Capturing Reliable Data for Computer-based Forensic Handwriting Analysis II: Pen-position Activations

Katrin Franke
Norwegian Information Security Laboratory,
Gjøvik University College, Norway.
kyfranke@ieee.org

Abstract

The forensic investigation of a questioned signature written on a piece of paper is a challenging task. Electronic pen-tablets for recording writing movements are considered valuable tools to assist in this effort. However, little is known about the precision and reliability of such electronic devices that are not intended as forensic equipment originally. Moreover, very few studies are conducted on the minimal requirements that would support appropriate forensic signature analysis. This paper presents a systematic study on the accuracy of online pen positions, which extends our previous work on the reliability of pen-force records. Implications of pen-tip displacements are discussed in the context of on- and offline signature data that is produced simultaneously. A basic method and advanced morphing algorithm are detailed that tackle (in)deterministic positioning errors. Experimental results on the processing of 100 authentic signatures and 93 skilled forgeries are reported finally.

1. Introduction

In the computer-based forensic analysis of handwritings, digitizers, such as digital image scanners and electronic writing tablets, are being employed as measuring instruments. This presupposes a profound knowledge of the technological idiosyncrasies and the resulting limitations regarding the accuracy and reproducibility of the data captured. Given that the digitalization is the first step in the workflow, it is essential for the feasibility of further processing as well as the reliability of the analysis results [2].

The use of recorded pen movements constitutes an extension of the graphics-related handwriting examinations, with implications for handwriting shape and stroke-morphology analysis. The investigation of questioned and disguised handwriting, in particular, will benefit from the consideration of kinematic and kinetic handwriting aspects [1]. With the help of sophisticated methods that use combined online and offline procedures for handwriting analysis, a scientific basis can be sought for the inference of temporal characteristics from static images of script [3]. However, the question to what extend digitizing devices affect the handwriting data and whether those capture devices are reliable in the sense of forensic analysis is not answered comprehensively.

Figure 1. Simultaneously produced on- and offline handwriting samples: (a) pen tilt $< 45°$, (b) pen tilt $\approx 55°$ and (c) pen tilt $\approx 90°$. Due to a tablet displacement error and a varying pen tilt, on- and offline handwriting samples do not match.

In order to evaluate the accuracy of pen positions captured by means of electronic pen-tablet, a dedicated experiment was conducted. It was launched after our observation that simultaneously produced on- and offline ink traces could not be superimposed in a trivial manner, i.e. by translating and scaling the handwriting samples (see Figure 1.) Even with careful manual overlaying, an appropriate match of the on- and offline data proved to be impossible. Lallican et al. [6, 10] observed similar mismatches between simultaneously produced on- and offline samples,

978-0-7695-3725-2/09 $25.00 © 2009 IEEE
DOI 10.1109/ICDAR.2009.255

but did not proceed to investigate the potential causes. We assumed complex cross-coupling effects between pen orientation and pen position, since the displacements were not observed during earlier tablet tests [8], using a robot. Pen orientation was fixed in these cases, so we concluded that a variation of the pen-tilt angle in the act of handwriting is a possible source of error. The experimental manipulation of the pen tilt confirmed this hypothesis (see Figure 1.) Hence, we opted for a systematic study of the observed phenomenon. We aimed to test (1) whether the pen orientation influences the absolute position activation of the electronic tablet, and (2) whether such effects result in a deterministic displacement of simultaneously produced on- and offline traces. Subsequently there would be the need to study (3) whether correctives can be supplied by considering some control parameters, or (4) whether displacements are non-deterministic, which would require an adaptive method.

The paper addressing these questions is organized as follows: Section 2 details a systematic study on cross-coupling effects between pen orientation and pen position. An elaborated method for assigning / superimposing digitized offline ink traces and recorded online pen trajectories is provided in Section 3. Experimental results and conclusion on the performed studies are reported in Section 4 and 5.

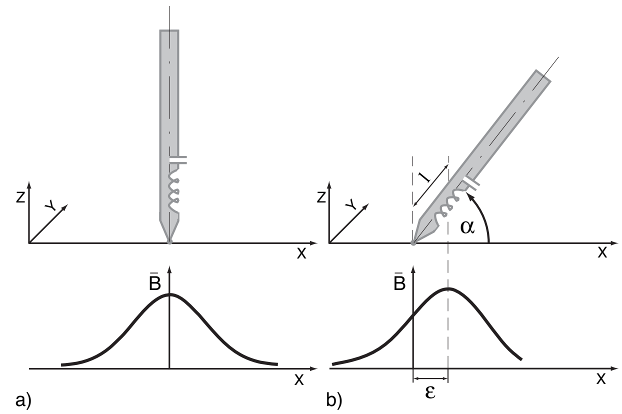

Figure 2. The established magnetic field $\vec{B}$ varies, depending on the pen's construction, its aerial characteristic and inclination. (a) With a perpendicular pen position the magnetic field $\vec{B}$ is symmetric. (b) In contrast, with a pen tilt α the magnetic field $\vec{B}$ is skewed, which leads to a displacement ε of the maximal activation [9].

