A Multi-expert System for Dynamic Signature Verification

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Abstract. This paper presents a multi-expert system for dynamic signature verification. The system combines three experts whose complementar behaviour is achieved by using both different features and verification strategies. The first expert uses shape-based features and performs signature verification by a wholistic analysis. The second and third expert uses speed-based features and performs signature verification by a regional analysis. Finally, the verification responses provided by the three experts are combined by majority voting.

1 Introduction

The use of electronic computers in gathering and processing information on geographic communication networks makes the problem of high-security access basically important in many applications. For this purpose, several systems for automatic personal verification can be used [1]:

- physical mechanisms belonging to the individual (i.e. key or badge);
- information based systems (i.e. password, numeric string, key-phrase);
- personal characteristics (i.e. speech, finger-print, palm-print, signature).

Among others, personal characteristics are the most interesting since they cannot be lost, stolen or forgotten. Moreover, signature is the common form used for legal attestation and the customary way of identifying an individual in our society, for banking transactions and fund transfers. Therefore, automatic signature verification is of great interest also for commercial benefits due to the wide range of applications in which signature verification systems can be involved.

Signature is the result of a complex process based on a sequence of actions stored into the brain and realised by the writing system of the signer (arms and hands) through ballistic-like movements. More than other forms of writings, signatures of the same person can be very different depending on both physical and psychological condition of the writer: *short–period variability* is evident on a day-to-day basis, it is mainly due to the psychological condition of the writer and on the writing conditions

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(posture of the writer, type of pen and paper, size of the writing area, etc.); *long-period variability* is due to the modifications of the physical writing system of the signer as well as of the sequence of actions stored in his/her brain [2].
Therefore, the development of signature verification systems is not a trivial task since it involves many biophysical and psychological aspects related to human behaviour as well as many engineering issues [3, 4, 5].

Recently, many important results have been achieved toward a deeper understanding of the human behaviour related to hand-written signature generation [6,7,8], and several powerful tools (dynamic time warping [9], propagation classifiers [10], neural networks [11, 12]) and emerging strategies (regional-oriented comparison strategy [13], multi-expert approach [14,15]) have been successfully applied to signature verification [16,17].

In this paper, a new system for dynamic signature verification is presented. The system combines three experts for signature verification. The first expert uses shape-based features and performs signature verification by a wholistic analysis. The second and third expert uses speed-based features and performs signature verification by a regional analysis. Each stroke of the segmented signature is processed individually and its genuinity is verified. Successively, the verification responses for the entire set of strokes are averaged to judge the genuinity of the input specimen. The verification responses provided by the three experts are finally combined by majority voting.
The paper is organised as follows: Section 2 describes the process for signature verification. The architecture of the new system for signature verification is presented in Section 3. Section 4 presents the three experts for signature verification and the rules for decision combination. The experimental results are presented in Section 5.

2 The Process of Signature Verification

Figure 1 shows the main phases of the signature verification process [16]. The first phase concerns with the acquisition of the input signature. If on-line signature are considered, data acquisition is performed by graphic tablets or integrated graphic-tablet displays. The second phase concerns preprocessing, whose aim is to remove noise and to prepare the input data for further processing. In this phase, the segmentation of signature into basic components and strokes is performed, depending on the particular strategy used for signature comparison. In the feature extraction phase, relevant features for the verification aims are extracted from the preprocessed signature. In the comparison phase, the extracted features are used to match the input signature and the reference specimens. The result is used to judge the authenticity of the input signature. Two types of errors can occur in signature verification: type I errors (false-rejection) caused by the rejection of genuine signatures, and type II errors (false-acceptance) caused by the acceptance of forgeries [16,17].

The information in the reference database (RD) about signatures of the writers enrolled into the system plays a fundamental role in the process of signature verification and must be carefully organised. RD is generally realised during controlled training sessions according to two main approaches. The first approach is based on the selection of an average prototype of the genuine signatures together with additional information about writer variability in signing. [18]. The second approach uses as reference information one or more genuine specimens. Even if this approach implies time-consuming verification procedures it is more suitable for modelling the singular process of signing whose nature is extremely variable [9].

