

Dynamic Signature Recognition Based on Modified Windows Technique

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Abstract. The paper presents the method of signature recognition, which is a modification of the windows technique. This windows technique allows comparing signatures with the use of any similarity coefficient, without the necessity of using additional algorithms equalizing the lengths of the sequences being compared. The elaborated method introduces a modification regarding the repeatability of individual fragments of person's signature. Thus signature verification is performed only on the basis of signature fragments, characterized by the highest repeatability. Studies using the proposed modification have shown that it has a higher efficiency in comparison to the standard method.

Keywords: signature recognition, windows technique, similarity measure.

1 Introduction

Biometric techniques are currently among the most dynamically developing areas of science. They prove their usefulness in the era of very high requirements set for security systems. Biometrics can be defined as a method of recognition and personal identification based on physical and behavioural features [1,4,5,12]. Physiological biometrics covers data coming directly from a measurement of a part of human body, e.g. a fingerprint, a shape of face, a retina. Behavioural biometrics analyses data obtained on the basis of an activity performed by a given person, e.g. speech, handwritten signature.

Data collection process within a signature recognition process can be divided into two categories: static and dynamic. The static system collects data using off-line devices [11]. A signature is put on paper, and then is converted into a digital form with the use of a scanner or a digital camera. In this case, the shape of the signature is the only data source, without the possibility of using dynamic data. On the other hand, dynamic systems use on-line devices, which register, apart from the image of the signature, also dynamic data connected with it. The most popular on-line devices are graphics tablets. Thanks to tablets, a signature can be recorded in the form of an n -point set [5,6]. Values of individual features such as: position, inclination, and pressure of a pen are determined in each point. Fig. 1 presents an example of signature S_i .



Fig.1. Sample of signature S_i and its selected points.

When analysing signatures of the same person, it can be noticed that they differ from each other. Certain fragments of signatures are more similar to each other (repeatable) and other ones may differ considerably from one another. Example of such situation is presented in Fig. 2.

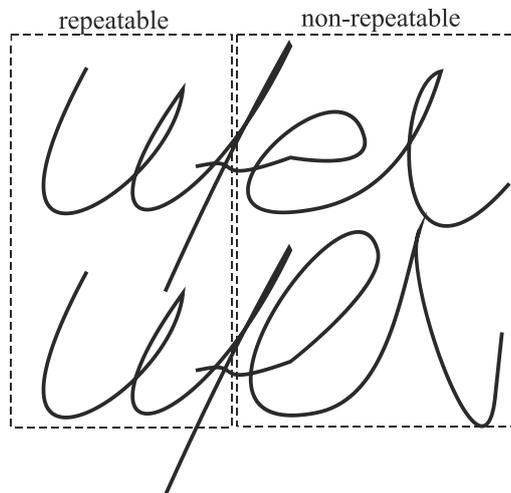


Fig.2. Two signatures of the same person with a repeatable beginning.

Many methods of determining the similarity between signatures require that the signatures being compared have the same length. This requirement is not always fulfilled, since the mentioned earlier differences between the signatures may result in their various lengths. This causes a necessity to use a method of equalizing the length of signatures.

Lengths of sequences can be equalized using many methods, such as DTW [16] or scaling methods [3]. A disadvantage of these methods is the need to interfere with the analysed data, which in turn may lead to distortion of the signatures being compared. The studies [13,14,15] present a method, called *windows technique*, which allows determining the similarity of signatures without the necessity of initial equalization of their lengths. In this way, the signatures being compared are not distorted as it happened in the case of the DTW algorithm or the scaling method.

The main goal on the investigation was to determine windows parameters to signature recognition level. The newest researches point out that new method of selection of some parameters gives better recognition level compare to previously reported work [13,14,15]. Between two compared signatures some differences can be observed, even for signatures of the same individual. It can also be observed that in many signatures some fragments are similar or not. For example one signer put signature almost the same at the beginning, while for other signer his signatures are very similar at the end. The main idea of the investigations is to find similarities and dissimilarities between fragments of the signatures. It will be more precisely explained in the next paragraphs of this paper.

2 Window Technique

In the *windows technique*, the S_i and S_j signatures being compared are divided into equal fragments. Each fragment contains h signature points. Such fragments are called "*windows*" and are designated as "*win*". The k -th window in the S_i signature is designated as $winS_i(k)$, while l -th window in the S_j signature - as $winS_j(l)$. Next windows in the signature can be shifted in relation to each other by a certain number of points designated as jmp . In the S_i signature this parameter was designated as $jmpS_i$, while in the S_j signature - as $jmpS_j$. Appropriate selection of values of the jmp parameter affects the speed and effectiveness of the method.