2. Online Position Accuracy

2.1. Technical Background

Electro-magnetic coupling between the tablet and the respective pen is the basic principle for recording online trajectories, e.g., [7]. Since the *sensed* aerial characteristic of the pen changes according to the pen's inclination α, the magnetic field $\vec{B}$ erected by the tablet wires varies (Figure 2.) The questions arising in this context are (i) whether this physical effect is aptly taken into account by tablet firmware, or (ii) whether there is a displacement error $\varepsilon = f(\alpha)$ between the pen tip and the recorded tablet activation, e.g., at the maxima of the magnetic field $\vec{B}$.

2.2. Experimental Procedure

Simultaneously produced on- and offline writing traces were studied in order to investigate the prospected displacement $\varepsilon = f(\alpha)$. An electronic ink-pen was used, whereby the ballpoint refill marks the exact pen-tip position on paper and the electronics of the pen led to position activations on the tablet. To avoid any human influence a writing robot is used [1]. It also enables the precise adjustment of pen tilt α and azimuth angle φ. The machine was programmed to perform two linear movements with offset δ_{cnc}. The lines were made with two different azimuth angles $\varphi = \{90°, 270°\}$. Pen tilt α was varied for $\alpha = \{50°, 55°, 60°\}$, which corresponds to the preferred pen-tilt range of human writers [4]. If possible, pen tilt α and azimuth angle φ were recorded by the electronic tablet supporting the paper. During the experiment movement velocity, acceleration and pen-tip force were constant. Finally, to determine the prospected displacement $\varepsilon = f(\alpha)$, the relative distances, denoted as δ_{on} and δ_{off} respectively, were measured between the on- and offline traces (compare Figure 3.) Please note that for the further numerical analysis offline traces were scanned optically and approximated by a 1-pixel broad line.

Two different electronic writing tablets with their respective ink pens were considered in the experiment. The significant difference between the two tablets is their ability to capture pen-orientation records. The first tablet, referred to as *tablet 1* (Wacom, Intuos2 A4), was used to collect the NISDCC dataset [11]. The second tablet (SmartPen SP0604) is referred to as *tablet 2*. It does not record pen orientation.

2.3. Displacement Errors

Assuming a displacement ε between the ink deposition on paper and the position activation of the electronic tablet, a superposition of on- and offline traces would not exist. Rather, there would be a constant offset δ, which is defined as: $\delta = 2\varepsilon = |\bar{\delta}_{\text{on}} - \bar{\delta}_{\text{off}}|$, with $\bar{\cdot}$ representing the mean.

Overlaid on- and offline traces are illustrated in Figure 3. These traces prove the existence of a displacement error ε.

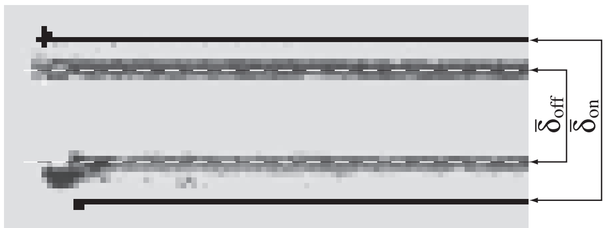

Figure 3. Superimposed on- and offline traces produced simultaneously. Note that cross-coupling between pen tilt and pen-position activation has resulted in a systematical displacement error between on- and offline traces.

	pen tilt		
	50°	55°	60°
tablet 1			
$\bar{\alpha}$	49.6	54.9	60.4
$\bar{\varphi}_1$	91.3	90.8	91.9
$\bar{\varphi}_2$	270.7	271.5	271.4
$\varepsilon_{300\,\text{dpi}}$	6.9	5.9	4.9
tablet 2			
$\varepsilon_{300\,\text{dpi}}$	11.1	8.2	5.0

Table 1. Displacement errors for various pen-tilt angles.

The obtained error ε is greater than the average line width of the offline trace. The numerical results for the displacement error ε are listed in Table 1. Records are listed according to the adjusted pen tilt α. Note that online coordinates were downscaled for the computation. For cross-validations in the case of *tablet 1*, the sample means of recorded pen tilts α and pen azimuth-angles φ are also provided.