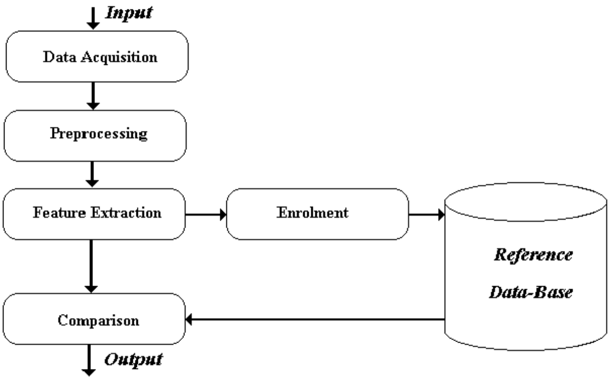

Fig. 1. The process of Signature Verification.

3 Strategies for Signature Comparison

In the comparison phase, the test signature S^t is compared against the N^r reference signatures S^r, r=1,2,...,N^r which are available in the reference database. This phase produces a single response R which states the authenticity of the test signature:

$$R = \begin{cases} 0 & \text{iff} \quad \text{the test signature is a forgery} \\ 1 & \text{iff} \quad \text{the test signature is genuine.} \end{cases}$$

In order to face the enormous variability in hand-written signatures, different strategies for signature matching have been used. They can be classified into two main categories: [16]: *wholistic* and *regional*.

➢ Wholistic matching. In this case the test signature S^t , considered as a whole, is matched against each one of the N^r reference signatures $S^1, S^2,...,S^{N^r}$. Of course this approach does not allow any regional evaluation of the signature. In fact, each matching of S^t with S^r produces the response R^r:

$$R^r = \begin{cases} 0 & \text{iff} \quad S^t \text{ results a forgery when compared to } S^r \\ 1 & \text{iff} \quad S^t \text{ results genuine when compared to } S^r. \end{cases}$$

Then, the final response R is defined as:

$$R = \begin{cases} 0 & iff \quad \forall\, r = 1,2,\dots,N^r \;:\; R^r = 0 \\ 1 & otherwise. \end{cases}$$

➢ <u>Regional matching</u>. In this case both the test signature S^t and the reference signature S^r are split into n segments (S^t_1, $S^t_2,\dots,S^t_k,\dots,S^t_n$) and ($S^r_1,S^r_2,\dots,S^r_k,\dots,S^r_n$), respectively. The matching between S^t and S^r is performed by evaluating the local responses R^r_k obtained by matching S^t_k against S^r_k, for k=1,2,...,n:

$$R^r_k = \begin{cases} 0 & \text{iff} \quad S^t_k \text{ results a forgery when compared to } S^r_k \\ 1 & \text{iff} \quad S^t_k \text{ results genuine when compared to } S^r_k. \end{cases}$$

This approach allows a regional analysis of the signature, but it is carried out in a one-by-one comparison process: i.e. the test signature is judged to be a genuine specimen if and only if a reference signature exists for which, in the comparison process, a suitable number of segments of the test signature are found to be genuine.

An improved regional strategy for signature comparison is the *multiple regional* [13,14,16]. In this case each segment S^t_k of the test signature is matched against the entire set of the corresponding segments (S^1_k, S^2_k, ...,$S^{N^r}_k$) of the N^r reference signatures $S^1,S^2,\dots,S^{N^r}$. Therefore for each segment S^t_k of the test signature, a local verification response R^t_k is obtained as:

$$R^r_k = \begin{cases} 0 \;\text{iff}\; \forall r = 1,2,\dots,N^r : S^t_k \text{ results a forgery when compared to } S^r_k \\ 1 \;\text{otherwise.} \end{cases}$$

The test signature is judged to be a genuine specimen if a suitable number of segments are found to be genuine. This approach allows a regional evaluation of the signature without requiring a large set of reference signatures [16].

