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ROTOMETRY AS A PROPOSAL FOR A NEW METHOD OF HANDWRITING VERIFICATION TESTING

Summary
The authors of the study proposed a novel research technique, not used before, of repeatedly measuring the same parameter (in this case, it is the so-called form factor) based on Brosson's method, which has been known for years. The novelty of the method, called rotometry by the authors, consists in rotating the record under examination by a certain partial angle and after each rotation repeating the measurement of the said coefficient. The measurement ends when the rotated sample returns to the starting position (that is, after a full 360-degree rotation). By examining the evidence and comparison material simultaneously in this way, two sequences of measurements (form factors) are obtained, the consistency (or inconsistency) of which is assessed using rank correlation. A prototype of a computer application for conducting such research has been proposed. In order to reduce subjectivity as much as possible in this type of graphometric research, the application limits (practically cuts out the expert), manual (and therefore subjective) determination of elements for testing.

Keywords: Brosson method, form factor, rotometry, scribal expertise, handwriting and signature forgery

Introduction

For more than a dozen years, specialized computer software (foreign and indigenous) has been used in scribal research. Polish experts are increasingly using it in their daily professional practice[1]. Computer programs that support scribal research are a huge step forward in the direction of objectifying this research and reducing the actions arbitrarily and subjectively taken by the expert.This is because the traditional method of analyzing the graphic features of writing is dominated by subjective methods of evaluating research materials, and only to a limited extent do experts use methods of a quantitative nature, which give a measure of objectivity (such as measurements of size, proportions, angles)[2]. Subjective evaluation criteria create the risk of misinterpreting similarities and differences between questioned and comparison material. This can result in an erroneous opinion, which, especially in the case of underqualified experts, is not uncommon[3].

Software developers are making efforts to ensure that successive versions of the software raise the level of objectivity of the research process. However, it must be made clear that there still is not and most likely will not be an application in which the process of verifying the compliance of records is completely independent of the knowledge and experience of the expert using it. It should also not be forgotten the need to absolutely respect the principle that these are only new tools for the work of the expert, which in no way can replace him. This is because always the final interpretation of the results and the choice of the appropriate research technique, and consequently the correctness of the opinion, will depend on the competence, experience, knowledge and qualifications of the expert[4]. The ideal application, eagerly anticipated in handwriting examinations (but also wherever signature verification is needed), would be one in which the expert's role would be limited

1 B. Goc-Ryszawa, *Computer programs assisting handwriting expertise and their practical use*, "Problems of Forensic Science" 2013, no. 282, pp. 59-65; M. Goc, *Modern model of handwriting expertise. Using New Research Methods and Techniques*, Volumina.pl Daniel Krzanowski, Warsaw-Szczecin 2020, pp. 240-242. See also: M. Goc, K. Łuszczuk, A. Łuszczuk, T. Tomaszewski, *Computer programs as a tool supporting handwriting expertise*, "Problems of Forensic Science" 2016, no. 294, pp. 13-15.

2 On the types of measurements in handwriting expertise, see, among others, A. Koziczak, *Level of subtlety of graphic structures vs. accuracy of measurement methods*, in: Z. Kegel (ed.), *Problems of Expert Evidence of Documents*, vol. I, University of Wroclaw, Faculty of Law, Administration and Economics Department of Criminalistics, Wroclaw 2002, pp. 240-246. The author distinguishes three levels (tiers) of graphic structures that constitute the object of measurement: the basic level (grammars, bindings and other sign elements), the macro-structural level (words, their sets and elements of text topography), and the micro-structural level (the line of writing - the line, its length, width and depth). See also eadem, *Analysis of the concept of cursive in scribal studies*, in: Z. Kegel (ed.), op. cit. pp. 277-278.

3 M.R. Hecker, *Forensische Handschriftenuntersuchung. Eine systematische Darstellung von Forschung, Begutachtung und Beweiswert*, Kriminalistik Verlag, Heidelberg 1993, pp. 56-57.

