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Age dependency in handwritten dynamic signature verification systems

Richard Guest *

Department of Electronics, University of Kent, Canterbury, Kent CT2 7NT, United Kingdom

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Abstract

An assessment of age dependency of biometric dynamic signature verification systems is presented. A number of commonly used features are extracted from multiple signature sample donated by 274 signers. These features are examined for repeatability both within a single signature capture session and between multiple sessions with particular consideration for any performance variation between age groups. Alongside this analysis, an age evaluation of test subjects' ability to enrol/validate on standard systems is presented. Performance is stable across all evaluated age groups proving the ability signature system to be deployed for use within a general population. Some performance features however vary significantly with age in terms of repeatability and mean feature value; characteristics which can be exploited and must be accommodated in the design of systems for use amongst a wide or specific population.

Keywords: Signatures; Handwriting; Age; Features; Biometric systems

1. Introduction

Dynamic signature verification is widely used as a means of biometric authentication and authorisation (Plamondon and Srihari, 2000; Jain et al., 2002). The effectiveness of such systems relies on the repeatability of features extracted from signature samples donated by user and matched against a template formed from previously collected data. These features relate to both the outcome of the signature (shape, size, etc.) and constructional aspects such as time, pen velocity and pressure.

Active research in the field of automatic signature verification can be seen to be concentrated, at the technological level, on two main strands: firstly the development of signature measurement features and novel methods of assessing the physical and constructional properties of a signature. Reported techniques within this first strand include pen direction and distance encoding, velocity and dynamic profiling, signature shape features, force and pressure characteristics and spectral and wavelet analysis. Studies have also analysed features derived from classical assessment of signatures from the forensic community. Secondly, the development of methods for selecting and combining feature measurements and verifying/identifying signature ownership. Other studies have assessed feature vector composition and stability for interoperability (Vielhauer and Steinmetz, 2004; Elliott, 2001; Guest, 2004). Techniques within this strand of research include multiple classifier structures and decision fusion algorithms, PCA, neural networks, probabilistic classification, dynamic time warping/matching and hidden Markov modelling. Important studies have also focussed on issues such as enrolment strategies, template storage and update, forgery assessment, and so on (see, for example, Plamondon and Srihari, 2000).

The majority of both publicly reported and commercial signature verification systems rely on both off-line data (features extracted from the completed 'image' of the signature) *and* on-line data (features extracted from the constructional aspects of signature production) for enrolment and verification. Although off-line features are implemented in most systems, work solely using off-line data

* Tel.: +44 1227 823717; fax: +44 1227 456084.
E-mail address: r.m.guest@kent.ac.uk

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within the field has been mainly focussed on applications of character/word recognition and document based signature analysis (for example cheque processing). Off-line signature systems have been developed, however, using both direct physical characteristics (such as signature shape descriptors) and also by implementing techniques used within the document forensics field for inferring pen stroke direction and speed.

Traditional signature verification systems have used graphic tablet devices to capture data in a pen position (X/Y) and pressure format at a constant sampling frequency. Over the last five years, signature verification systems have also found a use in securing mobile devices such as PDAs and mobile phones. Other recent device developments include a number of systems which collect data from accelerometers mounted in a pen which remove the need for a fixed capture surface (Martens and Claesen, 1997). Also, additional signal types for online signature verification such as pen altitude and pen azimuth signals have been explored for signature verification (Hangai et al., 2000). As mobile and 'novel' devices become more prevalent, addressing the issues of verification on these platforms will become an even greater focus of research—collecting and verifying samples on a non-standard interface introduce further questions of usability and algorithmic performance optimisation which need to be fully explored.