4. A Multi-expert System for Signature Verification

The system for signature verification presented in this paper is based on a multi-expert verification procedure which combines the responses of three experts by majority voting. The experts differ in terms of both strategies for signature comparison and feature type. The first expert performs a wholistic analysis of the signature by evaluating the effectiveness of the segmentation procedure. Shape-based features are used for this purpose. The second and third expert performs signature verification by a regional analysis based on speed-based features. A multiple regional matching strategy is adopted for this purpose. In the following the three experts are described and the combination rule is illustrated.

4.1 The First Expert (E1)

The first expert evaluates the genuinity of the test signature by the analysis of the segmentation results. For the purpose, a recent segmentation technique based on a dynamic splitting procedure is used [19]. It segments the test signature according to the characteristics of the reference signatures. The segmentation procedure consists of four steps.

❖ First, the procedure detects the local maxima (CSP^{MAX}) and minima (CSP^{MIN}) in the vertical direction of the signatures. These two sets of points are considered as Candidate Splitting Points (CSP) and a simple procedure is adopted to identify the points of CSP^{MAX} and CSP^{MIN} for the splitting. In the following we discuss the procedure for the set CSP^{MAX} (the procedure for CSP^{MIN} is similar). Figure 2a shows three reference specimens S^1,S^2,S^3 and a test signature S^t. The $CSPs^{MAX}$ are marked with “*”.

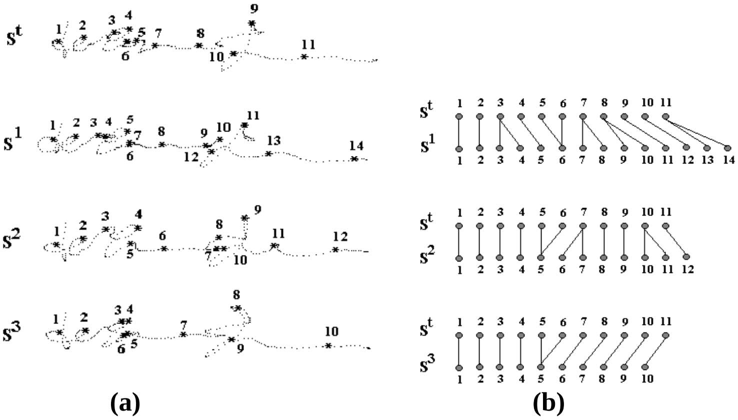

Fig.2. Matching between test and reference signatures

❖ In the second step, the procedure determines the warping function between the $CSPs^{MAX}$ of each reference signature and those of the test signature which satisfies the *monotonicity*, *continuity* and *boundary* conditions [20], and which minimises the quantity

$$D = \sum_{k=1}^{K} d(c_k),$$

where $c_k=(i_k,j_k)$, (k=1,2,…,K) is the sequence of indexes coupling $CSPs^{MAX}$ of the reference and test signature, and $d(c_k) = d(z^r(i_k), z^t(j_k))$ a distance measure in the representation space of the signatures. Figure 2b shows the best coupling sequences for the signatures in figure 2a.

❖ In the third step, the sequence of indexes $c_k=(i_k,j_k)$, k=1,2,…,K, is used to detect the CSPs^{MAX} of the reference and test signatures that are directly matched; i.e. that are one-by-one coupled [19]. Table 1 reports the set of CSP^{MAX} directly matched to points of the test signature (see Figure 2b).

Table 1. Set of CSP^{MAX} directly matched

1st Reference Signature	1,2,3,4,6,7,8,9,10
2nd Reference Signature	1,2,3,4,8,9,12
3rd Reference Signature	1,2,5,11,12

❖ In the fourth step the CSPs^{MAX} of the test signature that are always directly matched to all the reference signatures are used to segment the test and the reference signatures.

Table 2. Set of splitting points.

Test Signature	1	2	4	9
1st Reference Signature	1	2	4	8
2nd Reference Signature	1	2	4	9
3rd Reference Signature	1	2	5	11

For instance, the CSP^{MAX} number 1,2,4 and 9 of S^t are always directly matched to points of S^1, S^2 and S^3. Therefore the CSP^{MAX} number 1,2,4 and 9 are the splitting point for the signature S^t. The corresponding splitting points for S^1,S^2,S^3 are reported in Table 2.