4 M. Goc, op. cit., p. 319.

to preparing samples of evidence and comparison materials, entering them into the application, running it, and waiting for the verdict (of compliance or non-compliance) to be given by an appropriately programmed machine. The authors of this article, who are co-authors of existing programs on the market, included in the packages GLOGALGRAF[5], GLOBALGRAF II[6] and others outside these packages, being aware of the imperfections of existing solutions, propose a new research method **- “rotometry”** (and two tools of this method - programs **ROTOMETR Wk** and **ROTOMETR Pp.**). The proposed method aims to prevent different experts (e.g., living in different localities, working in different institutions) from giving opposite opinions based on the same research material. Indeed, verification opinions based on the same research materials should be consistent. To this end, discretion and subjectivity in taking certain actions must be reduced to a minimum (or preferably - eliminated) from the verification process.

What rotometry is all about

In all graphometric programs used to date, specific graphical line elements of the records under examination are determined for analysis manually by an expert[7]. Here, there is most often a lack of clarity and discrepancies occur. This is because each expert can designate different elements for analysis on the same material. Differences in the psychophysical predispositions of those conducting the analysis on a given day and the varying technical parameters (mainly resolution) of the monitors and computer displays of different generations used by the experts are also not insignificant, which has a not insignificant impact on the accuracy of determining (with a com-

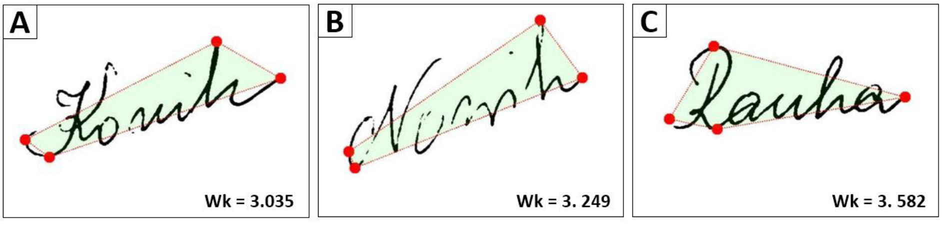
[5] GLOBALGRAF was developed in 2009-2011 within the framework of the project entitled “Development of program methodology and construction of a station for identification studies of writing and signatures using computer graphometry,” funded by the Ministry of Science and Higher Education. The project was a joint scientific and research endeavor of the Department of Forensic Science at the University of Warsaw and the Research and Training Center of the Polish Forensic Association (now the Institute of Forensic Science PTK). The package includes programs: GRAPHOTYP, KINEGRAPH, RAYGRAPH and SCANGRAPH.

[6] GLOBALGRAF II was developed in 2013-2016 as part of the DOBR-BIO4/038/13297/2013project titled „Measuring tools to support handwriting and signature analysis,” funded by the NCBiR and carried out by a scientific consortium: The University of Warsaw, the Central Forensic Laboratory of the Police and the Institute of Forensic Science of the Polish Forensic Association Ltd. (formerly PTK Research and Training Center Ltd.). The package includes programs: CENTROGRAPH, LINIOGRAPH, BARVOSKAN and PROFILOSKAN.

[7] In the programs of the GLOBALGRAF package, many graphic elements are determined manually, for example, in GRAFOTYP the outlines (contours) of records are determined manually, in KINEGRAF - points and “deflections” of sections, in RAYGRAF - lengths of sections and angles.

puter mouse on a computer screen) the elements indicated for analysis. This raises the question of what conditions would have to be met by the samples headed for testing so that the expert would not have to designate any graphic elements manually. There is only one condition. Samples must have a white background, which sometimes requires additional editing (although not always) at the stage of preparing them for testing. Given a graphic line of handwritten writing (some text, signature, paraphrase) on a white background, the computer can, using an appropriate algorithm, find, without the participation of an expert, the four extreme points of the examined graphic line: the extreme left, the extreme top, the extreme right and the extreme bottom. Connecting these points, we get a quadrilateral, usually irregular, which is a certain characteristic parameter for a given record. This is an obvious reference and similarity to the geometric projection method of P. Brosson[8], which has been known for many years (the middle of the last century). However, the similarity is limited only to the determination of the quadrilaterals, the further procedure no longer has anything in common with Brosson's method. A drawback of Brosson's method is the modest number of gabar points - only four. Calculating any numerical parameter on the basis of only four points, even if the shape factor Wk (as the quotient of the area by the square of the perimeter), which is known from GRAPHOTYPE, one gets an unreliable parameter, because in such a modest four-point outline one can "locate" practically any number of records (signatures) that will meet the conditions of gabbiness and give similar values of shape factors, and are different in content. Examples of this situation below in Fig. 1.

