Differentiation of Signature Traits vis-à-vis Mobile- and Table-Based Digitizers

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As the use of signatures for identification purposes is pervasive in society and has a long history in business, dynamic signature verification (DSV) could be an answer to authenticating a document signed electronically and establishing the identity of that document in a dispute. DSV has the advantage in that traits of the signature can be collected on a digitizer. The research question of this paper is to understand how the individual variables vary across devices. In applied applications, this is important because if the signature variables change across the digitizers this will impact performance and the ability to use those variable. Understanding which traits are consistent across devices will aid dynamic signature algorithm designers to create more robust algorithms.

Keywords: Dynamic signature verification, biometrics.

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I. Introduction

Digitized, digital, and dynamic signatures are three types of signatures used in commerce. The digitized (off-line) signature method creates a visual record of the signature after the signing event has taken place . Dynamic (on-line) signature verification (DSV) captures dynamic traits during the act of signing, including velocity and x, y coordinates. Capturing the dynamic as well as visual traits of a signature has two main technological advantages over the off-line verification method: the first is the increased recognition accuracy, and the second is the interaction between the user and the machine. Off-line verification techniques are less accurate than on-line techniques [1].

The ability to sign electronically whether at a point of sale or at a bank poses a number of questions, outside of that of the performance of a specific dynamic signature verification algorithm. The central question is that of the interoperability of the algorithm on different digitizers−are the variables collected on one device the same as those collected on another device, using the same DSV algorithm?

There are several different digitizers available in the marketplace, as each customer buys a digitizer related to their specific application. However, adoption of dynamic signature verification will only be application specific if the variable traits are not the same across devices.

The purpose of this research was to test signature verification software on both the traditional digitizer tablets and on wireless/mobile devices in order to assess how the dynamic variables of signature signing on such devices change. Specifically, this study will examine the differences on table-based digitizers (Wacom Intuit and Interlink Electronics E-Pad) and over mobile data collection devices and personal digital assistants (Palm IIIxe, Symbol Technologies SPT 1500, and

Symbol Technologies SPT 1740). These devices were chosen based on their use or potential use in a number of different applications where an electronic signature could be captured. Furthermore, the algorithm and forensic tools were available for these devices at the time of research.

II. Device Specification

All biometric devices have the potential to verify an individual for an e-commerce transaction. Image and template quality are also important for system performance. Many vendors publish specification sheets that outline some of the features of the device, including resolution. Other factors that will affect the quality of the image presented to the sensor will be the cleanliness of the sensor, ergonomics (size of the sensor and how it interacts with the body), as well as the feedback to the user (in signature verification, some devices display the signature under the pen in the same way as in a pen/paper interaction).

Detailed device specification is also important—dynamic signature verification uses a digitizer tablet, the quality of which will vary. Although some academic research papers do not list the specifications of the digitizer, it is of fundamental importance, affecting the quality and performance of the device within an e-commerce transaction environment. As technology improves, there is now no 'standard' digitizer, or hardware, to collect DSV variables.

There have been a number of dynamic signature verification studies that have centered on capturing these traits as a pen moves across a digitizer tablet [1]-[19]. These devices include both table-based digitizers and mobile computer (PDA type) digitizers, both of which are becoming more sophisticated, capturing an increasing number of measures such as x, y coordinates, velocity, and pressure. Furthermore, the evolution of mobile electronic commerce will increase the requirement to sign documents online with wireless mobile computing devices. As hardware progresses towards providing solutions to mobile and electronic commerce, there may be a shift away from table-based digitizers. Hardware properties can affect the variables collected in the data acquisition process, and therefore the quality and performance of the device. Different digitizers and software enable the capture of different parameters of the signature, such as differing resolutions and speed.

1. Device Characteristics

Numerous studies have used many different input sensors, and according to [6], there is no consensus within the dynamic signature verification community on which is the best device to use, although the table-based digitizer is by far the most popular. A study by [10] covers the size of mobile device screens and input devices. The Liquid Crystal Display (LCD) on a personal computing system PCS smart phone has a 0.2 mm dot pitch. A 6" × 2.5" phone will support a 640 × 240 screen [11]. The most popular PDA on the market is the 3 Com Palm (used in this study), which has a screen size of 55 × 55 mm. Newer point-of-sale signature devices have a signing space of 91 × 53 mm, with a resolution of 300 counts per second [6]. A WAP-enabled Nokia 9000i phone has a screen size of 115 × 36 mm. Newer models of WAP-enabled phones have smaller screen sizes, resulting in research into the effects of the dynamics of the signature on a smaller signing area. Typical digitizer tablets range from 100 × 120 mm to 300 × 450 mm [12].

