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e-BioSign Tool: Towards Scientific Assessment of Dynamic Signatures under Forensic Conditions

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Abstract

This paper presents a new tool specifically designed to carry out dynamic signature forensic analysis and give scientific support to forensic handwriting examiners (FHEs). Traditionally FHEs have performed forensic analysis of paper-based signatures for court cases, but with the rapid evolution of the technology, nowadays they are being asked to carry out analysis based on signatures acquired by digitizing tablets more and more often. In some cases, an option followed has been to obtain a paper impression of these signatures and carry out a traditional analysis, but there are many deficiencies in this approach regarding the low spatial resolution of some devices compared to original off-line signatures and also the fact that the dynamic information, which has been proved to be very discriminative by the biometric community, is lost and not taken into account at all. The tool we present in this paper allows the FHEs to carry out a forensic analysis taking into account both the traditional off-line information normally used in paper-based signature analysis, and also the dynamic information of the signatures. Additionally, the tool incorporates two important functionalities, the first is the provision of statistical support to the analysis by including population statistics for genuine and forged signatures for some selected features, and the second is the incorporation of an automatic dynamic signature matcher, from which a likelihood ratio (LR) can be obtained from the matching comparison between the known and questioned signatures under analysis.

1. Introduction

Forensic handwriting examiners (FHEs) have been carrying out studies about the authorship of handwritten signatures for court cases for over a century [14]. The great majority of works in the forensic field relates to off-line signature analysis [6, 7, 3, 24, 9, 2]. With the rapid evolution of technology, which allows the acquisition of dynamic signatures from tablets and smartphones, applications are spreading in the commercial sector to facilitate payments and also in banking to facilitate the digital storage of all the signed paperwork. Therefore, FHEs are being required to provide forensic evidence to determine the authenticity of handwritten signatures written on digitizing tablets [12], which can provide a static image of the signature but also, and most importantly, contain the dynamic information of at least the X and Y spatial coordinates over time.

Signature dynamics can be further processed to provide features such as the signing velocity, acceleration and other stroke information along the signing trajectory. However, there are very few research works in the field of dynamic signature for forensic examinations [1, 16, 8]. The majority of relevant literature regarding dynamic signature analysis is in the field of biometric recognition [4], which make use of algorithms such as Hidden Markov Models [5, 18] or Dynamic Time Warping [13, 17].

There are some commercially available tools for dynamic signature analysis (e.g., TOPAZ SigCompare[1] or KOFAX FraudOne[2]), which provide very limited functionalities to carry out a forensic analysis. This paper introduces e-BioSign, a new tool specifically designed to carry out forensic analysis of dynamic handwritten signatures in order to facilitate the work of FHEs and give scientific support to their conclusions. In this sense, a survey of the methodology employed by the FHEs has been conducted and included in the functionalities of the tool. Together with these functionalities, e-BioSign tool also allows the measurement of dynamic information contained in the signatures, not taken into account normally by FHEs. With the use of dynamic signatures there is a huge amount of additional information available which can be used to carry out a more comprehensive and reliable forensic analysis.

Additionally, e-BioSign tool includes two important functionalities. On the one hand, it gives statistical sup-

[1]http://www.topazsystems.com/sigcompare.html, accessed April 2015
[2]http://www.kofax.com/products/kofax-signature-solutions/kofax-fraudone, accessed April 2015

port to the FHEs for some selected parameters such as the duration, fluency or level of tremor of the signatures. Population distributions for these parameters were computed for genuine and forged signatures allowing to position the questioned and known signatures under analysis on these distributions and extract some conclusions with statistical support. On the other hand, a dynamic signature verification system is included, from which a likelihood ratio (LR) can be obtained from the matching comparison between the signatures under analysis which is complementary to the analysis carried out by the FHE.

The remainder of the paper is organized as follows. Sect. 2 describes the traditional forensic procedure to do the analysis of signatures. Sect. 3 describes e-BioSign tool with all its functionalities. Finally, Sect. 4 draws the final conclusions.

2. Forensic Practice for Signature Analysis

As mentioned, traditionally the practice of FHEs has been mainly concerned with the analysis of paper-based (off-line) signatures. In order to carry out an analysis regarding the authorship of a questioned signature FHEs normally use some kind of variant of the following protocol[3].

