NOWA KODYFIKACJA PRAWA KARNEGO

NEW CRIMINAL LAW CODIFICATION

Nowa Kodyfikacja Prawa Karnego 60, 2021

ACTA UNIVERSITATIS WRATISLAVIENSIS No 4039

Nowa Kodyfikacja Prawa Karnego 60, 2021

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NEW CRIMINAL LAW CODIFICATION

Tom/Volume LX

Redakcja/Edited by
Tomasz Kalisz
Rafał Cieśla

Wrocław 2021
Wydawnictwo Uniwersytetu Wrocławskiego

Nowa Kodyfikacja Prawa Karnego 60, 2021

ISSN 0239-6661 (AUWr)
ISSN 2084-5065 (NKPK)

Wersją pierwotną czasopisma jest wersja drukowana
The printed version of this journal is primary to the online version

Czasopismo w wersji elektronicznej znajduje się na stronie https://wuwr.pl/nkp/
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The journal is listed on the Ministry of Science and Higher Education journals index

Publikacja przygotowana w Wydawnictwie Uniwersytetu Wrocławskiego Sp. z o.o.
Publication prepared at Wydawnictwo Uniwersytetu Wrocławskiego Sp. z o.o.
50-137 Wrocław, pl. Uniwersytecki 15
tel. 71 3752885, e-mail: marketing@wuwr.com.pl

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https://doi.org/10.19195/2084-5065.60.1

Foreword

Questioned document examinations are among the most important forensic activities. They allow the relationship between various types of writings and their authors to be examined. The contemporary rapid development of technology has meant that for some time, document experts have expanded the field of handwriting examination to a much wider field related to other forms of communication. With the advancement of the electronic age, traditional handwritten documents are often replaced by electronic documents. However, this does not diminish the importance of document examination, but extends the research towards other scientific fields. The presented volume includes articles written by an international group of professional document experts. This formula allows presenting current research and discussing the results using reliable knowledge. The volume includes studies devoted to traditional examination of handwriting and signatures as well as research on electronic documents. There were also articles concerning the research on the relationship between handwriting and the sphere of human psychology. A separate group includes examining the age of documents and studies prepared with non-standard writing inks, as well as errors and mistakes made by document experts. It should be emphasized that the specificity of contemporary document research requires a multidisciplinary approach and fully justifies the need to internationalize such research. In this context, an exchange of views, including critical comments on the basis of document research, is highly desirable. Articles in the volume can be an important source of knowledge on forensic document examination.

Rafał Cieśla

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NOWA KODYFIKACJA PRAWA KARNEGO Tom LX
NEW CRIMINAL LAW CODIFICATION
AUWr No 4039 Wrocław 2021
https://doi.org/10.19195/2084-5065.60.2

Criminalistic conclusions on signature forgery process during building an offline signature verification intellectual system

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Abstract

The article describes details of the NSP-SigVer project, such as qualitative indicators of humans' ability to identify a signature forgery, which can be used to build an offline signature verification system based on an artificial neural network. The average accuracy of this action is 69.29%. The article also provides a classification of signature forgery and some features of the forgery process which are important for its identification.

Keywords: offline signature verification, signature forgery, signature dataset

Among the objectives of examining questioned documents is defining the signature's genuineness as one of the key details of a legally significant document. The genuineness/authenticity/lack of forgery signs is revealed at two levels: during an operational verification of a document (including a comparison of a reliably authentic document with a disputed one) and during an expert examination of a questioned document. In the first case, the subject of signature verification is often a person who does not have the appropriate knowledge and skills. This necessitates either advanced training of such persons or the creation of some tool to help in this process.

Such an instrument potentially can be created with the methods of intellectual verification of signatures based on artificial neural networks. These methods can be realized in forms of online and offline signature verification.

Online verification takes into account dynamic signs of signature execution as a complex, three-dimensional process; not only the final signature is analyzed, but also the process of its performing. This type of verification requires using a video recording or a touchscreen able to measure the pen movement speed and the pressure depth.

In turn, offline verification more reflects the practice: only the signature as a final graphic image is examined.

Since 2018, researchers from the Department of Criminalistics of the Ural State Law University have developed an experimental model of an intellectual system based on Siamese artificial neural networks for offline verification of a signature forgery called NSP-SigVer. We test the following hypothesis. Genuine signatures of different people have different degrees of variation. Moreover, the more stable the general and particular features of a signature, the less varied they are. And in this case, they are more likely to reflect the features of a particular person's handwriting. When analyzing a large number of signatures, the average value of these variational changes can be determined – thus, it is possible to form a certain "normalized state" for each signature, at the same time reflecting most of its particular features. The normalized state of the forged signature will differ from one of the genuine signature. During the training process, a system based on an artificial neural network must learn to distinguish a genuine signature from a forged one through comparing a reliably genuine signature with a questioned one (that can be either genuine or forged).

The human person as the subject of the practice signature forgery verification is an obvious exemplar to set criteria for the effectiveness of any system which optimizes human activity. Accordingly, a special questionnaire was organized within the project, aimed at setting indicators of human ability to distinguish genuine and forged signatures.

The probability of success in this operation directly depends on the person's experience and specialized education as well as the quality of the forgery. Each of the 127 respondents was offered a form for collecting

basic data: sex, age, level of education, special knowledge in the handwriting and document examination or related fields, subjective self-assessment of the respondent's own skills in identifying forged signatures. The questionnaire was carried out with time measurement: the average time for comparing the signatures was recorded.

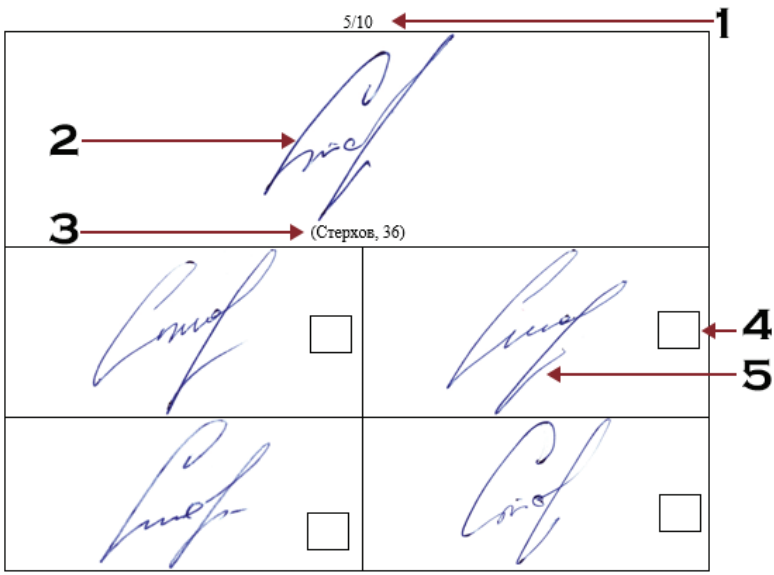
Every respondent was then given a form with 10 sets of signatures, one of which was genuine. The remaining four should be identified as either genuine or forged based on a visual comparison of the signatures (example of one such set in Figure 1). Of course, the selection is clearly not enough for a full-fledged experimental questionnaire; however, even conditionally accurate data is enough to formulate qualitative indicators for hypothesis; and if they are absent, the network quality can be evaluated even "against a coin toss" – the accuracy of the results should exceed 50%.

Based on the questionnaire results, the probability of correct verification of signatures does not exceed a 69% average (see Table 1), while women (see Table 2) show slightly better results than men (see Table 3). These data should also be evaluated critically: in real practice, a person assumes the document is genuine, while in this questionnaire the respondents could guess that among the presented signatures were some forged ones. The ratio of genuine and forged signatures in form was not known to the respondents.

Another important aspect of developing an intelligent system is its training dataset. The quality of decision-making by a person largely depends on their experience. Similarly, the operation of an intelligent system is determined by the content of the dataset for training. As part of this project, the first known dataset containing Cyrillic signatures was collected. For this moment, it contains 33 988 genuine signatures from 606 persons and corresponding 71 003 forged signatures. The dataset collection still continues.

Based on their execution methods, forgeries can be divided into three types: auto-forgery, simple, and skilled forgery. In the case of auto-forgery, the performer is the owner of the signature, the purpose of such forgery is the alleged future refusal to recognize the document as properly signed.

Simple forgeries can be considered differently. In the first variant, the forger has information about the signer's name and examples of their sig-



1 – the number of the kit in the questionnaire
2 – original signature
3 – surname and age of signer
4 – checkbox (a check mark is put if the respondent believes that the signature is genuine, a cross – if they believe that the signature is fake)
5 – questioned signature

Figure 1. A sample set of signatures for comparison in the questionnaire

Source: author's archive.

natures.[1] But signatures copied without information about the signature author's identity cannot really be considered as an issue: in reality, forging a signature is not valuable in itself but as a means of achieving a certain external goal. The forger almost always has sufficiently detailed information about the person whose signature is forged. Different situations occur, but their identification is not a significant problem. The second approach, which we support, considers simple forgeries to be forged signa-

[1] L.G. Hafemann, R. Sabourin, L.S. Oliveira, "Offline handwritten signature verification – Literature review", *Seventh International Conference on Image Processing Theory, Tools and Applications (IPTA)*, 28 November–1 December 2017, Montreal, Canada, p. 1.

Table 1. Summarized results

Number	Average age	Specialized knowledge	Self-assessment of skills (from 1 to 10), average	Time per set, sec.	Accuracy, average
127	24	5	4.89	51	69.29%

Table 2. Signature forgery verification: female

Age	Number	Self-assessment of skills (from 1 to 10), average	Time per set, sec.	Accuracy, average
18–29	68	4.92	52	70.36%
30–45	5	4.00	42	72.50%
45–60	3	3.66	27	65.00%
Total	76	4.80	50	70.23%

Table 3. Signature forgery verification: male

Age	Number	Self-assessment of skills (from 1 to 10), average	Time per set, sec.	Accuracy, average
18–29	47	4.76	56	67.02%
30–45	1	6.00	49	75.00%
45–60	3	7.30	103	80.60%
Total	51	4.90	54	67.90%

tures, performed by a person without special skills. Such forgeries often miss significant features of the initial genuine forgery.

Skilled forgeries in a given project not only are performed with examples of genuine ones present, but also require special skills on the part of the forgers, who are either professional artists or handwriting experts. In both cases, professional skills make it possible to very carefully copy the image of the signature.

Analyzing the forgery process draws a number of conclusions significant for criminalistics, both the science and the practice.

1. All our skilled forgers (and some of the unskilled ones) mentioned that it seemed to them they had seen the signatures they were forging before, which is absolutely impossible. Thus, we can conclude that from a non-expert's point of view, there are not so many options or types of sig-

natures. For one person, the signatures of two different individuals may seem identical and the difference between them can be possibly explained by variations in the signature, but not the difference between individuals.

2. The best results in forging appeared when using a small number of forged signature samples (1–3).[2] In this case, the variability in the forger's signature performance did not differ from the original signatures in terms of the variational change quality.

3. When using more signatures as samples, control over compliance with individual features was weakened. Presumably this can be explained by the fact that several alternative variants of the forged signature are "loaded" into the memory of the forger, after which a choice is made between these options. In this case, especially with the high pace of movements, random characteristics of the forger's own signature may get into the forged signature.

4. Slowing down the pace of the signature strokes reduces the number of misrepresented features, but at the same time reduced coordination of movements is a common signature forgery symptom.

5. Changes in the pressure on the new writing device, in its sliding ability on paper, or in its thickness together partially violate the finger movements, which also affects the temporarily developed skill of forgery.

6. The difference in the anatomical structure and size of the signer and the forger's hands in some cases does not allow the "appropriate" forging. This applies to large signatures made by a sweeping arc or oval movements. If the original signature is made by a person with a large palm size, the arc and oval elements can be presented as a compass, where one leg is a writing device and the palm plays the role of the other leg.

7. The most significant features – such as the placement of points characterizing the movement length relative to other signature elements, the placement of intersection movement points relative to other signature elements, or the shape and placement of connection points between elements relative to other signature elements – are rarely controlled when performing fakes.

[2] Forgers completed 28 forged signatures with 56 genuine ones provided.

8. A long-term attempt to form a temporary skill of performing a large signature while holding hand in weight does not give a positive result in the absence of drawing skills.

9. Signatures formed by separately written glyphs imitating the technical font or block letters did not cause difficulties in their forgery. People who graduate from technical educational facilities often have two handwriting patterns and all handwriting generated from technical fonts is very similar.

The above characteristics can be used in conducting handwriting examinations and in assisting employees who often encounter questioned documents. Thus, the automation of criminalistics processes, such as signature recognition, can also ensure the progress of classical criminalistics, providing data for traditional documentary research.

Acknowledgements

The reported study was funded by RFBR according to the research project no. 18-29-16001.

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Hafemann L.G., Sabourin R., Oliveira L.S., "Offline handwritten signature verification – Literature review", *Seventh International Conference on Image Processing Theory, Tools and Applications (IPTA)*, 28 November–1 December 2017, Montreal, Canada.

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NEW CRIMINAL LAW CODIFICATION
AUWr No 4039 Wrocław 2021

https://doi.org/10.19195/2084-5065.60.3

Determining the age of documents based on the stamp and seal impression

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Abstract

The present article discusses determining the age of a document based on a comparative analysis of the stamp impression in the questioned documents and an authentic document. The aim of the paper is to show that classical traceology methods are easily applied in judicial practice. Based on the analyzed instances of judicial practice, the main conclusion of the paper is that typical analysis of the stamp impression can precisely show the time frame for when the questioned document was created – no expensive and complex physicochemical laboratory analysis methods are necessary.

Keywords: determining the age of the document based on the stamp impression, comparative analysis of the stamp impression, general, individual, and identifying characteristics

Introduction

Forensically determining the validity of documents is important in modern society. The documents are essential in almost all segments of our lives – nearly everything important that happens to us or that we do. The

first crucial document in our life is our birth certificate, and the last – our death certificate. Between those two points of our lives, there are numerous documents, such as: contracts, checks, bonds, loans, tax reports, or wills. The validity of those documents can sometimes be questionable; in those cases it is a subject of experts' analysis before the court.[1]

One of the major challenges in forensic practice is determining the age of documents. The obtained results lead to reliable conclusions neither in the cases when the absolute age of the document is being determined (determining the time when the document was created) nor in cases when relative age of the document is being determined (which of the two documents is older, the chronology of certain written parts of the document, adding certain letters or numbers, backdating, etc.). This applies to simple microscopic methods, diffusion techniques, and methods using more advanced technologies, such as Raman spectroscopy, electrostatic examination, scanning, and confocal microscopy.[2]

In scientific and scholarly literature, the most frequently published papers are those which talk about the methods of *determining the age of a document based on the ink analysis* (ballpoint pens) used during document creation. They present the reliability of different methods, mostly physicochemical methods. Until now it has not been possible to determine the exact age of a document based on the ink analysis.[3] The conditions in which a document was stored affect the chemical properties of the ink, which further complicates the use of a physicochemical method in for-

[1] R.L. Brunelle, K.R. Crawford, *Advances in the forensic analysis and dating of writing ink*, Springfield, IL 2003.

[2] M. Goc, M. Miron, "Examination of the relative age of documents. Part I. Methods of examining the sequence of writing made using different techniques on a paper substrate – general issues", *Problemy kryminalistyki* (*Issues of Forensic Science*) 284, 2014, no. 2, pp. 1–4.

[3] For example: R.L. Brunelle, K.R. Crawford, op. cit.; G.M. LaPorte et al., "The identification of 2-phenoxyethanol in ballpoint inks using gas chromatography/mass spectrometry – relevance to ink dating", *Journal of Forensic Science* 49, 2003, no. 1, pp. 1–5; S. Lociciro et al., "Dynamic of the ageing of ballpoint pen inks: quantification of phenoxyethanol by GC-MS" *Science & Justice: Journal of the Forensic Science Society* 44, 2004, no. 3, pp. 165–171; J.H. Bügler, H. Buchner, A. Dallmayer, "Age determination of ballpoint pen ink by thermal desorption and gas chromatography–mass spectrometry", *Journal of Forensic Sciences* 53, 2008, no. 4, pp. 982–988.

ensics.[4] Apart from that, experiments show that different treatments of a document (exposure to a high temperature or strong light) artificially accelerate the aging of the ink and the document. After such treatments, the use of standard physicochemical methods will result in conclusions that a document is older than it is in reality.[5] When talking about challenges of determining the age of a document by using the physicochemical method of ink analysis, we also refer to a paper by Deviterne-Lapeyre[6] as well as more recent literature.

Fewer papers were published on the methods of *determining the age of a document based on the analysis of the age of paper*. The research subject here are the absolute and the relative ages of a document – that is, a paper document. It appears that in forensic practice determining the relative age of a document is more common than determining its absolute age (except in wills and some contracts). However, the prevailing opinion in literature is that determining the age of a document based on the physicochemical paper analysis method cannot fulfill the requirements of the modern judiciary – that is, numerous challenges are faced during such research.[7] In cases of determining the age of documents based on the paper analysis,

[4] O.A. Skoromnikova, R.A. Yurova, E.A. Stepanenko, "Актуальные проблемы применения методики «Определение давности выполнения реквизитов в документах по относительному содержанию в штрихах летучих растворителей»" (Ongoing issues with the use of the ink dating methodology based on relative content of volatile solvents in document entries), *Теория и практика судебной экспертизы* (*Theory and Practice of Forensic Science*) 13, 2018, no. 3, pp. 128–131.

[5] C. Weyermann, B. Spengler, "The potential of artificial aging for modelling of natural aging processes of ballpoint ink", *Forensic Science International* 180, 2008, pp. 23–31.

[6] C.M. Deviterne-Lapeyre, "Interpol review of questioned documents 2016–2019", *Forensic Science International: Synergy* 2, 2020, pp. 429–441.

[7] For example: R. Kumar, V. Kumar, V. Sharma, "Fourier transform infrared spectroscopy and chemometrics for the characterization and discrimination of writing/photocopier paper types: Application in forensic document examinations", *Spectrochimica Acta. Part A: Molecular and Biomolecular Spectroscopy* 170, 2017, pp. 19–28; L. Ortiz-Herrero et al., "Direct and indirect approaches based on paper analysis by Py-GC/MS for estimating the age of documents", *Journal of Analytical and Applied Pyrolysis* 131, 2018, pp. 9–16; C.S. Silva et al., "Chemometric approaches for document dating: Handling paper variability", *Analytica Chimica Acta* 1031, 2018, pp. 28–37; C.M. Deviterne-Lapeyre, op. cit.

published articles show that due to the conditions in which the documents were stored and various manipulations performed on the paper (such as exposure to light, heat, chemicals), the use of standard physicochemical methods will result in conclusions that a document is older than in reality.[8] There are also published papers based on the physicochemical methods in which the authors tried to find an answer to the question whether or not there was any artificial aging of a particular document.[9]

The smallest number of papers is dedicated to *determining the age of a document based on the stamp impression*. They describe physicochemical methods of using ultraviolet visible spectrophotometer[10] or Raman spectroscopy and gas chromatography[11] when studying the paper's ink absorption at the moment of impression. Those experimental studies are done in strictly controlled conditions and their implementation represents a great challenge for the modern judiciary when it comes to different types of ink, paper, or conditions under which certain documents were stored and possibly mechanically altered.

The observations based on the three types of characteristics which can be seen on the stamp and its impressions on paper are of particular interest not only for this paper, but also for the practical implementation of

[8] J. Zięba-Palus et al., "Analysis of degraded papers by infrared and Raman spectroscopy for forensic purposes", *Journal of Molecular Structure* 1140, 2017, pp. 154–162.

[9] K.O. Gorshkova, "Выявление признаков искусственного старения документов: исследование сигналов флуоресценции оптических отбеливателей с поверхности бумажного носителя" [Identification of signs of artificial aging of documents: study of fluorescence signals of optical brighteners from the surface of a paper carrier], *Современные тенденции развития науки и технологий Сборник научных трудов по материалам В международной научно-практической конференции*, г. Белгород [Modern trends in the development of science and technology: Collection of scientific papers based on the materials of the International scientific and practical conference in Belgorod], 31.08.2015, https://mepk-a.ru/bez-rubriki/vyyavlenie-priznakov-iskusstvennogo/.

[10] G. Ouyang et al., "Preliminary studies on the absorbance ratio method used to determining the age of stamp-pad ink seal", *Journal of Forensic Sciences* 64, 2019, no. 4, pp. 1203–1212.

[11] V.A. Kochemirovskiy et al., "Age determination of handwritten inscriptions and stamp impressions on documents using Raman spectroscopy and gas chromatography", *News of Science. Proceedings of Materials the International Scientific Conference*, Czech Republic, Karlovy Vary – Russia, Moscow, 30–31 August 2015, pp. 16–24, https://mepk-a.ru/bez-rubriki/age-determination-of-handwritten/.

stamp impression analysis in determining the age and possible forgery of a document. Firstly, there is possible damage which can occur during the manufacturing process, resulting in specific impressions the stamp leaves on the paper. Secondly, small damage can happen due to its use or misuse, including: worn letters and numbers, damaged rim, cuts – due to the low quality material used in its manufacturing – and some additional changes within the stamp, all of which can be significant in determining the authenticity of the stamp and possible forged documents. These changes have been described as bubbles, lumps in the surface, loose "fins" of rubber caused by defects in the molding, trimmed edges of the stamp's rubber base, etc. The third type of traces visible in a document during the stamp impression is caused by the accumulation of dirt, particles gathered in the crevices between the letters and numbers, or even a hair intertwined between letters. These changes are important for following the time sequence of the stamp impressions – they indicate the group and individual characteristics seen on a stamp. The significance of its individual characteristics affecting the impression is particularly emphasized. Forensic investigations of that type include comparative analysis, the use of microscopes, and enlarged photographs of the stamp impression.[12]

This paper presents the method of determining the age of a document based on the stamp and seal impression, used by independent expert witness Miroslav Busarčević for many years. The method is based on a comparative analysis of traces by using the magnifying equipment (stereo microscopes, enlarging the stamp impression photo on the computer screen). The characteristic of Busarčević's method is seen not only in the implementation and reliability of the proof in his experimental research, but also in real practice of forensic expertise and defense of the obtained results in the court of law.

Miroslav Busarčević has been employed as a professional police expert, currently court expert, in National Forensic Center at the Ministry of Internal Affairs since 1971. While conducting research on the issue of determining the age of documents, he developed the method for determining their exact age based on the stamp/seal impressions.

[12] *Scientific examination of questioned documents*, eds. J.S. Kelly, B.S. Lindblom, Boca Raton, FL 2006, pp. 258–263; D. Ellen, S. Day, C. Davies, *Scientific examination of documents: methods and techniques*, Boca Raton, FL 2018, pp. 176–178.

1. Theoretical basis for the method of determining the age of a document based on a comparative analysis of the stamp impression

When talking about stamps and seals, one should always bear in mind the tridimensional rubber part used for making ink impressions on the paper. A well-known fact in criminal forensics is that every stamp or a seal contains general and individual characteristics. General (also known as group) ones are its shape and size, along with the disposition, shape, and size of its certain elements. The general characteristics of the stamp and seal in their impressions on the paper, whether whole or partial, are always made as an image in the mirror and represent the general characteristic of the impressions made. Observation of these characteristics is used exclusively for elimination, to narrow the choice of the stamps and/or seals from which the impressions can (but do not necessarily) originate.

It is known that the individual characteristics of the stamp and seal are accidental (tridimensional) damage on the letters and other elements of the relief, visible to the naked eye or with a microscope. Some of the damage with stamps or seals can occur during manufacture due to a (tolerable) mistake, some can be created during the use (wearing) as well as by external factors, especially heat,[13] which, although slowly, can change the shape and dimensions of the stamp/seal. Some damage can disappear completely or new ones can be created, which all depends on the way the stamp/seal is stored and used. Individual characteristics of a given stamp or seal are unique and at any given moment distinguish the stamp/seal from others (for example forged ones) which can possess the same general characteristics.

However, individual characteristics of a stamp/seal can also be: temporarily stuck dirt and specks of dust, tiny hairs, and fibers of the textile or of other origin, which after few of the consecutive impressions can fall off the stamp/seal but they may stay on them for a longer period of time as well.

[13] Considering the heat tolerance of the relatively hard rubber into which the profile of a seal or stamp has been engraved.

Additionally, if the ink was applied only once to the stamp/seal's rubber surface, after which two or more consecutive impressions were made, one possible outcome is that some of the impression elements show damage of a matching or similar recognizable shape, made as a result of an uneven spreading of the ink along the surface of a stamp/seal. In such cases, damage created in the impressions have the same significance as the other individual characteristics of the stamp/seal.

Unlike the general characteristics of a stamp/seal, the individual ones in the consecutive impressions on paper can be various and specific but always in recognizable two-dimensional shapes, whether they are visible to the naked eye or only with the help of the optical magnifier and stereo-microscope. However, nowadays, the examination using the optical magnifier and stereo-microscope of the stamps/seals has been quite successfully replaced with scanning resolution of 1200 × 2400 pix/inch and photo editing in any of the Adobe Photoshop software versions – especially since it is currently an inevitable tool in presenting the results.

The two-dimensional reflection of individual characteristics of a stamp/seal in their impressions is called the "identifying characteristics"[14] by Busarčević because of their importance in the identification process. Their presence in the stamp/seal impressions with the same general characteristics represents, without a doubt, material evidence that they were made with the same stamp/seal. For a precise identification of a certain stamp/seal it is necessary that they, besides the shared general characteristics, contain at least one clearly recognizable individual characteristic present at the same spot.

Due to the different ways they are created, the origin of the identifying characteristics in the impressions of the stamp/seal, even though they objectively exist, can be questionable, especially if they are repeated in a few consecutive impressions of the same stamp/seal and there is no indication of their origin. Basically, only the damage in the stamps/seals whose position and recognizable shape are consecutively repeated in two or more impressions has the status of identifying characteristics, no matter how it was created. There can appear a mismatching in size

[14] It in general applies to all the imprints (for example, shoes, car tires, etc.), no matter what surface they are on.

due to a possible difference in the pressure strength and the angle the impressions were made with.

There is no impression of a stamp/seal whose optic examination cannot show at least one or more different signs of damage in their content, macroscopic as well as microscopic. Those signs can produce identifying characteristics of the impression. However, even though noticed damage can potentially become identifying characteristics, that can only be determined during the comparative analysis of other impressions of the same stamp/seal. On the other hand, the fact that changes of individual characteristics of the stamp/seal are necessarily reflected in the changes of the identifying characteristics of the impression enables us to determine the exact time the changes occurred. That fact served as the base for Busarčević's method of identifying the age of a document which contains the impression of a stamp/seal. The successful implementation of this method is directly affected by the number of documents used for comparison. Documents used for comparison should contain the impressions of the same stamp/seal as those in the questioned document(s) and they should originate from the same time period, including the date on the questioned document(s). For such purposes, only the original copies of the documents in question can be used, along with the original copies of the ones used for the purpose of comparing.

2. Examples of case studies presented before the court

This work will present three of many Busarčević's cases in which he used the mentioned method for determining the age of a document.

Case Number 1

In 2005 in one court proceeding two documents made in memorandum of a private company for manufacturing and exporting the industrial equipment needed to be checked and the real time of their making needed to be determined.

The first document is a receipt on a foreign currency loan from a person employed at the same company, dated 10.09.1995, containing the signature of the company's owner and the company's stamp impression.

The second document was the relationship agreement on the loan, dated 15.04.1997, containing the signatures of the lender – plaintiff in the case, and the previously mentioned company owner, along with the company's stamp impression. The text in the questioned receipt was written in Latin letters and Arabic numbers on the typewriter, and the agreement was written on a personal computer also in Latin letters and Arabic numbers, but in italics, and printed. According to the relationship agreement, the total sum was 1,328,947 DM. Both documents first appeared approximately in 2003, a year after the company owner, whose signature was on the receipt, died in a car accident.

In the court proceeding, the defendant, widow of the deceased company owner, stated that her late husband had never taken any loans from any individuals or the plaintiff, and that he had not made any relationship agreement on the loan. She claimed that her husband had immense trust in the plaintiff who, as an old friend, was given a job at the company. For the purposes of ordering supplies necessary for the production, the plaintiff was given the company's blank memoranda which, in the bottom right corner, held the signature of the owner and the stamp impression of the company. She also stated that the plaintiff abused that privilege and used two of the memoranda to make a false agreement and the receipt. She added that from the moment the company was founded, only PCs were used for financial transactions and that there was no need for her husband to use the typewriter which they had not even possessed.

Figure 1 shows the general layout of the original samples on both the questioned documents, and Figure 2 shows a closer look on the company owner's signatures with a stamp impression of the company.