Hamilton, Whelan, McLaren, and MacIntyre [13] used a low cost (under $5) digitizer that operates under paper using a conventional pen. The digitizer acquires samples at 200 points per second. The digitizer can also discriminate between palm pressure and pen pressure, allowing the collection of pressure data from the digitizer. Schmidt and Kraiss [14] used a pen that was equipped with a “special resonance circuit that is positioned on the digitizer tablet” using x, y, and z variables over time.

Komiya and Matsumoto [5] proposed an algorithm based on the traits of pen position, pressure, and pen-inclination as well as the number of strokes (a sequence of pen ups and pen downs as a function of time). Lee, Berger, and Aviczer [7] used a combination of x and y as functions of time, as well as x velocity, y velocity, x acceleration, and y acceleration, and Mingming and Wijesoma [15] used x and y variables over time.

Mingming and Wijesoma [15] also collected signature data as a discrete time vector. Lee, Berger, and Aviczer [7] examined dynamic traits and concluded that a 34-feature set provided the overall optimal performance of dynamic traits selected from a 42-feature set. The study concluded that the performance subsets of 24 subjectively selected features are the best among a subset of features selected from the 42 feature set. Plamondon and Parizeau [16] concluded that vertical signals ‘are the most discriminating’ and that the best representation of a two dimensional signature was speed. Plamondon [18] explored the stability of the pressure signals in handwriting. Three groups existed: those with a reliable pressure pattern, partial pressure control, and a third group which exhibited no control over pressure.

Mingming and Wijesoma [15] used ten shape-related features of which six are listed: height/width, length/width, horizontal mean-min difference, vertical mean-min difference, ratio of left and right side to the centric (the center of mass), and direction, as well as 14 dynamic traits including total signature time, pen down time, pen-down time ratio, max root mean square (RMS) deemed as the square root of the average of the squares of a set of numbers, RMS speed, and RMS minimum difference of speed.

Although the size of the signing area is important, a review of the literature also showed differences in the parameters collected. Digitizer pens collect pressure data, some tablets having 1024 levels of pressure [12]. In contrast, the E-Pad only has 128 levels of pressure [17]. A study by Texas Instruments used a graphics tablet to capture a signature on x and y coordinates at 100 to 200 times a second [2]. In prior research, the size of the largest rectangle required to fit a signature was 100 × 130 mm, the smallest was 20 × 50 mm [7]. The *Handschriflen-Erkennungs-System fur Normalstifle* (Handwriting recognition system for normal pens, or HESY) method of data collection used a writing pad with signing dimensions of 80 × 40 mm, with a sampling rate of 1600/sec with four sensors at 400/sec. The resolution of the force sensors is 4 × 12 bit or 4 × 4096.

Unlike table-based and pen-based devices, mobile devices such as the Palm PDA and Nokia phones do not measure pressure; therefore, pressure was not a variable used in this study. Hardware device selection was based on the current or potential use within both signature verification studies, electronic/ mobile commerce activities, and the availability of the software research tools for a given platform. The Palm III device, Palm VII, Symbol Technologies SPT 1500 and SPT 1700, Interlink Electronics E-Pad, and the Wacom Intuos (6 × 8) digitizer were selected for this study.

2. Ceremony and Habituation

Another factor to consider is the context sensitive nature of signing. For example, the signature applied to a credit card slip at the supermarket will not be given the same amount of 'thought' as that of a mortgage application or will—although in some cases the law does not provide for the electronic signing of a mortgage or will due to the required ceremony. Additionally, comments from the National Physics Laboratory also noted the importance of the selection of the environment. One example is given below:

To aid repeatability of the tests, the environmental set-up for the trial should be described. This could be in the protocol or with the reported results. The following environmental factors may have significance: Will volunteers be sitting or standing to give signatures? What height is the counter? Is it angled or horizontal? What is the size of the signature box on the paper they are signing? What is the temperature (it is harder to sign with cold hands)? Examining the act of ceremony is important in dynamic signature verification. Your signature will be different if you are signing a credit card application at the local gas station, as opposed to signing a will at a lawyer's office [24]. These questions regarding environment were included in the design of the test, as described in the results section.

The second issue is that of habituation. Signatures vary over time—studies have revealed that signatures vary in the following ways:

- over time and cyclically
- when the signing occurred—there is a significant difference between morning and evening specimens; the evening signatures are consistently about 2 mm longer than those given in the morning
- there is considerable long-term variation

Subjects were informed that they were to sign the device as they would a receipt at a point of sale, thereby keeping the ceremony activity constant when signing across the devices.

III. Testing Methodologies

Collection of environmental data was in accordance with other recently published biometric testing reports, the Facial Recognition Vendor Test [18], and the Biometric Product Testing Final Report [19].