As the use of biometric systems becomes more widespread then the concepts of Universal Access must be applied in that certain user populations should not be prevented from using particular technologies. A number of studies have investigated handwriting/drawing performance in elderly subjects using both *on-line* and *off-line* performance features (Plamondon and Srihari, 2000). Mergl et al. (1999) investigated the aging effects of on-line handwriting and drawing finding that there were differences in normal writing production with younger subjects writing with higher velocity and with more fluidity in their writing process (less changes in pen velocity). Other studies (Ketcham et al., 2003; Morgan et al., 1994) have supported these findings in relation to target location and shape drawing, respectively. Studies have investigated the stability of other biometric modalities as a function of age and have highlighted problems in terms of feature presence within an elderly population that cause difficulties for conventional systems for devices such as fingerprint, hand geometry and face (Jiang and Ser, 2002; Liu and Silverman, 2001).

In the context of using signatures as a biometric, it is important to assess if these reported variations amongst a population affect the performance of a standard system. As biometric systems rely on accurately matching a templates and donation signature it is also important to establish if variations occur between both multiple samples and multiple signature sessions for an individual as a function of age. In designing a system any differences in standard features values across a range of ages should be accounted for.

This study aims to investigate these questions using signature samples donated by a large subject group over a wide age range. In particular we assess the ability of all age ranges to produce stable and consistent signatures both within a single signing session and over multiple sessions separated by a period of time replicating the capture and storage of a template and verification against that template at a later stage. We also investigate the ability of groups of different ages to enrol and verify using standard dynamic signature verification systems. In this study it is important to note that we are not assessing the technology rather the ability of all age groups to use the system's capability. Finally we also present typical (alongside minimum and maximum) characteristics of feature values with significant group differences within each age range.

2. Methodology

Three experiments were conducted to assess the stability of signatures as a function of age. All three experiments were conducted using a common data set of signatures collected from members of the general public. Two hundred and seventy four subjects (97 male/177 female, 24 left/250 right normal signing hand) were included in the study donating a total of 6765 signatures. The number of signatures donated by each subject varied from 10 to 79 (mean of 24.7). The majority of the subjects exhibited no health problems that would affect signature production however 18 subjects wore glasses or other sight correction aid while 17 further subjects exhibited a range of medical problems that would possibly affect signature production (such as hand usage or complex sight problems). These subjects were not removed from the study as they are representative of a general population using a biometric system. Subjects were divided into three age groupings allowing analysis of age characteristics whilst imposing anonymity on the data samples. Table 1 details the number of subjects in each group.

Subjects were asked to donate several signatures at their first visit and invited to donate further signatures during subsequent visits to the test centre. All subjects in this trial donated 10 or more signature samples over two or more visits (or *sessions*)—*the first session containing at least seven signatures*. A different session was defined as being more than 10 min after the previous signature was donated with most sessions taking place over a week apart. Data was captured using a conventional graphics tablet

Table 1
Distribution of the sample population by age group

Group	Age range	Number of subjects	Number of signature samples
1	26–40	67	1495
2	41–60	119	2934
3	Over 60	88	2336

(304.8 × 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. Other than this temporal interpolation no other pre-processing was applied to samples. Subjects were asked to sign their normal signature in a bounding box measuring 70 × 25 mm with three of these boxes printed on a single sheet of paper overlaid on the graphics tablet. Subjects started and stopped the capture process by positioning the pen on 'start' and 'stop' active areas on the tablet surface.

2.1. Experiment 1—intra and between session stability

The aim of this experiment was to assess the stability of common features across a range of age groups. A series of global features (features measuring performance over the entire signature as opposed to a localized area of interest) were automatically extracted from the signature data (Table 2). Features defined in this study were inspired by a number of common implementations described in the literature (Lee et al., 1996; Kashi et al., 1998) and were included to assess common methods of signature evaluation. Global features were used as they are able to give an indication of general performance variation between signatures without the need for accurate and repeatable localization methods. These extracted features were categorised as either *static/off-line* or *dynamic/on-line.* Twenty five of the features were dynamic alongside eight static features enabling an analysis of measurements conventionally made by human examination and off-line systems. The dynamic features enabled an investigation to establish if signature repeatability is replicated in construction as well as outcome.