The values of the h and jmp parameters affect the number of the windows in the analysed signature. The number of all windows in the S_i signature is designated as nwS_i , while in the S_j signature - as nwS_j . The *windows technique* and the influence of parameters on the operation of this method have been discussed in detail in [14,15]. The division of the signature S_i into windows is shown in Fig. 3.



Fig.3. Division of signature S_i into windows, where $h=5$, $jmpS_i=1$.

The process of comparing signatures consists in successive determination of the similarity between each window in the first signature and all windows in the second signature. An example illustrating a comparison of the first window in the S_i signature with windows in the S_j signature is shown in Fig. 4.

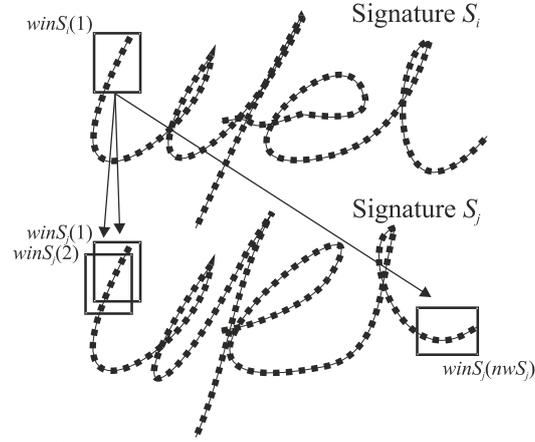


Fig. 4. Comparison of the windows in the two signatures.

That same amount of data in the windows being compared allows using any similarity measure M . For each pair of the windows being compared, $winS_i(k)$ in the S_i signature and $winS_j(l)$ in the S_j signature, their similarity is calculated using the following formula:

$$sim_{k,l} = M(winS_i(k), winS_j(l)), \quad (1)$$

where:

- M – similarity measure,
- k – number of the window in signature S_i ,
- l – number of the window in signature S_j .

The result of comparing the k -th window in the S_i signature with the windows determined in the S_j signature is the set of similarity values SIM_k :

$$SIM_k = \{sim_{k,1}, sim_{k,2}, \dots, sim_{k,nwS_j}\}, \quad (2)$$

where:

$sim_{k,l}$ – similarity between the compared windows $winS_i(k)$ and $winS_j(l)$, for $l=1, \dots, nwS_j$.

The SIM_k set is determined for all windows created in the S_i signature. After the similarity between all windows in the two signatures has been determined, the total similarity between the S_i and S_j signatures can be finally determined:

$$WS(S_i, S_j) = \frac{1}{nwS_i} \sum_{k=1}^{nwS_i} \max(SIM_k), \quad (3)$$

where:

$WS(S_i, S_j)$ – similarity between the S_i and S_j signatures.

The parameter in the *windows technique*, which affects the speed and effectiveness of the method, is *dist*. It narrows down the range of windows in the S_j signature, with which the window analysed in the S_i signature is being compared.

So far the value of the *dist* parameter has been the same for all the signatures of each person. A modification of the *windows technique* has been presented in this study, thanks to which the range of windows being compared is selected individually for signatures of each person. It allowed obtaining better results of the classification. The proposed modification is described in detail in the next section.

3 Modification of the Window Technique

The *Tabdist* arrays constitute a key element in the modification of the *windows technique*. The *PS* set containing the genuine signatures of a given person is required for creating these arrays.

$$PS = S_1, S_2, \dots, S_{ns} , \quad (4)$$

where:

ns – number of genuine signatures in *PS* set,

S_i – i -th signature of the person, where $i = 1, \dots, ns$.

The *Tabdist* arrays are created separately for each genuine signature $S_i \in PS$. The *PS* set must contain at least three signatures. However the number of elements in the *PS* set should be as large as possible, because it is easier to assess the repeatability of signatures in a larger set.

The algorithm for determining the *Tabdist* array involves comparing the signatures from the *PS* genuine set using the round robin method. The comparison is performed for the parameter values determined in the windows technique ($jmpS_i$). The operation of the algorithm for determining the *Tabdist* array for the $S_i \in PS$ signature can be presented in several steps.

Step 1 – let $k=1$.

Step 2 – determine successively the similarity between the $winS_i(k)$ of the S_i signature in relation to all windows created in the $S_j \in PS \setminus S_i$ signature, as shown in Fig. 4.

