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STUDIES AND ARTICLES

Graphic Indices in Romanian Forensic Graphoscopy

The Case of the Digitally Captured Signature

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Abstract: In the forensic examination of handwriting, graphic indices may be defined as distinctive elements that indicate changes in a person's handwriting in terms of movement, language, and spatial organisation. Among the new elements to be integrated into the field of Romanian forensic handwriting analysis is the digitally captured signature, which combines a digitised scriptural image with associated biometric data. The handwriting expert community must undertake research into how this type of signature can retain graphic indices, before working procedures can be harmonised with current legislation.

Keywords: signature; digital; handwriting; graphic indices; graphoscopy; forensics.

1. Introduction

As a forensic science, and as the sovereign domain for identifying individuals and objects based on traces created through interaction with the environment, in order to provide evidence in the judicial process, Criminalistics is in a constant process of adaptation to new technologies and to the full range of opportunities, challenges and risks brought by the information age through digitalisation. All classic fields of the forensic sciences today benefit from advanced techniques and tools, and from complex, high-performance software, and it seems only one short step remains before the futuristic scenes from the *CSI: Crime Scene Investigation* series of the 2000s are transferred into reality. But the excessively rapid pace at which information emerges and spreads requires, in addition to scientific knowledge of the specific digitalisation processes, the exercise of sound judgment as to how their implementation can be made possible and useful for forensic laboratories.

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One of the current areas of interest in this regard is forensic graphoscopy, through the shift from handwriting on conventional media to handwriting on digital media. The methods and principles of forensic handwriting examination are being extended to a trace significantly different from the graphic line deposited directly in wet ink on the paper surface: namely, the digital image of a scriptural trace (a signature or a piece of written text), whether or not associated with biometric data

For the past decade, Romania has supported the introduction of the electronic signature as a means of identification in electronic transactions within the internal market, with a view to enabling individuals and legal entities to 'participate in the digital society in safe conditions and to access public and private services online throughout the Union', as provided under EU Regulation No 910/2014 (hereinafter 'eIDAS Regulation')[1]. Although the eIDAS Regulation and the corresponding Romanian legislation[2] add this new type of signature alongside the traditional handwritten (holograph) one, the professional community of forensic graphoscopy experts has observed a lack of appropriate scientific frameworks for the development and implementation of specific working procedures, in line with those recommended by the European Network of Forensic Science Institutes (hereinafter 'ENFSI').

Among the numerous forensic investigation topics concerning digitally captured signatures, as a type of electronic signature within the meaning of the legal definitions, one stands out as particularly specific: *graphic indices*, which are scriptural elements denoting a deviation from the standard of written language or, most often, changes in handwriting arising from various factors in different circumstances. What remains to be understood is the importance of recording and visualising these indices in an electronically captured signature, alongside the evaluation and interpretation of the general and particular characteristics that give substance to the graphoscopic examination of handwriting.

2. Graphic indices – a new approach in forensic graphoscopy

This section introduces the concept of *graphic indices* within the broader framework of forensic graphoscopy. It begins by situating the signature as a specific object of graphoscopic analysis (2.1), before turning to the definition and classification of graphic indices themselves (2.2).

2.1. Forensic graphoscopy and signatures

As part of graphoscopy, the science of handwriting, and as a related field of forensic science, forensic graphoscopy 'studies the regularities of writing and develops methods for its examination, in order to identify the person, by way of expertise'[3]. Approaching handwriting as a dynamic trace created, most often, by the interaction of the writing instrument with the writing surface, resulting in a stroke of substance (i.e., most often, ink of various types), allows for assessments far more specific and complex than those concerning writing as language, which

[1] Regulation (EU) No 910/2014 of the European Parliament and of the Council of 23 July 2014 on electronic identification and trust services for electronic transactions in the internal market and repealing Directive 1999/93/EC [2014] OJ L257/73, art 1.

[2] Law No 214 of 5 July 2024 on the use of electronic signatures, time stamps and the provision of trust services based on them, Official Gazette of Romania, Part I, no 647 of 8 July 2024.

