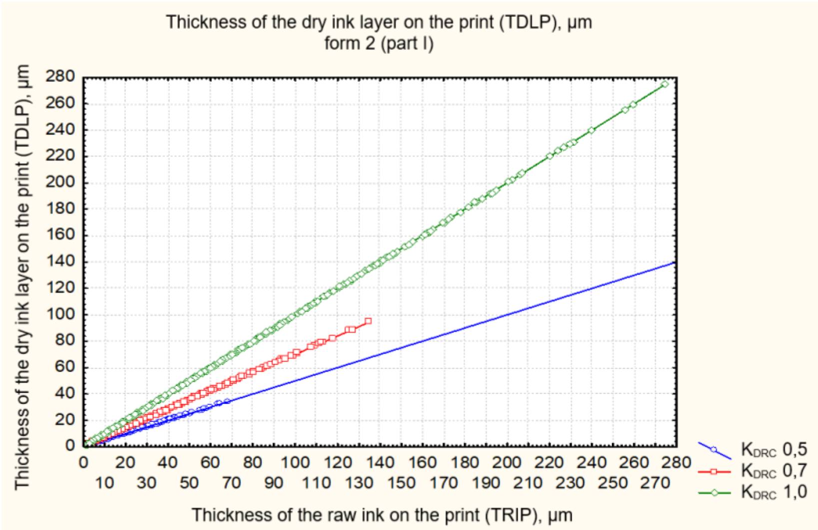

Figure 7: The regression dependence of TDLP from the technological parameters (TRIP, K_{DRC}), if the coefficients of spreading and absorption coincide

Formula (3) determines the regression dependence, which will be illustrated in Fig. 8 in the following form:

$$TDLP_{form2}\ (part\ I) = -20{,}3808 + 0{,}8768\ TRIP + 24{,}6616 \cdot KDRC \pm 5{,}2479 \qquad (3)$$

N=3096	Regression Summary for Dependent Variable: Thickness of the dry ink on the print (TDLP) R= ,98990242 R?= ,97990679 Adjusted R?= ,97989380 F=(2,3093)=75420, p<0,0000 Std.Error of estimate: 5,2479					
	Beta	Std.Err Of Beta	B	Std.Err Of B	t(3093)	p-level
Intercept			-20,3808	0,432410	-47,1329	0,00
Thickness of raw ink on the print (TRIP), μm	0,940717	0,002759	0,8768	0,002572	340,9502	0,00
Coefficient of the dry residue content (KDRC)	0,113820	0,002759	24,6616	0,597822	41,2524	0,00

Figure 8: Image of the software Statistica for the regression coefficients determining

After that, there was performed the correlation analysis (Fig. 9) of the technological process with the usage of the stencil printing form and the 100-micrometer-thick copy layer is above or thicker than the grid (part I). This analysis indicates the presence of a reliable direct dependence of TDLP from TRIP (the partial correlation coefficient r = 0,99) and a moderate linear dependence from the dry residue content coefficient (partial correlation coefficient r = 0,59). Simultaneously, TDLP is more strongly influenced by TRIP (0,94) and less by the coefficient of the dry residue content (0,11)

Variable	Variables currently in the Equation; DV: Thickness of the dry ink on the print (TDLP)						
	Beta in	Partial Cor.	Semipart Cor.	Tolerance	R-square	T(3093)	p-level
Thickness of raw ink on the print (TRIP), μm	0,940717	0,986956	0,869012	1,853362	0,146638	340,9502	0,00
Coefficient of the dry residue content (KDRC)	0,113820	0,595752	0,105144	1,853362	0,146638	41,2524	0,00

Figure 9: Image of the software Statistica for the correlation coefficients determining

The further step was to provide the regression analysis (Fig. 10) of the technological process with the usage of the stencil printing form and the copying layer surpasses the thickness of the grid by 100 μm (part II). This step shows that the dependence of the thickness of the dry ink layer on the print (TDLP) from the thickness of the raw ink on the print (TRIP) and the coefficient of the dry residue content (KDRC) is linear, as the coefficient of determination R2 = 0.96 is high (> 0.7).

