Signature Verification via "Hand-Pen" Motion Investigation

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Abstract: *A new signature based authentication approach is described, where signing clips are analyzed. Using a web-camera a series of frames is acquired that allows investigating the dynamics of the complex "hand-pen". For this a set of features describing the hand, pen and their mutual disposition at the time of signing is derived. The preliminary experimental results have confirmed the applicability of the approach.*

Keywords: *Image Processing, Signature, Feature Extraction, Verification, Classification*

1. INTRODUCTION

The signature has been and is still used as a principal mean for person authentication. This is due to the comparative stability of the graph and of the movement dynamics stemming from the stereotype built in the years. For this reason two major paradigms have been brought to life, known as *off-line* and *on-line* signature authentication.

The *off-line* mode is based on the evaluation of similarity in the graphs of compared signatures [1, 2, 4, 5, 7, 9]. Thus, it omits completely or uses insufficiently the important dynamics information. Another serious deficiency of this approach concerns the case of skillful forgeries, which are difficult to detect.

The *on-line* approach assumes a specific writing device that reads the pen's coordinates and may submit information about the applied pressure as well. This allows the graph and dynamics to be simultaneously analyzed [3, 6, 8, 10]. Since it is difficult to imitate dynamics, it is believed that this approach will be more resistant to forgeries. The non-standard way of signing, however, may cause deviations in the signature parameters and increase the errors. While the two above-mentioned approaches encompass both the signature graphics and dynamics, there is one more aspect of the writing process that might be of interest for the authentication problem. This concerns the hand position and parameters, pen orientation and its relevant position to the hand during the signing, i.e. the behavior of the complex "hand-pen". This aspect is briefly described in the paper and some preliminary results are reported. To the best of our knowledge, such investigation, where interconnected parameters, but of different character, reflecting the individual features of the signing subject, has not been carried out. An interesting approach based on the pen tip tracking is described in [11].

The paper is organized in the following way: in section 2 some preprocessing and segmentation steps are presented; section 3 describes feature extraction; section 4 introduces the decision-making rule; section 5 contains some experimental results; in section 6 some problems are discussed and the possibilities for further extension are outlined.

2. PREPROCESSING AND SEGMENTATION

The proposed method is based on image sequence processing. A web-camera placed above the desk captures images of size 320x240 pixels during the signing and records them in AVI file format. Depending on the signature length the series may contain between 100 and 200 frames. For further processing, videos are divided into frames in BMP format.

Detection of the signature's start and end points

To detect the start and end points of a signature, a subtraction of an empty frame from each frame in the series is used. The obtained differences are plotted in Fig. 1. The graph shows that when the hand enters the camera's view field the difference rises

sharply, then oscillates during the signing and diminishes with the hand's outdrawing. Calculating the gradient of the graph provides an easy detection of the "plateau" and thus of the beginning and the end of the signature.

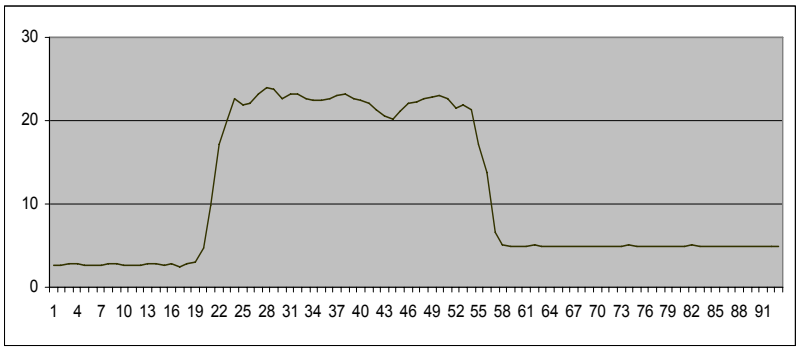


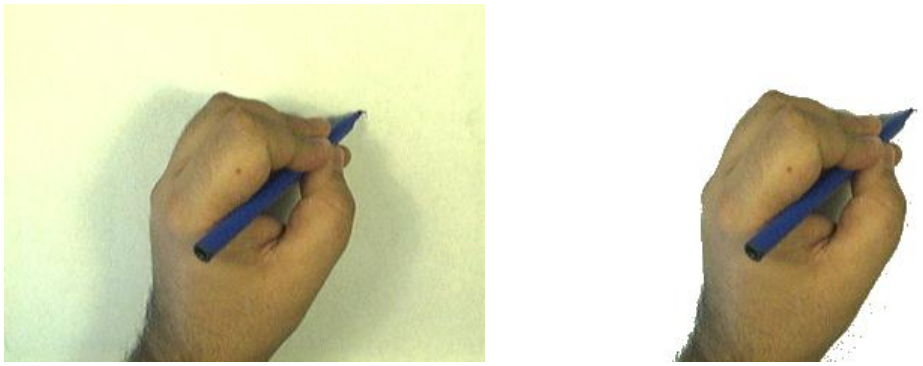
Fig.1. Graph of the absolute differences between consecutive frames and an empty frame during the signing

At this initial step, one of the possible features characterizing the subject can be obtained – the signature duration in number of frames.