[3] D Nicolae and I Anghelescu (eds), *Dicționar de criminalistică* (Editura Științifică și Enciclopedică 1984) 97.

falls within the broader field of graphoscopy. The process of learning to write, the occurrence of handwriting disorders (dysgraphia) and their associated therapies, pathological handwriting correlated with various conditions, and calligraphic (artistic) handwriting all converge within graphoscopy, so that its object (handwriting) becomes unique for scientific study, not only in all the aspects relevant to its natural and social development, but also in the descriptive notions attributed to its manifestations.

The signature represents a variant of handwriting, in that it is equivalent to the 'graphic image of the name'[4], and consists of complete, partial, or scripturally stylised handwriting in a manner specific to its author. The signer uses this 'graphic expression in order to approve, accept, [or] externalise an individual will'[5], to take ownership of the content of a document (e.g. a letter or literary manuscript), and to express consent as to the rights, obligations and tasks conferred and assumed by the text of a document.

From a forensic standpoint, the signature becomes the object of expertise for establishing its authenticity or detecting forgery, including, where applicable, identifying the author and the method of forgery. Like handwriting generally, individual and relatively stable, a person's signature will be analysed in detail to detect the identifying characteristics that give it uniqueness and unrepeatability[6]: linguistic, spatial (topographical), and 'purely graphic'[7] characteristics relating to movement and motor skills. These are divided into general (or generic) characteristics (e.g., appearance, style, general structure, and category membership, such as configuration, degree of simplification, level of mastery of the scriptural technique, speed, pressure) and particular characteristics, namely the individual manner of constructing literal or non-literal components, with particular emphasis on line quality. In the case of non-literal, stylised signatures, where allographs are not distinguished and language is therefore not directly involved (appearing only as meaning rather than as concrete content, which reduces the 'cognitive motor load'[8] and produces greater resistance to external influencing factors), the level of automation of the motor skill may exceed that of the same author's ordinary handwriting, even at the same frequency of use.

The fact that 'the forensic examination of the signature is one of the most difficult areas of forensic science'[9] compels ongoing scientific research into the ways in which this 'species of handwriting'[10] forms, evolves, transforms, and ultimately adapts to a dual variant of graphic expression, in which handwriting parameters (that is, graphic characteristics or features, and graphic indices) become connected with biometric ones through digital capture.

2.2. Definition and classification of graphic indices

Along with their identifying characteristics, which define their essence and uniqueness,

[4] L Ionescu, *Expertiza criminalistică a scrisului* (Junimea 1973) 226.

[5] S Alămoreanu and A Frățilă, *Comentarii la expertiza criminalistică a semnăturilor* (Alma Mater 2012) 28.

[6] A Frățilă and G Păşescu, *Expertiza criminalistică a semnăturii* (National 1997) 34.

[7] Ibid.

[8] LA Mohammed, *Forensic examination of signatures* (Academic Press 2019) 1.

[9] Ibid 9.

[10] Frățilă & Păşescu (n 6) 35.

signatures (like handwriting generally) executed with a writing instrument on a traditional surface may also include other scriptural elements. Among these, we consider that an important role is played by what we have termed graphic indices, which denote a deviation from the standard of written language or, most often, natural or artificial changes in handwriting occurring due to various factors in different situations.

Unlike identifying characteristics (features), graphic indices are not individualising or identifying in nature but instead indicate a specific situation affecting the signature at the level at which they appear: authenticity, modification, alteration, counterfeiting, or fortuitous event.

Since these indices concern all three coordinates of handwriting at which identifying characteristics are also outlined, they have been classified along the same lines: language, movement (motor act), and spatial organisation. At the same time, it is necessary to categorise them according to the causal factor that determines their appearance in handwriting and in the signature:

(1) *graphic indices of affectation/impairment*, which show either a deviation from the standard of written language (infantile writing, lower-level writing, writing/signature executed with another part of the body, dysgraphia), or natural changes produced in handwriting by pathological factors (illness, trauma, loss of an effector organ, intoxication), stressors (psychophysiological: fatigue, emotion, motivation, attention, nervousness, hypothermia, hyperthermia, haste), or conjunctural factors (writing position, position of the scriptural surface, type of scriptural instrument, type of document, state of hypnosis);

(2) *accidental*[11] *graphic index*, which demonstrates the occurrence of a fortuitous event at the time of signing, without the signature undergoing any significant change to its features (e.g., a twitching caused by an unexpected noise that startled the signer);

(3) *graphic indices of counterfeit*, which reveal fraudulent manipulation through disguise or simulation (imitation, copying).