The data listed in Table 1 give evidence of a systematical displacement error ε. It can be deduced that the increase of the displacement ε is indirectly proportional to the pen-tilt angle α. This can be quantified, e.g. for a spatial resolution of 300 dpi, where in the case of *tablet 1* $\Delta\,\alpha = 5° \rightarrow \varepsilon_{\Delta\,5°,\,300\,\text{dpi}} = 1$ pixel applies. This is even more extreme in the case of *tablet 2*, where a change of pen tilt with $\Delta\,\alpha = 5°$ results in a displacement of $\varepsilon_{\Delta\,5°,\,300\,\text{dpi}} = 3$ pixel.

2.4. Remarks and Implications

The manufacturer of *tablet 1* promises a spatial accuracy of $\pm\,1$", which corresponds to 25.4 pixels for a resolution of 2540 dpi. Comparing this with the displacement $\varepsilon_{55°,\,2540\,\text{dpi}} = 50.3$ pixel one can recognize that these displacements are 100 % greater than the allowed variation. However, the relative displacement $\varepsilon_{\Delta\,5°,\,2540\,\text{dpi}} = 8.4$ pixel that is caused by variations of the pen tilt complies with the manufacturer's specification. In conclusion, the displacement can consist in (i) an absolute component ε_α that applies to the whole tablet and one particular pen tilt α, and (ii) a relative displacement ε_Δ that is determined by the pen tilt variation. Hence, the displacement ε is defined as follows:

$$\varepsilon = \varepsilon_\alpha + \varepsilon_\Delta \tag{1}$$

For example, for human writing with an average pen tilt of $\bar{\alpha} = 55°$, an absolute displacement with $\varepsilon_{55°,\,300\,\text{dpi}} = 6$ pixels can be determined for *tablet 1*. Increasing or decreasing the pen inclination will result in a relative change of the displacement, e.g. for $\Delta\,\alpha = 5° \rightarrow \varepsilon_{\Delta\,5°,\,300\,\text{dpi}} = 1$ pixel, as stated before.

With a tablet that records pen-tilt and pen-azimuth information, one can adjust the online coordinates in the following way:

$$\tilde{x} = x - \varepsilon_{\Delta,\alpha} \sin\varphi \tag{2}$$

$$\tilde{y} = y + \varepsilon_{\Delta,\alpha} \cos\varphi \tag{3}$$

In the case of the tested *tablet 1*, with its relative accuracy of $\pm\,1$", this correction is relevant for writers with a pen tilt range $\Delta\,\alpha > 10°$. Note that this can frequently occur while writing extended ascenders or descenders, or if a writer steadily in- / decreases the pen tilt angle [4].

To make it worse, a number of tablets do not provide pen-tilt and pen-azimuth information, as is the case with *tablet 2*. An analytical correction of the relative displacement ε_Δ is impossible. Especially for less accurate tablets, this fact results in simultaneously produced on- and offline writing traces that cannot be superimposed properly. Keeping the various writing-process characteristics in mind, the displacement error can result in significantly shorter or longer online handwriting samples, e.g. due to a continuous pen-tilt increase or pen-tilt decrease, respectively. For writers with an oscillating pen tilt, online samples, such as loops, can be resized and / or slanted (Figure 1.)

3. Superimposing On- and Offline Samples

For superimposing displaced on- and offline signals in case of missing pen-orientation records, the following procedure was developed during our studies. In takes advantage of a newly introduced constrain that allows on-offline matching between previously assigned handwriting/signture regions only. These regions are bloated contour strokes [5]. With the algorithmic extension a set of possible morphing points can be masked that yield good stroke correspondence, while other possible on-offline matching candidates are neglected as for example point 8 in Figure 4. Our method is able to process (i) on- and offline handwriting signals that have been simultaneously produced, and (ii) digitized ink strokes that have been traced with an electronic pen-tablet or mouse. More elaborated procedures will be needed to assign on- and offline data that were produced at different times, either by the genuine writer or an impostor.