The first requirement is to have an appropriate set of signatures to perform the analysis, otherwise it wouldn't be possible to obtain convincing conclusions. Therefore, FHEs can ask the person whose signature is being investigated to provide a set of signatures (around 20) in order to have some samples produced with natural fluency.

Then, the analysis is performed taking into account aspects such as the **composition** of the signature (with or without name, surname, if legible, presence of flourish, etc.), **location** regarding other text or box (if it is close to the text or box on the right, left, etc.), **direction** (inclination of the written part regarding the horizontal, also the flourish), **written part** (FHEs carry out a comparison letter by letter), **flourish** (initial and final points and their direction), **fluency** and **pressure**. Even if in off-line signature analysis fluency and pressure can not be measured as accurate as with dynamic signatures, this dynamic information is considered as an important and discriminative factor and it is estimated by analysing the width of the stroke or the groove left in the paper.

Some important aspects taken into account by FHEs to detect forged signatures are the followings: in general the forger is only able to focus in one of the two main aspects required to obtain a good quality forgery: *i)* precision in the production of the signature (size, proportion and shape), or *ii)* written fluently. Therefore, in general the forgeries can be precise regarding the appearance but not fluent, or written fluently but imprecise. Other signs to detect forgeries are changes in velocity in different strokes, tremors, monotonous pressure, traces of practice or guiding lines, unnatural pen lifts, corrections, etc. Also, the complexity of the signature is an important aspect to take into account as complex signatures are much harder to be forged.

[3]Based on published documentation from the Spanish Guardia Civil [3], the Netherland Forensic Institute [2] and the Victoria Police Forensic Services Centre (Australia) [7].

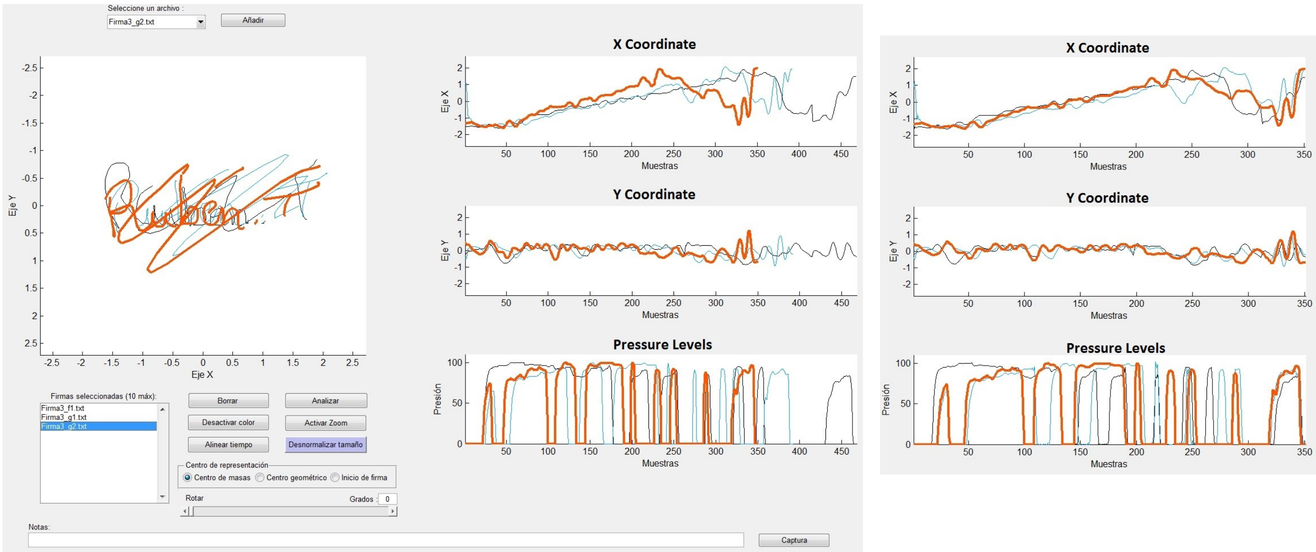
3. e-BioSign Tool

This section describes the main functionalities of e-BioSign tool, which is a tool designed to be used by FHEs to carry out the analysis of dynamic signatures and give scientific support to their forensic reports. This first version of the tool has been developed under Matlab GUI interface, but a second version of the tool as an independent application is under development. The most important functionalities of this tool are: *i)* several signatures can be loaded and visualised simultaneously (i.e., reference signatures and the signature under analysis); *ii)* signatures can be normalised in the spatial and time domains; *ii)* strokes can be manually selected for further analysis (to measure dimensions, angles, etc.); *iv)* statistical analysis of a selection of parameters can be conducted positioning the signatures under analysis in a population distribution; and *v)* automatic signature verification provides a matching score to complement the analysis of the FHE. Next, the functionalities of e-BioSign Tool are described. We have divided these functionalities in four main modules.