Comparative optical analysis of the stamp impression in the questioned receipt and questioned agreement showed that they are matching as far as the general characteristics are concerned – these being the shade of purple of the stamp ink impressed, the size[15] and the width of the double circle along with the joined disposition shape and size of the content elements (Latin letters, quotation marks, a Roman number and a six-pointed star). It has also been stated that in the same places both impressions possess

[15] Whenever the size of the stamp is concerned, especially its rubber relief surfaces, the possible deviation that depends on the pressure and the angle the impression was made with should always be taken into consideration

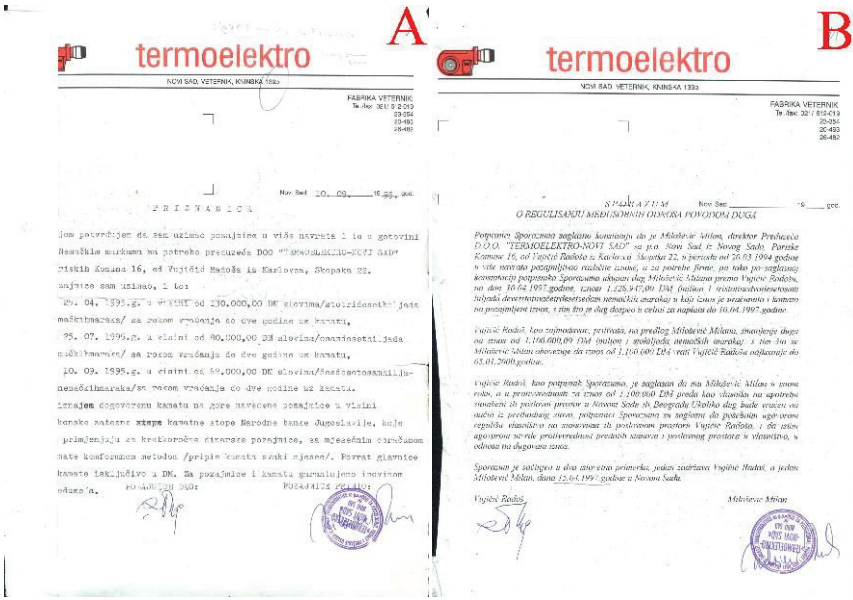


Figure 1. General layout of the document: the receipt (A) and the agreement (B)

Figure 2. Closer look on the company owner's signature with a stamp impression: in the receipt (A) and the agreement (B)

the same three identification characteristics, which represent the unquestionable proof that they were made with the same stamp.

All the features mentioned above are shown in Figure 3 where one of the characteristics appearing in both impressions looks like long drop in

the last letter "O" in the word "TERMOELEKTRO," marked by number 1. Second one is a light triangle-shaped area with a small dot on the inside rim of the outer circle, marked with a number 2, while the third one is represented by a blur and insufficiently clear lines of the upper parts of the joined capital letters "PR" in the word "PROIZVODNJU," marked by a number 3.

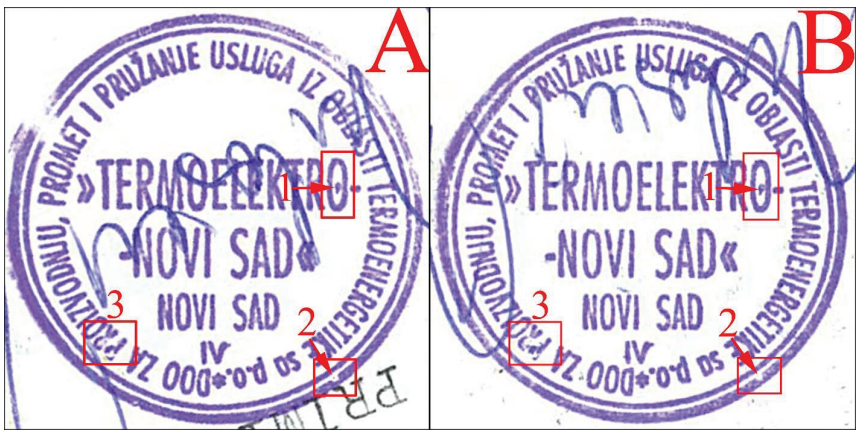


Figure 3. Comparative overview of the stamp impressions in the questioned receipt ("A") and questioned agreement ("B"). Joint characteristics of both impressions are marked with the numbers 1, 2, and 3

With the aim to determine the real time when the two questioned documents were made, the non-questioned documents from the company records were used as a base of unquestioned documents used for comparison. Since during the visual analysis of the numerous original copies of the documents from the company records not a single document written on the typewriter was found, nor one typed on a personal computer in italics, determining the exact time when the two questioned documents were made was based exclusively on optic comparative analysis of the stamp impressions in the questioned documents and the ones from the records. For that purpose, the original copies of the documents containing the stamp impression, ink color, and other general characteristics resembling the ones in the questioned documents were taken out of the records. Since the questioned receipt was dated 10.09.1995 and the questioned

agreement 15.04.1997, for the purposes of comparative analysis all the documents dated 1995, 1996, and 1997 that contained stamp impressions were taken out of the records.

Fifteen documents from the records dated from 10.04.1997 to 9.05.1997 contained stamp impressions with the identification characteristics marked by number 1. This can be seen in Figures 4 and 5 which, due to their size, were not put together into a single photo, but the documents with stamp impressions are shown in date order.

In the displayed line of the stamp impressions from the records, starting on 10.04.1997 and ending on 9.05.1997, we can notice the gradual formation of the described identification characteristics and their repetition through all the impressions until 9.05.1997, when they suddenly disappear and are no longer present in further documents.

Figure 4

Figure 5

The appearance as well as the disappearance of this identification characteristic can be explained by the gradual gathering of grains and/or speck of dust within the relief letter "O" in the stamp, possibly from the dirty surface of the ink pad which led to forming a temporary lump which at one point just fell off the stamp.

It is therefore obvious that the questioned receipt, dated 10.09.1995, as well as questioned agreement, dated 15.04.1997, were issued between 12.04.1997 and 9.05.1997.

Since the identification characteristic marked as number 1 in the stamp impressions on the questioned documents is the most similar to identification characteristics of the stamp impressions on the documents in the company records dated from 15.04.1997 to 24.04.1997, by its place, shape, and size we can conclude with the high level of certainty that this time frame represents *the real time* of creation of both these questioned documents.

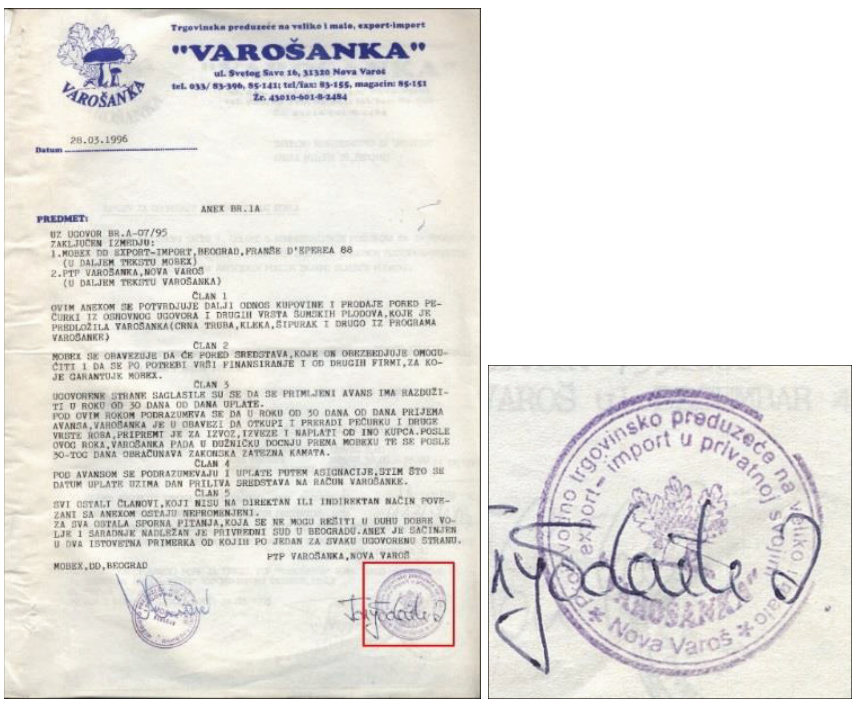
On the other hand, bearing in mind that both stamp impressions in the questioned documents are of the same purple color as well as that none of the stamp impressions in the documents from the company's records had identification characteristics marked as number 2 and 3, it can be concluded that in both these documents they were made exclusively as a consequence of uneven application of ink on the surface of a stamp which made the impressions. Thus, it can be concluded that both impressions were made *at the same time*, by consecutive stamp impressions without repeated ink application on its relief surface.

Case number 2

In year 2006, the court of law demanded an expert's analysis in order to determine whether the questioned document – annex to the contract number 1, dated 28.03.1996, was made on that date, and if not, when it was actually made.

The questioned annex to the contract number 1 was made on a memorandum of a wholesale and retail, export and import company called Varošanka between the mentioned company and one called Mobex, in which, apart from the text typed on a typewriter, there were also the signature of the directors and stamps of both companies. Figure 6 displays the original copy of the questioned annex, as well as the stamp impression of the Varošanka company in the annex.

Since the questioned annex was made on the memorandum of company Varošanka, their records were used to determine the time of its creation. When the records were inspected, it was determined that all the documents typed on a typewriter since the time when the company was founded in 1986 until the inspection date on 9.11.2006 were written on a different typewriter than the questioned annex. This led to the conclusion that the date of the annex creation can be determined only based on the stamp impression.



Trgovinska preduzeće na veliko i malo, export-import

"VAROŠANKA"

ul. Svetog Save 16, 31320 Nova Varoš

tel. 033/ 83-396, 85-141; tel/fax: 83-155, magacin: 85-151

Žr. 43010-601-8-2484

28.03.1996

Datum

ANEX BR.1A

PREDMET:

UZ UGOVOR BR.A-07/95

ZAKLJUČEN IZMEĐJU:

1.MOBEX DD EXPORT-IMPORT,BEOGRAD,FRANŠE D'ESPEREA 88
(U DALJEM TEKSTU MOBEX)

2.PTP VAROŠANKA,NOVA VAROŠ
(U DALJEM TEKSTU VAROŠANKA)

ČLAN 1

OVIM ANEXOM SE POTVRĐUJE DALJI ODNOS KUPOVINE I PRODAJE PORED PEČURKI IZ OSNOVNOG UGOVORA I DRUGIH VRSTA SUMSKIH PLODOVA,KOJE JE PREDLOŽILA VAROŠANKA(CRNA TRUBA,KLEKA,ŠIPURAK I DRUGO IZ PROGRAMA VAROŠANKE)

ČLAN 2

MOBEX SE OBAVEZUJE DA ĆE PORED SREDSTAVA,KOJE ON OBEZBEĐUJE OMOGUĆITI I DA SE PO POTREBI VRŠI FINANSIRANJE I OD DRUGIH FIRMI,ZA KOJE GARANTUJE MOBEX.

ČLAN 3

UGOVORNE STRANE SAGLASILE SU SE DA SE PRIMLJENI AVANS IMA RAZDUŽITI U ROKU OD 30 DANA OD DANA UPLATE.
POD OVIM ROKOM PODRAZUMEVA SE DA U ROKU OD 30 DANA OD DANA PRIJEMA AVANSA,VAROŠANKA JE U OBAVEZI DA OTKUPI I PRERADI PEČURKU I DRUGE VRSTE ROBA,PRIPREMI JE ZA IZVOZ,IZVEZE I NAPLATI OD INO KUPCA.POSLE OVOG ROKA,VAROŠANKA PADA U DUŽNIČKO DOCNJU PREMA MOBEXU TE SE POSLE 30-TOG DANA OBRAČUNAVA ZAKONSKA ZATEZNA KAMATA.

ČLAN 4

POD AVANSOM SE PODRAZUMEVAJU I UPLATE PUTEM ASIGNACIJE,ŠTIM ŠTO SE DATUM UPLATE UZIMA DAN PRILIVA SREDSTAVA NA RAČUN VAROŠANKE.

ČLAN 5

SVI OSTALI ČLANOVI,KOJI NISU NA DIREKTAN ILI INDIREKTAN NAČIN POVEZANI SA ANEXOM OSTAJU NEPROMENJENI.
ZA SVA OSTALA SPORNA PITANJA,KOJA SE NE MOGU REŠITI U DUHU DOBRE VOLJE I SARADNJE NADLEŽAN JE PRIVREDNI SUD U BEOGRADU.ANEX JE SAČINJEN U DVA ISTOVETNA PRIMERKA OD KOJIH PO JEDAN ZA SVAKU UGOVORNU STRANU.

PTP VAROŠANKA,NOVA VAROŠ

MOBEX,DD,BEOGRAD

Figure 6

General characteristics of the impression in the mentioned annex are its purple color, round shape, size, as well as the disposition, shape and size of the content elements. The impression also had damage which was clearly visible gaps in the outer rim, as well as dotted blurs in upper part of the penultimate letter "e" of the word "preduzeće," which can be ob-

served in Figure 7 where the mentioned signs of damage are marked by numbers 1, 2, and 3.

Figure 7

Taking into consideration that this damage of a stamp impression in the questioned annex dated 28.03.1996 can represent identification characteristics of the impression suitable for the exact determination of time of its creation, all the original copies of the documents with the stamp impressions of the same general characteristics were taken from Varošanka's records for the period from 19.03.1996 to 16.10.1997. After that date there was no document with the same impression in the records – since the company was re-registered on 18.10.1997, the stamp was not valid anymore and it was destroyed.

However, during the comparative optical analysis of the mentioned stamp impression from the questioned annex and the stamp impressions from the documents taken from the company records, it was determined that there are only four documents dated within the period from 19.03.1996 to 12.04.1996, including the one dated 28.03.1996 mentioned

in the questioned annex, which had none of the three signs of damage. This is displayed in Figure 8 where there are stamp impressions from the questioned annex and the mentioned four documents from the company records. The stamp impression from the questioned annex is marked by letter A; the one from the document dated 19.03.1996 is marked by letter B; the one from 21.03.1996 by letter C, from 5.04.1996 by letter D, and from 12.04.1996 by letter E.

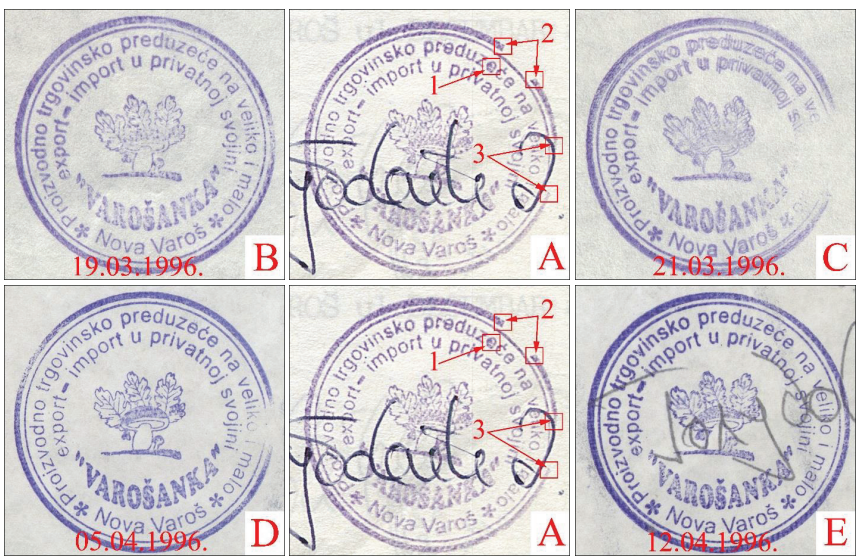


Figure 8

During the further comparative analysis, however, a document dated 1.10.1997 was found in the company records, bearing a stamp impression with all the three signs of damage visible in the questioned annex, as well as the same general characteristics and the same color. Because of their reoccurrence in both impressions, these losses have the status of identification characteristics which undoubtedly imply that they were made by the same stamp.

This is displayed in Figure 9, where the stamp impression in the questioned annex is marked by letter A, the one from the document from the records from 1.10.1997 by letter F, and the one from the records dated 16.10.1997 by letter G.

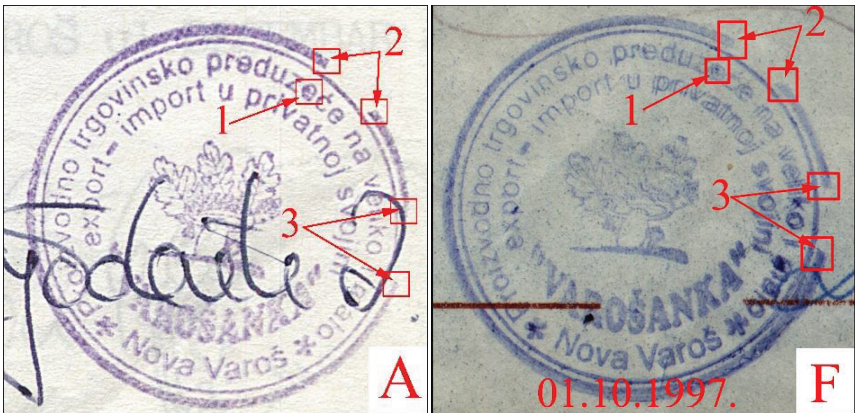


Figure 9

In the next and at the same time the last impression of the same stamp from the records, dated 16.10.1997, the change of the fault marked by number 3 can be observed, which does not exist as such anymore. One end of the broken line ends at the height of the small letter "e" in the word "veliko," while in the impression in the document from 1.10.1997 it ends at the height of the small letter "i" of the same word. This can be observed in Figure 10, which presents stamp impressions on the mentioned documents, marked by letters F and G, with the dates.

The gradual appearance of all three signs of damage can be observed in the stamp impressions during the period from 17.07.1997 to 1.10.1997, which is displayed in Figure 11 with a line of stamp impressions along with the dates when they were made.

The damage marked by numbers 2 and 3 is clearly formed as a consequence of the stamp's outer relief rim erosion, while the fault marked by number 1 is made as a consequence of the grains and traces stuck in the relief small letter "e" within the stamp.

With all the aforementioned data, it is clear that the questioned annex to the contract *was not* made on 28.03.1996 as it is stated, and that the *real time* of its creation is in the period between 18.09.1997 and 16.10.1997.

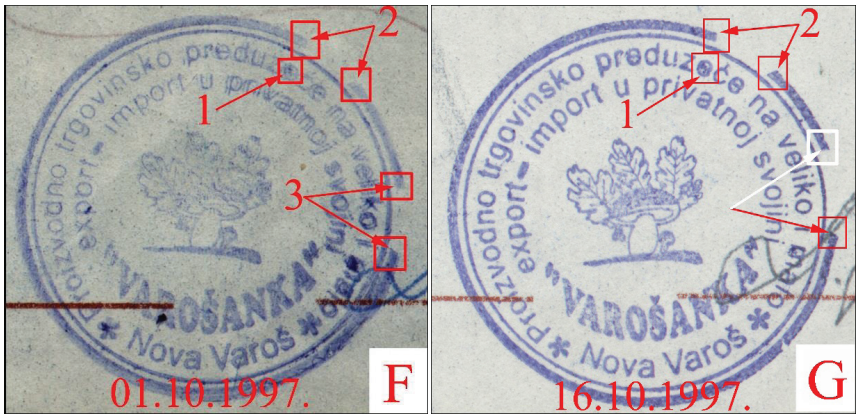


Figure 10

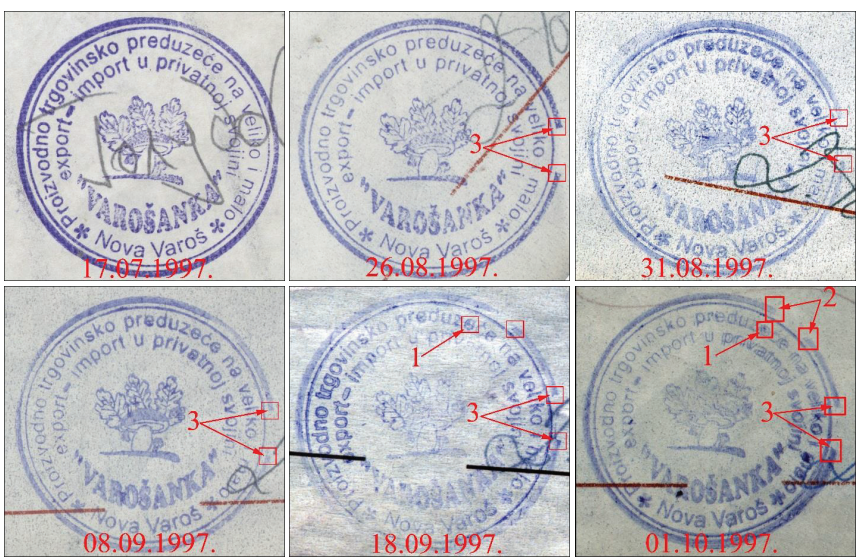


Figure 11

Case number 3

In one criminal proceeding in the year 2012, a court of law demanded expert analysis on the certificates of one company. It should have been

determined if the certificates from the company for trade and services called Integra Motors were issued at the same time or at the times stated in them. One was dated 18.10.2004 and the other 7.12.2004.

Both certificates were made on the memorandum of the company and contained printed text from the PC printer, a signature by the same employee, and the company stamp. General characteristics of both documents are displayed in Figure 12, where the certificate from 18.10.2004 is marked by letter A and the one from 7.12.2004 by letter B.

Since there were no other possibilities, the analysis whether the questioned certificates were made at the same time was based on the stamp impressions. Comparative optical analysis of both the original copies led to the conclusion that their general characteristics, such as shape and size, as well as the disposition, shape, and size of the certain content elements are matched. It is also determined that they have one mutual, clearly visible, pin-shaped microscopic identification characteristic (although not of the same size), which can be observed at the same place in both impressions: on the line of the letter "O" in the word "BEOGRAD." This, among other things, implies that the impressions were made by the same stamp. This is all displayed in Figures 13 and 14.

Original copies of the documents with stamp impressions matching the impressions in the questioned certificates in terms of general characteristics were taken from the company records for comparison.

During the comparative optical analysis of the stamp impressions in the questioned certificates and the impressions of the same stamp in the documents taken from the company records, four documents were found to have the same date as the questioned certificates. However, none of those impressions had the described identifying characteristic. Additionally, after 7.12.2004, in the company records there was no document with the required stamp impression, since it was not valid after that date – it was destroyed on 20.06.2005 and, along with two other company stamps, proclaimed invalid.

The stamp impressions in the four mentioned documents from the company records are displayed according to their dates of creation in Figures 15 and 16 and marked by letters C, D, E, and F.

Figure 12

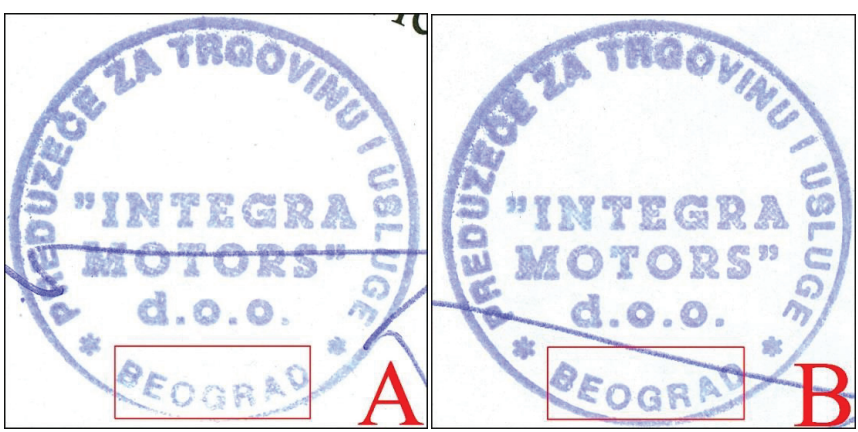


Figure 13

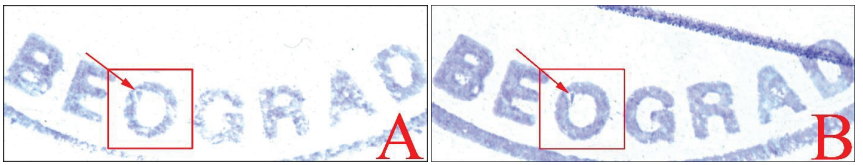


Figure 14

Figure 15

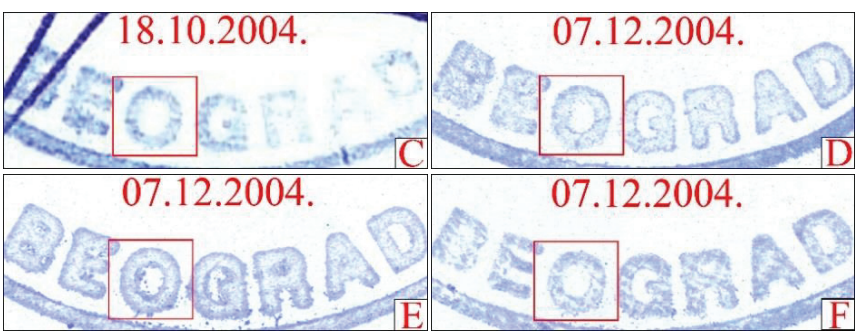


Figure 16

Since none of the impressions in the documents from the company records which are dated within the period stated in the questioned certificates contain identifying characteristics visible in the stamp impressions from the two questioned certificates, it is obvious that they were *not* made at the time stated in them.

If the described identifying characteristics of the stamp impressions in the questioned certificates were created as a consequence of a temporarily stuck grain or trace of a certain material[16] on a relief edge of the mentioned letter "O" within the stamp, it is possible that both certificates were made at the same time.

However, if the mentioned identifying characteristics were made as a consequence of physical damage to the mentioned letter's relief edge within the stamp, then both certificates could have been made only between 7.12.2004, when it was not valid, and 20.06.2005, when it was destroyed by the committee.

It was impossible to determine whether it was the case of a temporarily stuck grain or trace of a material or physical damage, since the stamp which made the impressions does not exist anymore.

Conclusion

Determination of the document's age (absolute and relative) always represents a challenge for an expert. In the practice of forensic expert Miroslav Busarčević, the method for determining age based on the comparison of stamp impressions in the questioned document and documents with the impressions of the same stamp in the documents from the company's authentic records has proven to be highly successful. This method includes scanning questioned and authentic documents in high resolution, analysing them in any of the Adobe Photoshop programs, finding questioned details in stamp impressions in questioned documents and comparing them with the details of stamp impressions in authentic documents. Unlike expensive physicochemical methods used in attempts to discover the age of documents, this method determines the exact time frame when the questioned document was created. This method is much cheaper and more accessible in everyday work of forensic experts.

[16] For example, paper.

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Nowa Kodyfikacja Prawa Karnego 60, 2021

NOWA KODYFIKACJA PRAWA KARNEGO Tom LX
NEW CRIMINAL LAW CODIFICATION
AUWr No 4039 Wrocław 2021

https://doi.org/10.19195/2084-5065.60.4

Handwriting analysis as an assessment instrument in legal psychology

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Abstract

Handwriting analysis has several advantages important for legal psychology over traditional instruments. However, being a projective method, it must be well validated. The article presents a formal system of psychological handwriting analysis, which allows an objective and transparent procedure and in particular ensures conditions for proper validation. Practical examples demonstrate that.

Keywords: handwriting psychology, formal handwriting analysis, computer application, legal psychology, validation

Introduction

Legal psychological examination is a field which especially requires objective and reliable methodological tools: the responsibility of an expert is very high. This expertise area is the generalisation of two fields: forensic and criminal psychology.[1] Criminal psychology is mainly to do

[1] D. Howitt, *Introduction to forensic and criminal psychology*, Harlow 2018.

with psychological aspects of criminal behaviour by individual persons and groups. This generally includes the origins and development of criminality. Forensic psychology deals mainly with courts and law – that is, with trials. However, it should be understood more widely. It includes all possible aspects of the legal system: investigation, policing, prisons, etc. It is applicable to criminal, civil, and family contexts. The objects of forensic psychology may be criminals, suspects, witnesses, family members, investigators, detectives, prosecutors, lawyers, experts, etc.

Generally, legal psychological assessment uses the same methods and instruments as other application fields of psychology. However, it has strong specifics. First, often an explicit involvement of the person under investigation or expert evaluation is not possible. The person is simply not available or refuses to participate in the testing. Second, the information from a person under investigation is not credible – the person would just manipulate their answers.

That is why alternative or additional methods, which could enhance the level of objectivity and credibility, are very important. One of such instruments is handwriting psychology. Previously known as graphology, it has been developed and used for decades and has a long path of experiences. It provides a wide coverage of personal characteristics and excludes social desirability, the latter being one of the major problems of psychometric instruments, especially questionnaire-based tests. However, traditional graphology lacks sufficient validation.[2] Computer-based instruments and the newly developed methods of formalised handwriting analysis demonstrate new promising validation results.[3]

In the current article, we are presenting some examples of handwriting psychology application. Generally, it can be used in different fields of legal assessment:[4]

[2] T. Chamorro-Premuzic, A. Furnham, *The psychology of personnel selection*, Cambridge 2014; U.P. Kanning. *Standards der Personaldiagnostik*, Hogrefe 2019.

[3] Y. Chernov, "Formal validation of handwriting analysis", [in:] *Handwriting research: Validation & quality*, Berlin 2018, pp. 37–68.

[4] V. Engalychev, "The place of handwriting analysis in legal psychology: Topical issues and research perspectives", *Aspects of Handwriting* 2020, no. 2, pp. 3–20.

1. criminal psychology – identifying typical patterns of criminal behaviour in general and leaders of criminal groups in particular; psychological specifics of criminals with different ethno-social backgrounds;

2. preventive psychology – identifying psychopathological potential in at-risk zone individuals; revealing anti-criminal and/or prosocial tendencies in suspect persons;

3. investigative psychology – classical (trace) psychological profiling; distant psychological profiling; detecting psychological specifics of different investigation participants (suspects, investigators, witnesses, etc.);

4. penitentiary psychology – evaluating the efficiency of specific punishment; psychological evaluation of correction dynamics and re-education efficiency.

Handwriting psychology covers many aspects of personality. Thus, in the mentioned areas it can supplement traditional instruments in various tasks a criminal or forensic psychologist faces. That includes, for instance:

1. in-person psychological forensic examination – psychological handwriting analysis supplements and specifies the list of characteristics obtained with the help of a standard psychological examination;

2. psychological forensic assessment *in absentia* – allows obtaining some unique psychological information about the personality under examination (usually done on suicides who left notes, letters, diary entries, etc. or regarding missing people);

3. non-forensic expert examinations conducted at lawyers' and human rights defenders' requests have become an important trend in the application of psychological handwriting analysis in recent years; examining handwritten materials of the surrender and first confessions often reveals indications of inadequate mental state of the subject that may point to them being under an illegal psychological impact;

4. criminal profiling enables the linking of an individual's action to its psychological profile; a person's handwriting can be one of the important information sources when others are hardly available. In particular, profiling is most often used to identify potential or acting terrorists, paedophiles, criminals demanding ransom for kidnapped people, etc. In this case, psychological examination is based on the traces left at the crime scene;

5. distant profiling allows the use of psychological handwriting analysis along with other techniques and methods such as analysis of video records, photographs, audio recordings, witness testimonies, video surveillance, etc. This results in building psychological portraits of criminal gang leaders, corruptionists, and others who are not available for a regular psychological examination.