Each subject's signature responses were processed in turn with features being automatically extracted from each signature sample. After assessing all of the signature samples within a particular session, a separate intra-session coefficient of variation (*Intra-Session COV*) was calculated for each individual feature using the samples collected *within that session*. A coefficient of variation (COV) expresses the standard deviation of a dataset as a percentage of the mean value. In this way the magnitude of feature results do not prevent a direct comparison in variation. COV is calculated:

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

Table 2
Implemented features

Feature identifier	Static or dynamic	Description
AVXV	Dynamic	Average velocity in the X plane
AVYV	Dynamic	Average velocity in the Y plane
CENTCROSS	Static	Number of vertical midpoint crossings in signatures
DIST1	Static	Total pen travel writing distance/signature area
DOTS	Dynamic	Number of pen down samples
DUR1	Dynamic	Duration when velocity in the X plane > 0/total pen down duration
DUR2	Dynamic	Duration when velocity in the X plane < 0/total pen down duration
DUR3	Dynamic	Duration when velocity in the Y plane > 0/total pen down duration
DUR4	Dynamic	Duration when velocity in the Y plane < 0/total pen down duration
FIRSTMOM	Static	First-order moment
INITDIR	Static	$(X_{\max} - X_{\min})/(Y_{\max} - Y_{\min})$
POSCENT	Static	Vertical midpoint—$Y_{\min}/(Y_{\max} - Y_{\min})$
PU	Dynamic	Number of pen ups within signature
SECTIME1	Dynamic	Time of second pen down/total signing duration
SIGDIST	Static	Signature length
TIME1	Dynamic	Total pen down duration/total signing duration
TIME2	Dynamic	Time of max pen velocity/total pen down duration
TIME2SIGN	Dynamic	Total pen down duration
TIME3	Dynamic	Time of max velocity in the Y plane/total pen down duration
TIME4	Dynamic	Time of min velocity in the Y plane/total pen down duration
TIME5	Dynamic	Time of max velocity in the X plane/total pen down duration
TIME6	Dynamic	Time of min velocity in the X plane/total pen down duration
VEL1	Dynamic	Mean velocity/maximum velocity
VEL2	Dynamic	Minimum velocity in the X plane/average velocity in the X plane
VEL3	Dynamic	Minimum velocity in the Y plane/average velocity in the Y plane
VEL4	Dynamic	First instance of velocity $\neq 0$
VEL5	Dynamic	Average velocity/maximum velocity in the X plane
VEL6	Dynamic	Average velocity/maximum velocity in the Y plane
VELCOR	Dynamic	Correlation between velocities in the X and Y planes
VELXZERO	Dynamic	Total number of samples when velocity $= 0$ in the X plane
VELYZERO	Dynamic	Total number of samples when velocity $= 0$ in the Y plane
XSIZE	Static	$X_{\max} - X_{\min}$
YSIZE	Static	$Y_{\max} - Y_{\min}$

A low intra-session COV indicates that a feature is repeatable (similar performance values are extracted) within a particular session whereas a high intra-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). Significant differences between age groups for their intra and between-session COVs were assessed using a Kruskall–Wallace non-parametric test (*K*-independent samples). This method uses sample value ranking in order to overcome problems with outlying values and sample size imbalances.

2.2. Experiment 2—system enrolment and validation

To assess practical usability a second experiment was conducted whereby collected samples were used to enrol and verify individuals on two standard commercial dynamic signature verification systems selected to be representative of deployed biometric solutions in everyday use. As the sole aim of this experiment was to assess the usability factors of typical systems across a range of subject age groups signature system were treated as 'black-boxes' in that the internal methods for signature enrolment and verification were ignored.

To perform this analysis, the signature database was divided up into separate enrolment and verification sets. To enrol a test subject on the first commercial system seven signature samples from a single capture session formed the enrolment set for each subject. A total of 1918 signatures (seven for each subject) were used in the enrolment phase. The first six signatures were used to form the template and a seventh used for an internal consistency check by the verification system determining whether a template could be formed and hence a person enrolled on the system. The second system used three signatures to form a template (822 signatures used for enrolment). As with the first system a variance check was conducted to assess a valid formation of a template.

