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A new algorithm for identity verification based on the analysis of a handwritten dynamic signature

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ABSTRACT

Identity verification based on authenticity assessment of a handwritten signature is an important issue in biometrics. There are many effective methods for signature verification taking into account dynamics of a signing process. Methods based on partitioning take a very important place among them. In this paper we propose a new approach to signature partitioning. Its most important feature is the possibility of selecting and processing of hybrid partitions in order to increase a precision of the test signature analysis. Partitions are formed by a combination of vertical and horizontal sections of the signature. Vertical sections correspond to the initial, middle, and final time moments of the signing process. In turn, horizontal sections correspond to the signature areas associated with high and low pen velocity and high and low pen pressure on the surface of a graphics tablet. Our previous research on vertical and horizontal sections of the dynamic signature (created independently) led us to develop the algorithm presented in this paper. Selection of sections, among others, allows us to define the stability of the signing process in the partitions, promoting signature areas of greater stability (and vice versa). In the test of the proposed method two databases were used: public MCYT-100 and paid BioSecure.

1. Introduction

Security of IT systems is related to, among others, effective identity verification of system users. This verification may be performed using various methods based on: (a) something you have (e.g. chip card), (b) something you know (e.g. password), (c) something you are (e.g. biometric features). The third approach is the most convenient for people whose identity is verified and the most difficult to forge for potential forgers. Therefore, it is very interesting and it creates possibilities for the development of new solutions. The biometric features used in this approach are divided into two categories: (a) physiological – related to the construction of the human body (e.g. fingerprint, iris, hand geometry, face) and (b) behavioural – related to the human behaviour (e.g. signature, gait, keystrokes). A handwritten signature occupies a special place among behavioural characteristics, its acquisition is not controversial and it is commonly socially acceptable.

In the literature there are two main approaches to signature analysis. The first one uses so-called static (off-line) signature and it is based on an analysis of geometric features of the signature, such as shape and size ratios, etc. (see e.g. [1–6]). The other approach is based on an analysis of the dynamics of signing process and it uses so-called dynamic (on-line) signature. Some authors have also presented a methods based on both these approaches (see [7,8]). The most commonly used signals, which are the basis of the dynamic signature analysis, are pen pressure on the tablet surface and pen velocity. Velocity signal is determined indirectly on the basis of pen position signals on the tablet surface. The dynamic signature verification is much more effective than the static one because: (a) dynamics of signing is a very individual characteristic feature of the signer, (b) it is difficult to forge, (c) waveforms describing the dynamics of the signature (even if you have them) are difficult to translate into the process of signing, but they are relatively easy to analyse. It should also be emphasized that the algorithms for the analysis of the dynamic signature can be relatively easily used in other areas of application in the field of biometrics, which are based on the analysis of dynamic behaviour (see e.g. [9,10]).

In the literature there are four main approaches to the dynamic signature analysis: (a) global feature-based approach (see e.g. [11–15]), (b) function-based approach (see e.g. [16–21]), (c) regional approach (see e.g. [22–29]) and (d) hybrid approach (see e.g. [30–32]). Among these approaches to the dynamic signature analysis, the methods based on signature regions are very interesting and effective. In the literature in this field one can find, among others, new methods of selection of the signature regions characteristic of the signer, new ways of interpretation of these signature regions and new ways of signature classification based on selected regions. Many authors use Hidden Markov Models (see e.g. [25]). Other authors propose ways of classification adapted to their methods. In [26] signatures are segmented into strokes and for each of them the reliability measure is computed on the basis of the feature values which belong to the current stroke. In [27] a stroke-based algorithm that splits velocity signal into three bands has been proposed. This approach assumes that low and high-velocity bands of the signal are unstable, whereas the medium-velocity band is useable for discrimination purposes. A more detailed review of the literature on the dynamic signature verification has been presented in our previous papers (see e.g. [22,23]).