The mentioned implementation areas are promising. However, they can be successfully realised only if handwriting psychology answers the requests to improve the quality and the validation process. That is possible only with formalised and clear procedures. In the current article, we consider in particular the computer system HSDetect, developed at Zurich Institute for Handwriting Sciences.

Method: Handwriting psychology

Before we describe the formalisation of handwriting analysis, let us compare the traditional psychometric instruments used for it (mainly questionnaires, for instance, NEO-FFI for big five, or 16PF for Cattel's scales). That allows to see its advantages and drawbacks as well as emphasise the improvement guaranteed by the formalised approach.

1. A typical psychometric test detects only separate psychological characteristics of a person. Handwriting psychology covers wide aspects of personality, so many psychological traits in one procedure. This includes the spheres of emotion, vitality, motivation, social, communication, mental, working, personal attitude, self-concept, and self-esteem.

2. A psychometric test presents a self-image of the persons who answer questions about themselves. Handwriting psychology is an external image and from this point of view can be considered more objective.

3. Psychometric tests are strongly influenced by the social desirability of the given answers. People mostly know what "the correct answers" are, especially when they are under expertise or during a recruiting process. Handwriting psychology makes it possible to completely exclude social desirability. The average person does not know how to manipulate their handwriting to get better assessment results.

4. A psychometric test typically is heavily language-dependent. In every country, it must be adapted to the local cultural environment. Hand-

writing psychology works with any European language without special adaptation. An expert can analyse specimens in an unknown language.

5. Any test requires a special test-session, so an exam situation of a sort. This makes people feel stressed, which can influence the answers and thus the result. Handwriting, to the contrary, is a natural process. Additionally, we can use previously written texts for the analysis, i.e. texts written in a normal situation, unrelated to the investigation.

Along with these advantages, traditional graphological analysis has some commonly known problems. First, it is less structured than a typical psychometric test. Both the process and the result report strongly depend on the expert. The report typically has the form of a plaintext, which can be ambiguously interpretable. Secondly, the whole graphological analysis procedure is not transparent. Thirdly, classical graphology is purely validated, which is mentioned in multiple publications on the topic (most commonly referred to).[5]

Handwriting psychology, especially the formalised computer-aided approach, makes it possible to overcome the mentioned issues. Through it handwriting analysis becomes more structured and transparent. This can be achieved in particular through mathematical modelling. This approach

[5] G. Ben-Shakhar et al., "Can graphology predict occupational success? Two empirical studies and some methodological ruminations", *Journal of Applied Psychology* 74, 1986, no. 4, pp. 645–653; H.J. Eysenck, G. Guidjonsson, "An empirical study of the validity of handwriting analysis", *Personality and Individual Differences* 7, 1986, no. 2, pp. 263–264; C. Dazzi, L. Pedrabissi, "Graphology and personality: An empirical study on validity of handwriting analysis", *Psychological Reports* 105, 2009, no. 3, pp. 1255–1268; A. Furnham, T. Chamorro-Premuzic, I. Callahan, "Does graphology predict personality and intelligence?", *Individual Differences Research* 1, 2003, no. 2, pp. 78–94; A. Furnham, B. Gunter, "Graphology and personality: Another failure to validate graphological analysis", *Personality and Individual Differences* 8, 1987, no. 3, pp. 433–435; B. Gawda, "Lack of evidence for the assessment of personality traits using handwriting analysis", *Polish Psychological Bulletin* 45, 2014, no. 1, pp. 73–79; R.N. King, D.J. Koehler, "Illusory correlation in graphological inference", *Journal of Experimental Psychology* 5, 2000, no. 4, pp. 336–348; R. Klimoski, A. Rafaeli, "Inferring personal qualities through handwriting analysis", *Journal of Occupational Psychology* 56, 1983, no. 3, pp. 191–202; E. Netter, G. Ben-Shakhar, "The predictive validity of graphological inferences: A meta-analytic approach", *Personality and Individual Differences* 10, 1989, no. 7, pp. 737–745; R. Vestewig, M. Moss, "On the validity of graphoanalysis", *Journal of Personality Assessment* 41, 1977, pp. 589–600.

is supported by the authors of the present article. Below we briefly describe the proposed mathematical model.

It is more complicated with validation. The lack of proper handwriting analysis validation is true, or at least partly true. Typically, the authors of critical works refer to the same old studies and meta-analyses. However, as was shown in our analysis,[6] these studies have serious methodological problems.

– Validation analysis is based on ambiguously interpretable free-style text graphological reports; this often takes place in validation studies, which involve graphologists.

– Improper handwritten specimens are used – they are too short or written with instruments improper for the handwriting analysis, such as ones with soft tips.

– Researchers evaluate handwriting samples themselves, without relevant training. They often draw their conclusions based on primitive graphological books, plenty of which are available.

– Improperly modelled test scales. In the validation studies, which compare handwriting analysis to psychometric tests, the scales of the tests are too simplified.

– Only several handwriting signs are considered because they are the simplest. Researchers ignore many important and relevant handwriting signs – that mostly happens when they evaluate the handwriting samples themselves.

– Validation experiments are poorly planned or too complicated and confusing.

– Poor statistical data and methods. In most cases, researchers use only straightforward Pearson correlation to check their handwriting analysis results against psychometric tests. Often the simple comparison would not work because the distribution of variables is not normal, the results are not measured on the continuous scale, etc. Besides, since the evaluation of handwriting is time-consuming and requires much effort, only a restricted amount of statistical data is available. That could be fine in a pilot study. However, the conclusions about the quality of handwriting analysis in general are not appropriate in these cases.

[6] Y. Chernov, op. cit.

– Subjectivity, prejudiced and biased approach. Often researches build their experiments around the opinion they already hold. They want to prove either uselessness or usefulness of the chosen method. In many studies one can see that this strongly influences the interpretation of the results.

This list of typical problems is merely a summary – more details and references to specific examples can be found in *Formal validation of handwriting analysis*. The vast majority of known studies have one or several problems. Due to that, we can draw no substantial scientific conclusions out of these studies.

We can state that there is not enough proof of validity, but there is also no reason to state that handwriting psychology in general is invalid. Validation should be evaluated by experiments that comply with quality requirements. This is possible with a clear formalised model of handwriting analysis and comprehensive, reproducible interpretation. That distinguishes handwriting psychology from graphology. Finally, we need an effective computer application and enough statistical data. Some promising results, including those in legal psychology, have been achieved with the HSDetect system.

Method: Formalized handwriting analysis with HSDetect

HSDetect is a computer system for handwriting analysis (by "handwriting analysis" we mean handwriting psychology and traditional forensic handwriting analysis for author identification). It includes several databases and a programming block.[7] Its design is based on the following principles:

– quantitative presentation of all data. That relates both to handwriting signs and psychological traits, as well as to the connections between them;

– statistical integration of different handwriting analysis methods. The models of psychological traits represent the sets of related handwriting signs. These sets were formed on the basis of multiple graphological publications and reflect the statistically accumulated experience. In spite of

[7] Y. Chernov, *Psychologicheskij analiz pocherka. Sistemnij podhod*, Moscow 2011; Y. Chernov, "Der Einsatz des Computers in der Graphologie", *Angewandte Graphologie und Persönlichkeitsdiagnostik* 2014, no. 2, pp. 18–37.

known validation problems, we should not forget that graphologists, who are often psychologist or physicians, made many interesting observations and summaries on the basis of their practical work. We should not simply ignore them – rather we should be very careful and critically validate their findings;

– a formal unambiguous definition of handwriting signs, which must be carefully preserved by their manual evaluation. Without this, further statistical calculations make little sense;

– algorithmic evaluation of psychological traits on the basis of manually evaluated handwriting signs. In principle, it would be much preferable to automatically evaluate handwriting signs. However, so far it is not possible. The existing systems can cover only a handful of signs and even then they are rather unreliable;

– open and adaptive character of the system. The existing solution is not a fixed system, but rather a framework. The databases include much data for algorithmic calculations. However, this data is being permanently enriched, partly based on the already done validation experiments.

Psychological handwriting analysis includes three objects: handwriting signs, psychological traits, and the relations between them. The relations are rather complicated: one sign relates to several traits and every trait depends on several signs.

In the HSDetect model, handwriting signs and personality traits are presented as variables on the continuous scale from 0 to 1. For signs, zero means that it is not present in the analysed handwriting sample, one – that the sign is obviously and strongly present. The analysis of handwriting samples, i.e. quantitative evaluation of handwriting signs, is done manually. To ensure unambiguity, signs (or more precisely: the way they are evaluated) are defined algorithmically. Let us take, for instance, one of the simplest signs – letter size. It is defined as the vertical distance from the lowers point of the letter to its highest point along the letter slope line. Only inner (excluding the first and last letters of a word) letters of the middle zone are considered. That means letters *a*, *c*, *e*, *m*, *n*, *o*, *r*, *s*, *u*, *v*, *w*. The size of every measured letter can have the following values: very small (< 1.5 mm), small (1.5–2 mm), medium (2–3 mm), big (3–5 mm) and very big (> 5 mm). Assume that we measure all corresponding letters in the handwriting sample. Let us denote the number of all inner middle zone letters in the investigated

handwriting sample as *M*. Then the number of letters of each mentioned size is correspondingly m_i. The values of handwriting sign "very small" equals m_1/M, "small" – m_2/M, "medium" – m_3/M, "big" – m_4/M, and "very big" – m_5/M. The sum of all m_i/M naturally equals one. Of course, in the analysed text, you typically do not encounter all possible sizes; typically, it is one or two, sometimes three. That is a theoretical, scientific approach. In practice, an expert will not measure every individual letter, but will use some heuristics. However, the "ideal" algorithm can be considered for the difficult and control cases.

Every trait is modelled as a function of several handwriting signs by means of what we call graphometric functions:

$$y = \sum_n a_i \cdot x_i \tag{1}$$

where y – the level of the trait; n – number of handwriting signs that indicate the trait; x_i – evaluated level of handwriting sign i; a_i – coefficient indicating the weight of handwriting sign i for trait y. The coefficients are calculated statistically (the algorithm is not in the scope of the current article). What is important is that the sum of a_i equals one.

Additionally, we consider the reliability of the trait evaluation. This reliability is specific for each individual handwriting sample. The more handwriting signs out of those included in the graphometric function are present, the higher the reliability of the evaluation. The final value of the personal trait is modelled as follows:

$$y = \sum_n ((a_i \cdot x_i)^{\alpha} \cdot (1-r^k)^{1-\alpha}) \tag{2}$$

where k – the number of handwriting signs out of n that are really present, i.e. $x_i > 0$, correspondingly $k \leq n$; r – the assumed probability of a false decision about the trait if we base its identification only on one handwriting sign out of n, i.e. only one sign out of n is present in the analysed sample, empirically $r = 0.8$; α – parameter identifying the trait level weight.

Formula (2) represents the elaborated model (E-model), which is being used for various research, including validation experiments. However, the absolute value of y is not very representative, especially when you want to compare different traits to one another. Traits depend on different handwriting signs and different n. That is why, although theoretical value inter-

vals for all of them are the same – between 0 and 1, the actual intervals are different. Thus, for one trait the value 0.4 might be low, and for another, which actually changes from 0 to 0.5, it is high. To understand the actual level of a trait, we should convert it from absolute to normalised values. That is possible when we have enough statistical data. The normalised value for a trait can be expressed as follows (in a standard way):

$$z = (y - Y) / \sigma \tag{3}$$

where Y is the expected value and σ is the standard deviation of statistical row of trait y. However, (3) can be used only if the row is normally distributed, which is often not the case. That is why we prefer a heuristic normalisation:

$$z = (y - y^{min}) / (y^{max} - y) \tag{4}$$

In (4) z changes from 0 to 1 and shows how strong the trait is in the investigated person compared to other people (statistical data is retrieved from the HSDetect database).

The model (1)–(4) is used mainly in research and personal assessments, when we need a complete psychological portrait of a person. When investigating a separate personal features it is often enough to evaluate them by a simplified W-model (weighted model) or P-model (plain model). W-model includes only (1) and (4). P-model includes (1) and (4), where additionally all $a_i = 1/n$ and x_i are dichotomous variable with two values: 0 or 1. In this case, we simply estimate how many handwriting signs out of n are present in the investigated handwriting. Our investigations showed that for the majority of traits the correlation between E-model, W-model, and P-model is strong enough. With some traits, the loss of information when we switch to a simplified model is substantial. In the examples presented in the present article, we can use the simplified models without significant distortion.

HSDetect includes over 700 handwriting signs and about 400 traits in total. The quality of individual trait modelling is different, which is natural for such a complicated system. Some traits are modelled with few handwriting signs, others – with dozens. On average, it is 22 handwriting signs for a trait. HSDetect has been successfully validated in several

studies against well-known psychometric tests and expert procedures.[8] The validation results are generally positive; at least they are better than in previously published studies on the same psychometric tests. That is promising, even though it is clear that the modelling of some traits should be additionally investigated and improved.

Results: Exemplary use cases

To demonstrate the possibilities of the formalised handwriting analysis in legal psychology, we will show two use cases.

Use case 1: Assessment of aggressiveness[9]

The phenomenon of aggression has always attracted scientists' attention. However, there is a broad diversity of approaches to understanding the psychological origins of aggressive behaviour and forms of aggression. Thus, there is no generally accepted definition of this phenomenon. Some authors[10] define aggression as any act that harms another individual who is motivated to avoid such harm. This definition is very broad and

[8] M.A. Nauer, Y. Chernov, "Psychodynamic diagnostics: Validation research based on computer modelling of handwriting psychology", paper presented at the 13th European Conference on Psychological Assessment (ECPA 13), Zurich, Switzerland, 22–25 July 2015; Chernov Y., "Validation of computer-aided handwriting analysis and its integration into psychological assessment", paper presented at the 15th European Conference on Psychological Assessment (ECPA 15), Brussel, Belgium, 7–10 July 2019; Y. Chernov, C. Caspers, "Formalized computer-aided handwriting analysis: Validation and integration into psychological assessment", paper presented at the XVI European Congress of Psychology, Moscow, Russia, 2–5 July 2019; Y. Chernov, C. Caspers, "Computergestützte Validierung in der Graphologie", *Angewandte Graphologie und Persönlichkeitsdiagnostik* 2015, no. 2–3, pp. 16–19, 41–53; Y. Chernov, C. Caspers, "Formalized computer-aided handwriting psychology: Validation and integration into psychological assessment", *Behavioral Sciences* 10, 2020, no. 1; Y. Chernov, "Formal modelling of projective techniques and their validation", paper presented at the 82nd Annual Meeting of the Psychometric Society (IMPS 2017), Zurich, Switzerland, 17–21 July 2017.

[9] Y. Chernov, V. Engalychev, "Distant profiling: Aggression evaluation with formalized handwriting analysis", *Armenian Journal of Forensic Expertise and Criminalistics* 2019, no. 1, pp. 87–95.

[10] R.A. Baron, D. Richardson, *Human aggression*, New York 1994.

can include a wide range of behaviours,[11] starting from those that do not include any harmful actions or passive-aggressive behaviours and ending with verbal and physical aggression that inflicts violence. Aggression is traditionally divided into affective (reactive) and instrumental.[12] The first one is associated with a negative affect, typically anger. The second is usually goal-driven and could be free from affect. The line between these two poles is very blurry.

Aggressiveness is expressed through a conscious or unconscious aspiration of a person to reach their aims and by this possibly cause harm to someone, destroy or damage something.

Aggressive actions are not always caused by the aggressiveness of the individual, and the aggressiveness is not always manifested in clearly aggressive actions. Aggressiveness is seen not only as the tendency of a person to act hostilely and aggressively, but also readiness for aggression. The concept of aggressiveness considers mental phenomena and properties such as motives,[13] states, personality traits, and temperament, as well as situational and stable forms of human behaviour as features of individuality. Aggressiveness is a relatively stable readiness for aggressive actions in various situations and should be understood as a personality trait.

In forensic psychological expertise, aggressiveness is studied as a motivational tendency fixed in a habitual way of reaction in various situations, together along with the personal structures hindering aggressive motives plays a crucial role in the formation of motivation for aggressive actions.[14]

In expert practice, a set of methods is used to study the level of a person's aggressiveness (as a personality trait). That includes standardized questionnaires, projective and semi-projective methods and subjective scaling, which makes it possible to assess the level of readiness for aggressive reactions from the point of view of not only rational self-esteem, but also tendencies less realized by the subject. In the practice of forensic examinations, different methods have proven to be effective in detecting a person's aggressiveness (among other individual psychological

[11] *Encyclopedia of mental health*, ed. H. Friedman, Oxford 2015.

[12] B.J. Bushman, C.A. Anderson, "Is it time to pull the plug on the hostile versus instrumental aggression dichotomy?", *Psychological Review* 2001, no. 108, pp. 273–279.

[13] J. Heckhausen, H. Heckhausen, *Motivation und Handeln*, Berlin 2018.

[14] F.S. Safuanov, *Psichologija kriminal'noj agressii*, Smysl 2003.

features): MMPI, 16PF, questionnaires of Sobchik, Shmishek, Strelyau, Lichko, Bass-Darky, Spilberg, Rosenzweig, Rotter, drawing tests, Zsondi test, and some others. However, all of them require the investigated person to be involved.

Handwriting psychology could be very useful for evaluating a person's aggressiveness. It cannot distinguish between fine aspects of aggressiveness, but allows detecting the tendency and comparing it with other people. We demonstrate aggressiveness modelling on the example of seven famous American criminals whose aggressivity arouses no doubts.[15] Charles Luciano (CL, 1897–1962), John Hinckley (JH, 1955–), Charles Manson (CM, 1934–2017), Clyde Barrow (CB, 1909–1934), John Dillinger (JD, 1903–1934), John Gotti (JG, 1940–2002), and Joseph Valachi (JV, 1904–1971). Aggressiveness in HSDetect is modelled by 31 handwriting signs. The results of the handwriting evaluation for the named persons is presented in Table 1, where the handwriting signs are given according to their weight (a_i).

Table 1. Handwriting evaluation for aggressiveness

Sign name	CL	JH	CM	CB	JD	JG	JV
Angular connections	x	x	x	x	x	x	x
Strong pressure	x	–	x	x	x	x	–
Long in-stroke	x	–	x	x	–	–	x
Tapering end-stroke	–	x	–	–	x	–	x
End-stroke goes backwards under the word	–	–	x	–	–	–	–
Elongated letter form	x	x	x	–	x	x	–
Signature is surrounded with enrichments or circle	–	–	x	–	–	–	–
Additional hooks on stroke ends	–	–	x	–	–	–	–
Last letters are accented	–	–	x	x	x	–	–
Upper zone is diminished or does not exist	–	–	–	–	–	–	–

[15] Y. Chernov, V. Engalychev, op. cit.

I-points are arrow- or comma-shaped	x	x	x	–	–	x	–
Lower zone is angular or has triangle-shaped	–	–	–	x	–	x	–
Capital letters are very small	–	–	–	–	–	–	–
Lower loops are not closed	x	–	x	–	–	x	x
Letters are broken	–	x	x	–	x	–	–
Diacritic marks are irregular	–	x	x	–	–	x	–
Signature is larger than text	x	x	–	–	–	–	–
Pressure is stronger on vertical strokes	x	x	x	x	x	x	–
Middle zone is smaller than upper and lower zones	x	x	x	x	x	x	x
Sharp strokes	x	x	x	–	–	x	–
Upper and lower loops overlap allied lines	x	x	x	x	–	x	x
Connected handwriting	x	x	x	x	x	x	x
Quick handwriting	x	x	x	x	–	–	x
Poor arrangement	x	x	x	x	–	x	x
Stronger pressure on diacritic marks	x	–	–	–	x	x	–
Back-stroke of lower zone is on right from the base stroke	–	–	–	–	–	–	–
Poor readability	–	–	–	–	–	–	–
Left margin is widening	–	–	x	–	–	–	–
First letters are accented	–	–	x	–	–	–	–
Uneven distribution of pressure	x	x	x	x	x	x	x
Lower loops are transformed in plane lines without back-stroke	–	x	–	–	–	x	x

To make the interpretation easier let us use the plain P-model. According to it, the absolute aggressiveness level for the evaluated persons (y) looks as follows: CL – 0.52, JH – 0.52, CM – 0.71, CB – 0.39, JD – 0.35, JG – 0.52, and JV – 0.35. The statistical mean value (m) based on the HS-Detect database is 0.19 with the standard deviation (σ) 0.09. This means that the 99% level ($m + 3\sigma$) is reached at 0.46 and the 95% level ($m + 2\sigma$) at 0.37. Therefore, four out of seven persons have an extremely high level

of aggressivity and the remaining three – a very high one. That closely corresponds with our expectations.

Use case 2: Assessment of credibility

Credibility is another important trait, or more precisely a construct, since it actually reflects several traits. To what extent different participants of an investigation and a trial can be trusted? The construct is very important not only in the criminal environment, but also in business. Actually, what is more interesting is the opposite side of the spectrum – non-credibility.

The experiment was done with students in one of the St. Petersburg military universities(the complete results of the experiments are not published yet). Experts (17 lecturers) evaluated 70 students whom they had known for several years. That means every student received 17 opinions about their credibility. Some evaluations could not demonstrate good interrater reliability. Thus, we took 24 absolutely clear cases with the strongest agreement among experts: 12 with the highest credibility (group A) and 12 with the lowest one (group B). The handwriting evaluations were done according to the HSDetect model (Table 2).

Table 2. Handwriting evaluation for credibility

Handwriting sign	Incredibility	Credibility
Letter intervals	narrow	
letter width		wide letters
Lines	letter zones intersect	
Slant	left or direct	right
Letter form	threading complicated with additional and rolling elements terminal letters are wavy or bend	simplified
Capital letters	complicate form	simple, print form
Handwriting form	disordered with distorted or broken letters corrections and striking out missing some letters and letter elements	angular or garland

Connections	thread or arcade not stable, changing joins	
Fullness	full handwriting	
Pressure	weak	strong
Speed	low	high
Ovals	closed with loop open at bottom	closed, simple form open at top
Strokes	covering strokes	
Diacritic signs	connected to a neighbour letter	moved to the right
Form-Dymanics relation	dominating form	

Based on the handwriting analysis, we inquired whether it is credibility or incredibility that dominates among the subjects. In group A, in 9 out of 12 handwriting samples the dominance of credibility was detected. In group B, incredibility was dominating in 10 subjects. Thus, the agreement with the experts is obviously quite high, much higher than a chance coincidence.

Discussion

The presented examples illustrated the possibilities of the handwriting psychology in legal psychological assessments. International standards for the assessment methods in legal psychology are unknown to us. However, we can orient ourselves in the corresponding standards of organisation psychology.[16] The proposed procedure of formalised handwriting psychology supported by HSDetect meets the standard requirements. It is formal, unambiguous, and transparent. Thus, we can say that it meets the required quality level. HSDetect provides a qualitative framework for implementing the method. However, a good procedure alone does not assure satisfactory results. Currently, the HSDetect model is based on the statistically balanced, but still traditional graphological rules. We know

[16] ISO 10667-2:2020. Assessment service delivery – Procedures and methods to assess people in work and organizational settings – Part 2: Requirements for service providers.

that in certain cases, i.e. for certain traits and constructs, they work well – their validity was proven by the corresponding studies. However, that does not mean that the models for other traits are automatically valid as well. That should be properly evaluated and the models (graphometric functions) adapted based on real legal cases, experiments, and further statistical evaluations. Nevertheless, handwriting psychology has proven its usefulness in certain cases, even today.

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NOWA KODYFIKACJA PRAWA KARNEGO Tom LX
NEW CRIMINAL LAW CODIFICATION
AUWr No 4039 Wrocław 2021

https://doi.org/10.19195/2084-5065.60.5

Influence of Raman spectra measurement conditions on the dating results of writing compositions

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Abstract

When establishing the age of a document using spectral methods, the result is influenced not only by the storage conditions, but also by the methods of measuring the spectra and mathematical processing of the results. This work analyzes the influence the modes of

measuring Raman spectra have on the result of measuring the writing composition spectra. The analysis area includes the correlation coefficients of the full spectral matrices as a criterion for the reliability of the determination date. The influence of focusing accuracy, correctness of subtraction of the baseline, sample irradiation time, and varying the number of repetitions is investigated. In the study, chemometric tools for the analysis of Raman spectra were also applied. The influence of mathematical spectra processing shows that the components PC4, P5, and PC6 are most closely related to the shelf life, although they do not make the maximum contribution to the variance in the system. Taking into account all the requirements for measuring spectra, the PCA method applied to the Raman spectra of writing compositions allows clustering samples by manufacturer's brands and by the sample shelf life.

Keywords: dating documents, questioned document examination, Raman spectroscopy, chemometric analysis, PCA

Despite the large number of chromatographic methods used to determine the dating of documents, no one has yet achieved breakthrough results. The accuracy of determinations varies around 70–80% of hits on control samples with a known initial composition and storage conditions. Interlaboratory tests show insufficient convergence of results; therefore, chromatographic studies are currently developing in three main areas.[1]

Attempts were made to calculate the regression parameters of the volatile component content that are independent or weakly dependent on the initial compositions and storage conditions of the handwritten inscription. In the terminology of Díaz-Santana et al.[2] – these are called "dynamic dating methods," the study of changes in the concentration of one or more ink components over time.[3] It also includes searching for time markers that correspond to a particular life period of a handwritten item. Sharma

[1] O.A. Díaz-Santana, F.B. Conde-Hardisson, D.C. Vega-Moreno, "Comparison of the main methods for six ballpoint pen inks", *Microchemical Journal* 138, 2018, pp. 550–561.

[2] Ibid.

[3] V. Sharma, R. Kumar, "Dating of ballpoint pen writing inks via spectroscopic and multiple linear regression analysis: A novel approach", *Microchemical Journal* 134, 2017, pp. 104–113; V.N. Aginsky, "Measuring ink extractibilty as a function of age. Why the relative aging approach is unreliable and why it is more correct to measure ink volatile components than dyes", *International Journal of Forensic Document Examiners* 4, 1998, pp. 214–230.

and Kumar call these static dating methods[4] – relative dating methods based on comparing two independent ink samples available in the same document. This is mainly used for analyzing documents with some changes (additions, corrections).[5]

By default, all researchers assume that there are two main reasons for the span of results on determining the inscription age: the uncertainty of the initial composition and of the storage conditions, primarily temperature. However, there are many factors that have not yet been studied in detail, so the list can still be expanded.

The problem of normalizing the chromatographic signal to the inscription mass has long been discussed in the literature. A large number of authors suggest solving it by normalizing the chromatographic signal intensity to the optical density of the dye extract according to spectrophotometric analysis.[6]

This approach seems indisputable, given that the optical density of the extract is additive for each component, provided that the content of all other components in the mixture is constant. A real mixture undergoes temporary changes and can change its composition and non-additively change the optical density simultaneously for several components. The proposal to use the inscription width as a mass characteristic looks entirely frivolous.[7]

However, this approach to spectroscopic data gives correct results, since the lines of the same spectrum are compared as a result of a single measurement rather than two independent ones performed by two completely different physical and chemical methods on two heterogeneous objects (dye and volatile components).

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[4] C. Weyermann, D. Kirsch, B. Spengler, "A GC/MS study of the drying of ballpoint pen ink on paper", *Forensic Science International* 168, 2007, pp. 119–127; R.L. Brunelle, "Ink dating: The state of the art", *Journal of Forensic Sciences*, 37, 1992, pp. 113–124.

[5] A. Cantú, R.S. Prough, "On the relative aging of ink: The solvent extraction technique", *Journal of Forensic Sciences* 32, 1987, pp. 1151–1174.

[6] Y. Xu, J. Wang, L. Yao, "Dating the writing age of black roller and gel inks by gas chromatography and UV-vis spectrophotometer", *Forensic Science International* 162, 2006, pp. 140–143.

[7] E.A. Trosman et al., "Methodology: Age-dating of document attribute entries by the relative content of volatile solvents in strokes", *Теория и практика судебной экспертизы* (*Theory and Practice of Forensic Science*) 30, 2013, no. 2, pp. 80–88.

The second direction of chromatographic research – the search for time markers corresponding to a particular life period, is based on a similar principle that has long been used in art history, archeology, and historical analysis.[8] The method is to find the concentration ratios of various ink components that have been stored for a long time and subjected to artificial aging. The results obtained are not presented in an analytical form, but rather compared with different existence periods of the inscription. The most prominent representatives of this direction are the works by Aginsky.[9] The ratio of the amounts of the inscription component recovered by the extraction method compared to standard samples is selected here as a temporary marker.

Given the new data, researchers have a growing understanding that the possibilities of the monomethodic approach are limited and combinations of heterogeneous methods are the future. There is a growing interest in research using spectral methods. This is because, despite the multiplicity of chromatographic methods, no one has yet been able to achieve ideal results. At the same time, the trend is such that it is not a question of abandoning chromatography; the possibilities of spectroscopy complement its capabilities.[10]

[8] L. Giorgi et al., "In-situ technical study of modern paintings. Part 2: Imaging and spectroscopic analysis of zinc white in paintings from 1889 to 1940 by Alessandro Milesi (1856–1945)", *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy* 219, 2019, pp. 504–508; J. Lee et al., "Scientific investigation into the water sensitivity of twentieth century oil paints", *Microchemical Journal* 138, 2018, pp. 282–295; A. Burnstock, K.J. van den Berg. "Twentieth century oil paint. The interface between science and conservation and the challenges for modern oil paint research", *Issues in contemporary oil paint: Proceedings of the Issues in Contemporary Oil Paint (ICOP) symposium*, 28–29 March 2013, Amersfoort, Netherlands.

