The Repeatability of Signatures

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Abstract

Signatures are the most widely used form of legally binding identification and authentication. The repeatability of a person's signature underpins its recognition and hence usefulness in everyday authentication situations. This study aims to assess the stability of a set of common features used for analysing signatures both within a single capture session and over time (multiple sessions). Secondly, the physical characteristics of signatures which result in the most repeatable performance for each feature are also analyzed. These results have implications for biometric signature verification systems and the document forensic field in that it gives an indication as to the stability of features leading potentially to improved performance and the types of features that should be analyzed given particular characteristics of the signature under investigation.

1. Introduction

The human signature is still the most widely used form of authentication and certification forming a legally binding method of document-based authorization. Interest in the automatic analysis of signatures has been renewed through the prominence of biometric and security systems with the required ability to accurately and repeatedly assess (or verify) the ownership of a signature [1]. This is also a requirement when assessing signatures as part of a documents forensic examination – this process must find features that uniquely describe a person's genuine signature and not that of a forgery [2]. In such systems, the ideal situation is to have a set of features extracted from each signature that do not change over time (i.e. are highly repeatable) and hence an accurate comparison can be made between the original (enrolment) sample and the signature under examination [3].

Although signatures usually contain only relatively small amounts of handwriting, they are often written in a highly individual and stylised manner and an examination by a forensic document examiner can yield useful evidence of authorship. In a forensic signature comparison, the features of the specimen signatures – construction (how the pen has moved across the paper), shape, proportions and fluency - are assessed from the static signature image [4]. The features determined from the specimen signatures are then compared with the same features in the questioned signature(s) and an assessment of the significance of any similarities or differences that are found is then made. Studies within the field of computer-based analysis of signatures have tended to concentrate on the validation of a captured signature image or sequence of time-based pen locations to prove identity [5, 6]. Most studies and systems within the signature biometric field have examined both the static data relating to completed signature image and also the dynamic data relating to timing and constructional information often derived from the coordinates of the pen during signing.

The aim of this study is to investigate the properties of signatures that make it repeatable and hence increase the reliability of uniquely identifying a person using a signature over time. Utilizing common signature analysis features, the repeatability of an individual feature is assessed for a particular test subject within several signature samples captured in a single session and, secondly, over two or more capture sessions. Using this process it is possible to establish which of the features produce varied results and which are consistent both within and between sessions and hence indicate the best selection for a reliable feature set. After establishing repeatable features within each subject, an investigation is carried out to identify the performance characteristics of signatures that were highly repeatable for a particular feature and those that showed a large variation. In this way it is possible to assess the likelihood of a signature being repeatable given particular physical characteristics. This study concentrates mainly on the static data (and the spatial elements contained therein) as, in many situations, this is the only information that is available (i.e. the completed signature image). We do, however, assess a small number of common dynamic features to prove their repeatability or otherwise.

2. Data capture

The signature samples analysed in this study were collected from members of the general public who used the Hedge End Post Office and Newsagent, Southampton, UK on a regular basis. A lower age limit of 18 years was adopted, but otherwise no restrictions were imposed. 286 subjects (99 Male, 187 Female) were included in the study donating a total of 6566 signatures. Subjects were asked to donate several signatures at their first visit and invited to donate further signatures during subsequent visits to the Post Office. Only subjects donating 10 or more signature samples over two or more visits (or *sessions*) were included in the investigation. A different session was defined as being more than 10 minutes after the previous signature was donated. Most sessions were over a week apart. Data was captured using a conventional graphics tablet (304.8 x 304.8 mm) at a resolution of 500 lines per inch (19.56 lines per mm). The sample rate was 100 Hz, although this was software interpolated to 300 Hz using spline interpolation techniques. Storing the sample data as a series of time-stamped coordinates enables the constructional aspects of signature production to be assessed alongside conventional 'completed signature' image.

3. Features

A series of features were automatically extracted from the signature data. These features were categorised as either *static* (pertaining to the outcome of the signature, i.e. data directly measured from the completed signature image) or *dynamic* (timing aspects of signature construction). The majority (18) of the features were static enabling an analysis of measurements conventionally made by human examination. In addition to these, 4 dynamic features were extracted to enable an investigation as to signature repeatability is replicated in construction as well as outcome. The features are detailed below:

- **Pixel Centroid – X and Y** (Static) – two separate features containing the mean *x* and *y* plane position of all signature pixels (pixels forming the signature ink).
- **Number of Pixels Within Loop** (Static) - the number of pixels within a fully enclosed loop as part of the signature.
- **Loop Pixel Centroid – X and Y** (Static) – two features containing the mean *x* and *y* plane position of all loop pixels.
- **Pen Travel Distance** (Static) - total distance in mm traveled by the pen in forming the signature. Calculated by summing the Euclidean distance between pairs of sample points.
- **Signature Height/Width** (Static) – two features containing the height and width of signature in pixels.
- **Width/Height Ratio** (Static) - ratio of signature height to width.
- **Vertical Centre Crossings** (Static) - the number of times the pen crosses the y plane pixel centroid.
- **Invariant Moments** (Static) - 8 separate shape descriptors.
- **Average Pen Velocity – X and Y** (Dynamic) - pen travel velocity (in mm s^{-1}) in the x and y plane. Third order, four coefficient polynomial modeling was used to obtain a derivative of displacement at each coordinate point
- **Signature Execution Time** (Dynamic) - the execution time (in seconds) to draw the signature.
- **Pen Lifts** (Dynamic) - the number of times the pen was removed from the tablet during the execution time not including the final pen lift at the end of the signature.

While many of the features are self-explanatory, some of the more complex features are described in detail below:

3.1. Pixel Centroid (X and Y)

The pixel centroid feature sums the signature pixel positions in an individual plane and calculates the mean value of these positions, thereby locating the 'centre point' of the signature. Separate centroids are calculated for the X and Y planes:

$$\text{Pixel Centroid} = \frac{\sum_{p=1}^{n} \text{Pixel coordinate in particular plane at } (p)}{n}$$

where n = number of signature pixels

3.2. Number of Pixels Within Loop

This feature calculates the number of pixels within a signature image that are fully enclosed within an image loop boundary. Fully enclosed pixels are defined as background pixels that cannot be reached by filling in the background from the edge of the image. In the example below, Figure 1a shows the original image, the filled areas in Figure 1b are the fully enclosed pixels and Figure 1c are those pixels with the original image removed. The feature counts the number of filled pixels within this final image.

3.3. Loop Pixel Centroid (X and Y)

Using the centroid calculation described in Section 3.1, these features calculate the centroid of those pixels located within a loop, giving an indication of where loops are located within a signature image.

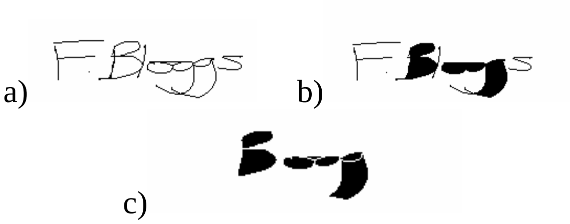

Figure 1: Signature Loop Pixels

3.4. Vertical Midpoint Pen Crossings

This feature calculates the number of times the pen passes through the calculated mean vertical centre of the signature. Two passes are made through the data: Firstly the mean vertical coordinate of all the sample points within the individual signature file is calculated. A second pass through the stream of coordinates is then made counting the number of occurrences of the pen passing through this midpoint. Figure 2 shows an original signature and the calculated vertical midpoint.

Figure 2: Original Signature and Vertical Midpoint Crossing

3.5. Invariant Moments

Invariant moments can be used to provide information about the shape of an image [7]. Moments in binary images can be calculated according to the following formula:

$$M_{pq} = \sum_{x=1}^{R} \sum_{y=1}^{S} x^p y^q f_{xy}$$

where:
R = horizontal size of the image
S = vertical size of the image
p and q = moment orders
f_{xy} = binary values of the pixel at coordinate x, y (1 = background, 0 = signature image).

Table 1 shows the physical interpretation of the 8 moment coefficient combinations that have been extracted from the signature images. Dividing the result of the moment calculation by the value of the zero order moment (M_{00}) ensures that the moment result is invariant to the size of the image.

Central Moment	Physical Interpretation
M_{00}	Number of points comprising image - image "mass"
M_{10}	Sum of horizontal coordinate values
M_{01}	Sum of vertical coordinate values
M_{11}	Diagonality - indication of quadrant with respect to centroid where image has greatest mass
M_{12}	Horizontal divergence - indication of the relative extent of the left of the image compared to the right.
M_{21}	Vertical divergence - indication of the relative extent of the bottom of the image compared to the top.
M_{30}	Horizontal imbalance - location of the centre of gravity of the image with respect to half horizontal extent.
M_{03}	Horizontal imbalance - location of the centre of gravity of the image with respect to half vertical extent.

Table 1: Invariant Moment Descriptions

4. Experiments and Results

Two experiments were conducted, the first to assess feature repeatability and the second to establish the feature characteristics of signatures leading to repeatability.

4.1 Feature Repeatability

Each subject's signature responses were processed in turn with features being automatically extracted from each signature sample. After assessing each of the signature samples within a particular session, a separate Session Coefficient of Variation (Session COV) was calculated for each individual feature using the samples collected *within that session*. In this way it was possible to assess the variation of a particular feature for signatures captured consecutively.