Fig. 1. Approximate form factors of records of different content



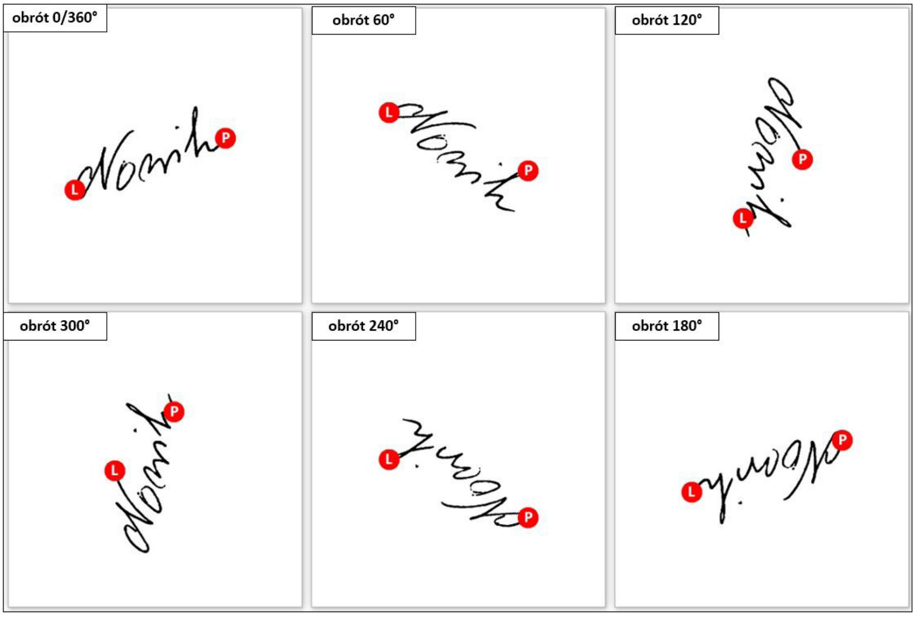
Source: own study.

[8] A. Koziczak, *Metody pomiarowe w badaniach pismoznawczych*, Wydawnictwo Instytutu Ekspertyz Sądowych, Cracow 1997, pp. 56-57.

The concordance of the Wk coefficients of the records shown in Fig. 1 ranges from 85% (image A and C) to 93% (image A and B). The shapes of quadrilaterals A and B are visually most similar. Therefore, if only on the basis of "dry" numbers (Wk values) it was necessary to decide on the compatibility of records, forgetting about content differences, then such a decision would have to be positive (compatible records), which is clearly not true. Verifying the consistency of records based on geometric shapes of four-sided Fig.s is unreliable and should be *de facto* unaccepTab.. It is therefore necessary to increase the number of outline points (vertices of the polygon) so that the outline can be detailed to highlight the structural differences of the studied graphic lines.

How, then, to increase the number of points, when a computer without human input can determine only four? Here we come to the essence of rotometry. Well, subjecting the sample to repeated rotation (rotation) by a certain angle, we can observe that the location of the gabar points changes. Figuratively speaking, these points "travel" along the graphic line. After each rotation, the computer finds these points in a different place, and they remain the same points, i.e. left, top, right and bottom with the difference that with each rotation they lie in different places on the graphic line. In this way, their number is, so to speak, virtually "multiplied." This "multiplication" should be well understood, because the points are not physically increasing. As a result of each rotation, we still have four gab points, but the analysis as a whole is based on a multiple of these, derived from the number of rotations. Fig. 2 shows how the position of the gabar points changes during rotation. For simplicity and better readability of the Fig., only two (out of four) gabar points are shown, the left one labeled "L" and the right one "P", and six rotations of the sample by 60 degrees are assumed.

Fig. 2. Changing the location of gabar points on the graphic line during rotation



Source: own study.

To visualize the virtual "increase in the number" of gabar points, Fig. 3 shows "superimposed" images from Fig. 2.

Fig. 3. "Superimposed" images of two dimension points after six rotations of 60 degrees

Source: own study.