On the basis of the segmentation results, the expert computes the following index to evaluate the genuinity of the test signature:

$$R_1 = \frac{\text{Number of splitted strokes of the test signature}}{\text{Number of Candidate Splitting Points of the test signature}} .$$

The verification rule is the following:

- if $R_1<T^1_1$ then: Test signature = "False"
- if $T^1_1 \le R_1 \le T^1_2$ then: Test signature = "Rejected"
- if $T^1_2<R_1$ then: Test signature = "Genuine"

where T^1_1 and T^1_2 are two personal thresholds (different from writer to writer) detected from analysis of the minimum and maximum value of the index R_1 for the set of genuine specimens.

4.2 The Second Expert (E2)

The second expert adopts a multiple regional verification strategy and an elastic matching procedure for the verification of each segment of the test signature. The authenticity of each stroke of the test signature is evaluated by matching the stroke against the corresponding stroke of each reference signature. In our system, a speed-based dissimilarity measure is used to match couple of genuine specimens S^r and S^t:

$$D = \sum_{k=1}^{K} d(c_k)$$

where $d(c_k) = d(z^r(i_k), z^t(j_k))$, and $v^r(i_k)$ and $v^t(j_k)$ is the velocity of the tip of the pen (computed from the displacement vectors) of the signatures S^r and S^t, at points i_k and j_k, respectively. The stroke is considered a genuine sample if and only if the least value of the dissimilarity measure is lower than the regional threshold which is the worst dissimilarity measure obtained by matching all the pairs of coupled strokes of the reference signatures [9,19]. This procedure provides the vector of local verification responses for the strokes of the test signature $(R^t_1, R^t_2, \ldots R^t_{Nt})$ where, for each stroke S^t_k, the local verification response R^t_k is:

$$R^r{}_k = \begin{cases} 0 \text{ iff } \forall r = 1,2,..., N^r : S^t{}_k \text{ results a forgery when compared to } S^r{}_k \\ 1 \text{ otherwise.} \end{cases}$$

From the vector of local verification responses, the second expert computes the index:

$$R_2 = \frac{\text{length of genuine strokes of the test signature}}{\text{length of the test signature}} .$$

The verification rule is the following:

- if $R_2 < T^2_1$ then: Test signature = "False"
- if $T^2_1 \leq R_2 \leq T^2_2$ then: Test signature = "Rejected"
- if $T^2_2 < R_2$ then: Test signature = "Genuine"

where thresholds T^2_1 and T^2_2 are detected from analysis of the range of variability of R_2 for set of genuine specimens.

4.3 The Third Expert (E3)

The vector of the local verification responses $(R^t_1, R^t_2, \ldots R^t_{Nt})$ is also used by the third expert. The verification index for this expert is:

$$R_3 = \frac{\text{Number of genuine strokes of the test signature}}{\text{Number of strokes of the test signature}} .$$

The verification rule is the following:

- if $R_3 < T^3_1$ then: Test signature = "False"
- if $T^3_1 \leq R_3 \leq T^3_2$ then: Test signature = "Rejected"
- if $T^3_2 < R_3$ then: Test signature = "Genuine"

also in this case the threshold values T^3_1 and T^3_2 are detected from analysis of the range of variability of R_3 for set of genuine specimens.

4.4 The Combination Criterion (E-MV)

The decisions of the three experts are combined by majority voting [15,16]:
- if at least two decisions are "genuine" the final response is "genuine";
- if at least two decisions are "false" the final response is "false";
- otherwise the final response is "rejected".

5 Experimental Results

For the experimental phase, fifteen writers have collected the genuine signatures and other fifteen persons have produced the forged samples in daily writing sessions. In each session, the writer has had about ten minutes to practice himself with the electronic tablet and five minutes to affix up to five signatures. The forgers attended the writing sessions and training themselves in imitating the genuine signatures. After enrolment, for each writer a database of fifty genuine signature and fifty forgeries were available. All specimens have been suitably normalised [19]. Five additional genuine specimens have been collected for each writer and used to find out the optimal set of three specimens for reference, according to a correlation-based analysis on the local stability [21,22].