Step 3 – determine the SIM_k similarity set containing the results of comparisons between the k -th window of the S_i signature and the windows created in the S_j signature.

$$SIM_k = sim_{k,1}, sim_{k,2}, \dots, sim_{k,nwS_j} , \quad (5)$$

where:

$nw S_j$ – number of the window in signature S_j .

Step 4 – determine the maximum value of the similarity from the SIM_k set and remember the number of the ms_k window in the S_j signature, for which this value was determined. This number can be determined from the formula:

$$ms_k = \arg \max_i sim_{k,i} \in SIM_k, \quad i=1, \dots, nwS_j. \quad (6)$$

Step 5 – determine the number of the S_j signature point, in which the window with the ms_k number begins:

$$pms_k = ((ms_k - 1) \cdot jmpS_j) + 1, \quad (7)$$

where:

pms_k – number of the signature point, in which ms_k window begins.

Step 6 – normalize the pms_k value to the $[0,1]$ interval using the following formula:

$$nmpps_k = \frac{pms_k}{m}, \quad (8)$$

where:

m – number of S_j signature points.

Step 7 – write the value of the $nmpps_k$ parameter in k -th column of the *Tabdist* array.

A sample $nmpps_k$ value, for $k=1$, calculated when comparing the S_i and S_j signatures is presented in Table 1.

Table 1. Table *Tabdist* completed for first window in S_i signature.

	$nmpps_1$	$nmpps_2$	$nmpps_3$	...	$nmpps_{nwS_j}$
$S_i \leftrightarrow S_j$	0.018	...	...	...	...

Step 8 – repeat steps 2 through 7 successively for $k=2, \dots, nwS_i$.

As a result of carrying out the steps 1 through 8 of the aforementioned algorithm, the first row of the *Tabdist* array is populated with values (Table 2).

Table 2. Table *Tabdist* completed for all windows in S_i signature.

	$nmpps_1$	$nmpps_2$	$nmpps_3$	...	$nmpps_{nwS_i}$
$S_i \leftrightarrow S_j$	0.018	0.027	0.036	...	0.943

Step 9 – repeat the steps 1 through 8, comparing each time the S_i signature with the next genuine signature from the *PS* set. As a result of comparing each pair of the signatures the next row of the *Tabdist* array is obtained.

Sample *Tabdist* array for the S_1 signature from the $PS=\{S_1, S_2, S_3, S_4\}$ set is presented in Table 3.

Table 3. Fragment of the table *Tabdist* completed for S_1 signature.

	$nmpps_1$	$nmpps_2$	$nmpps_3$	...	$nmpps_{nwS_i}$
$S_1 \leftrightarrow S_2$	0.018	0.027	0.036	...	0.943
$S_1 \leftrightarrow S_3$	0.026	0.040	0.053	...	0.917
$S_1 \leftrightarrow S_4$	0.013	0.026	0.039	...	0.918

Step 10 – after the *Tabdist* array for the S_i signature has been created, mean values \overline{npms} and standard deviation values σ for individual columns of the *Tabdist* array are determined (table 4).

Table 4. Fragment of the table *Tabdist* completed for S_1 signature.

	$npms_1$	$npms_2$	$npms_3$	...	$npms_{nwS_1}$
$S_1 \leftrightarrow S_2$	0.018	0.027	0.036	...	0.943
$S_1 \leftrightarrow S_3$	0.026	0.040	0.053	...	0.917
$S_1 \leftrightarrow S_4$	0.013	0.026	0.039	...	0.918
\overline{npms}	0.019	0.031	0.043	...	0.926
σ	0.006	0.008	0.009	...	0.015

Step 11 – remove from the *Tabdist* array the columns, in which the standard deviation value is greater than a certain threshold value $\zeta \in 0,1$. Removing these columns from the *Tabdist* array causes that the non-repeatable signature fragments are not compared with each other.

Thanks to the *Tabdist* array the k -th window in the S_i genuine signature is compared with a sequence of windows in the S_j signature. The number of the first and the last window in the sequence is determined using the following formulas:

$$\begin{aligned}
 pwin(k) &= \text{round}(\overline{npms}_k \cdot m), \text{ for } k = 1, \dots, nwS_i, \\
 pwin_{\min}(k) &= \text{round}(pwin(k) - \sigma(k) \cdot m), \text{ for } k = 1, \dots, nwS_i, \\
 pwin_{\max}(k) &= \text{round}(pwin(k) + \sigma(k) \cdot m), \text{ for } k = 1, \dots, nwS_i.
 \end{aligned} \tag{9}$$

where:

- $pwin(k)$ – the middle window in the sequence,
- $pwin_{\min}(k)$ – the first window in the sequence,
- $pwin_{\max}(k)$ – the last window in the sequence,
- \overline{npms}_k – the mean value read from the k -th column of the *Tabdist* array for k -th window in the S_i signature,
- $\sigma(k)$ – the standard deviation read from the k -th column of the *Tabdist* array for k -th window in the S_i signature,
- m – number of the S_j signature point,
- nwS_i – number of the window in signature S_i .