1. Enrollment Procedures

Subjects signed on the table-based digitizers (Wacom digitizer, Interlink E-Pad) and the mobile devices (Palm III, Symbol SPT 1500, and SPT 1700) three times in order to create templates. Additionally, the signing area on the Wacom device was restricted to the signing area of the Interlink E-Pad and the Palm devices. In total, 29 signatures were taken from each subject. Subjects signed once on the Wacom device at the halfway stage and at the end of the session in order to measure the order effects of dynamic signature verification. Table 1 shows the order of the devices in the testing protocol.

Table 1. The order of the devices.

Scenario number / Signing number	Random / Fixed ordering	Signature number	Device
1	Fixed	3	Wacom
2	Random	6	Any device
3	Random	9	Any device
4	Random	12	Any device
5	Fixed	16	Wacom
6	Random	17	Any device
7	Random	20	Any device
8	Random	23	Any device
9	Random	26	Any device
10	Fixed	29	Wacom

The signature capture software was in "forensic" mode in order to capture all the signatures provided by the crew. The earliest testing time was 6:30 am, and the latest time was 10:30 pm. Temperature and humidity were not controlled, although there are environmental restrictions in place due to the study occurring in a computer lab.

IV. Results

1. Volunteer Crew

The volunteer group was made up of 203 individuals, primarily university students, with demographics tending towards the 19 to 26 age group due to the composition of the testing environment and population. Although not representative of the U.S. population except for gender, the test population was representative of the population in college and university environments. Males accounted for 66% of the volunteer crew and females 34%, with females typically being older than the males. Right-handed members of the volunteer crew accounted for 91% percent, and left-handed members accounted for 9%.

A. Failure to Enroll

The proportion of individuals for whom the system is unable to generate repeatable templates is a failure to enroll rate [26]. The system in this study accepted all the signatures, and the failure to enroll rate was 0.0%.

B. Failure to Acquire

Mansfield, Kelly, Chandler, and Kane [18] and [19] define the "failure to acquire" rate as the "proportion of attempts for which the system is unable to capture or locate an image of sufficient quality." Typically, this is the case when an individual is unable to present a biometric feature to the device due to either an injury or to insufficient image quality. As such, this does not apply to dynamic signature verification because the biometric feature (signature) is presented by a stylus rather than direct interface with the biometric sensor. Therefore, a paradox arises between a signature that is repeatedly signed and acquired by the sensor yet provides an image different to a normal paper based signature. One subject did have difficulty in providing a signature that is similar to a pen and paper version; although the system acquired the image, the signature was thrown out, as it was a statistical outlier with over 15,000 segments as opposed to 2 to19 segments exhibited by other crew members. The failure to acquire rate in this study was 0.0%.

2. Groupings and Hypothesis Development

The central focus of the study was to examine whether there are statistically significant differences in the measurable variables across devices. The hypotheses were as follows:

- Wacom 6 × 8 (restricted as a signing space of the Interlink E-Pad), versus the Interlink E-Pad, sitting down
- Wacom 6 × 8 (restricted as a signing space of the Palm IIIxe), versus the Palm IIIxe
- 8PT 1500 versus the Palm IIIxe
- 8PT 1700, strap and no strap
- Interlink E-Pad, sitting against standing

Device groupings examined the differences of the individual signature traits (individual variables) within the specific groupings.

3. Grouping Result

A. Wacom Digitizer with Signing Space Restricted to That of the Interlink Electronics E-Pad

This grouping measured the difference in variables from the Wacom digitizer tablet, with the signing space restricted to the same size as the available signing space on the Interlink E-Pad, against that of the Interlink E-Pad. This hypothesis was designed to examine whether variables change over these two digitizers, excluding the signing space as a variable. Subjects signed the devices seated.

The statistical test was a one-way ANOVA, with an alpha (α) level equal to 0.01. This simple statistical test was performed for a number of reasons. The first is that the research simply examines which of the variables are significantly different. The null hypothesis (that there is no statistically significant difference in the measurable variables across groups) can be rejected for 64% of the individual variables. One variable that exhibited statistically significant differences in means was the number of segments (a pen-down, pen-up sequence). This is interesting as the number of pen-up, pen-down sequences should not change significantly when the signing space is restricted. Furthermore, pen-up, pen-down sequences are an important variable that is used in a number of dynamic signature verification algorithms. Another interesting result is that the uptime variable was also significantly different at an $\alpha=0.01$ level. Durations of the signature, i.e., the time for individual 0.01 mm groupings, are also significantly different across these two devices. When examining the variables associated with the graphical nature of the signature, there was no significant difference in the number of variables relating to the signing area of the device. Area was not a factor, as it was held constant on both devices; and those variables measuring area, such as distance (p-value = 0.181), net area (p-value = 0.676), and rubber area (p-value = 0.344) show that there is no statistically significant difference in the signing areas of the two devices and that in these cases the null hypothesis can be retained.