The experiments carried out [12] have shown satisfying precision in the signature start and end points detection. Variations of no more than 2 frames have been observed.

Object detection

The complex "hand-pen" is the object that we are interested in. Its detection is simplified to a large extent because of the constant and uniform background. This allows a good separation using the difference between the current frame and the reference background image. After this operation, some "salt and pepper"- type noise could be noticed in the image (Fig.2b), but it could be easily removed using morphological or heuristic techniques.



a) b)

Fig.2. a) Original image; b) background subtracted

Hand – pen segmentation

For the analysis of the hand and pen movement, a separation of the two elements is required. This provides the possibility to estimate their mutual position in each frame and its variation during the sequence. To facilitate the task, a blue color pen is used which makes good contrast with the predominant skin color (red with blue and green tinges) and the sheet of white paper. The use of the "red/blue" relation in the pixels leads to a good separation of the hand from the pen (Fig. 3).

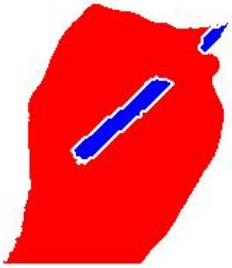


Fig.3. Separation of the pen from the hand

3. "HAND-PEN" SYSTEM FEATURES EXTRACTION

The essential authentication features include hand characteristics and movement, pen position and mutual hand-pen disposition. The hand features relate to its color and contour geometry. As a general color feature, the average values of the pixels of the hand can be used. This may help the person's race determination. It is also possible to use color properties in different parts of the hand directly for verification purposes. The features representing the hand geometry are extracted from the contour line as described further.

Hand contour extraction

As seen from Fig. 3 the upper contour line *K* used in this study could be easily detected scanning columns until the first red pixel from above is met. To avoid accidental noise or spurs, the line is smoothed using [-3, +3] curvilinear interval.

The slope angle *α* of the line *l: y = ax + b*, that approximates *K* the best way in the sense of minimal mean-square deviation, could be used as a general characteristic of the hand contour. *a* and *b* are evaluated minimizing the sum

$$S = \sum_{x=0}^{M-1} [y - (ax + b)]^2 \qquad (1)$$

where (x, y) $\in$ *K* and *M* is the contour points number.

For different frames this line will be different because it depends on the hand position, on the way it holds the pen and on its movement while signing.

Extraction of geometric features

The geometric features are extracted using the characteristic points of the hand contour. End points and points of curvature larger than a predefined threshold are assumed as "characteristic". End points are easily detected because they coincide with the beginning and the end of the contour. For the other point detection, evaluation of the curvature *c* is required. Different techniques could be used for this. To simplify the calculations, we have used the following formula

$$c = \frac{\left|\overline{PP_{-q}}\right|\left|\overline{PP_{+q}}\right|}{\left|\overline{P_{-q}P_{+q}}\right|} \qquad (2)$$

where *P* denotes the current point, and P_{-q} and P_{+q} are the points remote *q* points far from *P* in both directions. Different geometric parameters of the obtained polygon like perimeter, area or distances from its centre to specific points could be measured.

Pen features

The pen position could be described by the angle *γ* of its tilt towards the plane and the angle *β* of its projection in the plane. Since the pen length *l* is fixed, the first angle may be easily determined by the ratio of the projection length *l'* to *l*. To determine *β* and *l'* we

have to determine the major axis of the pen. For this its center (C_x, C_y) is evaluated first. After that the characteristic equation

$$|\Sigma - \lambda I| = 0, \tag{3}$$

where Σ is a covariance matrix and *I* is the unitary matrix is solved, the largest value λ_1 is determined and β is evaluated according to the formula

$$\beta = arctg\left(-\frac{\mathrm{cov}_{11} - \lambda_1}{\mathrm{cov}_{12}}\right). \tag{4}$$

To determine the angle γ, a straight line of angle β is drawn through the center (C_x, C_y) and the distance *l'* between the utmost pixels from the pen coinciding with the straight line is evaluated. γ is obtained from the equation

$$\gamma = \arccos(l' / l). \tag{5}$$

Hand-pen relative position

The mutual position of the hand and pen may be evaluated from their geometric parameters in the frames. The following approaches seem to be reasonable.

a) The difference $\delta = \alpha - \beta$ between the angles of the straight lines described above.

b) The distances between the pen center and hand contour. For this a straight line perpendicular to the pen's longitudinal axis and passing through the center (C_x, C_y) is used. The distances $r_1(C, H_1)$ and $r_2(C, H_2)$ between the two points of intersection H_1 and H_2 of that line and contour are evaluated (Fig. 4).