Since the first category of scriptural elements is the one most frequently encountered in the forensic examination of classical (conventional[12]) wet-ink signatures, a list of the main *graphic indices of affectation* is set out below, without claiming to be exhaustive:

(1) *graphic indices of movement*: sinuosity (1), tremors (2), drag line at the attack of the graphic sign (3), *spider webs*[13] (4), repeated initial pen lifts, or 'false start' (5), angularisation (polygonisation, breaking of arcs) (6), jerky feature (7), final long and jerk drag line (8), involuntary overlaps (9), atypical fragmentation of letters/figures (10), looped connections (11), significant and non-specific increase/decrease in execution speed (12), significant increase/decrease in pressure (13), micrography (14); oversized letters (15); unequal size of letters (16);

(2) *graphic indices of language*: partial or total illegibility (17), repetition of letters and words

[11] HH Harralson and LS Miller, *Huber and Headrick's Handwriting Identification: Facts and Fundamentals* (2nd edn, CRC Press 2018) 45.

[12] ENFSI, *Best Practice Manual for the Forensic Handwriting Examination,* ENFSI-BPM-FHX-01 (4th edn, September 2022) 80 **https://enfsi.eu/wp-content/uploads/2023/02/BPM-Handwriting-Ed.-4.pdf** accessed 5 May 2026.

[13] Thin, long or tangled drag line between strokes, like a spider web or a ball of thread.

(18), significant absence of letters/words (19), faultily construction of graphic signs (20), corrections (rectifications) made at sight (21), omissions/spelling and punctuation errors (22), non-specific interleaving of uppercase and lowercase (23), textual incoherence (24);

(3) *graphic indices of spatial organization*: major misalignment (25), significant descent of the baseline (26), defective/chaotic margining (27), increased/decreased spacing (28), disorganisation/chaotic appearance (29).

The identification of graphic indices in a signature, whether simultaneous with, or subsequent to, the establishment of its identifying characteristics, contributes not so much to its attribution to a specific author, but rather to the construction of a narrative, sometimes incomplete and sometimes complete, as to how, why, and when the person signed, or even as to their own existence and transformation, as reflected in their handwriting.

3. Digitally captured signature

The ENFSI *Best Practice Manual for the Forensic Examination of Handwriting*, together with the graphoscopic literature of the last two decades, sets out both a description of the types of electronic signature (symbolic, biometric, and digital) and several synonyms for the digitally captured signature, which the legislation in force includes within the category of *simple electronic signatures*, to which the broad statutory definition applies: 'data in electronic format, attached to or logically associated with other data in electronic format and which are used by the signatory to sign'[14].

In addition to the widely accepted term 'digitally captured signature'[15], the signature executed by an author on a tablet or similar device (e.g., pad, smartphone) using a stylus or even a finger is also referred to as biometric signature, biodynamic signature, holographic digital signature, holographic electronic signature, dynamic signature, online signature[16], or e-signature[17]. Such signatures are forms of simple electronic signatures, insofar as they satisfy the broad definition of an electronic signature under the eIDAS Regulation without necessarily meeting the specific requirements applicable to advanced[18] or qualified electronic signatures[19]. Other varieties of simple electronic signatures are made either by typing one's name and surname into an email, or by inserting a photocopied signature in the form of an image (e.g., in JPEG format) into an electronic document.

Digital signatures, however, are based on cryptographic technology and must be distinguished from the simple electronic signatures described above. The notion of 'digital signature' refers primarily to a technical mechanism for authenticating electronic data, rather than to a distinct category under the eIDAS Regulation. While digital-signature technology may be used in the creation of advanced and qualified electronic signatures, such concepts are not synonymous.

[14] eIDAS Regulation (n 1) art 3(10).
[15] ENFSI, *BPM for the Forensic Handwriting Examination* (n 12) 75.
[16] Ibid, 75.
[17] Mohammed (n 8) 179.
[18] eIDAS Regulation (n1) arts 3(11), 26
[19] Ibid, arts 3(12), 25.

Given their cryptographic nature, digital signatures are particularly suited to forensic examination of the authenticity and integrity of the signed data.