1. Binarize digitized ink-trace image I_{off} with an appropriate document preprocessing method.
2. Estimate the average stroke width $\bar{w}_{\text{off}}$ of the binarized ink trace.
3. Produce a second binary handwriting image I_{on} in a similar spatial resolution by means of the recorded handwriting trajectory (online signal), with the estimated stroke width of $\bar{w}_{\text{off}}$ and an appropriate brushing function.
4. For on- and offline signature specimens, compute the centers of gravity $C_{\text{on, off}}$ of all black image elements, with $C_{\text{on}} = cog\{I_{\text{on}} | I_{\text{on}}(x, y) = 0\}$ and $C_{\text{off}} = cog\{I_{\text{off}} | I_{\text{off}}(x, y) = 0\}$, respectively.
5. Perform principal component analysis on obtained handwriting images I_{on} and I_{off} separately. By sorting the eigenvectors E in the order of descending eigenvalues (largest first), one can find the directions $\vec{D}_{\text{xy, on}}$ and $\vec{D}_{\text{xy, off}}$ with the largest variance of the data, with $\vec{D}_{\text{xy, on}} = E_1\{I_{\text{on}} | I_{\text{on}}(x, y) = 0\}$ and $\vec{D}_{\text{xy, off}} = E_1\{I_{\text{off}} | I_{\text{off}}(x, y) = 0\}$, respectively.
6. Determine translation $T_{\text{xy, on off}}$ between on- and offline handwriting specimens by means of centers of gravities C_{on} and C_{off}.
7. Determine rotation $R_{\text{on-off}}$ by using the derived principal components $\vec{D}_{\text{xy, on}}$ and $\vec{D}_{\text{xy, off}}$.
8. Perform affine transformation A_{on} on the online signal using the translation $T_{\text{xy, on off}}$, rotation $R_{\text{on-off}}$ and scaling factor $S_{\text{on:off}}$ according to the ratio between the spatial resolution of the on- and offline data.
9. Produce a third binary handwriting image $I_{\text{on-trans}}$ in the appropriate spatial resolution by means of the affine-transformed online trajectory, using the estimated stroke width of $\bar{w}_{\text{off}}$ and brush.
10. Apply signature region matching [5] for the newly generated third binary handwriting image $I_{\text{on-trans}}$ and the binarized offline imageI_{off}.
11. For all globally aligned, online sample points - find the matching region [5] and within this the nearest offline ink-trace element, and map the online data point to this position (compare Figure 4.)

It must be pointed out that any transformation of the online data leads to disturbances in the subsequently derived velocity signal.

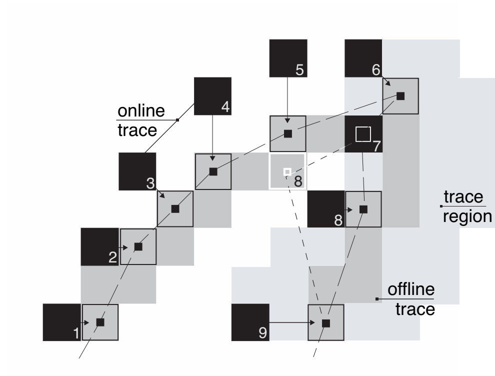

Figure 4. Schematic overview of the superpositioning of on- and offline specimens. A general alignment of the on- and offline strokes is followed by the constrained morphing of online sample points to the nearest offline trace element of the assigned region.

4. Experiments with NISDCC dataset

Few datasets that combine on- and offline handwriting data exist. To evaluate the superimposition of simultaneously produced data we chose a subset of the NISDCC signatures [11] which comprise genuine and skilled forgery samples. The samples are provided in their original unprocessed form so that the morphing procedure proposed above can be tested. Five signature probes for twenty genuine writers and three simulations by 31 forgers were picked. In total 100 genuine and 93 forged on-/offline signatures were available. Binary images with 300 dpi were used in the experiment without further preprocessing. Online data was additionally preprocessed to remove stop points and to resample the trajectory equidistantly.

In order to generate a ground-truth set to be used for the performance evaluation later on, all data was processed semi-automatically. The global alignment of on- and offline data was done first, results have been visually incepted and corrected according to the subjective opinion of the operator. In a second automated processing local on-/offline morphing was performed. Again the results were visually inspected and corrected if necessary.

Finally, the performance of the proposed algorithm was determined by computing the point-wise difference between semi-automatical generated ground-truth and automatically generated test set. If the local difference was greater than 1.5 of the estimated stroke width, then the on-/offline matching was labeled fail. Overall performance was measured on the signature and on the stroke/region level yielding 84.3% and 91.6% correct assignments, receptively.

Since these are the first systematic experiments conducted ever we were most interested in the reasons for failure. It turned out that signatures by writers with continuous in- or decrease of the pen tilt are most problematic since the signature pattern is somehow stretched or shortened. Other problem areas are extended ascenders, descenders as well as extended loops.

5. Conclusions

In this paper, a study on the position accuracy of recorded online handwriting data is presented. It is motivated by the use of kinematic handwriting characteristics in the forensic investigation of questioned signatures. An experiment is detailed that focuses on cross-coupling effects between pen orientation and pen-position records. The findings regarding the tablet's inaccuracy call for procedures to deal with displacements of the online trace. In order to employ recorded writing movements in the analysis / measuring of residual ink traces on paper, a method for assigning / superimposing digitized offline ink traces and captured online pen trajectories is provided.