In Fig. 3 you can see how the “multiplication” of the gabar points, and note that for simplicity only two are shown (left and right), the top and bottom have been omitted, and only six rotations have been performed.

Thus, it is possible to calculate the parameter of interest (e.g., the aforementioned shape factor Wk) repeatedly, at each new sample position, i.e., as many times as the sample has been rotated. In the simplified example in Fig.s 2 and 3, only six rotations of 60 degrees each were assumed, which is too few. After a number of tests, it was determined that for an accurate representation of the graphic line design (and for subsequent statistical verification), the number of 15 rotations of 24 degrees each was optimal. So, if the sample is rotated 15 times by 24 degrees (to get a full rotation of 15 × 24 = 360 degrees), the result is that each gabbiness point will change position 15 times, meaning that a total of 15 × 4 = 60 gabbiness points are available. If now the Wk coefficient is calculated after each rotation then, we will get a sequence of 15 values of the Wk shape factor. If we rotate simultaneously, for example, two test samples (evidence and comparison material), we will obtain two sequences of 15 Wk coefficients each, which, subjected, for example, to rank correlation, can be verified for executive conformity. It is clear that other parameters, such as the ratio of diagonals (Pp) of the quadrilaterals under study, can be calculated in a similar way.

The proposed method is graphometric in nature, but due to its specificity, using rotation, it is postulated to call it rotometry, and the computer programs used to carry out tests by this method - rotometers. Particularly noteworthy is the fact that all measurements take place without manual participation of the person operating the programs. The only stage when manual interference is possible is when preparing samples for testing. However, interference at this stage does not affect the course of the analysis.

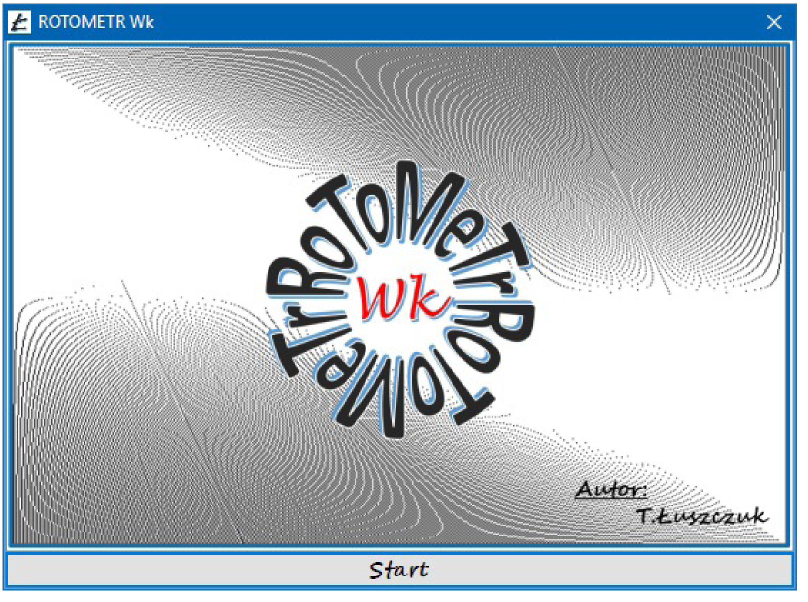
The rotometric method outlined above requires multiple transformations of the bitmaps, which are the image files of the samples targeted for analysis. Multiple image transformations (especially of large sizes) are very labor-intensive activities, and without appropriate software, it is impossible to perform such analyses.

Computer program ROTOMETR Wk

The ROTOMETR Wk computer program, as you can easily guess, simultaneously calculates the form factors, denoted WkA for sample A and WkB for sample B. The samples are simultaneously rotated by the same angle, i.e. 24 degrees. This means that after each rotation, the corresponding form factor is calculated and stored. After the analysis is completed, i.e.

after a complete 360-degree rotation, the arithmetic averages of the obtained shape coefficients are calculated and their percentage agreement is examined, and the strings of WkA and WkB shape coefficients are subjected to rank correlation. Verification of the consistency of the records involves checking the relationship between the R-Spearman rank correlation coefficient and the consistency of the average values of the ZgWk form factors. The program's start page is shown below in Fig. 4.