3.1. Module 1: Signatures Loading

Module 1 allows to load several signatures for further analysis. The signatures can be visualized simultaneously, i.e., both the spatial image of the signature and the dynamic information of the X and Y coordinates and pressure. This is very useful as questioned and known signatures can be visualised at the same time allowing to analyse similarities and dissimilarities. Fig. 1 shows a screenshot of Module 1 of e-BioSign tool with three signatures loaded, two of them genuine and one forgery.

When loading the signatures the information regarding frequency sampling (in Hz) and spatial resolution (pixel per inch) needs to be entered in a pop up window. In the example shown in Fig. 1(a) it is interesting to see how the two genuine signatures (orange and blue) have similar time duration, while the forgery (black) has a longer duration. In Module 1, it is also possible to normalize the loaded signatures both in the spatial domain and in the time domain. In the spatial domain, three position normalizations are possible considering different reference points: i) center of mass, ii) geometric center, or iii) beginning of the signatures. A size normalization can be also applied maintaining the aspect ratio of input signatures. In the time domain, the signatures can be resampled to have the same time length. Fig. 1(b) shows the same three example signatures shown in Fig.



(a) (b)

Figure 1. (a) Screenshot of e-BioSign tool Module 1, which allows to load several signatures and carry out a joint analysis. (b) Same signals normalised in time.

1(a) after time normalization. In this case, it is possible to see how the two genuine signatures provide a good match in X, Y and pressure values, while there are dissimilarities (especially in the pressure) regarding the forged signature.

3.2. Module 2: Signature Analysis

Module 2 allows to analyse the input signatures independently, and also to select strokes from each signature for further analysis. In order to analyse each signature, it is possible to reproduce the realization of the dynamic information of the signature, both in the spatial and time domains, with or without considering the pen up dynamics. The pen up dynamic information can be also visualized in the spatial representation. This is very interesting as this information can be very discriminative. Also, the pressure level information of each point can be incorporated in the visualization through a color map. Fig. 2 shows a screenshot of Module 2 with one signature represented with a color map based on the pressure values, and also the pen up information is visible (in pink). This module also allows to select strokes from the signature for a more detailed analysis. The strokes can be selected both by choosing initial and final points in the spatial representation of the signature, or using sliding bars in the time representation.

3.3. Module 3: Strokes Analysis

Module 3 allows to carry out a more detailed analysis of the selected strokes. It is worth noting that the whole signature can be also selected as one stroke. Fig. 3 shows a screenshot of Module 3. On the left part, it is possible to visualize the dynamics of the velocity and acceleration, and below again the X and Y coordinates and pressure. The analysis here can be conducted on single or multiple strokes at the same time, from one or more different signatures.

The middle part of Fig. 3 shows some additional functionalities: it is possible to rotate the stroke regarding the center of representation chosen (geometric center, center of mass or any other fixed points), the stroke thickness can also be selected, it is possible to zoom in and out the stroke and also the real sample points of the signature can be visualized. This module also allows to take measurements of the length (in pixels and cm) and the angle of any segment with respect to the horizontal line (in degrees).

Module 3 also allows to carry out a statistical analysis of some features automatically extracted from the signatures, as can be seen on the right part of Fig. 3. The idea is to provide the forensic expert with a population distribution of genuine and forged signatures for a selection of features together with the actual value of these features for the signatures at hand. For the initial release of e-BioSign Tool five global features have been selected. Three of them are common in feature based dynamic signature recognition systems [21, 18]: total duration of the signature, average velocity and average acceleration. The other two parameters are commonly used in offline signature forensic analysis [6, 7, 3, 24, 9]: time fluency and spatial tremor. These two parameters are normally considered as good indicators to discriminate between genuine and forged signatures.