The studies support that one cannot rely on the fidelity of electronic pen and tablet data. With a rather easy testing scenario, which consists in the simultaneous production of on- and offline handwriting records, one can examine whether the on- and offline handwritings match and whether the pen-position accuracy is acceptable. The evaluation of the writing tablets has proved that there is a systematic displacement ε between the ink deposit on paper and the electronic tablet activation. This displacement error can be divided into an absolute component ε_α and a relative one ε_Δ that depends on the relative pen-inclination variation. Both components can be experimentally measured. Knowing the absolute displacement ε_α, one may correct the offset between simultaneously produced on- and offline handwriting samples by quite a simple translation. More sophisticated methods are necessary for correcting the relative displacement error ε_Δ. Electronic tablets and pens that produce strange displacements, and in addition, do not support pen-orientation records, are not recommended. For such devices special algorithms for morphing online into offline traces are required. The presented approach performs a constrained matching that takes a previously masked stroke region into account only. The transformation of the online data leads to disturbances in the derived velocity signal.

With respect to the envisaged forensic applications, it can be said that for a simple reconstruction of the writing sequence, and / or sensing the ink deposit along the offline trace, tablets with and without pen-orientation records are qualified. It has also no influence whether online data was simultaneously produced with the ink trace or whether it was recorded while tracing an offline sample. However, for deriving hypotheses on special, offline ink-trace effects caused by real handwriting movements, e.g. with regard to the writing velocity and pen-tip force, only tablets with a high relative accuracy and the registration of pen orientation are appropriate.

Acknowledgment: The author would like to thank Professor Lambert Schomaker for his valuable remark on the functional principle of writing tablets inspiring extensive tablet and algorithmic studies. Special thank goes to Dr. Louis Vuurpijl and Dr. Elisa van den Heuvel for their contribution in collecting and digitizing the NISDCC dataset.

References

[1] K. Franke. *The Influence of Physical and Biomechanical Processes on the Ink Trace - Methodological foundations for the forensic analysis of signatures*. PhD thesis, Artifical Instelligence Institute, University of Groningen, The Netherlands, 2005.

[2] K. Franke. Capturing reliable data for computer-based forensic handwriting analysis. In *IEEE Three-Rivers Workshop on Soft Computing in Industrial Applications (SMCia)*, pages 115–120, Passau, Germany, 2007.

[3] K. Franke and S. Rose. Ink-deposition model: The relation of writing and ink deposition processes. In *Proc. 9th International Workshop on Frontiers in Handwriting Recognition (IWFHR)*, pages 173–178, Tokyo, Japan, 2004.

[4] K. Franke and L. Schomaker. Pen orientation characteristics of on-line handwritten signatures. In H. Teulings and A. van Gemmert, editors, *Proc. 11th Conference of the International Graphonomics Society (IGS)*, pages 224–227, Scottsdale, Arizona, USA, 2003.

[5] K. Franke, Y. Zhang, and M. Köppen. Static signature verification employing a Kosko-Neuro-Fuzzy approach. In N. Pal and M. Sugeno, editors, *Advances in Soft Computing - AFSS 2002, LNAI 2275*, pages 185–190. Springer Verlag, 2002.

[6] P. Lallican. *Reconnaissance de l'Ecriture Manuscrite Hors-ligne: Utilisation de la Chronologie Restaurée du Tracé*. PhD thesis, IRESTE, Universite de Nantes, Nantes, 1999.

[7] Patent EP0694863. *Position detection method and device*. Wacom Co. Ltd. (JP), 1996.

[8] W. Penk. Entwicklung, Implementierung und Erprobung von Verfahren zur Evaluation von elektronischen Schreibtablets. Master's thesis, Berlin College of Technology and Business Studies (FHTW), Berlin, Germany, 2003. in German.

[9] L. Schomaker. Personal discussion, December 2001.

[10] C. Viard-Gaudin, P. Lallican, S. Knerr, and P. Binter. The IRESTE On/Off (IRONOFF) dual handwriting database. In *Proc. International Conference on Document Analysis and Recognition (ICDAR)*, pages 455–458, Bangalore, India, 1999.

[11] V.L. Blankers, C.E. van den Heuvel, K. Franke, and L.G. Vuurpijl. The ICDAR 2009 signature verification competition with on- and offline skilled forgeries - http://sigcomp09.arsforenscia.org. 2009.