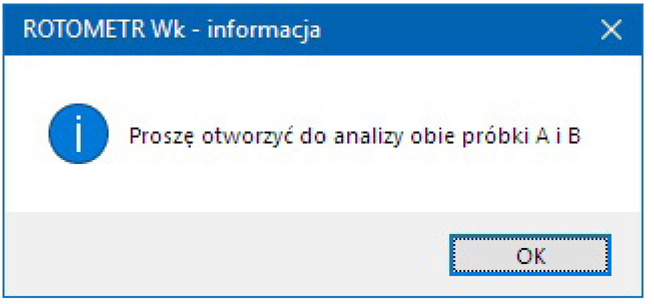
Fig. 4. Title page of the ROTOMETR Wk program



Source: own study.

Upon startup, the program's main interface window is displayed and a message appears reminding the user to open two samples for testing as shown in Fig. 5.

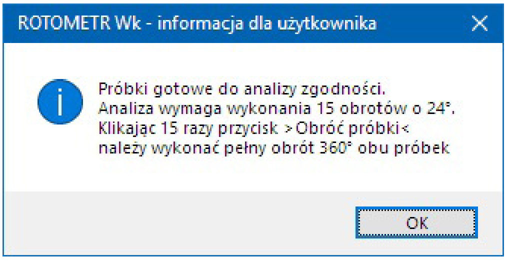
Fig. 5. Information about the need to open samples A and B



Source: own study.

Failure to meet this condition causes the computer to generate an appropriate error message. After opening both samples, the computer generates a new message indicating that the samples are ready for analysis, which will consist of pressing the "Rotate Samples" button fifteen times. The message that the samples are ready for analysis is shown in Fig. 6.

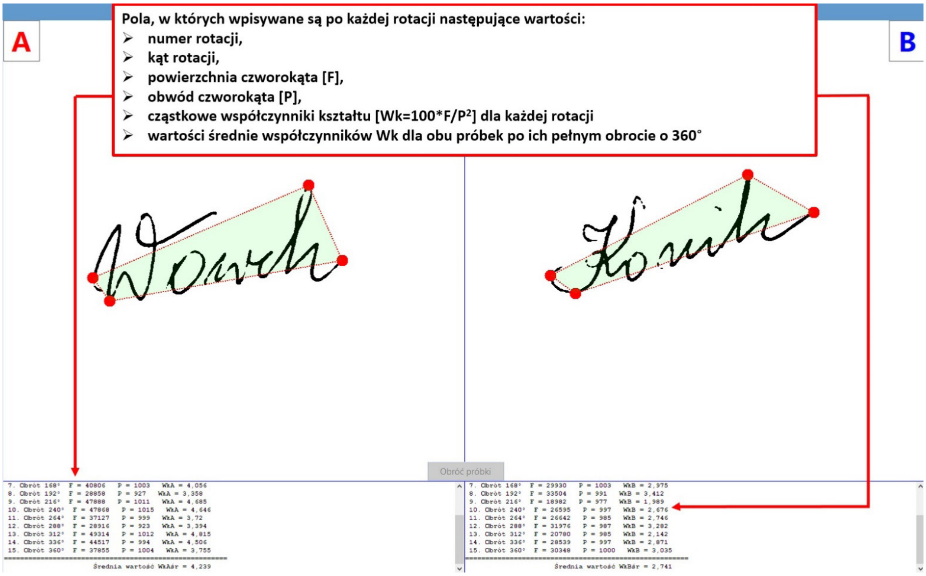
Fig. 6. Information about the readiness of samples for analysis



Source: own study.

Below, in Fig. 7, the window of the main interface is shown after analyzing the compatibility of two fictitious, content-different records "Wowek" and "Konik." These records were consciously selected as having very similar quadrilateral contour shapes and high (80.8%) initial similarity of shape coefficients WkA = 3.755 and WkB = 3.035.

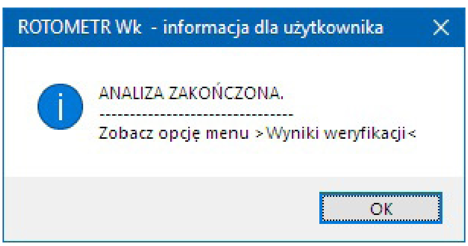
Fig. 7. Program interface after the study is complete



Source: own elaboration.