The **time fluency** of the signature is related to the number of samples with very low velocity in X and Y coordinates. Therefore, the time fluency was calculated following: $Fluency = (-(N_{Vx} + N_{Vy})/N$, where N_{Vx}, N_{Vy} and N

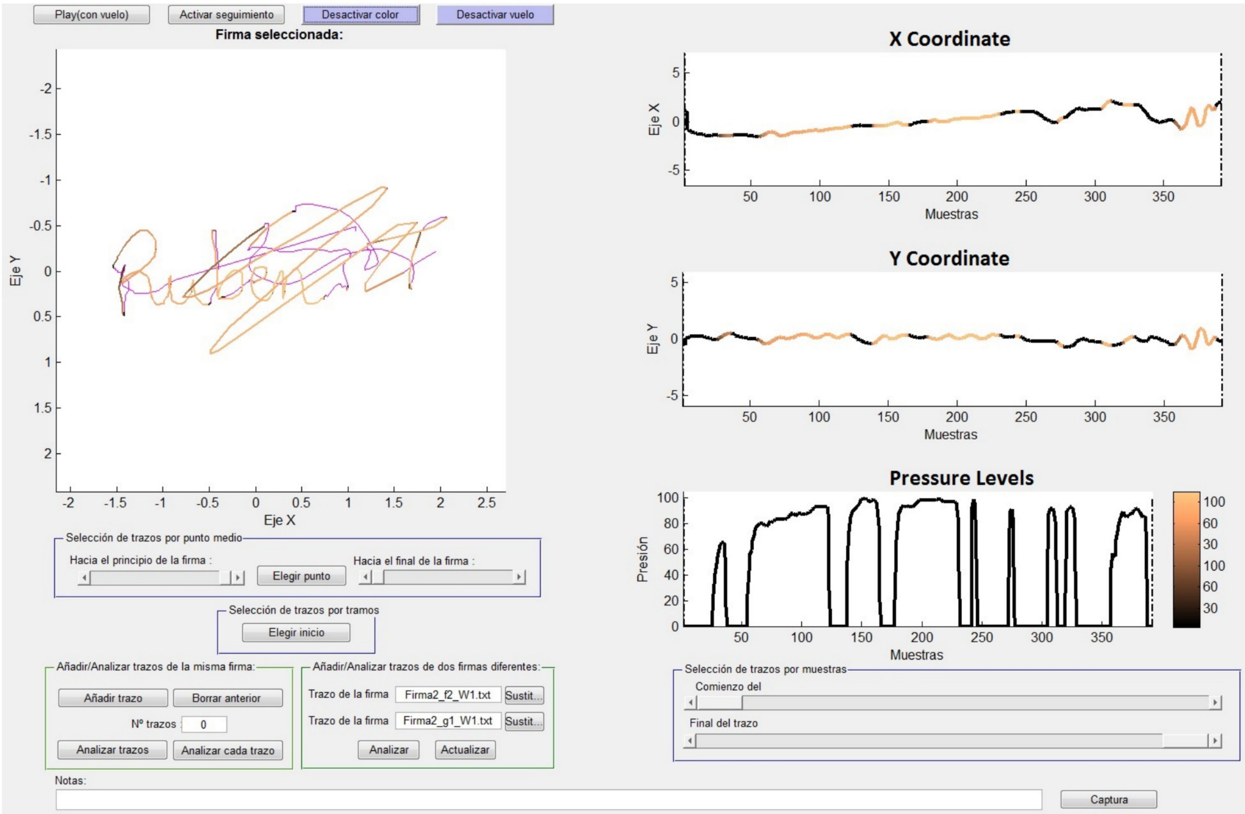


Figure 2. Screenshot of e-BioSign tool Module 2, which allows to analyse signatures individually reproducing the dynamic of the signature and showing the pen up information. Strokes can be selected for further analysis.