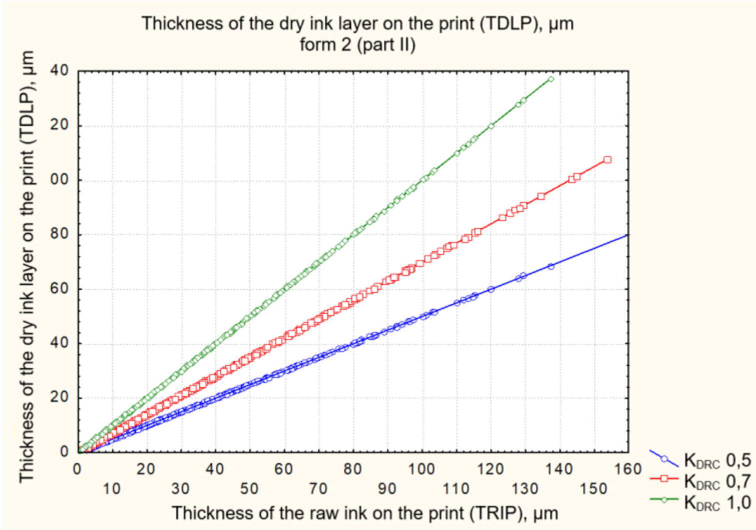

Figure 10: The regression dependence of TDLP from the technological parameters (TRIP, K_{DRC}), if the coefficients of spreading and absorption are opposite

The regression dependence will take the following form (Fig. 11) in the formula (4):

$$TDLP_{form2}\ (part\ II) = -22{,}4819 + 0{,}75\ TRIP + 29{,}9759 \cdot KDRC \pm 4{,}8814 \qquad (4)$$

	Regression Summary for Dependent Variable: Thickness of the dry ink on the print (TDLP) R= ,97807848 R?= ,95663751 Adjusted R?= ,95660947 F=(2,3093)=34118, p<0,0000 Std.Error of estimate: 4,8814					
N=3096	Beta	Std.Err Of Beta	B	Std.Err Of B	t(3093)	p-level
Intercept			-22,4819	0,405694	-55,4159	0,00
Thickness of raw ink on the print (TRIP), µm	0,953362	0,003744	0,7500	0,002946	254,6189	0,00
Coefficient of the dry residue content (KDRC)	0,218492	0,003744	29,9759	0,513692	58,3538	0,00

Figure 11: Image of the software Statistica for the regression coefficients determining

Then the correlation analysis (Fig. 12) of the technological process with the usage of the stencil printing form (the copying layer surpasses the thickness of the grid by 100 µm (part II) was conducted. This stage indicates the presence of a reliable direct linear dependence of TDLP from TRIP (the partial correlation coefficient r = 0,98) and from the dry residue content coefficient (partial correlation coefficient r = 0,72). At the same time, TDLP is more strongly influenced by TRIP (0,95) and less by the coefficient of dry residue content (0,22).

	Variables currently in the Equation; DV: Thickness of the dry ink on the print (TDLP)						
Variable	**Beta in**	Partial Cor.	Semipart Cor.	Tolerance	R-square	T(3093)	p-level
Thickness of raw ink on the print (TRIP), µm	0,953362	0,976967	0,953362	1,000000	-0,000000	254,6189	0,00
Coefficient of the dry residue content (KDRC)	0,218492	0,723892	0,218492	1,000000	-0,000000	58,3538	0,00

Figure 12: Image of the software Statistica for the correlation coefficients determining

3 Conclusion

A significant number of new and improved technologies have been developed to reproduce Braille. The main task of these technologies is to ensure the reproduction of Braille elements of the appropriate height for high-quality perception by people with visual impairments One of these methods of provision is screen printing, which requires mathematical modeling of the effect of printing processes on the reproduction of the height of Braille elements.

A regression analysis was carried out for two types of stencil printing forms with different thickness of the copying layer. This analysis was also carried out in cases where the spreading and absorption coefficients were equal and opposite. As a result, a linear dependence between the thickness of the dry and raw paint layer of the relief dot image on the print was determined, as well as the coefficient of the content of the dry residue. With the help of the modeling of the Braille printing process the relationship between the parameters of the printing process was determined.

The results of experimental studies show that the height of relief dot images (thickness of the dry ink layer on the print) exceeds 100 microns, which ensures tactile perception of Braille by people with visual impairments.

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