A coefficient of variation (COV) expresses the standard deviation of a dataset as a percentage of the mean value. The magnitude of feature results therefore does not prevent a direct comparison in variation. COV is calculated:

$$\text{COV} = \frac{\text{standard deviation}}{|\text{mean}|} \times 100$$

A low Session COV indicates that a feature is repeatable (similar performance values are extracted) within a particular session whereas a high Session COV shows that variation occurs between signature samples and a feature is not repeatable. To assess if a feature is consistent over a period of time for a particular subject, a Between-Session COV was calculated by examining the results from an individual feature *across* all of a subject's donation sessions. A low Between-Session COV indicates that a feature was consistently repeatable for a particular subject between all sessions (i.e. not varying over time). Two individual measurements were taken from these feature COV calculations across all subjects in the trial to assess of the repeatability of features:

Mean of all Session COVs for a particular feature: A low mean value for this measurement shows that a feature had high repeatability *within* all sessions for all subjects. The results, including the standard deviations, are shown in Table 2. The features in these tables are arranged in rank order of ease of repeatability. As can be seen, the repeatability of individual features varies considerably. It can also be noted that the most repeatable dynamic features have a similar mean of all session COVs as the most repeatable static features.

Mean of all Between-Session COVs for a particular feature: A low mean value for this measurement indicates that a feature is repeatable for all subjects *across* multiple sessions. These results are also shown in Table 2. As can be noted, the performance ranking of these features is almost identical to the mean of all session COVs. These results have implications for uniqueness and signature verification in that is may be expected that a low mean all Subject Between-Session COVs would indicate a characteristic which does not fluctuate between sessions and hence will provide high detection accuracy over a long period of time for all subjects.

4.2 Repeatability Characteristics

In order to explore the characteristics of signatures that result in high feature repeatability over time, the Between-Session COVs for a particular feature from all subjects were ranked and divided into quartiles. Individual subjects were then assigned to one of four repeatability groups for a particular feature according to the where their Between-Session COV fell within the quartiles. Subjects placed in Group 1 were in the lowest quartile and represented the subjects who had the best repeatability across sessions for the particular feature. Groups 2 and 3 represented the middle two quartiles and Group 4 represented those subjects with the most variation for a particular feature (low repeatability). Using these repeatability groupings it was now possible to establish any specific characteristics of a feature that causes high or low repeatability. To enable this analysis, a mean subject feature value (MSFV) was calculated for each separate test subject across all their attempts and sessions for a particular feature. The correlation between the MSFV and repeatability group was calculated. A one-way ANOVA was also conducted individually for each feature using the repeatability groups as the factor and the MSFV as the dependant. Significant differences between groups were investigated using post-hoc Bonferroni correction. Significant differences between groups indicate a trend in feature value which has an effect on repeatability.

Table 3 details the ANOVA results. Significance between two groups show that there were clear differences between the mean feature values as a function of repeatability within that feature. For example, for Signature Height there is a significant difference in mean height between those subjects who produce signatures with highly repeatable height (Group 1) and those subjects whose signature height is highly variable (Groups 3 and 4). 'ns' indicates that the differences were not significant. In this analysis no effects were noted due to number of samples donated or number of sessions attended. The features in Table 4 show a significant linear trend between groups 1 (most repeatable) to 4 (least repeatable). Shown for each feature are the MSFV for the two extreme groups and a comment on the implications of the findings.

5. Conclusions

The work documented in this paper has shown that a range of commonly used features for assessing human signatures have a wide range of repeatability both within a single signature capture session and across multiple sessions. Interestingly, the features generally maintain their rank order of repeatability both within and between sessions indicating a general stability in human signature production. The sizing and positional elements (such as height, width and centroid) seem to more repeatable than shape-based descriptors. In terms of repeatability the majority of the dynamic features performed as well as the standard static forms of evaluation indicating the importance of measuring time and velocity in the evaluation of handwriting systems.

The study has also investigated the particular physical characteristics of individual signatures in order to assess factors for repeatability. Certain attributes of signatures have been shown to contribute significantly to the expected levels of repeatability. The results from the characteristics study give an indication as to the likelihood of a signature being repeatable given a set of physical measurements. An optimal system could therefore be designed that chooses a feature set which best suit the characteristics of the signature under investigation. The findings of this study have direct implications for document forensic analysis as it will reveal which measurement and features are repeatable and hence show those which vary significantly within a person's signature. Equally, this information is relevant to biometric signature analysis systems as it demonstrates normal amounts of variation to be expected within a genuine signature. Not allowing for this variation will lead to such a system reporting many verification errors. Within the work presented in this paper we have not assessed the repeatability of signatures with respect to the outcome of a particular signature verification engine, rather we have assessed some generic and typical signature features. Further work leading from this study will establish if the statistical analysis of repeatability presented in this paper translates into enhanced performance within a conventional signature verification system for particular groups of signers.