[9] V.N. Aginsky, "Forensic examination of 'slightly soluble' ink pigments using thin-layer chromatography", *Journal of Forensic Sciences* 38, 1993, no. 5, pp. 1131–1133; V.N. Aginsky, "Determination of the age of ballpoint pen ink by gas and densitometric thin-layer chromatography", *Journal of Chromatography A* 678, 1994, no. 1, pp. 119–125; V.N. Aginsky, "Measuring ink extractibilty as a function of age. Why the relative aging approach is unreliable and why it is more correct to measure ink volatile components than dyes", *International Journal of Forensic Document Examiners* 4, 1998, pp. 214–230.

[10] N. Grechukha et al, "Analysis of the aging processes of writing ink: Raman spectroscopy versus gas chromatography aspects", *Applied Sciences* 7, 2017, no. 10, p. 991.

The electronic spectrum of the writing compositions (a complex organic compound) is a non-selective and non-additive parameter. Therefore, temporary chemical changes can affect the spectrum in different directions. An example of this is the dynamics of the Raman scattering spectra of writing compositions studied by Gorshkova et al.[11] In this work, physicochemical mechanisms of degradation of triarylmethane dyes were proposed and spectral lines were determined that change over time as a result of dye oxidation by atomic oxygen.

Raman dye spectroscopy has many advantages over other spectral and chromatographic methods. This is primarily a non-invasive nature of the impact on the document. The spot of "exposure" of the inscription is only 5 microns in diameter and is not noticeable to the human eye. Dyes are the most stable components of the writing composition. All transformations with them are slow. This allows going beyond the two years that chromatographic studies are limited to. Finally, the main advantage is selectivity. The Raman spectrum of an ink dye consists of a set of narrow lines, each of which can be correlated with the oscillation of a specific bond in the dye molecule. UV and IR spectra consist of wide absorption bands, in which it is often difficult to distinguish the contribution of a particular ink component. Therefore, interest in the method is growing, although so far it is used mainly for tasks of identifying ink, toners, and other writing materials.[12]

Therefore, the primary current trend in developing methods for dating inscriptions of writing compositions is the simultaneous use of several heterogeneous physical and chemical methods and mathematically pro-

[11] K.O. Gorshkova et al., "The investigation of dye aging dynamics in writing inks using Raman spectroscopy", *Dyes and Pigments* 131, 2016, pp. 239–245.

[12] I. Geiman, M. Leona, J.R. Lombardi, "Application of Raman spectroscopy and surface-enhanced Raman scattering to the analysis of synthetic dyes found in ballpoint pen inks", *Journal of Forensic Science* 54, 2009, no. 4, pp. 947–951; M. Kunicki, E. Fabiańska, A. Parczewski, "Raman spectroscopy supported by optical methods of examination for the purpose of differentiating blue gel pen inks", *Problems of Forensic Sciences* 95, 2013, pp. 627–641; P. Buzzini, C. Polston, M. Schackmuth, "On the criteria for the discrimination of inkjet printer inks using micro-Raman spectroscopy", *Journal of Raman Spectroscopy* 49, 2018, no. 11, pp. 1791–1801.

cessing a complete data array.[13] The use of spectral and chromatographic analysis methods to determine the dating of handwritten inscriptions leads to the need to use new methods of mathematical signal processing. First of all, these are methods for processing multidimensional data arrays.

Currently, principal component analysis (PCA) is widely used for chemometric data processing. This method reduces the dimension of the original data set by calculating a new set of variables called principal components. The capabilities of chemometrics allow obtaining more objective results than visual assessment. The chemometric approach allows determining the number of main factors R equal to the number of ink component forms, whose the mutual conversion is due to the dispersion of the analytical signal.[14] This method provides a unique solution to the equation that describes the maximum variance using a fixed number of variables. However, for reliable application of the method, it is necessary to evaluate the influence of measurement modes in order to exclude all possible systematic errors that are not associated with temporary dye degradation.

This paper describes experiments related to obtaining reliable spectral data suitable for applying chemometric data processing procedures for Raman spectroscopy of writing compositions to the problem of dating handwritten inscriptions on documents.

Methods and materials

Writing compositions of various brands that are most often found in the market were used for the research.

The following substances were used in the study: dyes/pigments in the form of powders: fat-soluble violet K, alcohol-soluble blue phthalocyanine, cationic turquoise, straight violet, basic violet K, acid violet C, acid bright blue Z, blue phthalocyanine pigment, Victoria blue, crystal violet, methyl violet, rhodamine Y, varnish basic blue K.

[13] K.O. Gorshkova et al., "Investigation of the new possibility of mathematical processing of Raman spectra for dating documents", *Science & Justice* 60, 2020, no. 5, pp. 451–465.

[14] E.R. Malinowsky, D.G. Howery, *Factor analysis in chemistry*, New York 1980, p. 251; R. Tauler, A. de Juan, "Multivariate curve resolution", [in:] *Practical guide to chemometrics*, ed. P. Gemperline, London 2006, p. 421.

Raman spectra were obtained using a Bruker SENTERRA Raman spectrometer equipped with three lasers with wavelengths of 488, 532, and 785 nm. The authors also used an Olympus confocal microscope module and a fiber-optic sensor for recording the spectra of samples in an external cuvette compartment. The spectra were measured in the range of 280–1735 cm^{-1}.

The method of mathematical signal processing by PCA was used. For this purpose, a database was formed, which is a set of Raman spectra obtained for samples of writing compositions no. 1–5 (Table 1) with a different period of application on a paper base. The selected writing compositions include a different set of coloring agents.

Table 1. The main characteristics of the studied writing compositions

No. (DB)	Writing composition brand	Type[15]
1 (17)	Paper Mate Korea pen	B*
2 (23)	Easy Clicker BEIFA pen	B
3 (25)	Erich Krause refill	B
4 (4)	ICO Silver pen (Parker type)	B
5 (24)	Erich Krause U18 Pen	B

*B – ballpoint pen

Raman spectra were obtained from the same inscription from different points with an interval of about 5 months, for storage periods: 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90 months; 100 spectra for each date. The database used for calculations has more than 7 000 spectra.

The PCA of spectra was implemented in the R Studio program in the R programming language. All the spectra were loaded into the program in the form of tables without preprocessing, after which the "prcomp" function was applied, which uses singular value decomposition rather than spectral (unlike the "princomp" function). The variables were scaled before the analysis using the "scale" function – it accepts a numeric matrix

[15] According to K.O. Gorshkova et al., "The investigation of dye aging dynamics…"; K.O. Gorshkova et al., "Investigation of the new possibility…".

as input and performs column scaling, where scaling is performed using the following formula:

$$\frac{x_i - mean\ (x)}{sd\ (x)}$$

where sd (x) – standard deviation, mean (x) – the average value of x. After that, the main components were calculated.

The Raman spectra were obtained using the same parameters. Python was chosen as the programming language as it is one of the most widely used languages for data analysis and has a large number of packages for all modern methods of data processing and visualization.

Three collections of samples were formed to solve this problem:

1. provided by arbitration courts in different cities of Russia,
2. provided by a third-party commercial organization,
3. provided by the State Expert Institution of the Russian Federation.

Samples are extracts of inscriptions of writing compositions on a paper basis with different storage periods under natural conditions (pressure 1 bar = 105 Pa = 750.06 mm Hg; temperature 298.15 K = 25°C) without exposure to extreme factors such as high temperature, direct light, etc.

For each series of images, the possible terms for applying the corresponding writing compositions to the paper base are determined. At this stage, the authors focused on the study of writing compositions assigned to type B,[16] since the majority of samples of type B are randomly selected. Fifteen B-type samples were obtained from each collection. All deadlines were set by the blind method to avoid subjectivity in the study.

Results

The Raman spectra for the writing composition assigned to type B, obtained using a wavelength of 532 nm, are resonant, since the maximum absorption for blue dyes of the triarylmethane group is in the area of 540–600 nm. These stripes are related to the π-π* transitions in the aromatic

[16] K.O. Gorshkova et al., "The investigation of dye aging dynamics…"; K.O. Gorshkova et al., "Investigation of the new possibility…".

ring of the dye, due to which the symmetric vibrations of the chromogen, in this case – fuchsonimine, are more active in the Raman spectrum.[17]

Table 2. Frequencies and waveforms in the Raman spectrum obtained for writing compositions containing triarylmethane group dyes (assigned to type B) and literature data for the crystal violet dye

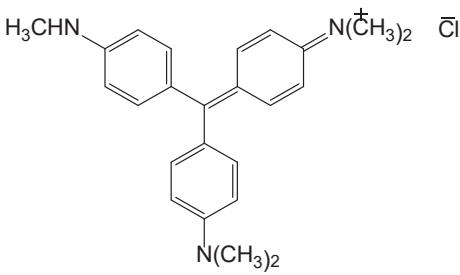
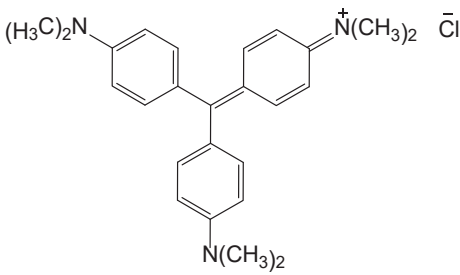
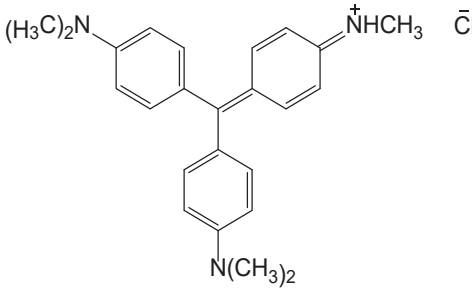
Raman shift, cm^{-1}		Oscillation [75, 80–81]
Exp.	Lit. data [75, 80–81]	
526	524	δ (CNC)
563	558	γ (CCC) / δ (CNC) / δ ($CC_{center}C$)
729	724	*v (CN)*
765	767	ν_s ($CC_{center}C$) / ν_s (CN)
805	805	δ *(CH)*$_{ring}$
915	915	*v (CC)*$_{ring}$
974	973	δ ($CC_{center}C$)
1176	1178	ν_s ($CC_{center}C$) / δ $(CCC)_{breathing}$ / δ_r (CH_3)
1308	1300	ν_{as} ($CC_{center}C$) / δ $(CCC)_{ring}$ / δ (CH)
1369	1369	ν ($C_{center}C$)
1448	1447	δ_{as} (CH_3)
1488	1480	δ_{as} (CH_3)
1536	1536	ν *(*$C_{ring}N$) / δ_s (CH_3)
1587	1591	ν *(C* – C$)_{ring}$
1620	1622	ν *(C* – C$)_{ring}$

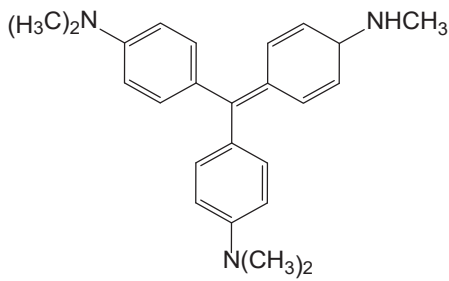
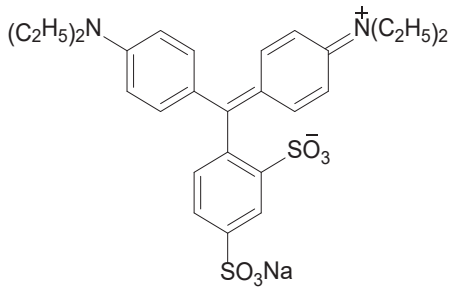
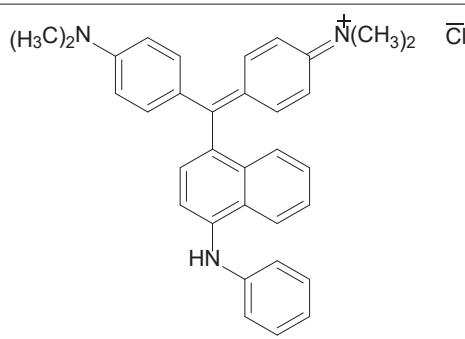
v: valence vibrations
δ: plane deformation vibrations
γ: out-of-plane deformation vibrations
s: symmetric
as: asymmetric

It is established that the basis of writing compositions assigned to type B may include the following triarylmethane group dyes: basic violet K, crystalline violet, methyl violet, fat-soluble violet K, Brilliant Acid Blue G, Victoria blue BO; the structural formulas of the latter are presented in Table 3.

[17] B.I. Stepanov, *Vvedenie v himiju i tehnologiju organicheskih krasitelej* (*Introduction to chemistry and technology of organic dyes*), Moscow 1984.

Table 3. Structural formulas of coloring substances that make up the basis of writing compositions assigned to type B

Name	Structural formula
Basic purple K	
Crystal purple	
Methyl violet	

Fat-soluble purple R	
Brilliant Acid Blue G	
Victoria blue BO	

The interpretation of the obtained Raman spectrum (Figure 1), based on the literature data, is presented in Table 2.

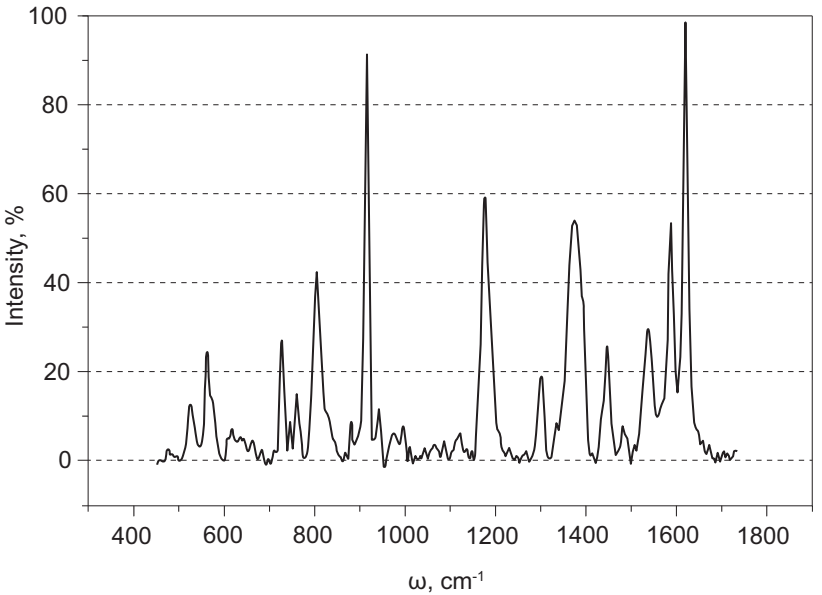


Figure 1. Raman spectrum of the writing composition from the database (Erich Krause Fiore), the coloring base of which includes dyes from the triarylmethane group (assigned to type B). The spectrum was obtained using a laser radiation wavelength of 532 nm

Errors are calculated for each series of writing compositions. Table 4 shows the calculated confidence intervals for determining the timing (in months) for samples from different collections.

Table 4. Confidence intervals for the average deviation from real terms for confidence probabilities of 99 and 95%

Confidence probability	Confidence interval for the average deviation from real terms, months				
No. 1 collection (AC)					
95%	0.9	<	1.6	<	2.3
99%	0.7	<	1.6	<	2.6
No. 2 collection (CO)					
95%	1.6	<	3.1	<	4.6
99%	1.0	<	3.1	<	5.2

No. 3 collection (EC MD)					
95%	6.5	<	10.8	<	15.1
99%	4.9	<	10.8	<	16.7

Since 15 samples from each collection were obtained, student quantile values of 2.145 with a confidence probability of 0.95 and 2.977 with a confidence probability of 0.99 were selected from the tables. A normal distribution is constructed for the relations of experimentally obtained terms from real ones (Figure 2).

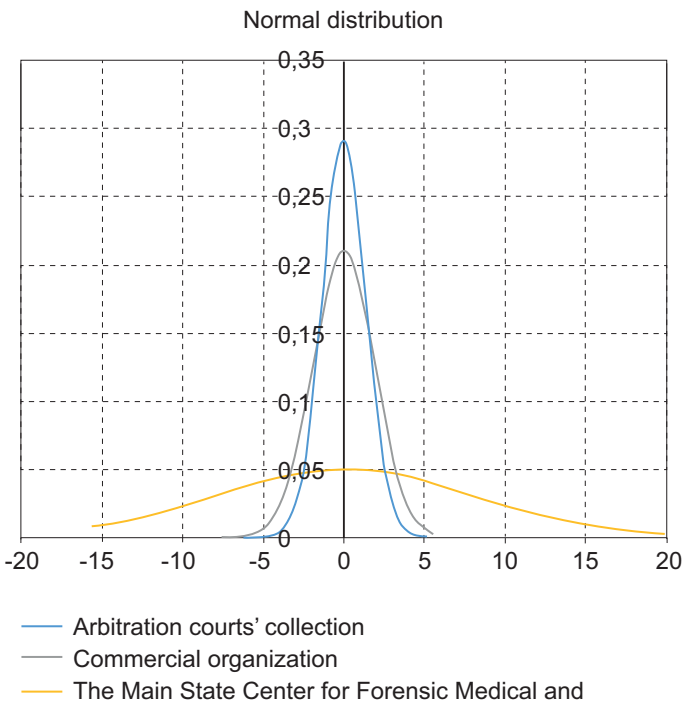


Figure 2. Normal distribution for the analyzed collections

It was found that the results obtained for collection 1 were the best: most of the values were based on the model dependence[18] with the smallest

[18] K.O. Gorshkova et al., "The investigation of dye aging dynamics…".

spread – about 1.6 months. The most unsatisfactory results were obtained for collection 3: the deviation was about 10.8 months.

Full correlation matrices were calculated for each sample to understand what might be the cause of deviations for different collections. For the convenience of performing and presenting calculations, a script for implementing a simplified version of the database interface was written. The elements of the correlation matrix are the correlation ratios between all variables of this population; in this case, ones between the intensities of all peaks in 5 spectra obtained for 1 sample.

The correlation ratios were calculated for the 13 most intense peaks in the sample spectrum (Figure 3) using the formula:

$$r_{xy} = \frac{\sum_{i=1}^{m} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{m} (x_i - \bar{x})^2 \sum_{i=1}^{m} (y_i - \bar{y})^2}} = \frac{cov(x, y)}{\sqrt{s_x^2 s_y^2}}$$

where $\bar{x}$, $\bar{y}$ – sample means x^m and y^m; s_x^2, s_y^2 – sample variances $r \in [-1.1]$; $|r_{xy}| = 1 - x, y$ are linearly dependent; $r_{xy} = 0 - x, y$ are linearly independent.

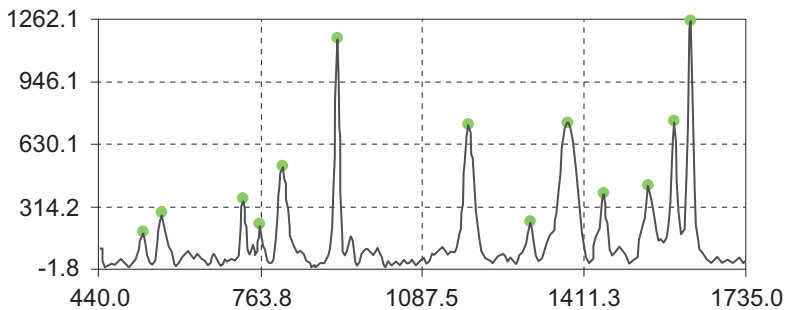
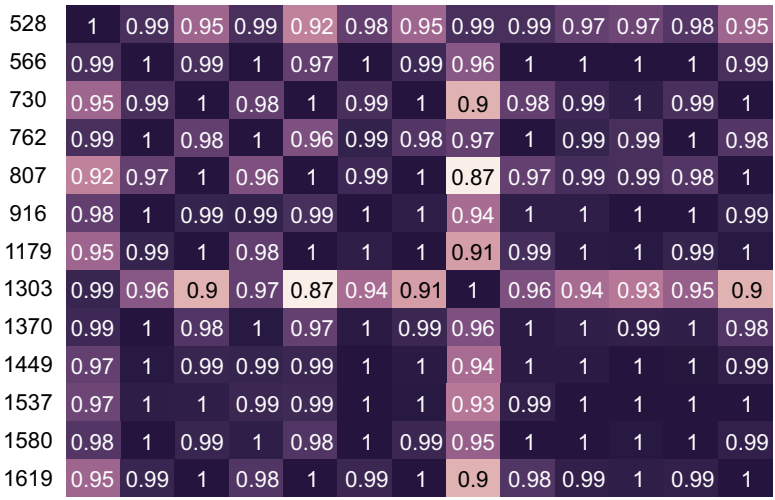
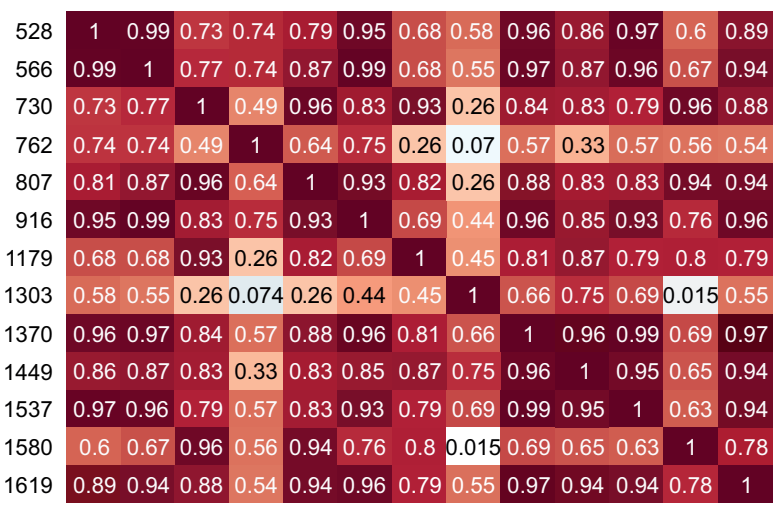


Figure 3. Peaks used for the calculation of correlation matrices

The "complete correlations matrices" are calculated (elements of the main diagonal are equal to 1, denoted by R_1; Figure 4). By placing 1 on the main diagonal or correlations of each variable with itself, the authors take into account the full variance of each variable represented in the matrix, thus taking into account the influence of general and specific factors:

It was expected that samples with uncorrelated matrices would have the largest deviation of the experimentally calculated term from the real one.





A) correlated: the sum of the correlation ratios for 13 peaks was 165.85 (1.9% less than the maximum);
B) uncorrelated: the sum of the correlation ratios is 129.74 (23.2% less than the maximum).

Figure 4. Examples of calculated correlation matrices

Table 5. Deviation of the experimentally established term from the real one

Δ (months)	AC	CO	EC MD
≤ 5	100%	54%	31%
6–10	0	38%	19%
≥ 11	0	8%	50%

Table 6. Sums of correlation ratios for 13 × 13 matrices

$\sum r_{xy}$ (%)	AC	CO	EC MD
100–95	71%	43%	63%
94–89	18%	21%	25%
≤ 88	11%	36%	12%

Table 7. Sums of correlation ratios for 8 × 8 matrices (with deduction of uncorrelated peaks)

$\sum r_{xy}$ (%)	AC	CO	EC MD
100–95	88%	72%	81%
94–89	6%	7%	7%
≤ 88	6%	21%	12%

Tables 5–7 show the percentage of samples with different deviations of the experimentally established period from the real one (for deviations less than 5 months, from 6 to 10 and more than 11 months); with different amounts of correlation ratios for the 13 × 13 and 8 × 8 matrices (for 100–95%, 94–89%, and less than 88%) for each of the studied collections.

The greatest deviations from the actual experimental terms were found for the collection provided by the State Expert Institution of the Russian Federation. The developed method is only suitable for analyzing the collection provided by arbitration courts since the deviations for all the samples under study were less than 5 months. This may indicate that the method is suitable for the study of samples stored under the same conditions.

From the results, the assumed relationship of the correlation ratios sum with the actual term of applying the writing composition to paper is

absent, and the sum is not a determining factor for the sample to fall into the model dependence.[19]

It is also important to note that the correlation ratios for peak intensities at 729 and 1580 cm^{-1} used for calculations range from 0.983 for the collection provided by a commercial organization to 0.997 for the collection provided by arbitration courts (Table 8), which indicates a close relationship between these peaks.

Based on the data obtained, it can be concluded that to develop the most accurate and effective method for determining the timing of writing compositions on paper, it is necessary to further study possible ways of external factors influencing the process of writing compositions.

Table 8. Average values of the correlation ratio between the peaks of 729 and 1580 cm^{-1}

Peak position (cm^{-1})	AC	CO	EC MD
729/1580	0.997	0.983	0.991

Influence of conditions on obtaining Raman spectra

The authors can distinguish sample degradation during spectrum measurement, focusing accuracy, and the correctness of subtraction of the baseline among the factors that can have a significant impact on the characteristics of the spectra of writing compositions and dyes/pigments. Usually, these parameters are monitored visually during the measurement process. A number of experiments were conducted, aimed at studying the conditions for obtaining Raman spectra and their relationship with the obtained measurement results to improve the measurement accuracy.

For the experiments, the authors used the writing composition inscriptions of the ballpoint pen no. 21 from the database – Paper Mate 2 in 1 (Table A, no. 1). The basis of the writing composition no. 21 includes dyes from the triarylmethane group, presumably crystal violet and Victoria blue BO.

[19] Ibid.

Varying number of repetitions. Influence of mathematical processing of spectra

Ten consecutive measurements of Raman spectra were performed from the same point for the sample under study. The following instrumental parameters are used to measure the spectra: 50 × lens, aperture 25 × 1000 μm, resolution 3–5 cm^{-1}, the measured range 440–1735 cm^{-1}, wavelength 532 nm, laser radiation power of 0.2 mW, integration time – 5s, the number of repetitions – 2. The 11^{th} spectrum was measured 5 minutes after the end of a series of 10 measurements. A series of 11 spectra (hereinafter referred to as "the series") was measured for each test sample three times with a difference of 24 hours. This number of measurements was carried out to unambiguously exclude random errors in the process of measuring the spectra for a single sample.

Three different approaches were used to process the results to account for the impact of mathematical processing of spectra (such as baseline subtraction, smoothing).

1. The resulting spectrum was processed in the OPUS 7.5 program: baseline correction – 2 iterations, smoothing – 25 iterations; then the absolute peak intensities were calculated.

2. Two sections were cut from the resulting spectrum: 681–783 cm^{-1} and 1490–1700 cm^{-1}, after which each section was processed in the software: baseline correction – 2 iterations, smoothing – 25 iterations; then the absolute peak intensities were calculated.

3. Two sections were cut from the resulting spectrum: 681–783 cm^{-1} and 1490–1700 cm^{-1}, after which each of the sections was processed in the software: baseline correction – 2 iterations, smoothing – 25 iterations. In the OriginPro 9 program, each of the sections was decomposed into Gaussians, after which the absolute peak intensities were calculated.

According to the experiment results, dependency graphs of peak intensities in the area of 729 cm^{-1} to the peak in the area of 1580 cm^{-1} to the time of sample irradiation (during spectrum acquisition) were obtained using three methods of spectrum processing (Figure 5). The lowest confidence interval with a confidence probability of 0.95 was obtained using the third processing method and is ±0.023.

Even after irradiating the sample for 100 seconds (after measuring the tenth spectrum from one point), no visible changes occurred with the sam-

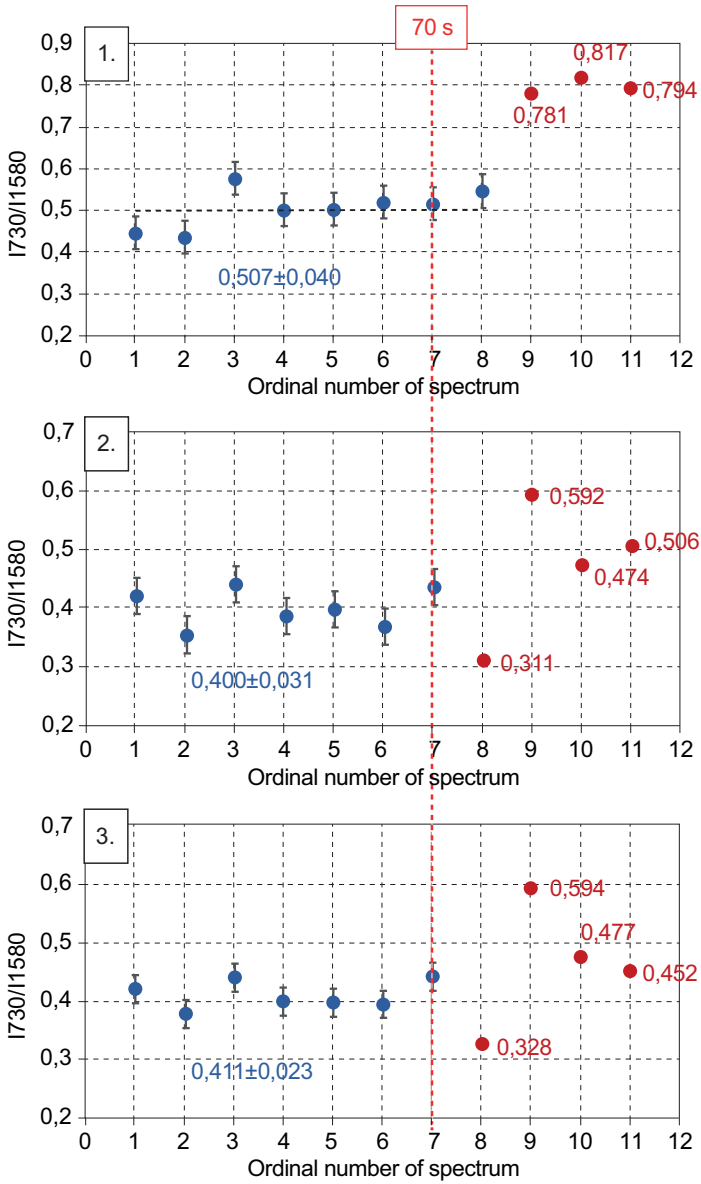


Figure 5. Dependency graphs of the peak intensities ratio in the 730 cm^{-1} area to the peak in the 1580 cm^{-1} area when using three methods for processing the Raman spectra of the writing composition sample no. 59 from the database (experiment no. 1)

ple (Figure 6), but after irradiating the sample for 70 seconds (after the 7th spectrum from one point), there was a sharp change in the value of the peak intensity ratio. After holding a pause of 10 minutes and measuring the 11th spectrum, the value of the peak intensity ratio became significantly greater than in the range from the 1st to the 7th spectrum (the difference was more than 0.1 relative units), which indicates that irreversible changes occur with the sample due to degradation under the influence of laser radiation. It can be concluded that the maximum sample irradiation time should be no more than 70 seconds at the power 0.2 mW.