Each time you click the "Rotate samples" button, the program displays for each successive position of the samples the current rotation number, the total angle of the current rotation, the area of the current quadrilateral and its perimeter, and the corresponding Wk aspect ratios. After 15 rotations, the analysis is complete. The average values of WkAśr and WkBśr coefficients are displayed, and the completion of the analysis (after 15 presses of the "Rotate samples" button) is indicated by the message shown in Fig. 8.

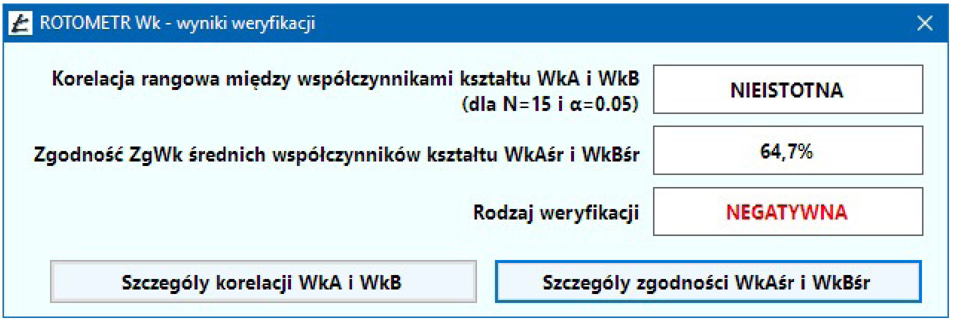
Fig. 8. Information on the completion of the analysis



Source: own elaboration.

After selecting "Verification results" from the menu, a new window with verification results is displayed, as shown in Fig. 9.

Fig. 9. Overall verification results



Source: own study.

Analyzing the results of the verification, it is worth noting that the found concordance of the average aspect ratios of 64.7% is much lower compared to the concordance of 80.8% that the same samples had before the analysis (as already mentioned). On the other hand, non-significant rank correlation definitively rules out similarity of records, which is obvious for records that are different in content. There are two buttons in the verification results window: "Details of WkA and WkB correlation" and "Details of WkAśr and WkBśr compatibility". These buttons provide details of correlation calculations (Fig. 10) and percent agreement of average form factors (Fig. 11).

Fig. 10. Details of the rank correlation

ROTOMETR Wk - korelacja rangowa współczynników kształtu WkA i WkB

ROTOGRAF Wk – korelacja współczynników kształtu

Data wykonania: 21.04.2019

Lp	Próbka A		Próbka B	
	Współczynnik WkA	Ranga	Współczynnik WkB	Ranga
1	4,642	7	3,201	3
2	4,732	4	2,068	14
3	3,916	10	2,69	10
4	3,817	11	2,886	6
5	4,775	2	2,728	9
6	4,769	3	2,409	12
7	4,056	9	2,975	5
8	3,358	15	3,412	1
9	4,685	5	1,989	15
10	4,646	6	2,676	11
11	3,72	13	2,746	8
12	3,394	14	3,282	2
13	4,815	1	2,142	13
14	4,506	8	2,871	7
15	3,755	12	3,035	4

Obliczony współczynnik korelacji rangowej R = -0,761

Krytyczny współczynnik korelacji rangowej Rkr = 0,441

Ponieważ R < Rkr korelacji brak dla N=15 i α=0.05

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Source: own study.

The calculated rank correlation coefficient R has a high negative value (–0.761) in this example (Fig. 10), which means that the series of WkA and WkB shape factor values obtained by rotating the samples are in opposite order to each other. This is analogous to the inverse relationship known in mathematics. It shows that there is an inconsistency between the values of the shape coefficients obtained by successive rotations of the samples, in other words, to sum up, there is no correspondence between the samples.

This is mathematically confirmed by the inequality between the calculated and critical[9] rank correlation coefficient (R < Rkr, Fig. 10).