4. AUTHENTICATION

The described in **3** set of features have to be measured for each individual whose signing has to be verified. Some of the features like skin color are single-valued and could be used straightforwardly for the verification. The others depend on the movement and will have values varying within the series. For the latter the mean value vectors $\boldsymbol{m}_i$ and covariance matrices $\boldsymbol{S}_i$ could be evaluated for each individual and used for the evaluation of the squared Mahalanobis distance

$$R_i(\boldsymbol{x}) = (\boldsymbol{x} - \boldsymbol{m}_i)^t \boldsymbol{S}_i^{-1} (\boldsymbol{x} - \boldsymbol{m}_i) \tag{6}$$

between the current signing $\boldsymbol{x}$ and the *i*-th individual from the data base (*i* = 1,2,…,N).

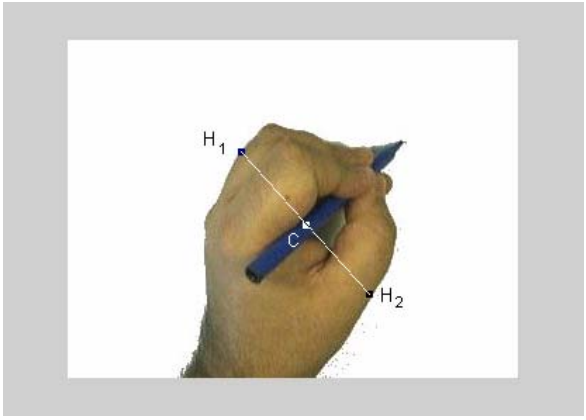


Fig. 4. Distances between the pen and hand contour

5. EXPERIMENTAL RESULTS

To test the described approach, 10 volunteers have taken parts in the experiments. 6 of them were right-hand writers, the other four used their left hand. 10 signatures have been acquired from each of them in different days and at different time of the day. In this study the following 8 features have been measured and used for the evaluation of $\boldsymbol{m}_i$ and $\boldsymbol{S}_i$: 1) signature duration *d* as a number of frames, 2) hand slope *α*, 3) pen projection angle *β*, 4) pen slope *γ*, 5) difference $\delta = \alpha - \beta$, 6) ratio r_1 / r_2 of the distances between the pen centre and hand contour, 7) perimeter *p* of the polygon defined by the characteristic points of the upper hand contour, and 8) area of the polygon. The feature "skin color" was not used because all the volunteers were from the same race.

Testing was carried out in the following ways.

1. *Simulation*. Using the mean values, covariance matrices and Matlab's random number generator, 1000 signatures have been simulated for every volunteer. Classification was carried out according to the formula (6). An average error rate of 0.31% was obtained. The maximal values of the false-positive and false-negative errors in percent were 1.2 and 0.6, respectively.

2. *Secure verification*. It is interesting to evaluate the 100% secure threshold for every participant. To do this, the same simulated signatures were used and the minimal distance

$$R_{i,\min} = \min_{x \ false \ positive} (R_i(\boldsymbol{x})) \tag{7}$$

was evaluated for *i* = 1,2,…,10. After that 5 more signings have been taken from every individual and processed. The evaluated distances have been compared to $R_{i,\min}$. This resulted in 16% rejections, 12% of which being genuine signatures.

3. *Unskilled forgeries*. In this test all the participants were asked first: to sign the others without looking at their signatures, and second: sign the others after having a glance at the corresponding signature. This resulted in 100% rejections in both cases.

4. *Skilled forgeries*. In this test one of the participants possessing some experience with signatures was given the possibility to practice. After that he was asked to forge three times the other signatures. As a result 94% of the forgeries were rejected using the evaluated thresholds $R_{i,\min}$.

6. CONCLUSION

A new approach that takes into account the dynamics of the complex "hand-pen" is suggested. It allows evaluating specific parameters of the hand and pen and their mutual position. This set of parameters reflects to some extend the writing stereotype of the individual.

While the acquired source information allows for the extraction of many features of different nature, only a small number of global features and a simple classification rule have been used in the investigation. Depending on the required accuracy more sophisticated local descriptors could be involved and more complicated rules could be suggested.

The preliminary experimental results aimed at the illustration of the approach have shown quite satisfactory results.

The future work will be aimed at the investigation of dynamics of the parameters, i.e. the analysis of their changes within the clips, comparison of the corresponding graphs, evaluation of the features significance and acquisition of more experimental data.

A possible extension of the approach may include different alternatives like: using a tablet instead of paper or capturing signature after signing and processing it in *off-line* mode. Thus, more accurate dynamic and/or static information will be obtained.

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