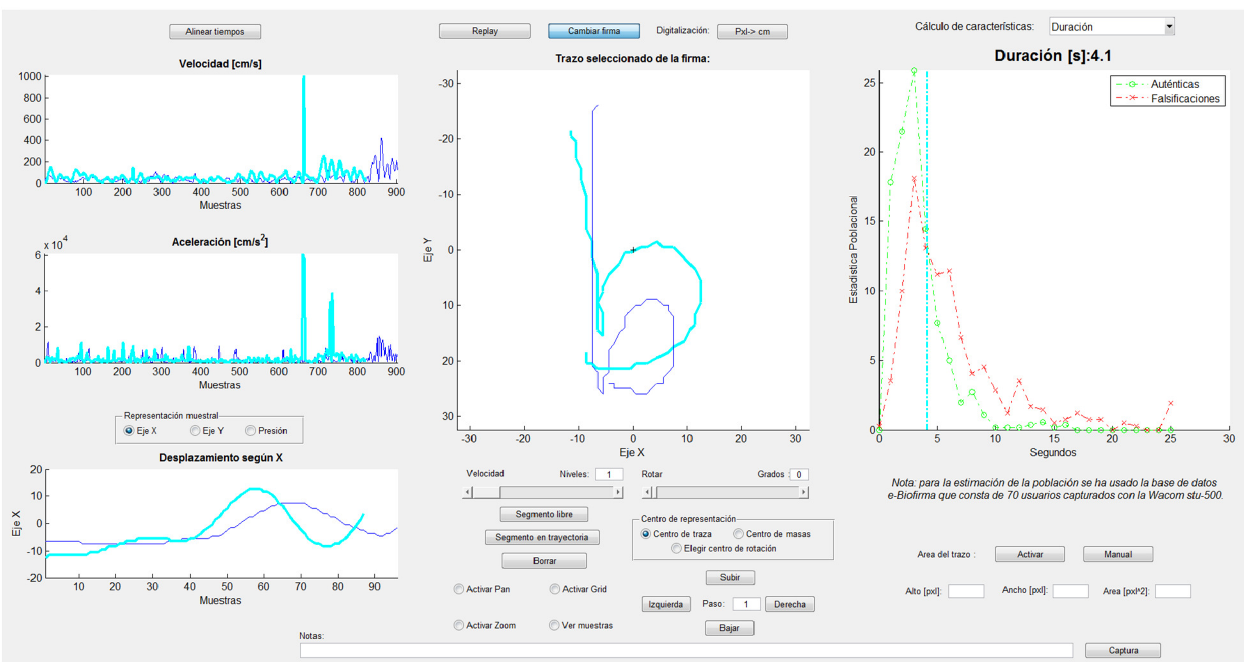
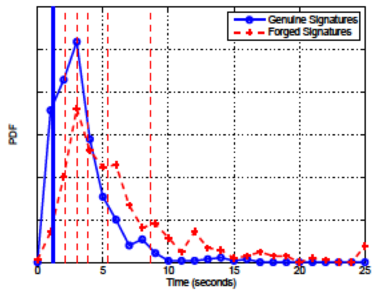
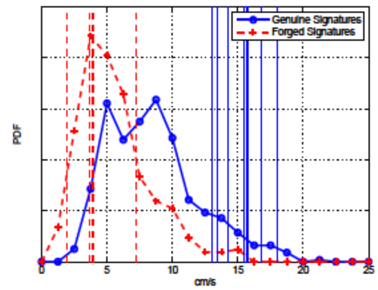


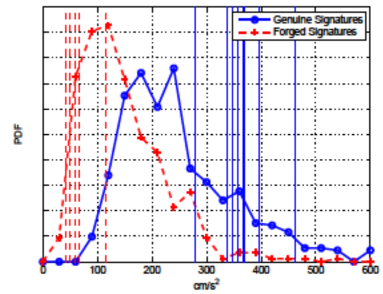
Figure 3. Screenshot of e-BioSign tool Module 3. This module allows to carry out a detailed analysis of the selected strokes, it also allows to position the selected strokes (or signatures) in a population distribution of genuine and forged signatures for five selected features.