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7. References

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Feature	MSFV / Repeatability Group Correlation	Group Significance	Groups 1 and 2 Significance	Groups 1 and 3 Significance	Groups 1 and 4 Significance
Static Features					
Signature Height	0.4672	p<0.001	ns	p<0.001	p<0.001
Vertical Centre Crossings	0.4621	p<0.001	ns	ns	p<0.001
Number of Pixels Within Loop	0.3511	p<0.001	ns	p<0.001	P<0.001
Width/Height Ratio	0.3168	p=0.025	ns	ns	p=0.015
Pixel Centroid – Y	0.2996	p=0.008	ns	p=0.035	p=0.014
Invariant Moments – p1q0	0.2481	p=0.004	p=0.019	ns	p=0.007
Invariant Moments – p2q0	0.2353	p=0.001	p=0.018	p=0.001	p=0.003
Invariant Moments – p0q0	0.2068	p<0.001	p=0.007	ns	p<0.001
Signature Width	0.1947	p<0.001	p=0.003	p=0.001	p<0.001
Invariant Moments – p3q0	0.1838	p=0.002	p=0.024	p=0.005	p=0.011
Pen Travel Distance	0.1744	p=0.012	ns	ns	p=0.009
Invariant Moments - p0q1	0.1617	p=0.022	ns	ns	ns
Loop Pixel Centroid – Y	0.1293	p=0.002	p=0.010	p=0.004	p=0.029
Dynamic Features					
Pen Lifts	0.6050	p<0.001	p=0.012	p=0.001	p<0.001
Average Pen Velocity – Y	0.1849	p=0.006	ns	ns	ns

Table 3: Feature ANOVA results.

Feature	Mean Within Session COVs	Std. Dev. Within Session COVs	Mean Between Session COVs	Std. Dev. Between Session COVs
Static Features				
Loop Pixel Centroid - Y	6.204	3.788	8.437	3.062
Signature Width	6.440	4.010	8.841	3.274
Pen Travel Distance	6.890	4.208	10.101	3.348
Invariant Moments - p1q0	6.927	4.241	9.301	3.656
Pixel Centroid - Y	6.933	4.246	9.303	3.658
Invariant Moments - p0q0	7.675	4.431	10.859	3.396
Loop Pixel Centroid - X	8.169	4.842	10.699	3.377
Invariant Moments - p0q1	9.016	5.430	11.619	3.852
Pixel Centroid - X	9.061	5.473	11.665	3.864
Signature Height	9.957	5.953	13.021	4.240
Width/Height Ratio	11.256	6.471	13.889	4.075
Invariant Moments - p1q1	12.199	6.998	16.651	5.322
Vertical Centre Crossings	14.998	10.747	18.176	8.217
Invariant Moments - p2q1	17.154	10.014	23.997	8.566
Invariant Moments - p3q0	19.314	11.641	26.671	11.311
Invariant Moments - p1q2	20.206	11.594	27.453	8.759
Invariant Moments - p0q3	25.722	15.205	34.618	12.124
Number of Pixels Within Loop	62.743	42.847	83.770	54.956
Dynamic Features				
Signature Execution Time	6.171	4.792	8.557	3.739
Average Pen Velocity - Y	6.561	3.661	8.656	2.386
Average Pen Velocity - X	6.675	4.067	9.072	3.470
Pen Lifts	17.988	27.606	22.330	22.009

Table 2: Mean and standard deviation for all Session COVs and Between Session COVs of individual features.

Feature	Group 1 MSFV	Group 4 MSFV	Comment
Signature Height	15.33mm	10.45mm	*Taller signatures tend to be more repeatable than shorter signatures*
Vertical Centre Crossings	14.46 crossings	10.31 crossings	*Signatures that cross the centre point more often are more repeatable than those that cross less frequently*
Number of Pixels Within Loop	572.25 pixels	109.04 pixels	*Signatures with more loop area are easier to repeat.*
Pixel Centroid – Y	96.27	82.56	*Signatures with a lower Y centroid are easier to repeat*
Signature Width	49.76mm	40.94mm	*Wider signatures are easier to repeat.*
Pen Travel Distance	154.46mm	120.97mm	*Longer signatures are easier to repeat.*
Loop Pixel Centroid – Y	100.30	88.39	*Signatures with a lower loop Y centroid are easier to repeat.*
Pen Lifts	6.7 lifts	2.99 lifts	*The more pen lifts within a signature, the more consistent the signer is in producing these lifts*

Table 4: MSFV group values of significant group performance differences.