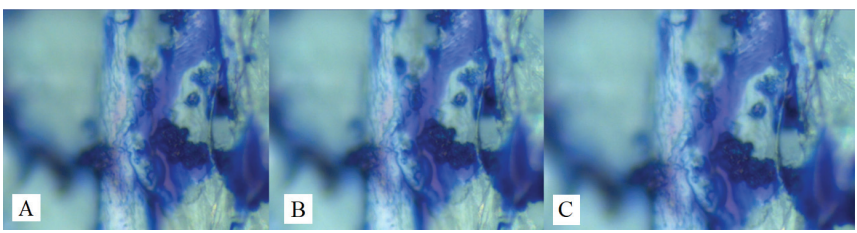


Figure 6. Optical micrographs of the area from which the Raman spectra were obtained after measuring the 1st (A), 5th (B), and 10th (C) spectra (50 × magnification)

Varying the integration time

The sample was measured 5 times in a row in modes with the same number of repetitions (2 repetitions) with increasing integration time: 5 × 2, 10 × 2, 20 × 2, 40 × 2, 80 × 2 from the same point. The measurements were taken on a single day. Three approaches were used to process the results, as in the previous experiment (cl. 4.8.1).

The experiment results show that the luminescence signal level increases linearly with increasing integration time. The intensity of the Raman signal increases linearly with increasing sample irradiation time (Figure 7).

The dependence of the ratio of peak intensities 730/1580 on the sample irradiation time (Figure 8) obtained in experiment 2 is similar to the dependence obtained in experiment 1 (Figure 5). A sharp change in the peak intensity ratio occurs after irradiation of the sample for more than 70 seconds (after the 3rd spectrum in experiment 2; Figure 8).

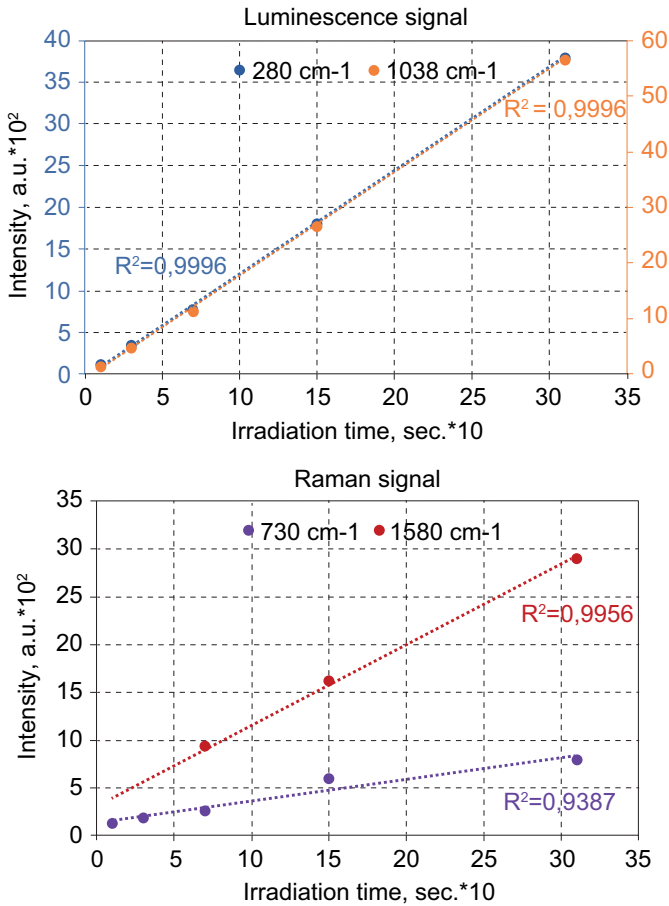


Figure 7. Dependency graphs of the signal level (on the left – the luminescence signal, on the right – the Raman signal) on the irradiation time of the writing composition sample no. 59 from the database

Even after irradiating the sample for 310 seconds (after measuring the 5th spectrum from one point), no visible changes occurred with the sample (Figure 9), but after irradiating the sample for 70 seconds (after the 3rd spectrum from one point), there is a sharp change in the ratio of peak intensities, as in the previous experiment (Figure 5). After holding a pause

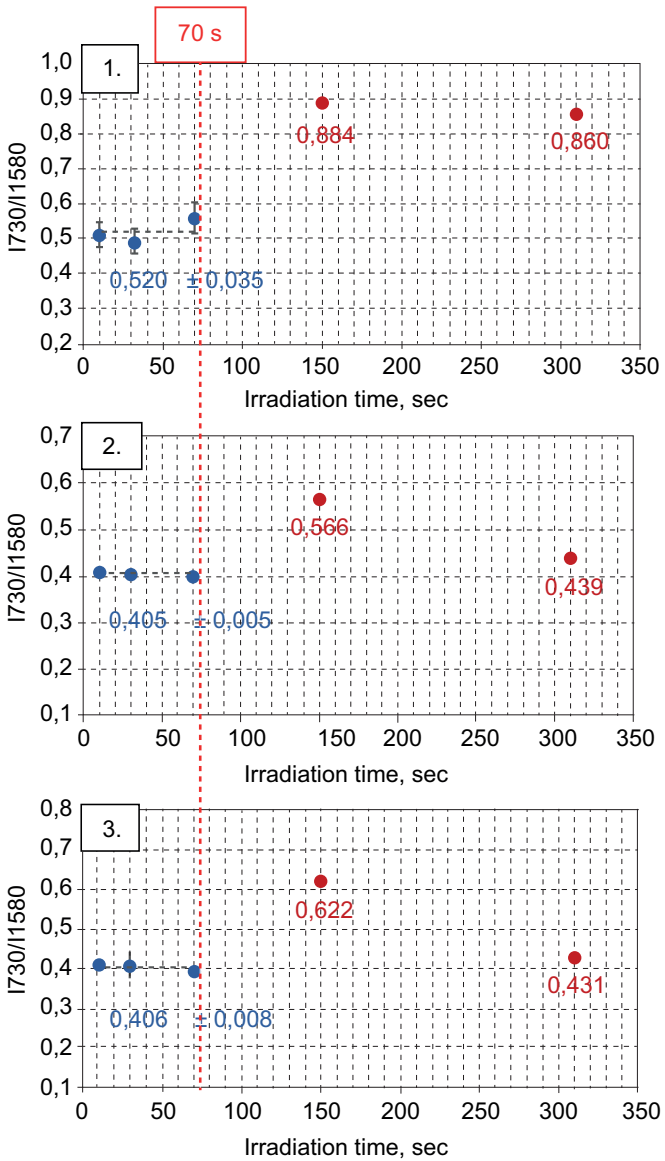


Figure 8. Dependency graphs of the ratio of peak intensities in the area of 730 cm^{-1} to the peak in the area of 1580 cm^{-1} to the irradiation time of the sample of writing composition no. 59 from the database using three methods of spectrum processing (experiment no. 2)

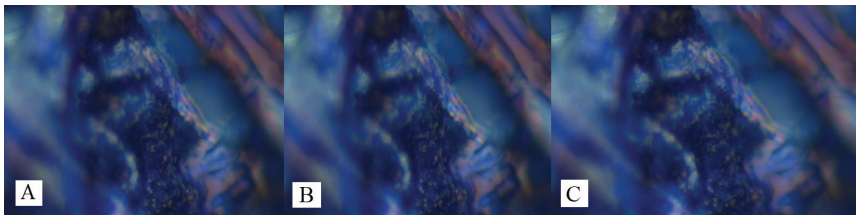


Figure 9. Optical micrographs of the area from which the Raman spectra were obtained after measuring the 1st (A), 3rd (B), and 5th (C) spectra (50 × magnification)

of 10 minutes and measuring the 5th spectrum, the value of the peak intensity ratio remains greater than in the range from the 1st to the 3rd spectrum. It can be concluded that to prevent the introduction of errors related to the degradation of the sample according to the results of experiments no. 1 and no. 2, the recommended irradiation time of the sample should not exceed 70 seconds.

The values of the peak intensity ratios obtained when processing the Raman spectra by various methods (Figures 5, 8) differ significantly. When using the 1st method of processing, the spectrum is considered as a whole; the baseline is subtracted immediately in the entire range of 440–1735 cm^{-1}. Since the baseline is complex, automatically subtracting the last one immediately over the entire range can lead to additional systematic error, which affects the results obtained.

Figure 10 shows the spectra obtained using the 1st processing method (used for the first model). As previously stated, the value of luminescence signal increases with more prolonged exposure to laser radiation on the sample, while there is an increase in "breaking" the baseline, which can be interpreted in two ways: either this effect is associated with the presence of multiple maxima of the luminescence and can be explained directly by the composition of the sample or by the feature associated with the processes occurring in the sample with increasing time of exposure to laser radiation. As a result, it is not possible to correctly subtract the baseline in software (for example, using Opus) immediately in the entire range. When trying to subtract the baseline using the first method of spectrum processing, there is an area of "residual luminescent background" in the area of the peak of 730 cm^{-1}. The intensity of this "residual luminescent background" area also increases proportionally to the integration time and its position shifts to the short-wave part of the spectrum (Figure 10–11).

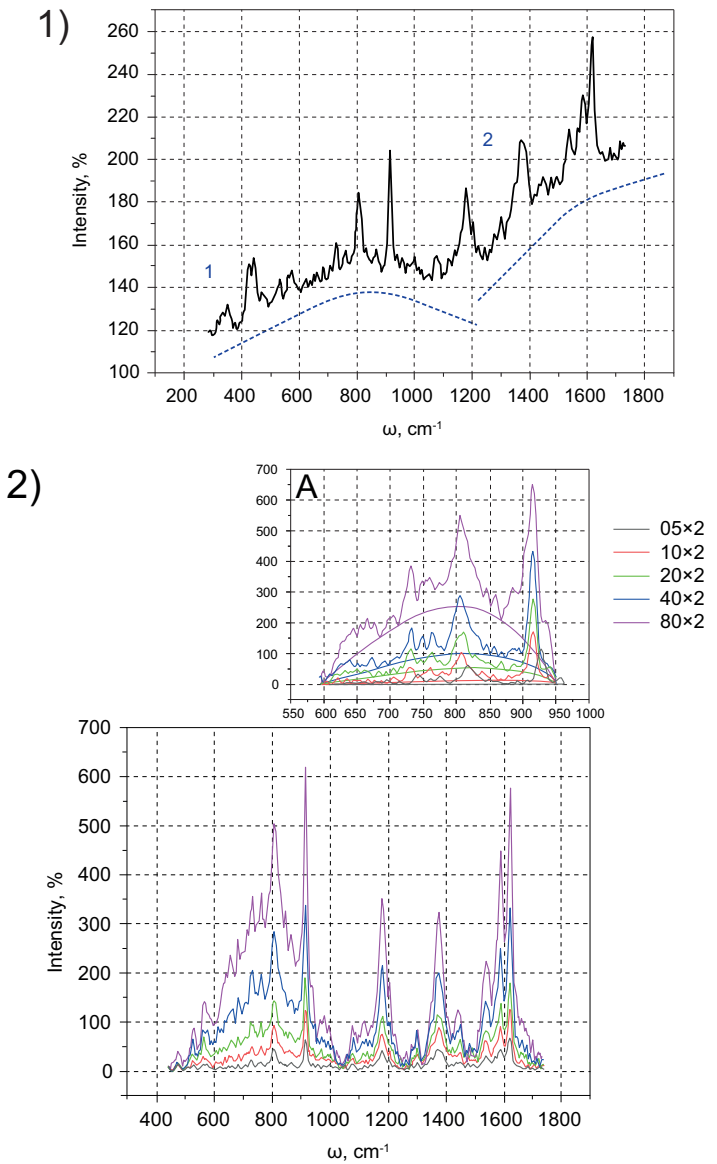


Figure 10. Raman spectra of the writing composition sample no. 59 from the database: 1) before processing by the 1st method; 2) after processing by the 1st method; A – enlarged spectral area in the area of 400–950 cm^{-1} with an approximation of the "residual luminescent background" area for better visualization

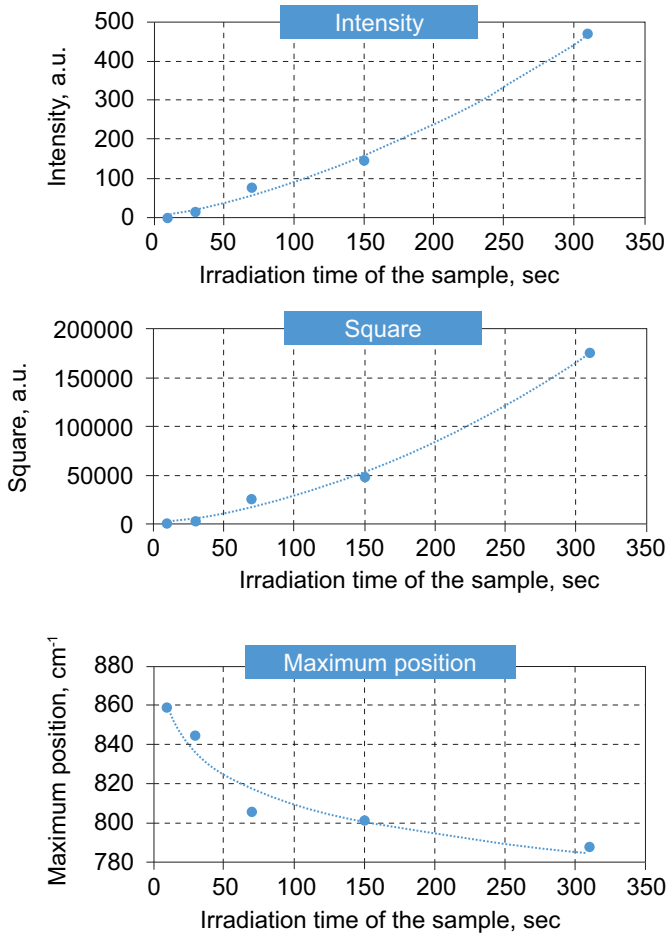


Figure 11. Characteristics of the "residual luminescent background" area obtained by subtracting the baseline using the 1st method from the irradiation time of the sample for the area, the maximum value, and the maximum position

The results indicate that the calculations must take into account changes in the luminescence signal from the sample.

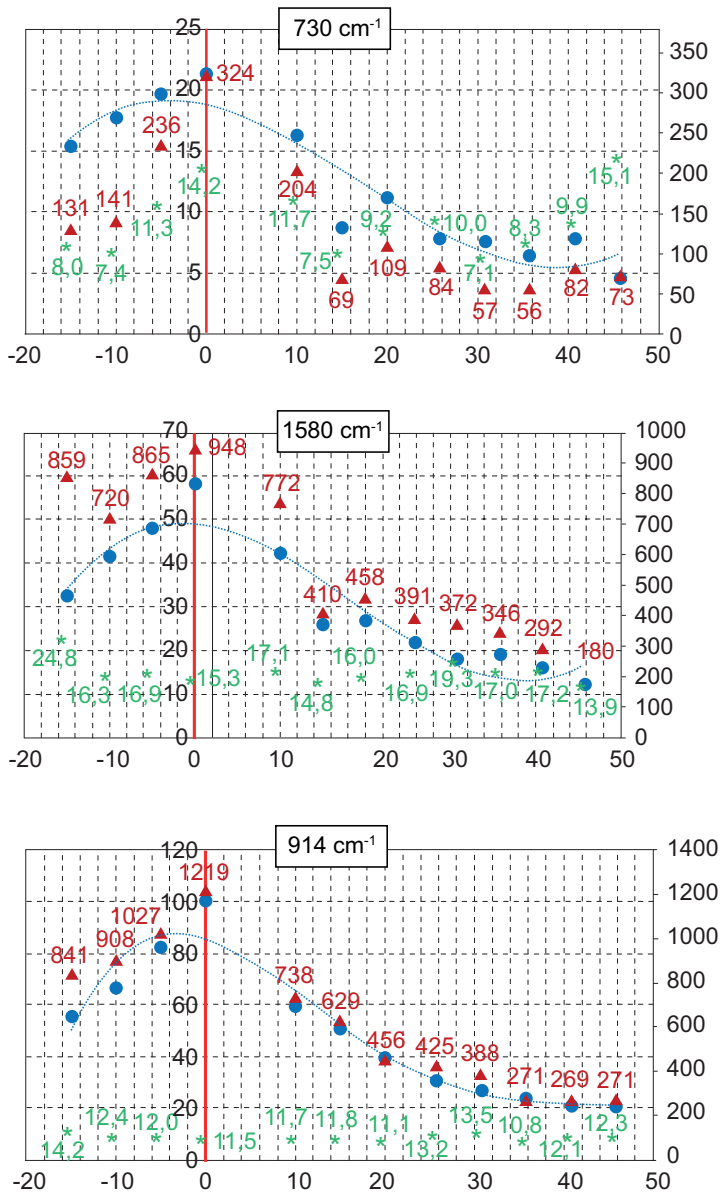


Figure 12. Dependency graphs of intensity (points), areas (triangles), and half-width at half-height (asterisks) for the peaks 730, 1580, and 914 cm^{-1} on the z-axis coordinate, the visual focal point is assumed to be 0

Evaluating the contribution of focus accuracy to measurement results

The maximum achievable focusing on the sample was performed (focusing accuracy was determined visually) to study the effect of focusing accuracy on the measurement results, after which a coordinate 40 units higher was set for the motorized table along the z-axis. Then a series of spectra was obtained from one point in increments of 5 units along the z-axis. The spectra were processed using the 3rd processing method (cl. 4.8.1), since the minimum value of the standard deviation for the average is achieved wthrough it. The spectra were obtained using the following parameters: the laser radiation power – 0.2 mW, the integration time – 3 seconds, and the number of repetitions – 2. For the study, the main characteristics were calculated for the peaks of 730 and 1580 cm^{-1}, since they were used to obtain time dependencies.[20] The "model" peak was used at 914 cm^{-1}, as it is an intense, free-standing peak.

Based on the experiment results, the authors can conclude that when approaching the focus point, the values of the intensity and area of the peaks increase and fall after passing the focus point. The half-width at half-height remains constant and does not depend on the focus (Figure 12). From the presented graphs, it is clear that the visually defined focus point coincides with the actual one.

For the peaks of 730 cm^{-1} and 1580 cm^{-1}, the largest spread of values is observed, due to the error that occurs when approximating these peaks by Gaussian (for example, the spread of half-width values at half-height can reach 30%). Next to the 730 cm^{-1} peak, there are a number of closely spaced peaks (for example, the peak at 726 cm^{-1}), as a result of which the latter overlap and the Gaussian approximation of the peak at 730 cm^{-1} becomes much more complicated. In addition, the intensity of the 730 cm^{-1} peak is significantly less than the 914 cm^{-1} peak, which increases the approximation error of this peak. The optimal pattern is observed for a peak of 914 cm^{-1}. The half-width value at half-height averages 12.2, with a standard deviation of 1, which is 10% of the average. There are no other nearby peaks near the 914 cm^{-1} peak, i.e., there is no overlap with other peaks. The behavior of this peak corresponds to the theoretical assumptions as much as possible.

[20] Ibid.; K.O. Gorshkova et al., "Investigation of the new possibility…".

Similar dependencies were obtained for samples with storage periods of 25, 39, 58, and 88 months. Dependency graphs of peak intensity on the z-axis position can be divided into three linear sections (Figure 13). For further calculations, the authors selected three angles between linear sections and the positive direction of the x-axis as well as the fourth angle between straight lines (Figure 13).

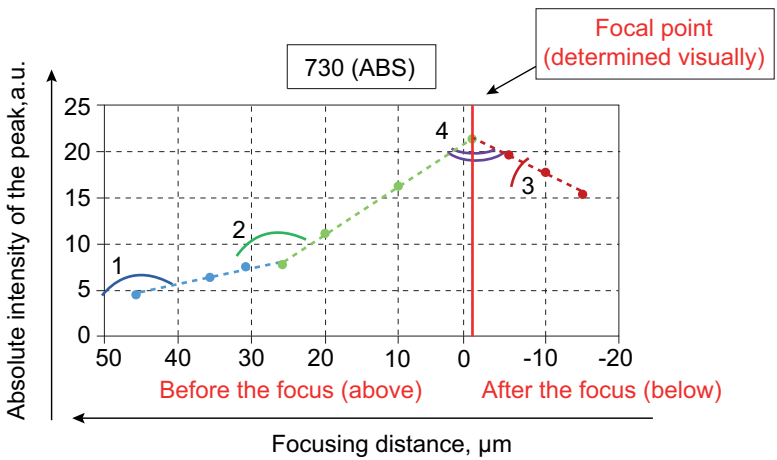


Figure 13. Example of a dependency graph of peak intensities on the z-axis position indicating the angles used for calculations, the visual focal point is taken as 0

Figure 14 shows the dependences of the tangents of angles 1–4 on the sample shelf life for peaks 730, 1580, and 914 cm^{-1}. The standard deviation for the studied angles 1–3 does not exceed 0.4.

A different character of the dependence is observed for angle 4. If the dependence for the angle tangent within 25–58 months has a form similar to the parabolic dependence with a minimum of 39 months, then after 58 months there is a sharp increase in the value of the angle tangent, which indicates a decrease in the sensitivity of peak intensities to focusing. The peak intensity is most sensitive to focusing at the age of 39 months, and this sensitivity decreases with increasing time. It can be assumed that after reaching 39 months, the heterogeneity of the sample is maximal, and after 39 months, the heterogeneity of the sample decreases. When con-

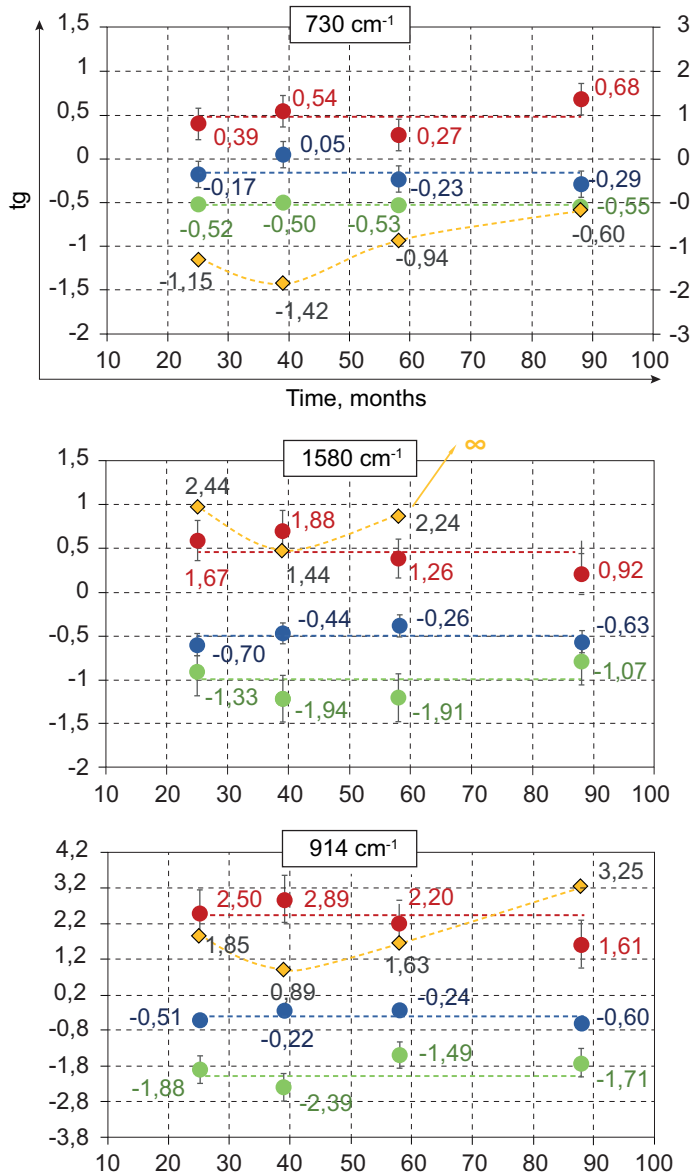


Figure 14. The dependence of the angle tangent 1–4 on the sample shelf life for peaks 730, 1580, and 914 cm^{-1}, the visual focal point is taken as 0

structing the first model of methodological development,[21] the minimum intensity ratio was observed for about 40 months. It can be assumed that 40 months is the period of maximum fluctuation of the sample properties, after which the processes are stabilized.

Dependencies of the ratio of peak intensities 730/1580 on the z-axis position were obtained (Figure 15). The intensities ratio has a large spread when obtaining spectra further than 30 μm from the focus point. Within 30 μm before the focus and 10 μm after the focus, the intensity ratio varies within the standard deviation ~ 0.03. When determining the focus visually, the error can be no more than 5 μm, and the standard deviation of the ratio within these limits is less than 0.01.

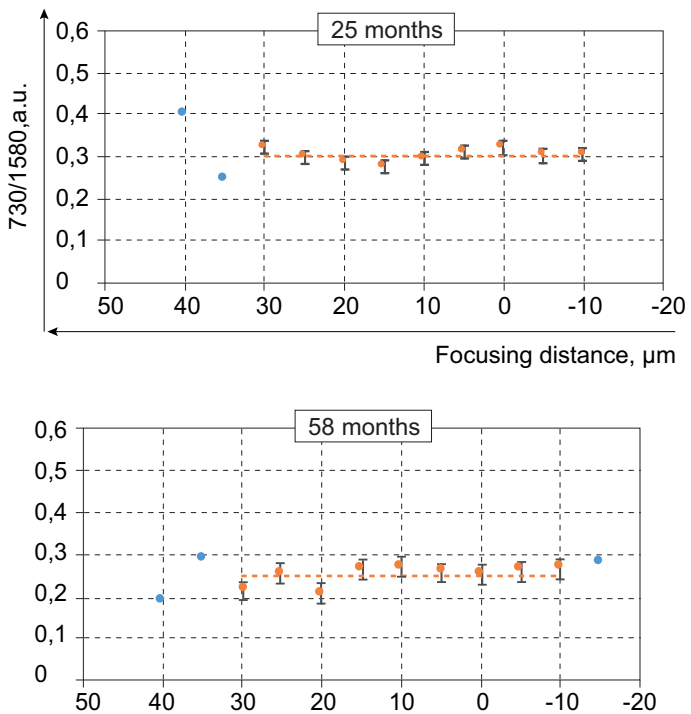


Figure 15. Dependence of the ratio of peak intensities 730/1580 on the z-axis coordinate, the visual focal point is taken as 0

[21] K.O. Gorshkova et al., "The investigation of dye aging dynamics…".

Based on the data obtained, it can be concluded that the visual definition of the focus point is sufficient for the study and does not significantly distort the peak intensity and characteristics of the writing compositions' Raman spectrum.

Application of chemometric tools for the analysis of Raman spectra

An attempt was made to use new methods of mathematical signal processing, namely the PCA method, to eliminate the contradictions identified at the previous stages.

The retention period was used to calculate the Pearson correlation ratio to identify the relationship between the components. Before the calculation, the nature of the data distribution was checked using histograms and quantile graphs, since both analyzed variables must be distributed normally to calculate the Pearson ratio.

The eigenvalue greater than 1 indicates that the main component preserves more variance than was accounted for by one of the original variables in the standardized data. This is usually used as the cut-off point for which the principal components are preserved.[22] The system under study has 4 main components. The main contribution is made by PC1, which explains 97% of the data variance. However, for further analysis, the authors used all the components to take into account the maximum number of factors that affect the system.

The correlation ratios of the components and the sample shelf life are calculated (Table 23). The components PC4 (0.286), P5 (0.252), and PC6 (0.259) are most closely related to the shelf life, although they do not make the maximum contribution to the variance in the system. This explains the need to consider not only the main components for analysis, but also those that have a connection with the sample shelf life.[23]

For better visualization, a 3D graph was constructed for averaged component values for samples with the same shelf life (Figure 16). Indeed,

[22] G.B. Anderson, *Principal component analysis in R. An examination of the different functions and methods to perform PCA*, https://www.ime.usp.br/~pavan/pdf/PCA-R-2013.

[23] K.O. Gorshkova et al., "Investigation of the new possibility…".

samples with a shelf life of up to 50 months and after 50 months of storage are separated in space, while samples with a shelf life of 40 and 65 months actually lie at the interface. The obtained result indicates the potential possibility of separating samples depending on the shelf life by the PCA method by improving the mathematical processing algorithm.