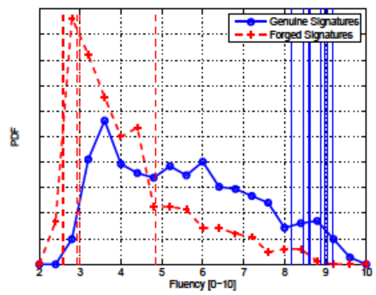
(a) Duration



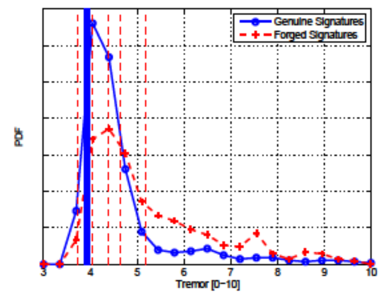
(b) Average Velocity



(c) Average Acceleration



(d) Time Fluency



(e) Spatial Tremor

Figure 4. Frequency histograms for genuine and forged signatures for the five selected parameters: (a) signature duration, (b) average velocity, (c) average acceleration, (d) time fluency, and (e) spatial tremor. Vertical lines show the positioning of the genuine and forgery signatures for a given user of the database.

correspond respectively to the number of samples with velocity in X or Y (*Vx* or *Vy*) equal or less than a threshold, which was set empirically to value 1 for obtaining 4, and N is the total number of time samples. The fluency is finally normalized in the range [0, 10] using an hyperbolic tangent normalization as per [15]. The **spatial tremor** present in the signatures can be due to low confidence in the realization of the (possibly forged) signature. The level of tremor of a signature was obtained using the Euclidean distance between the X and Y time functions of the signature to analyse and a smoothed version of them. This smoothed signature is obtained using a low pass Gaussian filter. Finally, these distance values for the tremor were also normalized to the [0, 10] range using also the hyperbolic tangent method.

Fig. 4 shows the population statistics for the five selected features. These distributions were obtained for a subset of e-BioSign database [23] which is comprised of 70 users signing on a Wacom STU-530 tablet. This database was comprised of 8 genuine signatures per user and 6 skilled forgeries collected in two different sessions with a time gap of at least three weeks. The skilled forgeries signatures were performed in two different ways: natural forgeries being able to visualize a recording of the realization of the signature to forge, and tracing genuine signatures from a printed copy. For each of the graphs shown in Fig. 4 we also show the position of the 8 genuine and 6 forgery signatures with vertical lines for one of the users (as an example of use) inside the population distribution. This can help the FHE to analyze if the questioned signatures are within the distribution of genuine signatures in general and for that user in particular. It can be seen that for that particular user genuine and forgery signatures are well separated, especially for the average velocity, average acceleration and fluency.

In a future release of e-BioSign Tool, in order to provide the FHEs with statistical support for these five parameters, apart from plotting population distributions, a LR will be also provided for each parameter, which would be calculated from a matching score using the signatures under analysis, and using a LR model trained on a reference database.

3.4. Module 4: Automatic Signature Verification

An additional functionality of e-BioSign Tool is Module 4, which is an automatic signature matcher. With this matcher, a questioned signature can be compared to a set of known or reference signatures to obtain a matching score.

The automatic signature matcher is based on a selection of time functions extracted from the signature such as the X and Y coordinates, the pressure, velocity, etc. Then, Dynamic Time Warping (DTW) is used to compare the similarity between the selected time functions extracted from the signatures [22]. The matching scores are then converted to likelihood ratios (LR) as commonly done in the forensic community [10, 19, 20]. In this case, e-BioSign database is used to train a likelihood ratio model following a logistic regression approach [11]. In a first release of this tool, a person-generic LR model is considered, therefore obtaining same-source scores and different-source scores (in this last case comparing genuine signatures with skilled forgeries signatures). In future releases functionalities to select a group of specific users by age, hand they use to sign, complexity of the signature, etc., will be provided to produce more meaningful LR models for the particular case.

4. Conclusions

This paper has described a new tool e-BioSign specifically designed to carry out dynamic signature forensic analysis and give scientific support to FHEs. This tool allows to analyse the traditional information taken into account by FHEs to carry out the analysis for paper-based signatures, and also permits to exploit the dynamic information contained in signatures acquired from digitizing tablets which can be very discriminative. As mentioned in Section 2 it is very difficult to perfectly forge a signature, good forgeries normally either have a similar appearance and shape but are not written fluently, or the opposite. With the analysis of both spatial and time information for dynamic signatures using e-BioSign, we believe it will be easier to FHEs to detect forged signatures. Additionally, the tool incorporates two important functionalities, the first is the provision of statistical support to the analysis by including population statistics for genuine and forged signatures for some selected features (signature duration, average velocity and speed, time fluency, and spatial tremor), and the second is the incorporation of an automatic signature matcher which can provide a matching score between the known and questioned signatures under analysis.

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