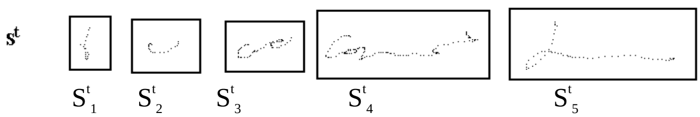

Fig.3. Verification result of a test signature

Figure 3 reports a test signature (genuine signature of writer #1). For this specimen the system provide the correct result since the verification responses of the three experts are:
⇒ (E1) (global analysis) Verification Response=G
⇒ (E2) (regional analysis) Verification Response=G
⇒ (E3) (regional analysis) Verification Response=G
(The local responses for E2 and E3 are: S^t_1=**G**; S^t_2=**F**; S^t_3=**G**; S^t_4=**G**; S^t_5=**R)**.

Table 3a. Verification responses: signer #1 - genuine signatures

n.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
E1	G	R	F	G	G	G	G	G	R	G	G	G	G	G	G	G	F	G	G	G	G	R	G	G	G	G	R	G	G	G	G	F	F	G	G	G	G	R	G	G	G	R	G	G	G	G	G	G	G	G
E2	G	G	F	G	G	R	G	G	G	G	G	G	G	G	G	G	G	G	G	G	F	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	F	G	G	G	G	G	R	G	F	G
E1	G	G	G	G	G	G	G	R	G	G	G	G	G	G	G	R	G	G	G	G	F	G	G	G	F	G	G	G	G	G	G	G	G	G	G	G	G	F	G	G	G	G	G	G	G	G	G	G	F	G
E-MV	**G**	**G**	**F**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**F**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**R**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**G**	**F**	**G**

Table 3b. Verification responses: signer #1 - false signatures

n.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
E1	F	F	F	F	G	F	F	R	R	F	F	F	F	R	R	R	F	F	F	F	F	F	F	G	F	F	F	F	F	G	F	G	F	F	F	F	F	F	F	F	F	R	F	G	F	F	F	F	R	R
E2	F	F	F	F	F	F	F	F	G	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	G	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
E1	F	F	F	F	F	F	F	F	G	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	R	F	F	R	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
E-MV	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**G**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**R**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**

The verification responses for signer #1 are reported in Table 3a (genuine signatures), and 3b (forgeries). This result shows to what extent the three expert are complementary. Precisely, E2 and E3 agree more times (88/100) than E1 and E2 (72/100), and E1 and E3 (71/100). In fact, E2 and E3 use speed-based features while E1 uses shape-based features and a different comparison strategy.

For the 15 writers, the performances for E1 are Type I Error = 5.1%, Type II Error = 0.75%, Rejection = 7.2%; for E2 are Type I Error = 4.5%, Type II Error = 1.05%, Rejection = 6.5%; for E3 are Type I Error = 5.7%, Type II Error = 0.95%, Rejection = 6.2%. When the decisions of the three experts are combined, the performances are reported in Table 4. The net result is Type I Error=3.2%, Type II Error=0.55%, Rejection=3.2%.

Table 4. System Performance

Signer	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**	**#12**	**#13**	**#14**	**#15**
Type I	6%	4%	4%	0%	2%	6%	2%	4%	2%	4%	0%	4%	2%	4%	4%
Type II	2%	0%	2%	0%	0%	0%	0%	2%	0%	2%	0%	2%	0%	0%	0%
Rejection	4%	2%	4%	2%	4%	2%	2%	4%	8%	2%	4%	2%	2%	2%	4%

6 Conclusion

A multi-expert system for dynamic signature verification is presented in this paper. The system combines three experts by majority voting. The experts are based on different features and verification strategies. Complementarity among experts has been achieved by different feature sets and classification strategies. The first expert uses shape-based features and performs signature verification by a wholistic analysis. The second and third expert uses speed-based features and performs signature verification by a regional analysis.

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