Successfully enrolled subjects were then verified using their remaining samples. In the first system a total of 4847 signatures were used in the validation phase. The number of samples in the verification sets varied from 3 to 72 for individual test subjects. In the second system 5943 signatures were used in the validation phase (number of samples varying from 7 to 76).

2.3. Experiment 3—feature value analysis

As a third experiment individual feature results were analysed to establish if there are any quantifiable differences in signature production as a function of age—the results of this experiment being largely of interest to systems developers establishing performance limits and characteristics to enable system usage amongst a wide population. Feature results from all 6765 signature samples were analysed in this experiment. Differences between pairs of age groups were investigated by Mann-Whitney *U* non-parametric test (2 independent samples).

3. Results

The results of the three experiments are presented below:

3.1. Experiment 1

Table 3 shows in alphabetic feature order, the significant (at the 0.05 level) between and intra-session COV differences for the three age groups using the Kruskall–Wallis non-parametric analysis. The results indicate that 20 of the features show stability in producing signatures between and within sessions across all age groups. Repeatability can be examined in more detail by assessing Table 4 which shows the mean and standard deviation COV values for each of the three groups for those features with significant differences. Key points which can be ascertained:

- As the majority of features were not significant it can be concluded that there is standard performance variation both within and between signature sessions indicating the usefulness of signatures as a biometric across a range of age defined populations.
- For those features that did produce significant differences in variation across ages these occurred more with sessions than between sessions. This can be attributed to the smaller sample size within each session.
- Assessing the mean values of features causing significantly different variation (Table 4—again in alphabetic feature order), features relating to timing and movement dynamics indicate that as the age of the population

Table 3
Significant differences for within and between session COVs

Feature	Between session χ^2	Between session significance	Intra session χ^2	Intra session significance
AVYV	7.688	0.021	NS	NS
CENTCROSS	6.174	0.046	13.588	0.001
DIST1	NS	NS	8.500	0.014
DUR1	NS	NS	17.680	<0.001
DUR4	NS	NS	6.181	0.045
PU	9.599	0.008	18.446	<0.001
TIME1	13.941	0.001	28.315	<0.001
TIME3	6.240	0.044	10.993	0.004
VEL1	NS	NS	9.699	0.008
VEL3	7.754	0.021	NS	NS
VEL5	10.396	0.006	27.660	<0.001
VEL6	NS	NS	11.390	0.003
VELCOR	15.228	<0.001	89.561	<0.001

NS = not significant.

