PERGAMON

Pattern Recognition 32 (1999) 1821–1823

PATTERN RECOGNITION
THE JOURNAL OF THE PATTERN RECOGNITION SOCIETY

Fusion of correlated decisions for writer verification

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Received 26 February 1999; accepted 9 March 1999

1. Introduction

In this paper a method is proposed for improving the reliability of signature verification systems [1] by means of a short handwritten sentence (Fig. 1). Fusion techniques are employed for this purpose. Increased verification efficiency is achieved since the writers' handwriting is taken into consideration. In the experiments a five-word sentence was used for writer verification. A computationally simple feature was selected to represent each word in the feature space [2]. From each word in the sentence a decision is derived using single hypothesis testing (local decisions). The local decisions are then combined by means of a decision fusion algorithm (DFA) in order to obtain the final and more reliable decision (global decision). The local decisions were correlated, since they resulted from words written by the same person containing similar line attributes. The degree of correlation among the decisions affects the verification efficiency at the DFA [4,5]. A very small discrimination error can be obtained at the DFA, depending on the operating points of the local decisions (probability of false alarm and probability of detection) as well as the number of words in the sentence. Simulation results describe the dependence of this error on the number of words in the sentence as well as the correlation among the decisions.

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2. The database

A large database was constructed for experimentally testing the proposed method. The developed database consists of two different short sentences, one written in Greek and the other one in English. Twenty writers were requested to write down each sentence 120 times. Consequently, 4800 sentences were recorded containing a total of 24 000 words. To the knowledge of the authors no other database, freely available in the Internet, was found suitable for testing the proposed fusion procedure.

3. Word-level decision

A granulometic feature vector was employed for word representation [2]. It contains spatial information about the orientation of the line segments in a handwritten pattern. A specific word sample is classified either as genuine (H_1) or forger (H_0) by means of single hypothesis testing, since the class H_0 is generally considered unknown and time variant [3]. Typically, we measure the distance y of a sample $\mathbf{x}$ from the mean M_1 of the class H_1 (normalised by the class covariance matrix C_1) according to equation

$$y = \{(\mathbf{x} - \bar{M}_1)C_1(\mathbf{x} - \bar{M}_1)^{\mathrm{T}}\}^{1/2}. \quad (1)$$

Classification of the unknown feature vector $\mathbf{x}$ involves the selection of two suitable thresholds y_1 and y_2 ($y_1 < y_2$) to decide upon the validity of either H_1 or H_0 [3]:

$$\begin{aligned} &H_1: \quad y_1 < y < y_2 \quad (u_i = 1),\\ &H_0: \quad \text{elsewhere} \quad (u_i = 0). \end{aligned} \quad (2)$$

PII: S0031-3203(99)00061-8

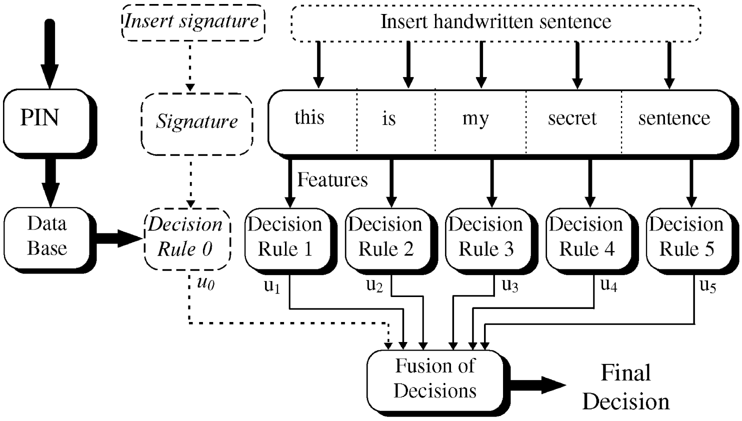

Fig. 1. The proposed system architecture.

The hard decisions $u_1, i = 1, \dots, 5$, extracted for all five words of each sentence form the decision vector U.

4. Fusion of decisions

The optimal combining scheme for the DFA, when the local decisions u_i are provided along with their correlation, is the randomized Neyman–Pearson (N–P) approach [5]:

$$\theta(U) = \begin{cases} 1 & \text{if } T(U) > t \\ \eta & \text{if } T(U) = t \\ 0 & \text{if } T(U) < t \end{cases} \quad \text{with} \quad T(U) = \frac{P_1(U)}{P_0(U)}, \tag{3}$$

where $\theta(U)$ corresponds to the final decision and expresses the probability of accepting the presence of a writer (H_1), given that the DFA observes U. $P_j(U)$ is the probability of U under hypothesis $H_j, j = 0, 1$. The randomization constant η and the threshold t must be chosen so that the overall system probability of detection and false alarm satisfies the N–P criterion $\{P_F \leqslant \beta$ and $P_D \geqslant \max_i(P_{d_i})\}$, where β is a pre-specified upper bound for the P_F. It is proven that the selection of the threshold t as well as the randomization constant η are determined by the following relations [5]:

$$t = \begin{cases} T(U_i) & \text{if } \lambda_i \leqslant \beta \leqslant \lambda_{i-1} \\ 0 & \text{if } \beta = 1 \end{cases}$$

and

$$\eta = \begin{cases} \dfrac{\beta - \lambda_i}{P_0(T(U) = t)} & \text{if } \lambda_i \leqslant \beta \leqslant \lambda_{i-1}, \\ \text{arbitrary} & \text{if } \beta = 1, \end{cases} \tag{4}$$

where λ_i are pre-calculated constants. The expression of $T(U)$ is obtained by means of the Bahadur–Lazarsfeld expansion series [4]:

$$T(U) = \frac{\prod_{i=1}^{5} p_{d_i}^{u_i}(1 - p_{d_i})^{1-u_i}\left[1 + \sum_{i<j}\gamma_{ij}^{1} z_i^1 z_j^1 + \sum_{i<j<k}\gamma_{ijk}^{1} z_i^1 z_j^1 z_k^1 + \cdots + \gamma_{12\dots5}^{1} z_1^1 z_2^1 \cdots z_5^1\right]}{\prod_{i=1}^{5} p_{fa_i}^{u_i}(1 - p_{fa_i})^{1-u_i}\left[1 + \sum_{i<j}\gamma_{ij}^{0} z_i^0 z_j^0 + \sum_{i<j<k}\gamma_{ijk}^{0} z_i^0 z_j^0 z_k^1 + \cdots + \gamma_{12\dots5}^{0} z_1^0 z_2^0 \cdots z_5^0\right]}, \tag{5}$$

where the set $\{\gamma\}$ represents the correlation coefficients and z_i are the normalized decision variables. Estimation of the parameters γ was experimentally carried out using the local decisions u_i and resulted in considerable values only for the second-order coefficients.

A correlation index ρ^j was employed [5] to represent the second-order correlation parameters γ_{ik}^{j}. Experimental results carried out for the entire group of writers and both sentences showed that the correlation index ρ^j is relatively low (< 0.3), with mean value 0.15, which was used to represent the correlation among the decisions u_j. The verification efficiency at the DFA was examined by means of its operating characteristics (the total probability of detection vs. the total probability of false alarm) with the correlation index ρ^j as a parameter. It was shown that the increase in the index ρ^j results in a linear decrease in the overall system efficiency. The discrete nature of the fusion procedure provides an adequate number of operating points at the DFA.

5. Experimental results

The performance of the decision fusion algorithm (DFA) was experimentally tested using our database along with simulated data. Firstly, half of the words in the database were used for cluster formation (training), while the rest were used for local decision making. In Table 1 the corresponding overall verification results from the DFA are provided. The DFA yields an improved verification performance regarding the overall probabilities of miss and false alarm. For the Greek sentences the total verification error was found to be 0.97%, whereas for the English ones this error amounts to 0.53% due to the longer words contained.

The simulated data comprise 10 000 decision vectors U with various local operating points (P_{fa_i} and P_{d_i}) and correlation index. Table 2 demonstrates the effect of the correlation index ρ on the final performance of the DFA for two different local operating points. The improvement in the P_D is better for smaller ρ. From Table 3 it is obvious that for the same global P_F the corresponding probability of miss $(1 - P_D)$ is improved when the number of words increases.

Table 1
Verification results at the DFA from three Greek (G) and English (E) writers

Writer no.	Minimum P_{fa_j}	Maximum P_{d_i}	Overall P_{FA}	Overall P_D
1G	0.046	0.983	0.000	1.000
2G	0.119	0.933	0.030	0.985
3G	0.013	0.983	0.003	0.990
1E	0.038	0.983	0.000	1.000
2E	0.083	0.967	0.011	0.995
3E	0.035	0.950	0.018	0.991

Table 2
The effect of correlation index on the performance of the DFA for five words in the sentence

	$P_{fa_i} = 0.1$ $P_{d_i} = 0.9$		$P_{fa_i} = 0.05$ $P_{d_i} = 0.95$	
ρ^j	P_F	P_D	P_F	P_D
0.0000	0.0086	0.9914	0.0012	0.9988
0.1000	0.0280	0.9720	0.0060	0.9940
0.2000	0.0454	0.9526	0.0109	0.9891
0.3000	0.0510	0.9370	0.0158	0.9842

Table 3
The performance of the DFA for different number of words, and the same local operating points ($P_{fa_i} = 0.1$ and $P_{d_i} = 0.9$) and correlation index $\rho = 0.3$

No. of Words	P_F	P_D
3	0.04	0.9310
5	0.04	0.9602
7	0.04	0.9877
9	0.04	0.9910

6. Conclusions

Using the proposed decision fusion method, security systems based on signatures can gain further reliability in writer verification. This is achieved by means of a short handwritten sentence. The words of the sentence are used separately to derive decisions about the authenticity of the writer, and are then fused for achieving higher verification performance. The correlation of the local decisions affect the overall system performance.

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