Fig. 11. Compliance details of average Wk

ROTOMETR Wk - zgodność średnich współczynników Wk

ROTOMETR Wk – zgodność średn. współczynników kształtu

Data wykonania: 21.04.2019

Lp	Próbka A	Próbka B
	Współczynnik WkA	Współczynnik WkB
1	4,642	3,201
2	4,732	2,068
3	3,916	2,69
4	3,817	2,886
5	4,775	2,728
6	4,769	2,409
7	4,056	2,975
8	3,358	3,412
9	4,685	1,989
10	4,646	2,676
11	3,72	2,746
12	3,394	3,282
13	4,815	2,142
14	4,506	2,871
15	3,755	3,035
	WkAśr = 4,239	WkBśr = 2,741

Zgodność ZgWk = (Wkśr mniejszy/Wkśr większy)*100%

ZgWk = 64,7%

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Source: own study.

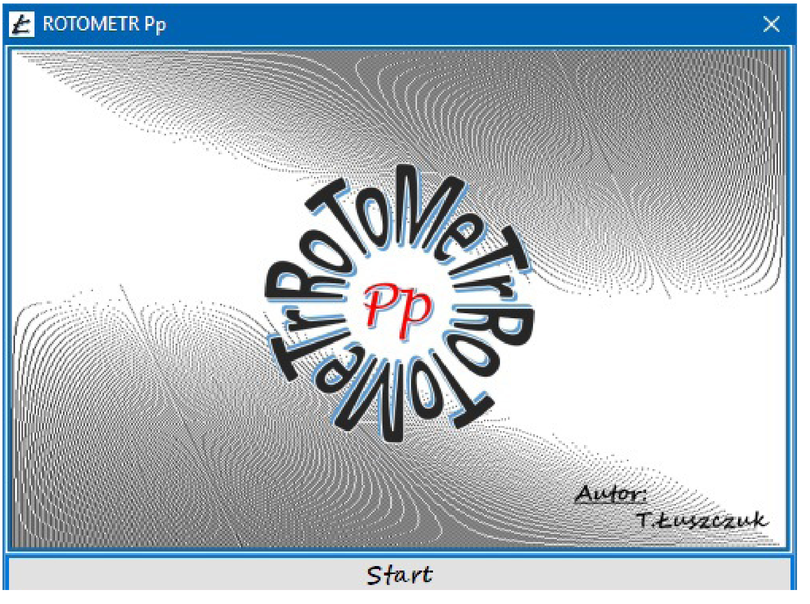
The windows with details displayed give the user the option to save the calculations as a text file in any folder of the computer.

9 Critical values of correlation coefficients are available in relevant Tab.s in statistics textbooks. This example uses: George A. Ferguson, Yoshio Takane, *Statistical Analysis in Psychology and Pedagogy*, PWN Scientific Publishers, Warsaw 1997, Tab. G, p. 588.

Computer program ROTOMETR Pp

The ROTOMETR Pp program has an identical interface and generates the same messages. The only difference is that instead of determining the quadrilaterals based on the gabar points, it determines the diagonals of these quadrilaterals and calculates their ratios (the quotient of the smaller to the larger value). It calculates average proportions and performs rank correlation of these proportions, and then generates a message about the compatibility or incompatibility of the tested samples, so a detailed description of this application has been omitted.

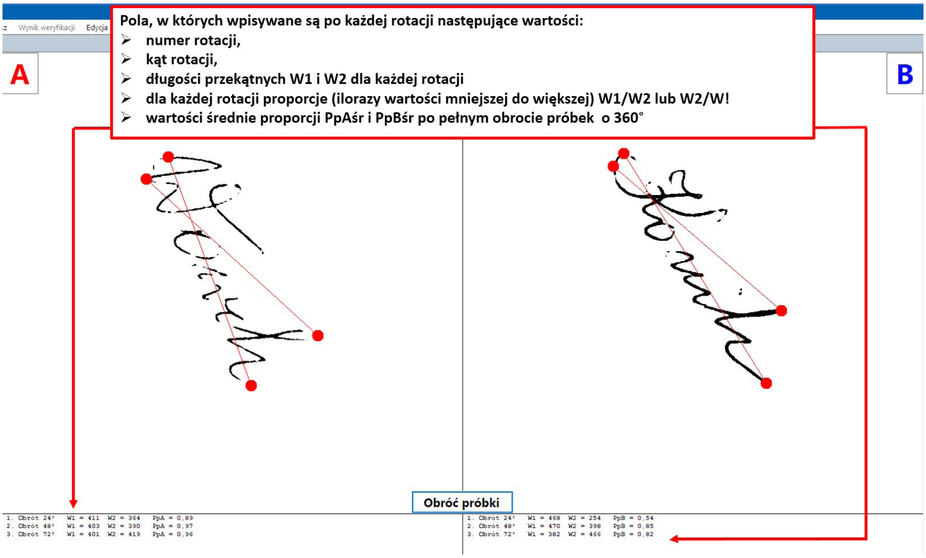
Fig. 12. Title page of ROTOMETR Pp program



Source: own study.