Table 4
Significant COV difference features for within and between session COVs

Feature	Age group	Between session mean value	Between session value standard deviation	Between session mean COV value	Between session COV standard deviation	Within session mean value	Within session value standard deviation	Within session mean COV value	Within session COV standard deviation
AVYV	1	653.05	276.13	9.07	2.59	NS	NS	NS	NS
	2	610.50	267.55	8.79	2.27	NS	NS	NS	NS
	3	587.89	189.01	8.06	1.96	NS	NS	NS	NS
CENTCROSS	1	13.74	5.46	16.55	8.59	13.72	5.76	14.09	10.38
	2	12.26	4.79	18.44	8.53	12.02	4.80	15.46	11.98
	3	12.50	4.20	19.43	7.43	12.55	4.43	16.00	9.89
DIST1	1	NS	NS	NS	NS	0.0008	0.0008	10.03	5.80
	2	NS	NS	NS	NS	0.0007	0.0007	10.73	6.38
	3	NS	NS	NS	NS	0.0007	0.0007	9.78	5.88
DUR1	1	NS	NS	NS	NS	0.20	0.07	9.24	6.94
	2	NS	NS	NS	NS	0.18	0.08	11.00	8.11
	3	NS	NS	NS	NS	0.20	0.06	9.67	6.86
DUR4	1	NS	NS	NS	NS	0.35	0.06	6.02	3.90
	2	NS	NS	NS	NS	0.33	0.06	6.76	4.75
	3	NS	NS	NS	NS	0.32	0.06	6.39	4.27
PU	1	4.33	2.72	28.10	26.36	4.43	2.71	22.89	30.48
	2	4.99	2.87	23.29	25.85	4.95	2.83	19.67	33.01
	3	5.53	2.78	17.01	9.64	5.37	2.75	14.79	19.25
TIME1	1	1.25	0.19	4.61	2.70	1.27	0.22	3.70	3.53
	2	1.30	0.17	5.87	4.72	1.30	0.18	4.30	4.81
	3	1.35	0.17	6.14	2.98	1.33	0.17	4.58	3.93
TIME3	1	0.46	0.17	56.08	28.08	0.46	0.22	51.14	39.01
	2	0.46	0.16	58.42	25.30	0.47	0.21	50.86	33.14
	3	0.41	0.13	64.27	26.12	0.41	0.19	56.51	36.32
VEL1	1	NS	NS	NS	NS	0.31	0.06	16.25	10.62
	2	NS	NS	NS	NS	0.29	0.06	18.30	11.44
	3	NS	NS	NS	NS	0.28	0.05	17.08	10.85
VEL3	1	0.52	0.17	9.16	2.75	NS	NS	NS	NS
	2	0.57	0.21	8.83	2.29	NS	NS	NS	NS
	3	0.55	0.17	8.08	2.01	NS	NS	NS	NS
VEL5	1	0.39	0.09	20.83	9.23	0.39	0.10	18.29	12.25
	2	0.38	0.10	25.21	8.96	0.38	0.11	22.58	13.74
	3	0.36	0.09	24.45	9.47	0.36	0.10	21.26	13.14
VEL6	1	NS	NS	NS	NS	0.44	0.12	17.95	12.56
	2	NS	NS	NS	NS	0.42	0.20	20.25	12.70
	3	NS	NS	NS	NS	0.39	0.09	19.62	12.74
VELCOR	1	2.23E+08	3.48E+08	47.85	25.72	2.38E+08	3.60E+08	39.05	31.39
	2	2.28E+08	4.71E+08	51.30	36.97	2.38E+08	5.17E+08	41.27	33.31
	3	2.41E+08	2.53E+08	36.02	23.07	2.48E+08	2.49E+08	27.73	24.89

NS = not significant.

increases a decrease in pen velocity and acceleration is noted along with an increase in drawing times. Allied with this time increase is an increase in variance both within and between sessions. It can be concluded that slower and less-repeatable drawing times are a function of age.

- Whilst pen velocities and accelerations are slower there is no correlation between age and performance variance.
- The number of 'pen-ups' increased in number but decreased in variation (i.e. more stability) as the population aged.

3.2. Experiment 2

Table 5 shows the number of cases in each group who were able to enrol using the two signature systems. As

Table 5
Subjects successfully enrolling on system

Age group	System 1 pass (%)	System 2 pass (%)
1	80.60	97.01
2	76.47	97.48
3	72.72	95.45

Table 6
Verification rates

Age group	System 1 Level 1 (%)	System 1 Level 2 (%)	System 1 Level 3 (%)	System 1 Level 4 (%)	System 1 Level 5 (%)	System 2 overall (%)	System 2 static (%)	System 2 dynamic (%)
1	95.36	92.81	89.33	82.95	82.83	65.20	98.32	68.53
2	92.82	89.66	86.81	82.72	82.48	63.06	98.25	66.18
3	97.37	95.13	93.30	90.02	89.86	68.68	96.78	66.18

can be seen the majority of cases in each group were able to enrol. There were no significant (at the 0.05 level) differences between the age groups ($p = 0.399$ for system 1, $p = 0.713$ for system 2) in the ability to enrol on the system which again highlights the ability of all age groups to use signature verification systems.

To confirm usability, the templates formed in the enrolment phase were used in the verification of the remaining signature samples for each subject. The first system used in this study has five matching thresholds which determine the template matching score that is required for a signature to be verified successfully. Level 1 is the lowest threshold (allowing a greater variance between template and sample) ranging to Level 5. Table 6 shows the verification rates of each age group for each of the 5 levels for the 211 subjects *successfully enrolling on the system*. As with the enrolment study no significant differences were found between the ability of each group to verify on any of the threshold levels. Table 6 also shows the results of the second system which provided separate verification results using static, dynamic and combined features. Again, no significant differences in performance between groups were noted showing the stability of representative signature systems across a multi-age population. These results provide success rates for enrolment and verification (100%—false reject rate). False acceptance rates are not reported as trials were not conducted on imitation or impostor usage.