Our experience with different methods for the dynamic signature verification based on the regional approach induced us to prepare the method presented in this paper. In [23] we propose a method which determines the importance of each time moment of signing process individually for each signer. The method takes into account stability of signing in the considered time moments. The stability is determined using reference signatures. In our other paper i.e. [22] we propose a method,

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Table 1
Main characteristics of the algorithms for the on-line signature verification based on regional approach (**f1** – Does the method allow to select partitions of signature associated with the time of signing process in order to increase accuracy of signature verification? **f2** – Does the method allow to select partitions of the signature associated with the dynamics of signing process in order to increase accuracy of signature verification? **f3** – Does the method focus on fast performance? **f4** – Does the method evaluate the stability of the signature in selected parts of the signature? **f5** – Does the method take into account a hierarchy of selected parts of the signature in the classification process? **f6** – Is a given way of classification interpretable?).

Characteristic of the method	f1	f2	f3	f4	f5	f6
Khan et al. [27]	no	**yes**	no	**yes**	no	no
Ibrahim et al. [34]	no	**yes**	no	**yes**	no	no
Fierrez et al. [25]	**yes**	no	no	no	no	no
Huang and Hong [26]	no	**yes**	no	**yes**	**yes**	no
Faúndez-Zanuy, Pascual-Gaspar [24]	**yes**	no	**yes**	no	no	no
Pascual-Gaspar et al. [28]	**yes**	no	**yes**	no	no	no
Zalasiński, Cpałka [35]	no	**yes**	no	**yes**	**yes**	no
Cpałka et al. [23]	no	**yes**	no	**yes**	**yes**	**yes**
Cpałka, Zalasiński [22]	**yes**	no	no	**yes**	**yes**	**yes**
Our method	**yes**	**yes**	no	**yes**	**yes**	**yes**

which allows one to select some typical areas in the signature of the user, created as a result of an analysis of pen velocity and pen pressure signals. These areas are associated with high and low pressure and high and low velocity. The proposed methods work with high accuracy and they also have several other important advantages (determination of weights of areas, taking into account all the regions and their weights in the signature verification, signature classification based on the fuzzy classifier), so we have decided to develop a new method that would be a combination of those two methods. Initial attempts to introduce this method are outlined in [33]. However, the algorithm presented in the mentioned paper required an iterative determination of the so-called border of inclusion of reference signatures. In this paper we managed to eliminate this procedure and thus greatly simplify evaluation of the similarity of test signatures to their reference signatures. Thanks to this fact, the system to evaluate the similarity of test signatures to their reference signatures is a full one-class classifier. Moreover, interpretation of the partitions selected by the method described in [33] is different from the interpretation in the algorithm proposed in this paper and the partition analysis in the mentioned method is less precise. Different interpretation of the partitions resulted in the need to change the work of the algorithm in every step. Thus, the algorithm for signature verification proposed in this paper is a new one, which has not been presented in the literature so far.

The following features (see Table 1) distinguish the proposed method from the others:

- It uses fuzzy sets and fuzzy systems theory in evaluation of the similarity of test signatures to their reference signatures. Character of such similarity is not precise and it is difficult to describe it using the classical theory of sets and two-valued logic. In the proposed method we used "high similarity" and "low similarity" fuzzy sets to describe similarity values (see [36]). Next, we formulated fuzzy rules and we used approximate inference. Thanks to this we obtained a complete fuzzy system used in the phase of the test signature verification. In the rules description the system takes into account the weights of importance of selected partitions.
- It allows to interpret the knowledge accumulated in the system used for signature verification. These possibilities result from the fact that: (a) The construction of the fuzzy rules takes into account interpretability criteria of the clear fuzzy rules described in the literature (e.g. in [37]). (b) For all signers we used consistent structure of the fuzzy classifier, in which only the values of the rules' parameters change, but the reasoning scheme remains unchanged. (c) Input and output signals of the fuzzy classifier and the parameters of its rules have a specific interpretation, referring to the similarity of test signatures to their reference signatures. Thanks to this, the parameters (i.e. the parameters of membership functions and importance weights of the rules) can be determined analytically and the system does not require a learning process.
- It selects partitions of the signature which have the following interpretation: high and low velocity in the initial, middle and final time moments of signing, high and low pressure in the initial, middle and final time moments of signing.
- It determines values of weights of importance for each partition. Weights values are proportional to the stability of reference signatures in the partitions. Thanks to this, the proposed method uses all partitions in the evaluation of signature similarity (with varying intensity).
- It bases on four types of signals: a shape signal of the trajectory x, a shape signal of the trajectory y, a pressure signal of the pen z and a velocity signal of the pen v. They are available as a standard for graphics tablets: the first three of them are acquired directly from the graphics tablet and the velocity is the first derivative of a signature trajectory. Various types of tablets may have different sampling frequency, so in this case acquired signals are subject to the standard normalization procedure. In addition, the signatures should be pre-processed using other standard methods to match their length, rotation, scale and offset.
- It allows to flexibly adjust a set of signals describing the dynamics of the signature to specific areas of application and hardware capabilities. There are two most common variants of the method. The first assumes that a graphics tablet is used in the training phase and in the verification phase. In this case the precision of the proposed method is the highest, because the signals describing not only the shape of the signature, but also its dynamics, are used in both phases. The second variant assumes that in the training phase the graphics tablet is available and in the verification phase we have a stand-alone (not connected to the computer) device with a touch screen (e.g. a smartphone, a tablet, etc.), from which it is impossible to obtain information about the pen pressure. In this case, the partitions are determined in the training phase on the basis of velocity and pressure. Verification phase takes into account only the shape of the signature. In the description of the method we took into account the second variant, assuming that in the signature verification phase the signals describing the dynamics of the signature may not be available. Obviously, in practice there may be also indirect modes of action (e.g. based on the generation of velocity trajectories in the training phase without knowing the pressure trajectory or using the angle of the pen to the tablet surface during the signing process), but the proposed method can be adapted to each of them.

In summary, the proposed new algorithm for identity verification based on the analysis of a handwritten dynamic signature is mainly characterized by new definition of the dynamic signature features (so-called hybrid partitions of the dynamic signature), new way of their processing and use of authorial one-class neuro-fuzzy classifier, whose structure is determined individually for each user without using forged signatures. Due to the above-mentioned mechanisms, the proposed algorithm works very precisely and individually for each user.

To test the proposed method we used two databases of the signatures: public MCYT-100 (see [38]) distributed by the Biometric Recognition Group – ATVS (see [39]) and paid BioSecure (BMDB) distributed by the BioSecure Association (see [40]).

This paper is organized into 4 sections. Section 2 contains a detailed description of the algorithm. The simulation results are presented in Section 3. The conclusions are drawn in Section 4.

2. Detailed description of the algorithm

The proposed algorithm for the dynamic signature verification based on hybrid partitioning works in two phases (see Fig. 1): the training phase (Section 2.1) and the test phase (Section 2.2). In both of them a procedure of signature normalization is performed (see Fig. 2). In this procedure for each user the most typical reference signature, called base signature, is selected. It is one of the reference signatures collected in the acquisition phase, for which the distance to the other reference signatures is the smallest. The distance is calculated according to the adopted distance measure (e.g. Euclidean). Training or test signatures are matched to the base signature using the Dynamic Time Warping algorithm (see e.g. [41–43]), which operates on the basis of matching velocity and pressure signals. The result of matching the two signatures is a map of their corresponding points. On the basis of the map, trajectories of the signatures are matched. Matching by way of using DTW could not be done directly with the use of trajectories, because this would remove the differences between the shapes of the signatures. It would have a very negative impact on training. Elimination of differences in rotation of the signatures is performed by the PCA algorithm which in the literature is commonly used to make image rotation invariant (see e.g. [44]). The scale and offset are compensated by standard geometric transformations. Various normalization techniques are described in detail in the literature, so their description will not be included in this paper (see e.g. [17,34,45,46]).

2.1. Training phase

At the beginning of the training phase partitioning of the reference signatures of each user is realized (Section 2.1.1). Partitions are hybrid because they are created from a combination of vertical and horizontal sections. Vertical sections are time intervals indicating the initial, middle and final phase of signing. Horizontal sections are created in each vertical section. In this process signals describing the dynamics of a signature are taken into account. If