Returning to the digitally captured signature, it must be said that it represents a graphic image of the name made with a stylus or finger on the digital (electronic) writing surface incorporated into the digital tablet device, which is equipped with specialised software for converting the writing movement into digital data: equivalent to recording and measuring the parameters of the movement that generates the path of the signature. Where signing takes place on paper placed over the tablet screen, a so-called 'hybrid signature'[20] is created, comprising both a conventional graphic line and related numerical values resulting from the measurements taken by the software.

Forensic handwriting expertise applied to the digitally captured signature faces procedural difficulties on three fronts:

(1) the quality and type of the device and its associated software;

(2) the quality of the comparison evidence, since digitally captured signatures should ideally be compared with one another (comparing a biometric signature against conventional ones may produce inconclusive results);

(3) and the expert's own training, which must combine knowledge of the technology, the ability to obtain, extract and compare numerical data, and the ability to corroborate that data against scriptural data evaluated and interpreted qualitatively.

In Romania, public forensic laboratories do not currently carry out forensic graphoscopic examination of the digitally captured signature; however, the professional community of forensic experts has expressed a legitimate interest in scientific studies and in internal standards aligned with international ones[21].

Among the issues relevant to this theme for Romanian forensic science (and, by extension, for graphic expertise), the following may be highlighted:

– developing a specific and unified terminology, in accordance with national and international legislation;

– designing a database concerning digital devices used to capture handwriting and signatures, together with their dedicated software, the metadata they provide, and their archiving and access arrangements, as well as the institutions and economic operators that use them;

– conducting experiments to identify both the limitations and the advantages of digitally captured signatures, and to establish the possibility of obtaining optimal comparison models for forensic expertise;

– creating specific working procedures for the graphoscopic examination of digitally captured signatures and harmonising them with those applicable to the graphic examination

[20] J Heckeroth and others, 'Features of Digitally Captured Signatures vs. Pen and Paper Signatures: Similar or Completely Different?' (2021) 318 *Forensic Science International* 110587 https://doi.org/10.1016/j.forsciint.2020.110587.

[21] A Mitrofan and others, 'Digitally captured signatures – a complementary approach to forensic examination of handwriting' (2025) 4 *Romanian Journal of Criminalistics* 487.

of conventional signatures.

As forensic experts rightly note[22], the correct question at present is not *whether* graphoscopic expertise of biometric signatures will be carried out in Romania, but *when*: social and economic dynamics require a genuine and effective connection between the possibilities available to forensic practice and the enormous challenges posed by the digital revolution.

4. Graphic indices in digitally captured signature

Signing on a tablet screen introduces differences compared to conventional signing, some of which are considerable and produce an immediate effect on the interpretation of handwriting characteristics. This section takes into account the fact that digitalisation in Romania remains at an early stage, and access to tablets with styluses is, for now, confined to a small part of the population and to certain socio-economic or cultural sectors, in which only some operators have implemented an internal biometric electronic signature system.

First, signing on a tablet can be an unusual and even intimidating experience, one liable to provoke emotion in the writer through anticipation of possible clumsiness when confronted with modern technology. The excessive sensory and perceptual processing of information required when using the tablet (e.g., screen space, brightness, the visual distinctness of the signature path, tactile contact with the glossy surface) evidently affects the cognitive motor task, and in very different ways, through the complementary feedback required at the visual, tactile, proprioceptive, and even auditory levels. The situation becomes still more complicated where the signer must trace the signature with a finger, so that the resulting movements differ slightly from the automated motor scheme associated with manipulating a writing instrument. In addition, the size of the device (often smaller than an A4 sheet of paper) together with the space reserved for the signature, which is frequently separated from the text of the document, may contribute to an oversized inscription, further affecting the writing movements.

Second, the surface of the digital device does not reproduce the fine roughness of a sheet of paper: the stylus glides across it without encountering the minimal resistance ordinarily generated by the friction between a writing instrument and the fibres of paper[23]. The writer may struggle to manoeuvre the stylus, and its sliding motion on the glossy surface may impair the coordination of the handwriting movement, with the effect of altering the direction, size, and placement of certain compositional elements.

Some tablet models claim that their attached stylus gives the writer the sensation of writing on paper[24], but this claim is relative and does not entail a corresponding decrease in the actual speed at which the signer draws on the glossy screen.

Naturally, all these influences generated by the moment of signing on a tablet depend on the writer's experience and, most importantly, on their motor skills and the type of signature

[22] Ibid, 484.

[23] HECKEROTH and others (n 20) 5.