3.3. Experiment 3

Features that produced significant (at 0.05) group differences in mean feature values in the third experiment are shown in Table 7. A subset of those features which showed repeatability issues also showed differences between the mean features results across the age groups. Details of mean values and standard deviations are shown in Table 8.

From a dynamic perspective the results verify those of Experiment 1 in terms of trends in pen lifts, timings and velocities providing an insight into the range of values that have to be considered when designing signature capture systems. Feature range for some of the non-significant features also produces some interesting observations: Signature height shows a maximum of 40 mm across all signatures; a characteristic that needs to be observed when designing capture areas in order to prevent restricted use. Within the dynamic features, the longest execution time observed was 13.7 s. Again capture systems must be able to cope with this length of data stream.

Table 7
Mean feature values significant group differences

Feature	1 vs 2 Significance	1 vs 3 Significance	2 vs 3 Significance
DIST1	0.04	0.01	NS
DUR4	0.01	<0.01	NS
PU	NS	<0.01	NS
TIME1	0.03	<0.01	NS
TIME3	NS	NS	0.04
VEL1	<0.01	<0.01	NS
VEL6	0.01	0.00	NS
VELCOR	NS	0.02	<0.01

NS = not significant.

Table 8
Mean feature values of significant group differences

Feature	Age group	Mean	Std. deviation	Minimum	Maximum
DIST1	1	7.773E−04	2.902E−04	3.157E−04	2.148E−03
	2	7.147E−04	2.426E−04	2.877E−04	2.751E−03
	3	6.849E−04	2.140E−04	2.645E−04	1.633E−03
DUR4	1	0.347	0.063	0.145	0.498
	2	0.329	0.065	0.120	0.561
	3	0.322	0.061	0.169	0.498
PU	1	4.446	2.798	0	17
	2	4.930	2.933	0	19
	3	5.386	2.818	0	23
TIME1	1	1.270	0.218	1.000	2.384
	2	1.302	0.201	1.000	3.448
	3	1.340	0.188	1.000	2.187
TIME3	1	0.462	0.303	0.001	1.000
	2	0.474	0.299	0.001	1.000
	3	0.415	0.284	0.001	1.000
VEL1	1	0.311	0.081	0.038	0.547
	2	0.290	0.082	0.027	0.537
	3	0.278	0.073	0.017	0.480
VEL6	1	0.439	0.152	0.074	1.440
	2	0.421	0.227	0.065	3.640
	3	0.388	0.116	0.061	1.209
VELCOR	1	2.33E+08	3.61E+08	4.17E+04	2.15E+09
	2	2.38E+08	5.34E+08	4.51E+03	6.93E+09
	3	2.42E+08	2.56E+08	1.54E+04	3.37E+09

4. Conclusions

This study can be seen to have shown two essentially apposing outcomes both of which emphasise the strength of signatures systems deployed across an adult population. The first observation is that there were no significant differences between the ability for all age groups to enrol and verify on standard dynamic signature verification systems and that no age group is disadvantaged in using such a system. In assessing the repeatability through performance variation of a range of standard features the majority (20 out of 33) showed no difference between age groups. These findings indicate that signature performance, in terms of reproducibility, does not differ with age. Furthermore, it has been shown that all age groups are able to repeat standard features within signatures both within and between signing sessions.

The second observation is in contrast to this finding of universality in that there are a number of features that do show instability as a function of age. This study has shown that feature relating to execution time and pen dynamics such as velocity and acceleration exhibit clear differences between age groups. The feature value experimentation has revealed performance characteristics that must be considered when designing systems for the capture of biometric data.

Further work in this area will explore characteristics of features that produce stability and enhanced enrolment ability, enrolment prediction scores from feature characteristics and further user group stability assessment.

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