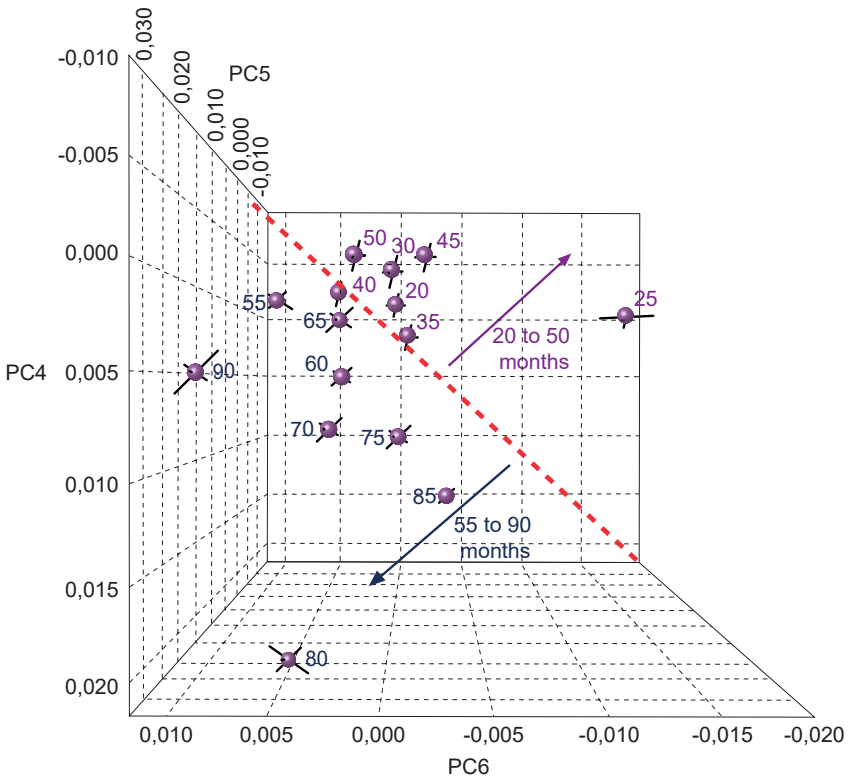


Figure 16. 3D graph in coordinates PC4/PC5/PC6 for the system under study, points – averaged component values for all samples with the same shelf life

The authors also managed to achieve clustering depending on the brand (Figure 17). For different writing compositions, the value of PC2 differs, which allows separating the studied writing compositions. Figure 17

shows a graph of the PC2 values for the number of writing compositions. Table 9 illustrates the calculated values of the average value of the second components and the standard deviation of the latter. It should be noted that the values of PC2 for writing compositions no. 3 and 5 are very close since both writing compositions belong to the Erich Krause brand (Table 1).

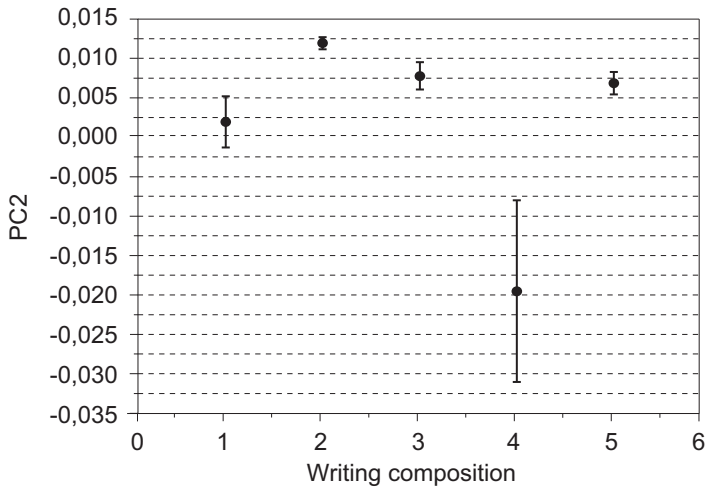


Figure 17. Values of PC2 for each studied writing composition

Table 9. Calculated value of PC2 for each studied writing composition

No. of pen	PC2 value	Standard deviation
1	0.0020	0.0032
2	0.0119	0.0008
3	0.0078	0.0017
4	-0.0195	0.0115
5	0.0069	0.0014

At this stage, the entire sample spectrum was used for PCA analysis. When analyzing such data, too many fluctuations contribute to each of the components, so it is difficult to interpret the resulting picture unambiguously.

Discussion

The following can be concluded based on the results of the work performed:

– the dynamics of the Raman spectra of writing compositions is determined by the spectral dynamics of the dye that is the basis of the latter;

– the main parameters for measuring the Raman spectra of writing compositions are determined;

– the laser power – 0.2 mW, the integration time – 10 seconds, and the number of repetitions – 4;

– in the process of obtaining the spectrum, the irradiation time of the sample should not exceed 70 seconds;

– it is necessary to consider individual sections of the spectrum containing characteristic peaks instead of the entire spectrum to calculate the physical characteristics of the spectrum. The peaks must be approximated using the Gaussian distribution.

Visual determination of the focus point is sufficient for conducting research and does not significantly distort the peak intensity and characteristics of the Raman spectrum of writing compositions. Calculations must take into account changes in the intensity of Raman peaks and the luminescence signal from the sample.

It can also be noted that 40 months is the period of maximum fluctuation of the writing composition properties, after which the transformation processes of the writing material components are stabilized. A similar result was obtained earlier in Gorshkova et al.[24]

Taking into account all the requirements for measuring spectra, the PCA method applied to the Raman spectra of writing compositions allows clustering samples by manufacturer brands and by the sample shelf life. The dependency graph of the components confirms this with the highest values of the correlation ratio with the shelf life – PC3/PC5 (Figure 18). For Figure 18, 5 areas correspond to different sample shelf life: 20–25, 30–50, 55–70, 80–85, and 90 months.[25]

[24] K.O. Gorshkova et al., "The investigation of dye aging dynamics…"; K.O. Gorshkova et al., "Investigation of the new possibility…".

[25] K.O. Gorshkova et al., "Investigation of the new possibility…".

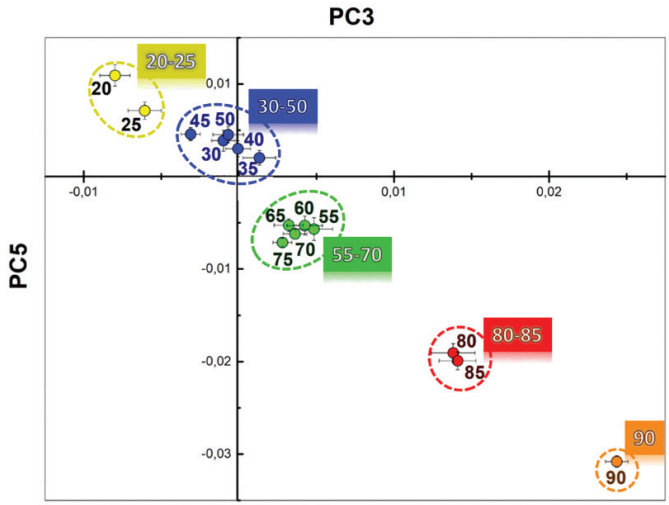


Figure 18. Dependency graph of PC5 values on PC3 values

The developed clustering method is the most objective since its implementation uses all points in the Raman spectra, and the "human factor" error is minimized.

A similar approach to examining the questioned document was also described by Łydżba-Kopczyńska et al. and Cieśla.[26] The developed clustering method is the most objective since its implementation uses all points in the Raman spectra, and the "human factor" error is minimized.

Acknowledgments

The work was supported by the Ministry of Education and Science of the Russian Federation (Project FSRM-2020-0006).

[26] B. Łydżba-Kopczyńska et al., "Application of chemometric methods for the determination of fading and age determination of blue ballpoint inks", *Journal of Raman Spectroscopy* 52, 2021, no. 1, pp. 159–169; R. Cieśla, "Questioned document examination with the use of alternative and complementary non-destructive methods", *Nowa Kodyfikacja Prawa Karnego* 57, 2020, pp. 149–167.

The work was supported by Federal State Budgetary Institution "Assistance Fund development of small enterprises in the scientific and technical sphere," Agreement no. 4101ГС1/65634.

The research was partially funded by the Ministry of Science and Higher Education of the Russian Federation under the strategic academic leadership program "Priority 2030" (Agreement 075-15-2021-1333, dated 30.09.2021).

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NOWA KODYFIKACJA PRAWA KARNEGO Tom LX
NEW CRIMINAL LAW CODIFICATION
AUWr No 4039 Wrocław 2021

https://doi.org/10.19195/2084-5065.60.6

Trends in the development of computerization of forensic handwriting examination

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Abstract

Forensic handwriting examination is one of the most complex and controversial types of forensic research, the results of which are often disputed in court. One of the reasons for that is experts' subjectivity. Using quantitative methods and introducing computer technology in the process of handwriting examination can increase its objectivity. Thus, the article analyzes various ways to improve handwriting research, which in the future may increase its objectivity. The author examines the development trends of quantitative methods and the use of computer technology in handwriting examination process.

Keywords: judicial handwriting, forensic handwriting examination, computerization, computer technology in the process of handwriting examination

Introduction

The contemporary era is strongly characterized by the rapidly developing information technology. Scientific and technological progress plays a crucial role in the life of modern society, both on an individual and state level. It is obvious that using computing technology can simplify and improve most human professional activities. One of them is forensic expertise, and in particular forensic handwriting examination.

Launch of computer technologies and science investigations in handwriting examination occurred in the USSR between the 1960s and the 1970s. The major contributors were Russian criminologist R.M. Lanzman together with mathematicians V.A. Yakubovich and B.N. Kozinets. Further followers of this direction and research of theoretical and practical provisions of this field included scientists such as: A.A. Zhuravel, N.V. Troshko, L.G. Edzhubov, A.Y. Lerner, V.N. Vapnik, I.B. Siroja, A.M. Companets, A.R. Shlyakhov, V.A. Poshkevichus, V.F. Orlova, A.V. Smirnov, N.G. Sakharov, P.V. Bondarenko, N.A. Zamaraeva, and others.

Related works

Looking back at its history, we can notice that handwriting examination was the first branch of criminalistic examinations where the attempts of using computer technologies took place. However, even then, the aforementioned scientists realized that increasing objectiveness of handwriting examination was a necessity. I believe it is also important today due to a number of reasons.

1. Forensic handwriting examination is still partially subjective. Despite the fact that an expert is bound by a well-established set of rules, his evaluations may not be entirely objective. Some internal and external factors might affect an expert's work, which may lead to a wrong conclusion, which is utterly unacceptable.

2. Current mathematical methods developed for purposes other than handwriting examination may cause some difficulties for experts. Computer technologies can adjust the above methods, making it possible to use them in such examinations.

3. Today, the signature is certainly among the most popular objects of handwriting expertise, as well as identification research of signature – is a very important task during the work on criminal, arbitration, and other cases. Despite the common practice being the use of a traditional method, there are still some rare tasks which cause significant difficulties and require a special approach. The study of simple, concise, and simplified signatures, as well as signatures with letter-free transcription, can be con-

sidered such a task. The system of general and specific features was created in 1964 for research on overly informative handwriting implementations. The problem is that this system is not appropriate for small and short handwriting objects. That is why science society faced the necessity of developing new handwriting features system with the use of computer technologies.

4. Using computer technologies in other types of criminalistic expertise. For example, the common use of such software and technical complexes as ADIS, Dakto 2000 (NGO Todes, Minsk), Sonda (LLP Pathfinder, Miass), Arsenal (TO papilon, Miass), PTC for the compilation of subjective portraits FRS-2 (MSTU called Bauman's).

All these factors explain the wide interest in implementing computer technologies into handwriting examination. Years ago, Russian criminalistic experts did research which proved the potential of using computer technologies in handwriting examination. This fact stimulates new research. Unfortunately, some authors and scientists note that the developed theoretical and practical statements and programs are not often used in real life. I believe that one of the reasons is the low level of programing knowledge in that time, which lead to bad research results and faulty implementation of computer technologies. Besides, there are also organizational issues: the absence of economic, political, financial, technical, and other resources. There are also individual factors, such as a low motivation level.

Computerizing handwriting examination is a difficult process, consisted of integrating legal and technical knowledge. Research on this issue should be done in a new way, with the use of previous experience and simultaneous attention to the modern circumstances. I am sure that computerization of handwriting examination should be classified as a new concept. Besides, a more systemic approach is necessary. The basis for this new conception is scientific research, results of which form theoretical and methodological foundations for implementing computer tools into the handwriting examination practice. To my mind, the priority of computerization is identifying the general direction as well as describing useful methods and operations.

Conclusions

Modern technologies create opportunities to develop handwriting examination. The analysis of modern studies with common topics suggests that the next decade will be a time of improvements in this branch of criminalistic examination. Computer technologies will lead to the development of automated databases, which will help solve unique cases. This is going to be the time of computers recognizing handwritten texts and signatures, the development of separate automated methods, the integration of automated technical tools into the process of handwriting expertise, as well as the development and study of new trends such as the biometric signature.

I managed to analyze key historical aspects of handwriting examination computerization in Russia. Specific programs and tools are not popular among experts. There are no universal and general methods or complexes. Unfortunately, there are also theoretical and methodological gaps in computerization of handwriting examination. That is why continuing the research is still necessary.

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Nowa Kodyfikacja Prawa Karnego 60, 2021

NOWA KODYFIKACJA PRAWA KARNEGO Tom LX
NEW CRIMINAL LAW CODIFICATION
AUWr No 4039 Wrocław 2021

https://doi.org/10.19195/2084-5065.60.7

Deciphering writings created with erasable/disappearing ink: A new method

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Abstract

A document examiner may face a large variety of cases pertaining to handwriting, ink, and paper examination. In cases of ink examination, issues may include identifying the ink as well as determining its permanency. These days there is an increasing number of cases pertaining to a cheque presented in the bank with an amount which was later denied by the drawee. Upon physical examination with the naked eye in daylight, the claim of the drawee appeared to be true – however, in case of doubt the financial institutions dealing with such transactions, including banks, send the document for examination.

Nowa Kodyfikacja Prawa Karnego 60, 2021

It has been observed that a good number of ink pens are available in the market whose writings get invisible after some time ranging from hours to days. These types of writing pens are manufactured for fabric/garment manufacturing companies to mark the fabric for tailors, instructing them where cuts should be made. These marking pens are used now a day quite frequently throughout the world by the criminals to write the cheque and to later deny the amount on the cheque because of the fact the writings written with such inks fade or become invisible. Thus, the document is sent for examination. A number of methods have been reported to deal with the problem of decipherment of such writings but in present study very simple and readily accessible technique has suggested to visualise the writings which disappeared on heating. In this work, the disappeared writings which were produced by the PILOT FriXion erasable ink pen are made visible by cooling the document containing the aforesaid writings in a freezer of an ordinary refrigerator.

Keywords: erasable, visualisation, microwave-oven, freezer, thermal, disappearing ink

Introduction

The problem involving visualization/decipherment of the secret writings is not a new in the field of forensic documents. Every time, with advancement of technology, new ink fluids are invented. In the past, colorless fluids such as distilled water, lemon juice, onion juice, etc. were used for producing sympathetic writings. When such types of documents are exposed to controlled heat, the portion where writing exists gets oxidized and burns faster than the surrounding paper. The fluid portion turns brown, thus developing the invisible ink.[1] Another method to decode the invisible ink was by using some salt on the paper. Further, these writings can be made visible using UV light[2] along with the study of the indentation, if present on the back side of the document. With time, some coloured fluids/inks are used to produce visible writings which become invisible after certain chemical/physical treatment. The first of these types of inks which came to the knowledge of the authors is based upon the pH value of the ink. These fluids/inks are blue in colour, with their pH value over 7, i.e. they are alkaline in nature. Carbon dioxide present in the atmosphere combined with the water vapours to produce carbonic acid which further

[1] *Invisible ink experiment*, https://explorable.com/invisible-ink-experiment (accessed: 12.11.2017).

[2] W.R. Harrison, *Suspect documents*, Delhi 1997, p. 135; O. Hilton, *Scientific examination of questioned documents*, Boca Raton, FL 1993, p. 148.

reacts with the ink and neutralize its alkaline nature. Due to neutralization, the pH value of the ink decreases, which causes the change in the colour of the ink, i.e. it becomes colourless. The resultant document can be used for committing crime, particularly in bank get-rich-quick schemes, where the writings of the bank instrument are written with disappearing/erasable ink and the signatures – with the usual non-disappearing ink. The invisible writing was made visible using spot light option/arrangement present in the VSC-2000.[3]

Although heat was applied to develop the invisible ink, in the present case heat is used to make the visible writing invisible. A thermosensitive pen PILOT FriXion erasable ink pen (Figures 1 and 2) is easily available on the market and has ink that can be removed by heat produced due to friction of the eraser provided along with the pen[4] as one of the factors. Due to the eraser, the surface of the document might get affected and its presence can be felt by a trained document expert. Since heat is responsible for disappearing ink, as such it is assumed that when the document is heated in a microwave oven at controlled temperature and time, the writing will disappear. In such cases, assuming the process is reversible, the writing can be developed by cooling the document.

Material and methods

Sample document in the form of a blank bank cheque was prepared by writing with the PILOT FriXion erasable ink pen. The document was then kept properly in the microwave oven and heated gradually. Proper care is taken so that the document does not get charred. It is found that the writing became invisible when the document is heated at around 50°C temperature. Since thermal effect causes the ink to disappear, it was therefore assumed that the process is reversible. As such, the document was kept in the freezer of an ordinary refrigerator at around 0°C and, as per our assumption, the writings became visible. The experiment was also

[3] B.A. Vaid et al., "Visualization of disappearing ink writings", *Journal of Problems of Forensic Sciences* 92, 2012, pp. 311–318.

[4] "The science behind frixion erasable pens", https://www.nippon.com/en/features/c00520/ (accessed: 27.11.2019).

conducted by writing on a bank cheque using the PILOT FriXion pen and keeping it in the sunlight for more than 3 days, but the writing failed to disappear. Furthermore, it was found experimentally that when the writing produced by the FriXion erasable ink pen on the cheque is erased with the eraser provided with the pen and the resultant document is kept in the freezer at around 0°C, the writings re-appear.

Results and discussion

Figures 3 to 6 indicate the various stages of experiments performed during this research on decipherment of erased writings. Figure 3 is the photograph of the original blank cheque considered for experimentation. Figure 4 is the photograph of the writings produced on the cheque using the PILOT FriXion erasable ink pen. Figure 5 is the photograph of the cheque after controlled heating in a microwave oven for a short time (about 5 minutes) at around 50°C. Figure 6 is the photograph of the cheque after keeping the original from Figure 5 in the freezer of a refrigerator for 3 to 4 hours; however, the duration can be extended if deemed necessary. The original writings could easily be read from Figure 6 and are photographed for further examination and record.

Chayal et al.[5] also reported the decipherment of the erasable inks but they did not try this innovative method. They could decipher such type of writing in an actual case with the help of video spectral comparator (VSC). Throckmorton[6] has reported in detail about such a type of writing inks which could be deciphered by pH variation mechanism through applying a simple reagent used in washroom cleansing. It was found that this reagent contains sodium hydroxide, which reacts with the contents of the ink made invisible and gives colour to the erased writings.

Since the pH-based pens are not easily accessible to an ordinary person, while the above-mentioned thermal pens are widely available on the market at a reasonable price, as such the probability for its misuse is very

[5] V.M. Chayal et al., "A sensitive non-destructive method for detection of document frauds using thermal ink", *Australian Journal of Forensic Sciences* 48, 2016, no. 5.

[6] G. Throckmorton, "Disappearing ink: Its use, abuse, and detection", *Journal of Forensic Sciences* 35, 1990, no. 1, pp. 199–203.

high. Moreover, with such a very simple, easy, and readily accessible technique, fraud committed with the pen could even be detected by an ordinary person with a little technical knowledge. This may also be helpful in reducing the burden on heavy-loaded forensic document examiners and take forensic science to the doorstep of an ordinary citizen. Combining the mentioned technique with other available methods may increase the probability of deciphering the disappearing ink and enhancing objectivity in the visualization of disappearing writings for forensic document experts.

Precautions

1. While cooling the document, every precaution should be taken so that the moisture, if present in the freezer, does not affect the document/writings.

2. Prior permission should be taken from the competent authority before keeping a questioned document/cheque supposed to contain a thermal secret ink in a freezer.

Suggestions

1. Always use a personal pen for writing/signing all important documents.

2. Bank officials should be given training in dealing with such types of frauds in various forensic science laboratories or courses which may be organized for them by forensic scientists.

3. As per the mode of operation in such frauds, the signature on the bank cheque was created with original non-disappearing ink, while the body writing – with the disappearing ink, so is manipulated. Hence, bank officials should take extra precautions while dealing with bank instruments which are written and signed with two different inks.

Acknowledgement

One of the authors (BAV) is grateful to Dr. O.P. Jasuja, professor at Punjabi University, Patiala, for his valuable suggestions and guidance.

Figures

Figure 1. PILOT FriXion erasable ink pen

Figure 2. Front and reverse side of wrapper of PILOT FriXion erasable ink pen

Figure 3. Original blank cheque considered for experimentation

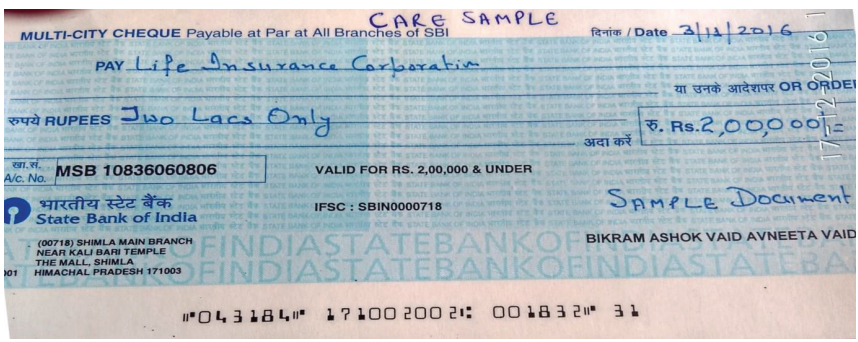

Figure 4. Writing produced on the above cheque using the PILOT FriXion pen

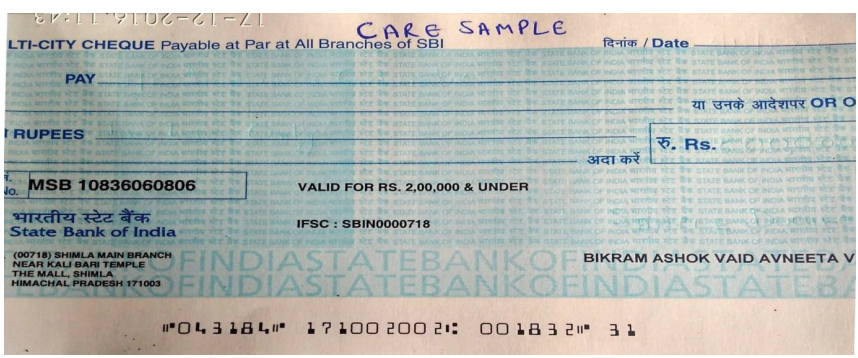

Figure 5. Cheque after controlled heating in the micro-oven for a short time at minimum temperature

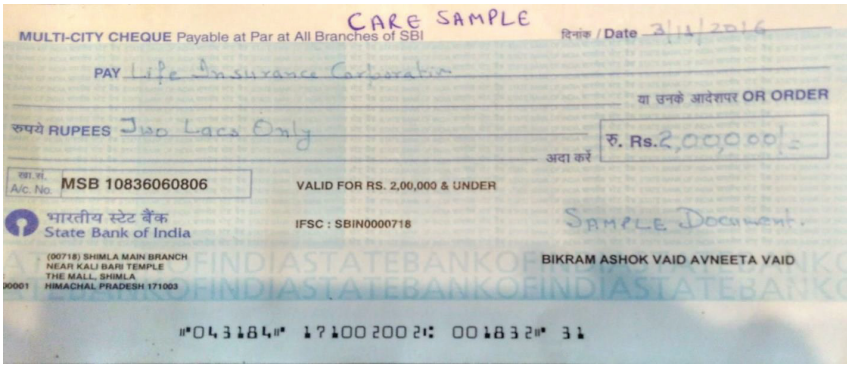

Figure 6. Cheque after keeping the original of Figure 3 in the freezer of a fridge

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NEW CRIMINAL LAW CODIFICATION
AUWr No 4039 Wrocław 2021

https://doi.org/10.19195/2084-5065.60.8

The role of paper embedded security features in effective border control

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Abstract

Security documents are crucial types of documents, whose authenticity is genuine and cannot be counterfeited. For different types of security documents, a security paper is used, which possesses the property of being impenetrable to mileage, high temperature with unequivocal GSM, haziness, and thickness. This makes it sensible for merging the security features that make it different from normal paper. The commonly used substrate for any security document manufacturing is either plastic or paper. The process of manufacturing a security document begins with paper manufacturing by mechanical and chemical processing of wood pulp, and the security elements are incorporated in the further processing stages. The raw material used is mainly pure cotton fiber-based cellulose mixed with titanium oxide. The major security features include security threads, fibers, planchettes, and water marks which play a critical role in keeping up the uprightness of the security record for a fruitful edge control. Identity theft as well as deceitful utilization of personality and travel reports are the fundamental dangers confronting the control at international borders, while checking the legitimacy of the travelers' character records assumes an essential job in guaranteeing the effectiveness of fringe control.

Keywords: substrate, security paper, watermark, fibers, planchettes, hi-lights, security thread

1. Introduction

The substrate is an underlying layer or substance over which a reaction takes place, an organism grows. Paper serves as a substrate for the evolution of various document types such as wills, deeds, currency notes, bank checks, stamps, as well as identity documents, passports, visas, driving licenses, etc. The role of paper used in the manufacturing of security documents is very significant in terms of their admissibility when converted into a precious and authenticated document. The security documents are generally produced on two major types of substrates: paper and plastic. The raw material used for security documents is mainly pure cotton fiber-based cellulose mixed with titanium oxide and various security features are embedded into it as per the requirement of security document production. The security papers possess the property of being resistant to wear and tear, high temperature with specific GSM, opacity, and thickness, making it suitable for incorporating the security features.[1]

Those features are the everlasting, capable, and sincere guards of document value – their role is not restricted to protecting private rights, they also protect borders by preventing illegal entry of criminals and terrorist imposters as well as supporting border guards with effective ways to perform their duties.

To put it differently, identity theft and fraudulent use of identity and travel documents are the main threats facing border control management systems, while verifying the authenticity of the identity documents of passengers plays a crucial role in assuring the efficiency of border control management. Most threats against identity and travel documents are represented by photo substitution, modifying alpha-numeric data, passport biodata page substitution, visa pages substitution, and so on. Accordingly, security features in identity and travel paper documents are of four main types: paper embedded features, printing techniques used in the docu-

[1] C.M. Deviterne-Lapeyre, "Interpol review of questioned documents 2016–2019", *Forensic Science International: Synergy* 2, 2020, pp. 429–441; Fabriano Security, "Banknote and security papers", http://www.fabrianosecurity.com/en/15/banknote_&_security_papers (accessed: 30.06.2020); M.B. Shaw, G.W. Bicking, *Research on the production of currency paper in the bureau of standards experimental paper mill*, Department of Commerce Bureau of Standards, Washington, D.C. 1926.

ment manufacturing process and personalization process, additional security features such as optical variable devices (kinegram and hologram), and data saved in an RFID electronic chip for e-passports. However, the most effective security feature is one that is easy to check and at the same time hard to imitate. This makes paper embedded security features in the forefront, knowing that the major forging and counterfeiting threats against identity and travel documents are focused on personalizing additive photos, identity, and other alpha-numerical information which is added to the paper and not embedded inside it.

In addition to paper substrate, polycarbonate, Teslin, polymer, and other types of substrates are used in value documents; despite that, the paper is the oldest type, still widely used all over the world for almost all kinds of value documents. This article is going to demonstrate the main paper embedded security features, starting from paper ingredients, watermarks, security threads, fibers, planchettes, and hi-lights, whose level of technological advancement is very high in order to ameliorate their strength and make any attacks more and more difficult.

2. Paper production

Pulps are produced from a diversity of cellulose-containing raw materials, such as hard and softwood as well as non-wood sources, including hemp, jute, flax, sisal, and cotton.[2] Moreover, compared to all kinds of natural fibers, cotton fiber has the highest cellulose content in nature – it constitutes 95–97% of its ingredients. Besides, cotton-based raw materials have a rich variety of excellent properties in physical and optical aspects. Firstly, the fiber length of cotton raw material is between 20–30 mm with diameter around 20 micrometers,[3] whereas softwood's fiber length is 3 mm and its diameter about 20 to 35 micrometers.[4] Secondly, cotton

[2] Z. Liu, H. Wang, L. Hui, "Pulping and papermaking of non-wood fibers", [in:] *Pulp and paper processing*, ed. S.N. Kazi, 2018, IntechOpen, https://www.intechopen.com/chapters/62223 (accessed: 10.07.2020).

[3] Ibid.

[4] *Mini-encyclopedia of papermaking wet-end chemistry: Additives and ingredients, their composition, functions, strategies for use*, https://projects.ncsu.edu/project/hubbe-paperchem/FIBR.htm (accessed: 18.07.2020).

fiber has the merits of excellent flexibility, good tenacity, elasticity and absorptivity, high strength and opaqueness, robust resistance to dilute acids and alkalis, and can be stored for a long time.[5] This gives an advantage to the cotton-based paper that is stronger than the first, durable, and will not turn yellow with time. All these features are extremely suitable for manufacturing security document papers such as passports and banknotes, which are used repeatedly and frequently for a long period. Conversely, wood-based paper has less flexibility, less elasticity, less durability than cotton-based paper, and will turn yellow with time.