B. Wacom Digitizer with Size Restricted to the Signing Area of the Palm IIIxe

This hypothesis measured the difference in variables from the Wacom digitizer tablet against the Palm IIIxe. The signing space was restricted on the Wacom to 2.3 × 2.3 inches, which is the same signing area on the Palm computers. There was a statistically significant difference between the two devices for 61 variables, including uptime, distance, and event variables. The signing area between the two devices was constant, and the variables related to area measurement such as measuring area, distance (p-value = 0.000), net area (p-value = 0.000), and rubber area (p-value = 0.000) showed significant differences. Variables constant across the two devices were the number of segments (p-value = 0.048), pen-down time (p-value = 0.070), and sum of the maximum bar durations (p-value = 0.934). Speed of the signature (p-value = 0.002), speed variation (p-value = 0.006), average velocity of the signing (p-value = 0.000), up-speed (the speed when the pen is off the digitizer) (p-value = 0.000), net speed (p-value = 0.000), and average uptime (p-value = 0.000) were all significantly different. In grouping one, speed, average velocity, net-speed, and average uptime were not significantly different across these devices.

C. Symbol Technologies SPT 1500 and Palm IIIxe

This group examined the differences in the variables from the Symbol SPT 1500 and the Palm IIIxe device (both palm sized personal digital assistants), selected due to the visual differences in the signature image. A t-test showed that 27% of the variables were significantly different across the grouping (SPT 1500 and Palm IIIxe) at an $\alpha=0.01$ level. The speed of the signature was also significantly different between the two devices, as was pen acceleration. X turns, the number of times the horizontal component of velocity changes movement, showed a p-value of 0.000 ($\alpha=0.01$). X and Y speed velocities and pen acceleration also showed significant differences ($\alpha=0.01$), with p-values at 0.000. The resulting p-values of the event, velocity, and acceleration could be an indication of sampling rate between the two devices. Eleven core variables did not show any significant difference with $\alpha=0.01$. It can be determined that the ergonomics of the two devices and how the subjects held the devices in their hand had an impact on the measurable variables.

D. Wacom Digitizer without Signing Restriction versus the Symbol Technologies SPT1500

This group examined the difference between the template signature on the Wacom digitizer tablet and the SPT 1500. Of the 91 variables, 53 were significantly different at $\alpha = 0.01$. The signing space on the Wacom is 8 × 6 inches, and the signing space on the SPT 1500 palm computer is 2.3 × 2.3 inches. From this difference, the signing area variables, including the bounding area of the signature, net area, and the ratio of signature ink length to area, were all significantly different. This result would validate the assumption that people sign with a larger signature when given a larger signing space. Again, the variables that differed on the SPT 1500 compared to the template signature on the Wacom digitizer were the local maximum or minimum ratios. Other variables that were statistically significant were velocity, the time the pen was on the digitizer, the average speed that the pen was on the digitizer, and the net speed of the signature.

E. Examination of the Use of a Strap to Secure the PDA to the Hand

Within the logistics sector, ruggedized devices such as the Symbol Technologies SPT 1700 have a strap, which is designed to secure the device to the hand while the user is doing other activities. Many subjects commented that the strap provided control of the device, and that "it fits the palm better." The hypothesis examined whether there was a difference in the dynamic signature verification variables when using the strap or not. If the null hypothesis were rejected, it would give additional information to those developing standards within the logistics sector. Only one variable, the average duration of the first event in each segment, had a significant difference at a = 0.01 with p-value = 0.001.

F. Interlink E-Pad

The final hypothesis was to examine whether there were any changes on one particular digitizer when an individual was sitting and then standing. There were no restrictions on the signing space. The motivation for this hypothesis was that in many environments where this digitizer was used, the user would sign both seated and standing. For example, in many retail environments, customers stand when signing a credit card receipt at a checkout; but in cases where the Interlink E-Pad is currently being used, for example in banking and brokerage, the user may also be seated. No differences were statistically significant when a t-test was performed at $\alpha=0.01$, showing that when a member of the volunteer crew stands and enrolls and then sits to sign, the variables of the signature do not differ statistically at the $\alpha=0.01$ level.

V. Conclusion

Based upon the research, the major conclusion that can be drawn from the study is that there are significant differences in signature trait variables across devices, yet these variables are not significantly different within device families (Wacom, Palm and Interlink E-Pad). When these devices are grouped together, these variable differences continue to be significant. The fact that the signature variables differ across devices is significant. Dynamic signature verification is used within the realms of electronic document management and contracts and will typically be verified only if the document validity is questioned. Therefore when deploying dynamic signature verification applications, it is important to note that the ergonomics of the device can have an impact on the variables collected, and depending on the weighting of the variables within a specific algorithm, the ergonomics may have an impact on the system performance. Furthermore, for audit control purposes, the type of device needs to be attached in some way to the signature so that document examiners can compare signatures captured on the same type of device.

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