Figure 5 shows the manner of comparing the windows, taking into account the *Tabdist* array.

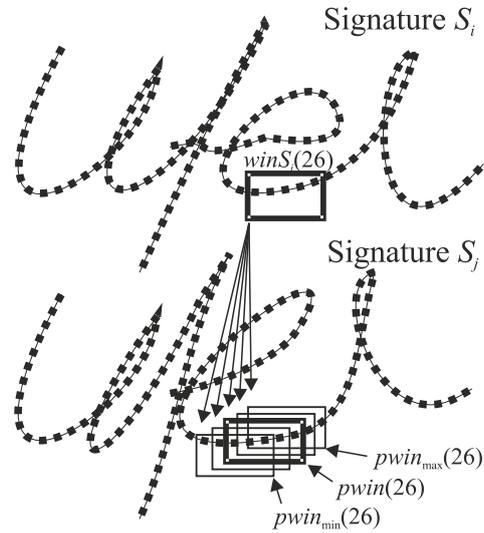


Fig. 5. The example of comparing the windows, taking into account the *Tabdist*.

Step 12 – end the algorithm, if the S_i signature has been compared with all the signatures from the *PS* set.

The result of the operation of the modified *windows technique* is the *Tabdist* array generated for each genuine signature. This array is then used in the signature comparison process.

4 Research results

The purpose of the studies was to determine the effectiveness of the proposed modification and its impact on the signature verification results. The standard windows method was compared with the modified method in the course of the studies. The studies were conducted with the use of signatures from the MCYT database [20]. The database used in the studies contained 1000 signatures of 100 persons. A recognized signature belonging to a given person was compared with 5 genuine signatures of the same person. The set of genuine signatures did not contain any recognizable signatures. The recognizable signatures included 3 other original signatures of a given person and 2 forged signatures of this person.

The studies were conducted for the following ranges of parameter values:

- $dist=[0.1, \dots, 0.5]$ with a step of 0.1,
- $h=[10, \dots, 50]$ with a step of 10,
- the standard deviation $\sigma=[0.05, \dots, 0.2]$ with a step of 0.05.

All combinations of the above parameters were examined. During the research, the several similarity coefficients have been used [14, 15]. The best results were obtained with the use of R^2 ratio [1]. During the studies, the following signature features were examined: coordinates (x,y) of signature points, pen pressure p at the point (x,y) . EER

was calculated for each measurement. The lower the value of EER, the lower error of a given measurement is. Table 5 shows the results of the studies obtained for the standard and modified windows method.

Table 5. The best measurements results for standard and modified window technique.

	Number of points in window h	Standard deviation values σ	EER [%]
Standard <i>window technique</i>	40	0.3	6.59
Modified <i>window technique</i>	40	0.2	3.20

5 Conclusions

The use of the modified windows technique allows to reduce verification error rate in comparison to standard windows technique. The obtained result EER = 3.20% is also competitive in comparison to other methods, known from the literature. Table 6 summarizes the well-known methods of signature recognition published in recent years. The methods shown in Table 6 were tested by their authors, as in the present study, using the MCYT signature database.

Table 6. Different online signature verification methods

Authors	Results (EER [%])
Presented method	3.20
Fierrez J., Ortega - Garcia J., Ramos D., Gonzalez - Rodriguez J. [2]	0.74
Lumini A., Nanni L. [7]	4.50
Maiorana E. [8]	8.33
Nanni L., Lumini A. [9]	21.00
Nanni L., Maiorana E., Lumini A., Campisi P. [10]	3.00
Vargas J. F., Ferrer M. A., Travieso C. M., Alonso J. B. [17]	12.82
Vivaracho - Pascual C., Faundez - Zanuy M., Pascual J. M. [18]	1.80
Wen J., Fang B., Tang Y. Y., Zhang T. [19]	15.30

The important advantages the proposed method is to determine of the parameter *dist*. It should be noted that this parameter is automatically selected. This selection is possible on the basis of analyzing of the *Tabdist* array. The obtained classification results encourage the further modification of the presented technique. In the next investigations stages using more complex methods of data analysis are planned. Additionally, time and memory complexity will be also estimated.

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