The cotton fiber has even more merits:

– the polymerization degree (the number of repeat units linked together to form the cellulose polymer) is between 9 000 and 15 000 (wood fiber: 600–1 500);

– crystallinity (which indicates that the fiber molecules are closely packed and parallel to one another) is about 73% (wood fiber: 35%);

– high level of hygroscopicity thanks to thinner fiber;

– good bendability that makes it hard to break;

– the best heat-resisting property among all-natural fibers – it remains flexible even at very low temperature and decomposed gradually when under long exposure to dry heat (above 300°F – 149°C);

– the high temperature required for the beating process to manufacture the paper;

– good mechanical properties such as friction and cohesion due to its natural bending.[6]

Wood paper manufacturing process

It aims at preparing a pulp of cellulose fiber to produce paper. As for wood-based raw materials, the manufacturing process begins from wood logs, which are placed in a rotating drum to remove the bark, then moves

[5] CNBM International Pulp & Paper, "Cotton pulp making", http://www.paper-pulpingmachine.com/applications/cotton-pulp-making/ (accessed: 19.07.2020); Z. Liu, H. Wang, L. Hui, op. cit.

[6] Cotton Incorporated, "Cotton morphology and chemistry", https://www.cottoninc.com/quality-products/nonwovens/cotton-fiber-tech-guide/cotton-morphology-and-chemistry/ (accessed: 19.07.2020); CNBM International Pulp & Paper, op. cit.

to the chipping process to select a uniform chip size. For pulp formation, two main methods are used:

– chemical process – a digester with chemicals is used to cook wood chips aiming at removing lignin and fritting the wood chips into fibers, the majority of chemical wood pulp production in the world used to digest the wood chips are using alkaline kraft or sulphate process, by using caustic soda and sodium sulphate (around 80%), and the other method is represented by the sulphite pulping process (around 10%);

– mechanical process – it uses mechanical forces to separate fibers from groundwood, by rotating either drums, grinders, or refiners. However, wood chips are pre-softened by heating or chemical treatment when needed.

The bleaching stage aims at adding certain characteristics to the paper: strength, stability, cleanness, and brightness. All other embedded security features such as fibers, planchettes, hi-lites, and security threads are added to the pulp at this stage, before either being transferred for drying to the paper making pulp mill in an integrated process, or being pressed and dried in a wet state. Additionally, subsequent treatment and coating might be done to get the properties favorable to the purpose the papers will be used for.[7]

However, the manufacturing technology used for paper production can enhance and improve the embedded security features in the paper product, including anti-bacterial, anti-soiling, and additive chemical properties:

– antibacterial paper: is manufactured in response to banknotes being circulated through the hands of an uncountable number of people. This feature plays a preventive role against different types of bacteria to be shifted through the banknotes;

– anti-soiling paper: represented by adding a coat to the paper to increase its resistance to soil;

– paper intended for ink-jet personalization: for improving the quality and durability of the ink-jet personalization process by unique coating materials;

[7] European Bank for Reconstruction and Development, *Sub-sectoral environmental and social guideline: Pulp and paper*, 2014. https://www.ebrd.com/documents/environment/env-emanual-manufacture-of-paper-and-paper-products.pdf (accessed: 10.07.2020).

– the semi-synthetic paper: aimed to improve the quality of highly secured paper by adding specific organoleptic properties;

– Laser Engravable Anti-Counterfeiting Paper (LEAP®): a unique highly secured characteristic, represented by adding special components and coating solution to the pulp which allow applying personalized data by all available techniques, including laser engraving, to produce a clear, legible image without the need of additional laminate to the paper, and to draw an engraving trail on the paper surface as well as within the paper pulp, strengthening an image viewed through transmitting light. The records can be detected by touch;[8]

– chemically secured paper: aimed to protect imprinted data in the document from forging attacks and any unauthorized data-changing attempts using chemical reagents or solvents.

Cotton paper manufacturing process

The commonly used cotton pulp making process is cotton linter alkaline pulping, which includes five steps:

– material preparation of cotton linter to obtain a treated cotton linter with impurity rate between 1% and 3%;

– pulp cooking by cyclone separator and then adding some additives pulp digester;

– pulp washing by beating to increase the hydration degree and washing the pulp using various equipment, including a vacuum drum washer, a twin roll press, a single screw press, or others;

– pulp screening and degritting for removing various impurities and to separate the fine pulp and coarse screenings;

– pulp bleaching process that aims at meeting the specific paper characteristic requirements, and for this reason bleaching circumstances, conditions, equipment, and bleaching agent are strictly controlled.[9]

[8] Polish Security Printing Works (PWPW), "Security features", https://www.pwpw.pl/en/Competencies/Security_features.html#elementy_zabezpieczajace_w_papierze (accessed: 18.07.2020).

[9] CNBM International Pulp & Paper, op. cit.

The produced cotton-based paper is characterized by strength, durability, flexibility, elasticity, finesse, softness, and high opaqueness which are not found all together in any other kind of paper.

3. Watermark

The two main paper machine production types are Fourdrinier and cylinder mould machines. The first is used to produce a continuous web of paper, whereas the second is used for single sheet production.[10]

The watermark in papers is a method for securing documents, its main concept is changing density variation of paper thickness. A watermark formed during the production process by exerting pressure of special motif on the wet paper pulp to produce thick and thin areas, hence, fibers are distributed within the paper according to the design of the watermark motif, where darker areas contain a higher density of fibers and lighter areas contain a lower density of fibers,[11] and hence no additives are added to the paper.[12] Correspondingly, the authentic watermark comprises a refined variation in tone and both lighter and darker areas.[13]

However, checking the authenticity of a watermark needs transmitted light (holding it to a light source or shining a torchlight through the paper) which shows different shades of lightness and darkness to perform a special motif, such as an image, numbers, shapes, or a specific design, and could be distributed in the center of the page, in various locations, in a specific area, or covering the entire area of the page.[14] Additionally, the watermark represents one of the most distinctive, feasible, and inimit-

[10] H.A.A. Al Faleh Al Hiary, "Paper-based watermark extraction with image processing", doctoral thesis, July 2008, http://etheses.whiterose.ac.uk/1355/1/hazem.pdf.

[11] D. Ellen, S. Day, C. Davies, *Scientific examination of documents: Methods and techniques*, Boca Raton, FL 2018.

[12] P.K. Chahal, J. Kaur, P. Singh, "Digital watermarking on bank note", *International Journal of Soft Computing and Engineering (IJSCE)* 3, 2014, no. 6.

[13] Paper Money Grading (PMG), "Substrate feature: The watermark", 20.08.2013, https://www.pmgnotes.com/news/article/3525/Substrate-Feature-The-Watermark/ (accessed: 5.07.2020).

[14] P.K. Chahal, J. Kaur, P. Singh, op. cit.

able security elements – it is simultaneously very easy to check and very hard to reproduce.[15]

Such a production process makes the watermark unreproducible by the counterfeiters and hence a strong security feature protecting value documents from illegal attacks in the form of forging and counterfeiting.

There are many kinds of watermarks:

– linear watermark: wire and single-tone watermark, represented by areas either lighter or darker than the whole paper;

– dual-tone watermark: when areas both lighter and darker from the whole paper are found together;

– shadow watermark: or multi-tone watermark, represented by gradual transitions of lightness and darkness between various areas embedded in the same paper leaf, or a light and shade feature. The Bank of France was the first one issuing multi-tone watermarks in 1829, followed by the Bank of England in 1855, when first shaded watermarks in banknotes were issued;[16]

– combined watermarks: a mixture of linear and shadow watermarks in one paper leaf,[17] this type of watermarks started to appear in the 1990s;[18]

– pixel watermark: comprised of a regular or irregular matrix of dark-colored dots on a light background, it is tremendously difficult for forgers to copy;

– high-light watermark: are produced during the paper manufacturing process by eliminating the fibers to very low levels, which allows creating very light areas, aiming at increasing the visibility of a specific design motif (Figure 11) when examined with transmitted light; they appear as more prominent heightened areas within the other types of combined watermark (Figures 1, 3, 4);[19]

[15] Radecepapir Nova, "The watermark: The oldest and most reliable paper protection element", https://www.radecepapir.si/the-watermark-the-oldest-and-most-reliable-paper-protection-element/ (accessed: 5.07.2020).

[16] H. de Heij, "Banknote design for retailers and public", *DNB Occasional Studies* 8, 2010, no. 4, https://www.dnb.nl/binaries/OS0804_tcm46-244782.pdf.

[17] H.A.A. Al Faleh Al Hiary, op. cit.

[18] H. de Heij, op. cit.

[19] Louisenthal, https://www.louisenthal.com.

– digital watermark: a term was first used by Komatsu and Tominaga in 1988 (Figure 2).[20]

There are four main types of watermarks according to the position in the paper:

– general: the motif is repeated in consistent intervals all over a document page (Figures 5, 6, 7);

– local: the motif is repeated in a certain place on a document page (Figure 4);[21]

– cornerstone: located at the corners of the page (Figure 8);

– edgestone: located at the edges of the page.

Moreover, lightness and darkness of watermark areas are described concerning the general paper tone:

– single-tone: contains darker or lighter areas of a special motif in comparison with the general paper tone;

– dual-tone: contains darker and lighter areas of a special motif in comparison with the general paper tone;

– multi-tone: contains gradual transformation between darker and lighter areas to perform a shadow image or a specific motif.[22]

Furthermore, it is very rare to find a paper security document like banknotes and passports, without watermark, which indicates the high significance aspect of the watermark in protecting value documents. However, despite the tremendous technological development of document security features, watermarks are still the main recommended feature to be embedded in all the world's major banknotes[23] to ensure high performance of protection against counterfeiting.

As long as security papers are made from cotton, which consists of cellulose without bleaching additives, they are optically dead, which im-

[20] I.J. Cox, M.L. Miller, J.A. Bloom, *Digital watermarking*, San Francisco-London 2002.

[21] Arjowiggins Security Papers, "Security features", https://securitypapers.arjowiggins.com/security/ (accessed: 12.07.2020).

[22] Ibid.

[23] P.K. Chahal, J. Kaur, P. Singh, op. cit

plies that they absorb UV light and do not shine under it – in other words, the real watermark should never react under UV light.[24]

There are two main methods of watermark production for pacing a motif: a graphic, a pattern, a number, or an image into the fibers of the paper.

Dandy roll watermark

The first dandy roll was invented and used for watermark production in 1282 (Fabriano, Italy).[25] In 1826, John Marshall introduced a developed dandy roll machine which makes the watermark production process easier.[26]

During the paper manufacturing process, the initial step starts with paper pulp, which consists of around 99% water. The pulp is then transferred onto the wire from the headbox; during this process it loses 5–10% of its water. The paper web passes under a cylinder called a dandy roll, covered by embossed material with a special motif design (Figure 12).[27]

The roller is similar to a window screen and stronger than it – to depict the motif or special design, the screen is made of intersecting lines of laid wires and upon those chain wires, when the paper pulp moves in the passage within the web, the dandy roll trundles along with it when it is still fairly wet to create a faded impression on the paper pulp. However, the motif still fades until the paper dries.[28]

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[24] Home Office UK, National Document Fraud Unit, *Guidance on examining identity documents*, 2016, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/869551/Guidance_on_examining_identity_documents_v._February_2020.pdf.pdf (accessed: 19.07.2020).

[25] P.B. Meggs, *A history of graphic design*, Chichester 1998, p. 58; H. de Heij, op. cit.

[26] P.K. Chahal, J. Kaur, P. Singh, op. cit.; Paper Money Grading (PMG), op. cit.

[27] *Special techniques: Embellishments for paper*, http://www.csus.edu/indiv/c/cunninghamk/links/lectures/5special_process.pdf (accessed: 5.07.2020).

[28] Paper Money Grading (PMG), op. cit.; European patent specification, *Watermark formation element*, International publication number: wo 2016/075442 (19.05.2016 gazette 2016/20), 26.09.2018 bulletin 2018/39, https://patents.google.com/patent/US5766416A/en (accessed: 5.07.2020); M.B. Shaw, G.W. Bicking, op. cit.

Cylinder mould watermark

In contrast with the dandy roll, the Cylinder Mould roll contains different areas of relief conferring the special motif or design, in form of a sieve to create a three-dimensional image when rolled onto the wet paper pulp. Created in 1848, it is highly effective and most commonly used in the watermarking paper nowadays.[29] An embossed watermark on paper, that is imprinted in the sieve itself, is possibly produced under the development of this process, hence, one, two, or multi-tonal depths of grayscale effects on paper pulp could be created with the help of the relief of the sieve,[30] to produce clearer and more detailed watermark than the dandy roll method (Figure 10).[31]

There are many other uses for the watermark, it can be used for paper dating in forensic investigation, for example, the case of "Shakespearean quartos published by Thomas Pavier," when a false date given for all of them was 1619, whereas investigating these watermarks in 1908 by Sir Walter Greg provided the investigation with the proof that those quartos were published at three different dates, 1600, 1608, and 1619.[32]

On the other hand, significant investigative information about the size and quality of the original paper could be revealed from the size and orientation of the watermark, which leads to determining the usage of the paper, since the definite size of the paper was used for a specific purpose. By the same token, date and shape detail determination of paper watermark could be used to investigate forgeries of different kinds of value documents like wills, patents, bills, dons, contracts, and so on.[33]

4. Security thread

A thin metallic or polymer strip embedded into the paper web during the paper manufacturing process, integrated or woven and intertwined inside the paper. Additional security features can be added to the security

[29] Paper Money Grading (PMG), op. cit.
[30] Radecepapir Nova, op. cit.
[31] P.K. Chahal, J. Kaur, P. Singh, op. cit.
[32] H.A.A. Al Faleh Al Hiary, op. cit.
[33] Ibid.

thread, such as imprinted invisible UV ink on security threads, motion effect, negative and/or microprinting, etc.

Moreover, the incorporation methods of the security thread within the paper have many different forms: completely embedded the paper (latent), woven in rectangular visible shapes, or patent in the naked eye.

1. The latent security thread is entirely located in the paper and can be seen in transmitted light only (Figures 14 A, 14 B, 20).

2. Woven or diving security thread visible on the paper surface as rectangles which form a dotted line on the surface and a solid line when viewed in transmitted light (Figures 14 C, 14 D, 17, 18, 21);

3. Patent of figured security thread appears partially on the paper surface as a figured window and as a solid strip when viewed against the light (Figures 14 E, 14 F, 20).

Furthermore, a large variety of materials are used to perform additional security levels of threads, like metalized based threads without texts, metalized with microtext applied by demetalization (Figures 13 and 15), semi-transparent with texts (Figure 16), holographic (Figures 18 and 21), color-changing effect (Figure 17), luminescent under UV light (Figure 21), magnetic properties; with the "floating" motion image (Figure 21), optically variable effect "scate" where the image disappears from the security thread at a certain angle of view and leaves iridescent tints of the hologram (Figure 22), optically variable effect "chameleon" where the images applied on the security thread look positive under reflected light and negative in transmitted light (Figure 23), and kinetic mobile effect represented by shifting of certain images relative to each other by changing the angle of view.

Even though security thread by itself is classified as a first-level security feature, the additional embedded features such as microtext and UV glowing ink upgrade it to the second level, whereas higher ranking additional features like complicated patterns and designs, as well as materials interaction make the security thread add a very strong and highly effective security protection feature to the paper substrate.[34]

[34] J. Chambers et al., "Currency security and forensics: A survey", *Multimedia Tools and Applications* 74, 2015, no. 11, pp. 4013–4043.

5. Fibers

Security fibers are synthetic materials added to the pulp during the paper production process. They are randomly scattered all over the paper or concentrated in a certain area.[35] These fibers are of different types, visible to the naked eye (colored), invisible (colorless), monochrome colored (Figure 24), two-colored, and multi-colored with various fragments of different colors. Moreover, the fluorescence feature of these fibers under UV and/or IR lights might be added (Figures 25 and 26). Furthermore, the most known fiber shape is the simple monotone form with a persistent cross-section; however, a complex multitone width variation of fibers is a specified high-security feature (Figure 27).

Accordingly, when this paper is held up against a light source, these fibers glow and show different colors. Apart from other features, these security fibers are also imitated in some high-profile forgeries and counterfeiting. To the normal public, these features are not visible, but they can easily be examined by forensic tools and technologies.[36] They do not affect the physical and chemical constituents and characteristics of the paper and yet can readily be used to reduce the risks of counterfeiting. These fibers are both fluorescent and colored (Figure 26). The level of security in documents is highly increased when these security papers are administered with fibers. In addition to other security features, in further stages, laser and mechanical perforation are done to enhance the security.[37]

Currency paper in the U.S. has red-blue fibers that are added in the paper slurry and get dissipated all over in the paper. Visually they can be observed but a close examination and good light is required to detect and inspect them. They can get away with simple visual inspection but a careful examination deters counterfeiting.[38] Security optic fibers are dissipat-

[35] Regula Forensics, "Glossary of documents", https://regulaforensics.com/en/knowledge-hub/glossary-documents/ (accessed: 12.07.2020).

[36] J. Chambers et al., op. cit.

[37] A.B. Centeno et al., *Identity document and banknote security forensics: A survey*, 2019, https://arxiv.org/pdf/1910.08993.pdf.

[38] National Research Council, *Counterfeit deterrent features for the next-generation currency design*, Washington, D.C. 1993.

ed on both sides of the currency note and when it is observed through UV trans-illuminator, they show different colors.[39]

Counterfeiters also simulate these fibers, but while doing so the random pattern of the fibers are not achieved and gives a red flag while examining a suspicious piece of evidence. These specific fibers have a different reaction to UV light which helps to ascertain the authenticity of the substrate.[40]

6. Planchettes

Planchettes are tiny pieces of 1–4 mm size, rounded or different sided shapes, are added to the pulp during the paper production process, hence they are incorporated into the main paper as one of the security features of special security documents,[41] and distributed randomly into the whole paper sheet areas or in certain locations. As we may know, in forensic document examination, paper and fiber comparisons are done, planchettes are also examined as per the need.

To explain in a better way, planchettes are disc-type structures and are optically variable in nature, showing different effects and color change. These properties enable them to serve as security features.[42] They are usually made up of cellulose and round around 1.6 mm and are of different lengths and colors. They are put in paper pulp and appear randomly. Planchettes are of different types; they are visible in daylight or show fluorescence or phosphorescence under ultra-violet light.[43] They are disseminated at the time of paper production and they appear as tiny particles in the layer of paper. Planchettes have assertive characteristics that remain intact even after they are scattered in the paper. They are distinctive and can very easily be examined under the microscope. Usually, they are made

[39] A. Anjali et al., "Comparison of various security features of genuine, scanned and photocopied Indian currency note of the denomination 2000", *Journal of Forensic Science & Criminology* 5, 2017, no. 3, p. 305.

[40] Thales Group, *High-security printing for passport: The 2021 expert's guide*, https://www.thalesgroup.com/en/markets/digital-identity-and-security/government/passport/security-printing (accessed: 7.07.2020).

[41] Regula Forensics, op. cit.

[42] *Materials analysis in forensic science*, ed. M.M. Houck, Amsterdam 2016.

[43] Regula Forensics, op. cit.

of paper and sometimes can be metallic, polymer, and even transparent. Apart from their UV activity, planchettes can also exhibit a change in color if the material which they are made of is iridescent in nature.[44] These minute discs remain embedded over the paper and they become visible when they are held against a light source. For additional security, they have micro-printing on them.[45]

7. UV-Fluorescent Hi-Lites

Micro-particles of different sizes and various colors, or colorless, added to the pulp during the paper production process. In a similar manner to fibers and planchettes, the Hi-Lites are distributed randomly within the whole paper and fluoresce when exposed to UV light (Figure 32).[46]

8. Conclusion

The aim of paper utilized in the assembling of security archives is exceptionally critical in terms of their acceptability. Paper serves as a substrate for the advancement of different sorts of security documents. The crude material utilized for the equivalent is for the most part unadulterated cotton fiber-based cellulose blended in with titanium oxide where cotton fiber has the benefits of phenomenal adaptability, great industriousness, versatility, high quality, obscurity, vigorous protection from weaken acids and antacids.[47] Giving a favorable position to the cotton-based paper is more grounded than the principal, sturdy, of higher caliber, and will not turn yellow with time. The security papers have the property of being impervious to mileage, high temperature with explicit GSM, murkiness, and thickness, making it reasonable for joining the security highlights.[48] Iden-

[44] Security Paper Mill (SPM), "Security features in paper structure", http://spm.cz/en/products/security_papers/security_features_in_paper_structure.html (accessed: 7.07.2020).

[45] J. Chambers et al., op. cit.

[46] Regula Forensics, op. cit.

[47] CNBM International Pulp & Paper, op. cit.; Z. Liu, H. Wang, L. Hui, op. cit.

[48] C.M. Deviterne-Lapeyre, op. cit.; Fabriano Security, op. cit.; M.B. Shaw, G.W. Bicking, op. cit.

tity theft and deceitful utilization of character and travel reports are the primary dangers confronting outskirt border control frameworks, while confirming the genuineness of the personality archives of travelers assumes a urgent job in guaranteeing the proficiency of fringe control the executives. Most dangers against character and travel archives regard photograph replacement, changing alpha-numeric information, identification bio-data page replacement, visa pages replacement, expansion sticker replacement, etc.[49] The watermark in papers is a technique for checking records' validity, the primary idea of watermarks is changing thickness variety of paper. A watermark is delivered during the creation procedure by applying weight of unique theme design on the wet paper mash to create good and bad areas; hence, filaments are dispersed inside the paper as per the plan of the watermark theme, where darker regions contain a higher thickness of strands, and lighter regions contain a lower thickness of filaments.[50] The two principle paper machine creation types are Fourdrinier and cylinder form machines: the first is utilized to deliver a ceaseless trap of paper, the second is utilized for single sheets creation.[51] The security string was also discussed, which is a slim metallic or polymer strip implanted into the paper web during the paper producing process (Figures 20 and 21), incorporated or woven and interweaved inside the paper. Extra security highlights can be added to the security string, such as engraved imperceptible UV ink on security strings, movement impact, negative and additionally miniaturized scale printing, etc. Furthermore, the most realized fiber shape is the basic monotone structure with a constant cross-area; notwithstanding, a complex multitone width variety of strands is a predefined high-security include (Figure 27). Last but not least, planchettes are plate type structures and are optically variable in nature. These properties allow them to fill in as "security highlights."[52] They are typically comprised of cellulose and around 1.6 mm, and are of various lengths and colors. All the security highlights play a significant role in keeping up the integrity of the security record for a successful outskirt control.

[49] Ibid.

[50] D. Ellen, S. Day, C. Davies, op. cit.

[51] H.A.A. Al Faleh Al Hiary, *Paper-based watermark extraction with image processing*, doctoral thesis, July 2008, http://etheses.whiterose.ac.uk/1355/1/hazem.pdf.

[52] *Materials analysis in forensic science.*

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Appendix[53]

Figure 1. Highlight watermark, 1 000 Czech Korun (2008)

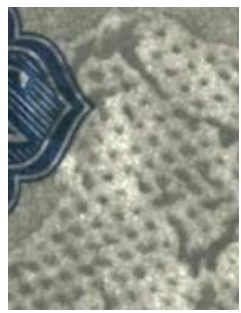


Figure 2. Pixel watermark, 1 000 Kazakh Tenge (2011)

Figure 3. Combined (halftone and highlight), 50 Gibraltar Pounds (2010)

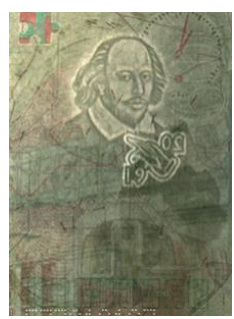


Figure 4. Great Britain, passport (2015), multitone shadow local watermark combined with electrotype watermark

[53] For information about the sources of illustrations, see the list of figures below. Most illustrations were taken from Regula Forensics, "Glossary of documents", https://regulaforensics.com/en/knowledge-hub/glossary-documents/ (accessed: 7.07.2020); Regula forensics, "Glossary of banknotes", https://regulaforensics.com/en/knowledge-hub/glossary-banknotes/ (accessed: 12.07.2020).

Figure 5. New Zealand, a travel document issued in 2016, dual-tone general watermark

Figure 6. Ukraine, refugee's document for traveling abroad issued in 2017, single-tone watermark

Figure 7. The Republic of Belarus, diplomatic passport issued in 2010, duotone watermark

Figure 8. Estonia, a travel document issued in 2013, cornerstone watermark

Figure 9. Dandy roll-made watermark

Figure 10. Mould-made watermark

Figure 11. Electrotype made watermark

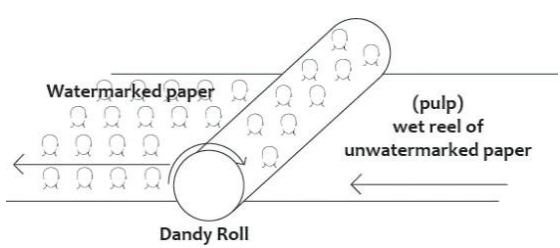


Figure 12. Dandy roll cylinder

Figure 13. Metalized (machine-variable) security thread

A, B – latent, 2000 Iceland Kronur (1986)
C, D – window, 50 Swaziland Emalangeni (1995)
E, F – figured, 1000 Russian Rubles (1997), modification of 2010
A, C, E – incident light
B, D, F – transmitted light

Figure 14. Three types of a security thread

A B

A – without texts, 2 000 Iceland Kronur (1986)
B – with microtext, 50 Swaziland Emalangeni (1995)

Figure 15. Metalized security thread

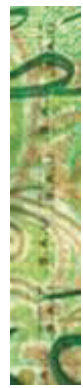
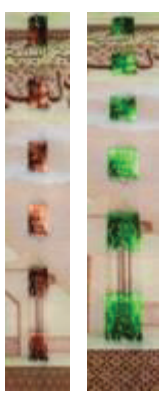


Figure 16. Semi-transparent with microtext, 10 UAE Dirhams (1982)



A B

A – at right angles
B – at an acute angle

Figure 17. Color changing, 50 Libyan Dinars (2008)

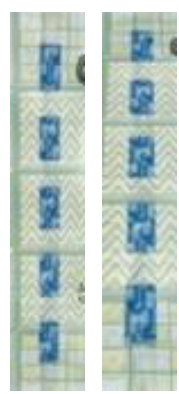
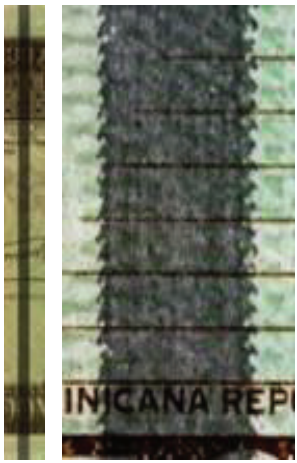


Figure 18. Motion effect, 100 000 Lebanese Pounds (2011)



A B

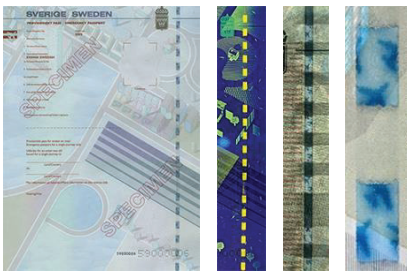
A – transmitted light
B – zoomed image in transmitted light

Figure 19. Dark thread without microtext, 20 Dominican Pesos (2009), in a polymer basis

A B C

A – page
B, C – latent security thread, transmitted light
C – cross-section of a document page

Figure 20. Poland, passport issued in 2001



A B C D

A – front side
B – MOTION® security thread, UV light
C – transmitted light
D – incident white light
The image of a plane moves when changing the angle of observation or illumination B and D.