As already mentioned, in this case the diagonals are rotated and after each rotation of 24 degrees, the quotient of their lengths resulting from the distance between the gabar points is calculated. The areas of the quadrilaterals, their perimeters and contour shapes are not included in this study. This is illustrated in Fig. 13.

Fig. 13. Interface after three turns of 24 degrees



Source: own study.

The further procedure is identical to that of the Wk ROTOMETER. The same research methods were used and the same way of displaying the final results. This raises the question of why two rotometers when a verification opinion can be obtained using only one. Well, the author of both applications was concerned with increasing the reliability and credibility of the research. If both give an identical result, then the reliability of the research and the categoricality of the verification opinion given is greater. However, there may be situations where these applications produce divergent results. In such cases, it is advisable to repeat the test on other samples (if available) or consider the verification inconclusive.

Conclusion

As mentioned in the introduction, graphometric applications exist and have been used in scribal research for many years, so it is reasonable to ask whether it is necessary to create more graphometric-type applications that examine the graphometric parameters of the records under study. The answer is obvious. If new research methods and tools, different from existing ones, can raise the level of categorical expert opinion, they should certainly be used. It is worth emphasizing that the rotometric applications proposed in this article "frees" the expert from manual determination for analysis of graphic line elements, and this is an activity that is completely devoid of the element of subjectivity, since in this regard the computer completely "relieves " the expert. The concordance results obtained by rank correlation are also completely independent of the expert. This is a major step toward objectivity in research. However, a touch of subjectivity and controversy remained. Namely, the limiting percentage concordance of average aspect ratios (Fig. 11) and average aspect ratios, or more precisely, the percentage concordance threshold above which samples are considered concordant, is at the discretion of the researcher. In the graphometric-type applications used by experts so far, it was assumed that the percentage similarity values obtained in the tests of more than 75% testify to the conformity of the parameters studied. The applications discussed in this article adopt 85%, which may be controversial, but is a tightening of this compliance criterion.

Bibliography

Goc M., *Współczesny model ekspertyzy pismoznawczej. Wykorzystanie nowych metod i technik badawczych*, Volumina.pl Daniel Krzanowski, Warsaw-Szczecin 2020.

Goc M., Łuszczuk K., Łuszczuk A., Tomaszewski T., *Programy komputerowe jako narzędzie wspomagające ekspertyzę pisma ręcznego*, "Problems of Forensic Science" 2016, no. 294.

Goc-Ryszawa B., *Programy komputerowe wspomagające ekspertyzę pismoznawczą i ich praktyczne wykorzystanie*, "Problems of Forensic Science" 2013, no. 282.

Hecker M.R., *Forensische Handschriftenuntersuchung. Eine systematische Darstellung von Forschung, Begutachtung und Beweiswert*, Kriminalistik Verlag, Heidelberg 1993.

Koziczak A., *Analiza pojęcia krzywizny w pismoznawstwie*, in: Z. Kegel (ed.), *Problematyka dowodu z ekspertyzy dokumentów*, vol. I, University of Wroclaw, Faculty of Law, Administration and Economics Department of Forensic Science, Wroclaw 2002.

Koziczak A., *Metody pomiarowe w badaniach pismoznawczych*, Publishing House of the Institute of Forensic Expertise, Cracow 1997.

Koziczak A., *Poziom subtelności struktur graficznych a dokładność metod pomiarowych*, in: Z. Kegel (ed.), *Problematyka dowodu z ekspertyzy dokumentów*, vol. I, University of Wroclaw, Faculty of Law, Administration and Economics Department of Forensic Science, Wroclaw 2002.