[24] reMarkable, 'reMarkable Paper Pro' **https://remarkable.com/products/remarkable-paper/pure** accessed 13 May 2026.

involved (in the case of a stylised signature, the level of automation is higher and the cognitive motor load is lower at the time of execution).

In the case of the digitally captured signature, given the space reserved for its execution on the tablet's dedicated screen (the equivalent of electronic paper) it will primarily be possible to trace the graphic indices of movement and, in the case of text-based signatures, the graphic indices of language, while the relevance of the spatial organisation indices is correspondingly reduced.

As for the latter, we consider that they can appear in the biometric signature subject to two conditions: the size of the signature box and the position of the signer relative to the tablet. Among the graphic indices of spatial organisation, it would be possible to distinguish a significant descent of the baseline and increased or decreased spacing between the letters of the signature, while the appearance of the remaining indices in this category depends largely on the signer's relationship to the surface of the electronic paper and on the presence of any text to which the signature is attached.

In the case of the graphic indices of language, it is evident that their appearance is less influenced by the conditions of signing on the tablet with a stylus (the emotional factor, perhaps, plays only a minor role): a text-based signature will be as illegible as one made on paper, and the repetition of letters and words, or the marked absence of letters or words, appears in the same way; the author may combine lowercase and uppercase letters, or make mistakes when writing their name and surname, which they may then spontaneously correct.

The graphic indices of movement best observed in the tablet signature are those converted into numerical data: a significant and non-specific increase or decrease in execution speed, a significant increase or decrease in pressure, inequality in the size of the letters, micrography, and dimensional enlargement of the letters (although the last of these may be more strongly influenced by the constraints of the tablet's signing space).

Sinuosity, tremors, and angularity are particularly susceptible to the combined influence of two factors: the sliding of the stylus, and the manner in which the handwriting movement is recorded by the device's software, which may capture the stylus's contact with the electronic surface with a delay or a positional discrepancy (e.g., where the sensor is not positioned at the tip of the stylus).

Graphic indices such as a long drag line at the start of the graphic sign, a final thinning drag line, spider webs, repeated initial pen lifts, or jerky features can be reproduced in the digitally captured signature only in the form of recorded air movements, and are therefore absent where the software does not integrate this function. Overlaps occurring along the graphic line, atypical fragmentation of letters or digits, and looped connections are all discernible in the biometric signature, just as in the conventional one.

All these graphic indices, added to the identifying handwriting characteristics considered in the forensic handwriting examination process used to establish the author of a digitally captured signature, can also serve as a primary element in medical assessments, through which clues are sought regarding written and spoken language disorders and numerous other pathologies known to cause changes in handwriting.

In conclusion, the possibility of identifying graphic indices in a digitally captured signature depends, to a large extent, on the characteristics and performance of the digital device and its associated software, and to a lesser extent on the manner in which the writer relates to the digital technique and executes the handwriting on the tablet. Nonetheless, further studies focused specifically on these handwriting elements would be valuable, for a fuller understanding of how digital devices might be adapted to meet the specific needs of forensic expertise.

5. Conclusions

The digitally captured signature, as the electronic counterpart of the classic wet-ink signature deposited with a pen on paper, is defined by the same handwriting characteristics, reflected through the prism of the technical capacity of the digital device. Graphic indices, defined as scriptural elements signalling natural or artificial changes in handwriting, or a deviation from the standard of written language, will be capable of optimal reproduction in the biometric signature only if the software associated with the stylus-enabled tablet allows for complex and accurate recording.

Although international research in recent years has led to recognition that the graphoscopic expertise of the digitally captured signature holds the same scientific validity, within well-defined limits[25], as the forensic graphoscopic expertise of a signature executed on paper, its implementation in the practice of Romanian forensic laboratories remains an open question, and an absolutely necessary and highly topical one to address.

The advance of digital technology will certainly continue to refine the programs used to capture and process digital data relating to signatures executed with a stylus on electronic paper, which has itself become qualitatively superior. Yet this progress will not, at least for a considerable period, be free from the many limitations that accompany the digitalisation process: cultural resistance to change, constrained financial resources, a shortage of applied scientific research, the absence of reliable solutions for archiving electronic data, and others besides. In parallel, handwriting on paper will continue to be part of human culture, ensuring, as before, its anchoring in history and in its own evolution.

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