Figure 21. Sweden, emergency passport issued in 2011

Figure 22. Optically variable effect "scate," 500 Russian Rubles (1997), modification (2010)

Figure 23. Optically variable effect "chameleon," 1 000 Russian Rubles (1997), modification 2010

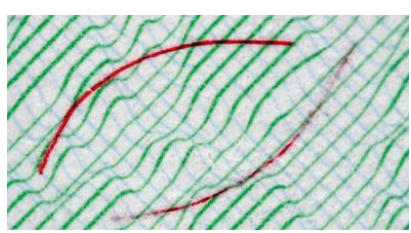


Figure 24. Azerbaijan, passport issued in 1998, visible simple monochrome fibers

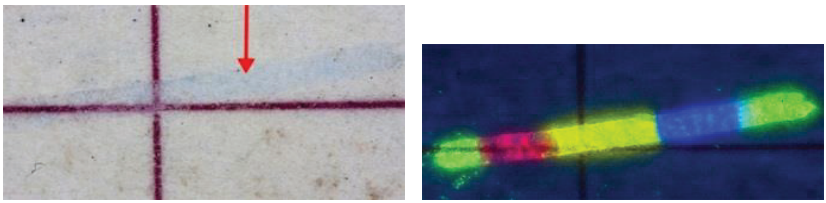


Figure 25. Great Britain, passport issued in 2010, invisible (colorless) simple fibers daylight, and the same under UV light

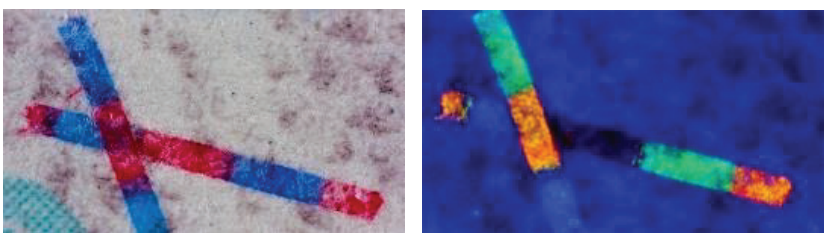


Figure 26. Great Britain, passport issued in 2010, visible (colorless) simple fibers daylight, and the same under UV light

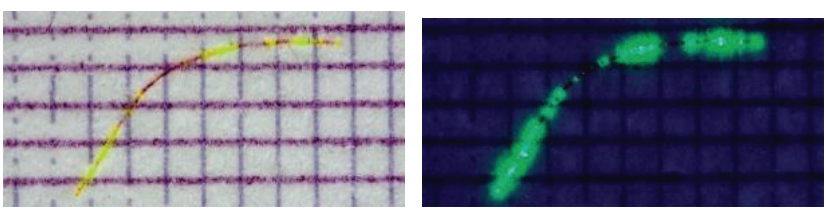


Figure 27. Russian Federation, passport issued in 2010, ZONA security fibers, two-colored with a variable cross-section daylight, and the same under UV light

Figure 28. UV fluorescent multi-color planchettes, invisible under daylight

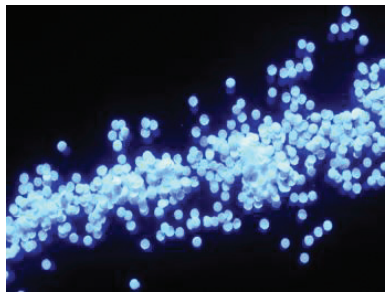
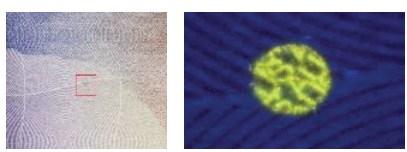


Figure 29. Planchettes, one color

Figure 30. Visible multi-color planchettes



A B

A – colorless planchettes viewed in white light
B – the same fragment viewed in UV light of 365 nm

Figure 31. Australia, passport – a travel document, 2008

Figure 32. Greece, alien's travel document, view in white light, view in UV light of 365 nm, UV-fluorescent hi-lites

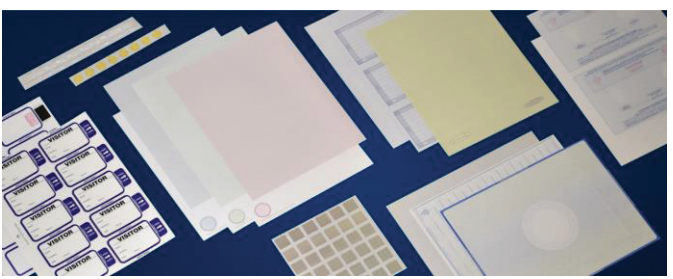


Figure 33. Different types of security paper

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Figure 7. The Republic of Belarus, diplomatic passport issued in 2010, duotone watermark; https://regulaforensics.com/en/knowledge-hub/glossary-documents/ (accessed: 7.07.2020).

Figure 8. Estonia, a travel document issued in 2013, cornerstone watermark; https://regulaforensics.com/en/knowledge-hub/glossary-documents/ (accessed: 7.07.2020).

Figure 9. Dandy roll-made watermark; https://coimages.sciencemuseumgroup.org.uk/images/290/432/medium_Y2006_0060_0074__0001_.jpg (accessed: 9.07.2020).

Figure 10. Mould-made watermark; http://www.fabrianosecurity.com/en/21/watermark (accessed: 9.07.2020).

Figure 11. Electrotype made watermark; http://www.fabrianosecurity.com/en/21/watermark (accessed: 9.07.2020).

Figure 12. Dandy roll cylinder; Chahal P.K., Kaur J., Singh P., "Digital watermarking on bank note", *International Journal of Soft Computing and Engineering (IJSCE).*

Figure 13. Metalized (machine-variable) security thread; Regula Forensics, "Sixty-seven years of passport design and security features: The evolution of the Federal German passport", https://regulaforensics.com/en/pressroom/news/sixty-seven-years-of-passport-design-features-the-evolution-of-the-federal-german-passport/ (accessed: 10.07.2020).

Figure 14. Three types of a security thread; https://www.security-web.nl/glossary-banknotes/#g648 (accessed: 11.07.2020); http://www.regulaforensics.com/images/glossary_banknotes (accessed: 10.07.2020).

Figure 15. Metalized security thread; https://www.security-web.nl/glossary-banknotes/#g648 (accessed: 11.07.2020); http://www.regulaforensics.com/images/glossary_banknotes (accessed: 10.07.2020).

Figure 16. Semi-transparent with microtext, 10 UAE Dirhams (1982); https://www.security-web.nl/glossary-banknotes/#g648 (accessed: 11.07.2020); Regula forensics, http://www.regulaforensics.com/images/glossary_banknotes/ (accessed: 10.07.2020).

Figure 17. Color changing, 50 Libyan Dinars (2008); https://www.security-web.nl/glossary-banknotes/#g648 (accessed: 11.07.2020); http://www.regulaforensics.com/images/glossary_banknotes (accessed: 10.07.2020).

Figure 18. Motion effect, 100 000 Lebanese Pounds (2011); https://www.security-web.nl/glossary-banknotes/#g648 (accessed: 11.07.2020); http://www.regulaforensics.com/images/glossary_banknotes/ (accessed: 10.07.2020).

Figure 19. Dark thread without microtext, 20 Dominican Pesos (2009), in a polymer basis; https://www.security-web.nl/glossary-banknotes/#g648 (accessed: 11.07.2020); http://www.regulaforensics.com/images/glossary_banknotes/ (accessed: 10.07.2020).

Figure 20. Poland, passport issued in 2001; https://regulaforensics.com/images/knowledge_hub/glossary_documents (accessed: 11.07.2020).

Figure 21. Sweden, emergency passport issued in 2011; https://regulaforensics.com/images/knowledge_hub/glossary_documents/ (accessed: 11.07.2020).

Figure 22. Optically variable effect "scate," 500 Russian Rubles (1997); modification (2010); https://www.security-web.nl/glossary-banknotes/#g648 (accessed: 11.07.2020); http://www.regulaforensics.com/images/glossary_banknotes/ (accessed: 10.07.2020).

Figure 23. Optically variable effect "chameleon," 1 000 Russian Rubles (1997), modification 2010; https://www.security-web.nl/glossary-banknotes/#g648 (accessed: 11.07.2020); http://www.regulaforensics.com/images/glossary_banknotes/ (accessed: 10.07.2020).
Figure 24. Azerbaijan, passport issued in 1998, visible simple monochrome fibers; https://regulaforensics.com/en/knowledge-hub/glossary-documents/ (accessed: 12.07.2020).
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NOWA KODYFIKACJA PRAWA KARNEGO Tom LX
NEW CRIMINAL LAW CODIFICATION
AUWr No 4039 Wrocław 2021

https://doi.org/10.19195/2084-5065.60.9

Dancing pen: The ultimate test of graphically matured skilled writer

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Abstract

Unconscious and automatic rhythmic production of handwriting by graphically matured skilled writers through perfect synchronization of muscular body parts is an activity that resembles a pen dancing on paper, analogous to a dancer performing on stage. This analogy can lead to beginners in the profession better understanding the complex and intricate writing process.

There are several routine activities requiring various complex co-ordinations of mental, sensory, and motor factors by humans, such as walking, talking, writing, dressing, drawing, sewing, using a typewriter, playing a piano or violin, riding a bicycle, driving a car, handling a tool, a tennis racket, or a golf club, etc., which are performed habitually, unconsciously, and automatically once they are learnt and practiced. One of these activities is (hand)writing, which is a complex learned motor behavior generally developed in a person in three stages: formative, impressionable, and graphic maturity. The stage of "graphic maturity" is finally reached when the writing has fully developed, resulting in unique individual characteristics that become habitual in execution, most of which remain relatively constant throughout much of the writer's active life. The complexities and intricacies of the writing process can be better understood by a beginner in the pro-

fession by comparing it with dancing, which is also a similar activity requiring perfect synchronization and coordination of all the body parts involved in the exercise.

Keywords: handwriting, dancing, neuromuscular coordination, graphic maturity, rhythm and harmony

Introduction

There are several routine human activities, such as walking, talking, writing, etc., which are performed habitually, unconsciously, and automatically. One of these activities is writing, which is a complex learned motor behavior, generally developed in an adult after three stages. During the first stage, called the "formative stage," handwriting acquisition begins, letter designs are being learnt and practiced, and writing skills are slowly, steadily developed. In the second stage, named the "impressionable stage," writing skills are further refined and mastered, but the master patterns of letters and writing characteristics are still being developed. During this stage, it is common for the writer to be influenced by some other sources, such as a parent or a role model. The writer will try and imitate someone else's writing and as a result, the changes in some of the letter formations that occur may be quite pronounced. The third stage, the "graphic maturity," is finally reached when the writing has fully developed, resulting in unique individual characteristics that become habitual in execution, most of which remain relatively constant throughout much of the writer's active life. Because handwriting execution becomes habitual and unique to the writer, the questioned handwriting on a disputed document can be identified by a forensic document examiner in comparison with known handwriting samples of the suspect in accordance with the principles of handwriting identification.

Morris[1] has described several conditions that must be satisfactorily fulfilled for a person to be called a graphically matured writer. Osborn[2] has described several human activities requiring perfection in neuromuscular coordination, which are routinely performed habitually, unconscious-

[1] R.N. Morris, *Forensic handwriting identification: Fundamental concepts and principles*, San Diego, CA 2000, pp. 1–18.

[2] A.S. Osborn, *Questioned documents*, Chicago 1929, pp. 98–99.

ly, and automatically. He has also stated some interesting analogies between writing and speech as well as dancing. All such human activities, including dancing and handwriting, require concerted efforts that aim for perfection in body–mind coordination for an optimum level of performance. Once the ability to write with perfect neuromuscular coordination has been achieved through various stages of handwriting development leading to the final stage of graphic maturity, and all body parts involved in handwriting activity start working in tandem with perfect rhythm and harmony, it can be seen and felt by an independent observer that the pen begins to dance over the paper with the same modulation and frequency, which is certainly a moment of satisfaction and joy for the writer. In reality, writers are dancers at heart; we sway to the words, we feel the meaning we wish to express, and we (write and) type to a rhythm with every piece of act we perform.

The main purpose of writing this article is to draw an interesting comparison between some of the human activities such as writing, talking, dancing, etc., for a better understanding of the handwriting process, which has been rightly described as a "neuromuscular controlled motor activity" by several authorities on the subject.

Graphic maturity considerations

Levels of graphic maturity

As stated by Morris,[3] there are different levels of graphic maturity, each governed by a number of different factors working together. Following the existing "impulse system," which is a basic concept in understanding graphic maturity, there could be several levels or stages of graphic maturity.

> An immature writer, i.e., a child learning to write, uses separate pen strokes to draw a letter [stroke impulse]. As his graphic maturity level increases, he moves from writing with a stroke impulse to writing with a letter impulse. At this level each letter is written as a complete unit [letter impulse].
>
> The next levels are the syllable and word impulse levels. Here, he knows how to write combination of letters as a single unit [word impulse].

[3] R.N. Morris, op. cit.

The highest level is the sentence/phrase impulse level. The writer, at this level, thinks and attempts to write in complete sentences or phrases; however, he finds that sometimes his thoughts are ahead of his pen, therefore, he goes on to enhance and refine his skill level further.

Criterion of graphic maturity

A writer is usually considered to be graphically matured when they have developed a full command over the writing process; they only remain conscious about the subject matter that is to be written, and more or less remains unconscious about the writing process itself – that is, how to write and what to write. Morris[4] has described several conditions that are to be met satisfactorily for achieving the desired level of graphic maturity:

– The writer has no doubt whatsoever about the form and movements necessary to write a letter.

– The writer has complete control of the pen and writing surface and there are no mechanical problems offered by either of them.

– […] there is no transitory or permanent factor affecting the writer's ability to write.

– […] there is no doubt on the part of the writer as to the legibility of the writing, relative pressure habits used to write the letters, relative spacing habits between letters, words, sentences, lines, paragraphs, the size and shapes of margins, etc.

– […] the writer is comfortable with the language and writing system, he is writing.

– […] they do not change from one language or writing system to another within the text of the writing.

– In summary, any act or occurrence of anything or event on the writer that causes him to pay more attention to the way he is writing than what he is writing will affect the writer's level of graphic maturity.

Limitations of graphic maturity

– Not all writers necessarily reach (or touch) the highest level of graphic maturity.

– Some psychological and physiological constraints and several limitations due to a lack of adequate interest, poor memory of letter forms, language, and grammar could restrict the level of graphic maturity of a writer, beyond which no further development in writing skill usually takes place.

[4] R.N. Morris, op. cit.

– Individual weakness or imperfection in the acquired art or skill of handwriting, together with peculiar departures from the copy book forms, may lead to individualization of handwriting within the acquired level of graphic maturity, differentiating it from many other writers.

– Every writer acquires their own level of writing skill and graphic maturity; individualization takes place within those constraints and at that level only.

Automatic and unconscious handwriting production

All the conditions of graphic maturity, as stated above, are consistent with the automatic and unconscious production of free, fluent, and natural writing by perfect neuromuscular control of reflex process. As stated by Osborn:[5]

> Writing is the result of a very complicated series of acts, being as a whole a combination of certain forms which are the visible result of mental and muscular habits acquired by long continued, painstaking effort. […]
>
> Developed, natural writing is an almost automatic act that follows the fixed grooves of habit, but as soon as attention is given to it, it necessarily becomes strained and unnatural. The nicety of adjustment of impulse is disturbed when muscles become tense as the result of extra effort and the best results can be achieved only when muscles are somewhat relaxed so that all work in harmony. […]
>
> A written form is simply a record of a motion and mature writing, by many repetitions, finally becomes what the psychologist calls an unconscious coordinated movement that produces a visible record. Most of our highly developed habits over and above walking or talking; for example, writing have become automatic through individual practice.

Writing and talking

According to Osborn,[6] there are many commonalities between the human activities of writing and speaking, some of which are reproduced below:

[5] A.S. Osborn, op. cit.

[6] Ibid.

There are, in fact, many striking analogies between writing and speech, two of these being the persistence with which habits acquired in youth are retained and the partia, or total unconsciousness of them. Whatever he says, as soon as he speaks a man begins to exhibit the quality of his culture and to tell where he was born and what is his education, companions, and environment have been, and by his writing he does much the same thing.

Habits of speech and writing become so automatic and unconscious that even by the most strenuous effort it is almost impossible to change them. This is well known regarding speech and is also shown to be as true of handwriting when a careful study is made of it. […]

Writing varies as speech varies; it may be large or small as speech is low or loud; it may be careful or careless, like speech, but both methods of human expression finally come to be settled habits of the individual acquired by thousands of repetitions of the same act. […] [A man's] writing, like his speech, is part of his very flesh and bones.

It is true that speech and writing may both be disguised and unnatural and may imitate a style very different from that usually followed, but average unconscious writing varies no more than average unconscious speech since both finally are simply the product of unconscious habits. If speech with all its quirks and mannerisms were actually visible how positively it would identify an individual! Writing is practically visible speech, or the 'talking paper', as the Indian says, and by all its thousands of peculiarities in combination is the most personal and individual thing that a man does that leaves a record which can be seen and studied.

The variation of any particular handwriting is a matter, however, that must always be taken into account and given proper consideration. Failure to give due consideration to the subject may lead to serious error.

Writing and dancing

In our view, there are several commonalities between the art of dancing and that of writing.

– Both are neuromuscular activities involving the application of physiology and neurology, though to varying degrees. Dancing involves the rhythmic movement of the whole body, whereas writing is restricted to moving some body parts, such as fingers, wrist, fore-arm, and whole-arm.

– Both these activities necessarily require near perfect coordination and synchronization, i.e., teamwork between the muscles involved in an individual's movement and conscious thoughts.

– Both are necessary to be learned and practiced in order to an optimum level of performance. Once the appropriate level of maturity has been acquired by an individual, both handwriting and dancing are rou-

tinely carried out habitually, automatically, effortlessly, and unconsciously, directing one's attention to the subject matter alone rather than the process itself.

– Both are subject to the laws of nature, such as the law of individuality and uniqueness, the law of progressive change and natural variations, laws of physics, including Newton's laws of motion and gravitation, etc.

– Because the physiological and mental levels combined together along with their coordination are necessarily different for different individuals, their performance levels vary greatly to the extent that no two people can walk, talk, behave, dance, or write exactly alike; and one person cannot mechanically repeat the exact same level of performance at different times for similar reasons.

– Both are affected by some extrinsic and intrinsic factors, such as injury, age, illness, mood swings, and, especially, the apparent anxiety to perform and deliver best results at a particular event and time, such as in a sports competition or attempting to produce someone's forged signatures with criminal intent rather than for a mere exhibition of forging skills.

– Both are prone to disguise and imitation in varying degrees, although the rate of success varies depending upon the respective levels of skill and the purpose.

– Both these activities require a balancing approach; balance between speed and legibility in the case of handwriting, and between various moving body parts in dancing for maintaining reasonable stability.

– Both are complex and intricate processes that require the services of trained experts for recognition and differentiation; a document expert for comparison of handwriting and a fully matured dancing professional for judging the performance of a single individual or a dancing group.

According to Osborn,[7] based on their respective levels of skill, pen control and movement, usually, there are four categories of writers.

> The pen of certain writers (1) dances over the paper with a springy, rhythmic motion that leaves a characteristic record; in other hands (2) the writing instrument moves in a stately way that suggests strength, but not speed, while as guided by other writers a pen (3) leaves an irregular, broken line that is the record of a rapid, nervous movement. The record of the pen of still another class of writers (4) leaves a heavy, uneven, ragged line due to lack of skill and constant variation in pen pressure.

[7] Ibid.

It is easy to understand how difficult it would be for a writer of the fourth class to successfully imitate first- or second-class writing. The same logic appears to hold good for the dancing activities as well.

While describing the significance of "rhythm," which could be applied to both handwriting and dancing, Osborn[8] has stated that:

> One of the qualities of handwriting is rhythm, which is defined as a harmonious recurrence of stress or impulse or motion, and handwriting can be classified by the quality or the perfection of its rhythm. This peculiar quality in handwriting is, of course, primarily the flowing succession of motions which are recorded in the written record. Harmony of action, as in dancing, is based mainly on the circle, or the ellipse, and is a succession of connected curved motions rather than a succession of straight movements and sudden stops, and this is also true of handwriting. What is accurately described as the 'flowing hand' is a coordinated succession of movement impulses that glide into each other with a rhythm which is the final perfection of fixed and cultivated habit. There is nothing in handwriting so difficult successfully to imitate as the exact quality of this muscular rhythm, and a violation of it is the most common symptom of forgery.

Furthermore, according to Hagan,[9] no two persons walk, talk, or do any other act which calls for the coordinate action of a series of muscular factors in precisely the same manner, and for the same reason no two persons write exactly alike. All individual habits in handwriting arise from the same pre-disposing causes as the differentiations that produce personalities in other respects.

Conclusion

It has been observed that humans have a remarkable range of movements. We have learnt to walk, dance, write, speak, and play different sports naturally, fluently, automatically, effortlessly, without thinking too much about how we move. An in-depth comparison of the art(s) of handwriting and dancing, which look very different on first impression, has revealed many commonalities between them. While a dancer dances on the dancing floor, the writer's pen, too, dances on the paper to perfection. It hardly needs emphasis that a pen is mightier than the sword. Certainly,

[8] Ibid.

[9] W.E. Hagan, *A treatise on disputed handwriting and the determination of genuine from forged signatures*, New York 1894, pp. 16–17, 37.

it is an excellent instrument to fix attention and inflame one's ambition. Truly, the magic of the pen lies in the concentration of thoughts on the subject; and a dancing pen is, to our mind, the ultimate test of graphic maturity and skill of an individual writer.

Acknowledgement

The authors thankfully acknowledge the valuable inputs through discussion provided by Dr. B.A. Vaid, former GEQD, Shimla during the preparation of this paper.

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Nowa Kodyfikacja Prawa Karnego 60, 2021

NOWA KODYFIKACJA PRAWA KARNEGO Tom LX
NEW CRIMINAL LAW CODIFICATION
AUWr No 4039 Wrocław 2021

https://doi.org/10.19195/2084-5065.60.10

The factors that cause the misjudgement in questioned document examination: Extraneous marks and deteriorating factors

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Abstract

Artificial defects on the documents can be classified into two categories: extraneous marks and deteriorating factors. Identifying and categorizing artificial defects of the examined document and determining some critical unforeseen details are the aims of

this study. Real case samples were collected from our archive and examined. It was found that 41 out of total 100 cases include either extraneous marks or deteriorating factors.

Keywords: questioned document examination, defects, document alteration, handwriting analysis, signature analysis

Background

In various cases, documents may be changed during the preparation or after their completion without attempts on anyone's part to perpetrate fraud. These situations are not new or challenging problems for questioned document examiners. Changes in the documents may cause misjudgement in terms of identifying questioned signature or handwriting and appear in different forms and shapes, which can be named as "artificial defects."[1]

We classified artificial defects into two groups: extraneous marks and deteriorating factors.

Extraneous marks can be categorized into: ink leakage from the pen; a trace formed because the pen did not write correctly during the first attempt; marks such as a cross or dots formed by another person for the purpose of pointing out the signature section on the document; masking the signature partially by stamp ink; stroke remnants from the previous person who halted their signature because of a wrong location; and overlapping signatures due to signing in a limited space.

On the other hand, deteriorating factors can be categorized into: partial loss of pen stroke in signature or handwriting on the folded or cut part of the paper; staple and/or puncher holes on the signed or written part of the document; superficial abrasion or tearing of the paper due to sloppy handling during the chain of evidence delivery; and attrition of the questioned document touched with adhesive materials such as envelope glue or upon contact with liquid or oil.

In his book, Hilton mentioned stains, which are among the artificial defects that disfigure the document. Some types of stains leave the document readable, but others obliterate its portions or seriously reduce the performance of document examination. He also mentioned that intersecting

[1] R.N. Totty, D. Baxendale, "Defect marks and the identification of photocopying machines", *Journal of the Forensic Science Society* 21, 1981, no. 1, pp. 23–30.

writing strokes may have distinctive patterns, depending upon the order of writing, the lapse of time between the two writings, the density of the two strokes, and the kind of inks, writing instruments, and paper used. Sometimes pen ink may create a stain on the document – it can overflow on the paper, spread discernibly into the adjacent paper fibres, and make a shade on some part of the questioned handwriting or signature.[2]

On some occasions, ambient humidity may be destructive for the documents which are not preserved under appropriate conditions. If the documents are exposed to moisture, the paper may adhere to itself. Penetration by the liquid may cause the ink to run or itself damage the paper due to adhesion.[3]

On other occasions, small deposits or traces of many different substances may be found on documents and may aid in reconstructing their history. Many of these are placed there purely through chance contacts with foreign objects during the preparation and subsequent handling or storing of the document.[4]

Partial loss of pen strokes may occur due to erasures of signature or handwriting. These can be either chemical or mechanical. The trace of chemical erasures can be found when the document is examined under UV light. In the case of mechanical erasure, such as with the traditional "rubber" eraser, an abrasive movement is made upon the writing to be erased. In many cases of standard writing materials, abrasion of the paper can be seen either with a microscope or a side light. However, some type of erasures and abrasions cannot be seen even under side light.[5]

Light exposure can also cause changes in the document in the aspect of paper or ink. Certain poorer quality synthetic dye inks and ballpoint pen inks, for instance, may fade due to long exposure to light, which can result in losing some important written parts of the document. Other types

[2] O. Hilton, *Scientific examination of questioned documents*, Boca Raton, FL 1992, pp. 111–114.

[3] J. Levinson, *Questioned documents: A lawyer's handbook*, San Diego, CA 2001, pp. 137–142.

[4] O. Hilton, op. cit.

[5] J. Levinson, op. cit.; J.S. Kelly, B.S. Lindblom, *Scientific examination of questioned documents*, Boca Raton, FL 2006, pp. 319–336.

of inks such as carbon and record typewriting inks remain virtually unchanged.[6]

In order to analyse degraded documents, various different methods such as lost part completion are digitally applied to visualize the lost part of the documents. However, the methods that make the missing part of the document visible do not always work well for the examiner.[7]

In this study, we had two goals. The first one was to identify and categorize the problems stemming from the examined document, and the second one – to highlight some critical unforeseen details and provide guidance to document examiners.

Material methods

Real case samples were collected from the Questioned Document Laboratory of Istanbul University, Cerrahpasa, Institute of Forensic Sciences and Legal Medicine.

A total of 100 even-numbered file cases were selected from the files that have been examined dated between January 2018 and August 2020. The images from these cases, which had been taken with VSC8000 (Foster & Freeman, UK), were obtained from electronic archives of our laboratory.

These cases were examined independently by two different handwriting examiners at first. After that, if there was a contradiction between their decisions, they evaluated and discussed their opinions interactively, and it was decided which of the two types described above the cases fit into.

Results and discussion

It was found that 41 out of total 100 cases include either extraneous marks or deteriorating factors. The results of extraneous marks and de-

[6] O. Hilton, op. cit.

[7] M. Diem, R. Sablatnig, "Recognition of degraded handwritten characters using local features", *10th International Conference on Document Analysis and Recognition*, July 26–29 2009, Barcelona, Spain, pp. 221–225.

teriorating factors' distribution are listed in Table 1 and Table 2. These tables also contain images of the defects.

Table 1. Distribution of artificial defects in the aspects of extraneous marks

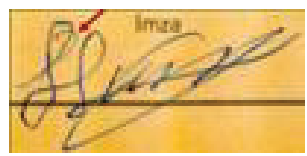
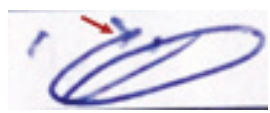
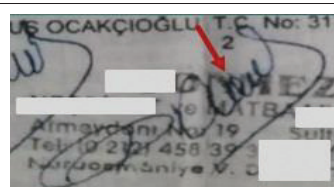
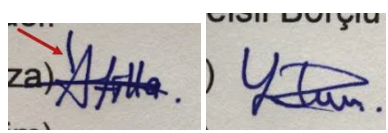
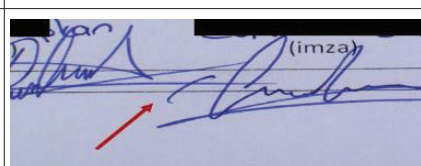
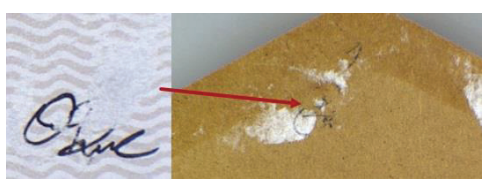
Number (percentage)	Extraneous marks	Images
7 (17.1%)	ink leakage from the pen	
9 (22%)	the trace formed because the pen did not write correctly during the first attempt	
11 (26.8%)	marks such as a cross or dots formed by another person for the purpose of pointing out the signature section on the document	
5 (12.2%)	masking the signature partially by stamp ink	
1 (2.4%)	stroke remnants from the previous person who halted their signature because of wrong location	
2 (4.9%)	overlapping signatures due to signing in a limited space	

Table 2. Distribution of artificial defects in the aspects of deteriorating factors

Number (percentage)	Deteriorating factors	Images
2 (4.9%)	partial loss of pen stroke in signature or handwriting on the folded or cut part of the paper	
2 (4.9%)	staple and/or puncher holes on the signed or written part of the document	
1 (2.4%)	superficial abrasion or tearing of the paper due to sloppy handling during the chain of evidence delivery	
1 (2.4%)	sttrition of the questioned document upon contact with adhesive materials such as envelope glue	

Extraneous marks are divided into two categories: as intentionally and unintentionally made according to our observations in this study. The first only applies in the case of a cross or dots marks formed by another person. The rest of the marks are carried out unintentionally.

Deteriorating factors, unlike the extraneous marks, cause deformation on the document. Four different types of these marks were found in our

study. These are: partial loss of pen stroke in signature or handwriting on the folded part of the paper; staple and/or puncher holes on the signed or written part of the document; superficial abrasion or tearing of the paper due to sloppy handling during the chain of evidence delivery; and attrition of the questioned document upon contact with adhesive materials such as envelope glue.

The most frequently encountered defects are crosses or dots formed by another person for the purpose of pointing out the signature section on the document. In Turkey, voters' list and bank agreements can be marked by a pen to show where to sign. Sometimes, those marks can be mistaken for part of signature. It can be confusing for the examiner if there is a similar symbol in the original signature. This made it hard to identify whether those were a related personal habit or a marking done by someone else.

The rarest cases are: stroke remnants, superficial abrasion or tearing of the paper, and attrition of the questioned document because of adhesive materials. These situations can occur in different ways. Sometimes people stop signing when they realized they had signed on someone else's spot on the documents – however, that missing signature looks like a part of the other person's signature and stroke remnants may occur. In the second instance, when a document is folded without paying attention, the folding part can overlap the signature and cause it to lose some characteristics specific to the individual. Finally, when documents are not stored carefully, different inks or materials can mess up the signature – this can then be recognised as an additional character or hand movement, or it can mask a specific character.

As a result, the amount of artificial defects we came across in this study demonstrated to us several precautions which should be taken to minimise the effects on the judicial process. Firstly, the impact of defects should be included in the training program for the candidates who want to become questioned document experts. Secondly, experts should keep in mind the possibility of artificial defects, which may help them avoid the misinterpretation. For example, signs used for indicative purposes should not be mistakenly considered as symbols. Last but not least, law enforcement and the judicial justice personnel in charge of evidence delivery and document processing should be trained to avoid creating these types of effects.

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Nowa Kodyfikacja Prawa Karnego 60, 2021

Nowa Kodyfikacja Prawa Karnego 60, 2021

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Wrocław University Press

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