Online Signature Verification Based on Global Feature of Writing Forces*

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Abstract. Writing forces are important dynamics of online signatures and it is harder to be imitated by forgers than signature shapes. An improved DTW (Dynamic Time Warping) algorithm is put forward to verify online signatures based on writing forces. Compared to the general DTW algorithm, this one deals with the varying consistency of signature point, signing duration and the different weights of writing forces in different direction. The iterative experiment is introduced to decide weights for writing forces in different direction and the classification threshold. A signature database is constructed with F_Tablet and the experiments results are present in the end.

1 Introduction

Classical user authentication systems have been based in something that you have (like a key, an identification card, etc.) and/or something that you know (like a password, or a PIN). With biometrics, a new user authentication paradigm is added: something that you are (e.g., fingerprints or face) or something that you do or produce (e.g., handwritten signature or voice). The convenience for paper and pen in the electronic era is the reason why people still use handwriting as a mean to convey, retain, and facilitate communication. Together with this kind of information, handwriting is also a skill that individualizes people Moreover, devices like PDAs, pocket PCs, tablet PCs, or 3G mobile phones might offer handwriting capabilities, due to the fact that handwriting is considered as being more natural for humans and also to the possibility of size reduction by eliminating the keyboard. From this point of view, signature is a social and legal acceptable biometrics personal authentication method.

When a person signs his name, he writes not only the characters, but also his identity, which is implied in the dynamic writing process and the static signature. Computer based online and offline signature verification approaches have been developed to extract the identity. Compared to the static handwriting image of offline approach, online one uses those dynamics during writing and has relatively higher classification

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rate. In online signature verification systems, different approaches can be considered to extract signature information; they can be divided into: i) function-based approaches, in which signal processing methodology is applied to the dynamically acquired time sequences (i.e., velocity, acceleration, force, or pressure), and ii) feature-based approaches, in which statistical parameters are derived from the acquired information. One can also specify different levels of classification, so it is possible to use and combine shape-based global static (i.e., aspect ratio, center of mass, or horizontal span ratio), global dynamic (i.e., total signature time, time down ratio, or average speed) or local (stroke direction, curvature or slope tangent) parameters.

The signature is the trajectory of the writing pen's contact movement on the writing surface driven by writing forces. So writing forces are one of the most important information of writing dynamics and many researches have been done on them. Crane and Ostrem developed a three-dimension force-sensitive pen to get the writing forces [1]. With input device of the SmartPen, Martens and Claesen devised an online signature verification system based on three-dimension forces [2]. Tanabe studied signature verification based on the pressure with digital pen device [3]. Sakamoto did research on signature verification incorporating pen position, pen pressure and pen inclination with WACOM Tablet [4]. Shimizu developed an electrical pen using two-dimensional optical angle sensor to get writing forces [5].

Although all kinds of writing pen devices are used to get the writing forces, they can't get the forces accurately, because a writing pen may be rotated during writing which would change the measure coordination. And WACOM Tablets can only get the writing pressure. A new writing tablet, named F_Tablet is used here to capture the three-dimension writing forces. And an improved DTW algorithm is used to verify those signatures. Compared to the general DTW algorithm, this one deals with the varying consistency of signature point, signing duration and weights of writing forces in different direction. The F_Tablet signature capturing device and the signature database are introduced in the next chapter. Chapter 3 discusses the improved DTW algorithm and iterative experiment. The experimental results are given in chapter 4 and conclusions are made in the last chapter.

2 Signature Acquisition

2.1 The F_Tablet

This F-Tablet is capable of capturing three perpendicular forces of the pen-tip to the contacting plane and two dimension torques directly because of the core part of a multi-dimension force/torque sensor. With the specially designed structure, the static trajectory of the pen-tip and other dynamic signals such as velocities, accelerations and writing angles can also be calculated indirectly [6]. The input tablet of 70×70 mm^2 is on the up-left side of the F_Tablet, as shown in Fig.1. The device is connected to computer via USB interface with a maximum sample rate of 120Hz. And there is no special requirement on the writing pen. Fig.2 displays the coordinate of the F_Tablet. The coordinate is fixed during design and it won't change no matter how the writing pen is rotated. Here the device is used to get the three-dimension writing forces, F_x, F_y and F_z.

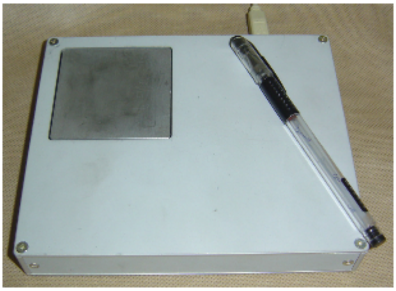

Fig. 1. Photo of the F_Tablet

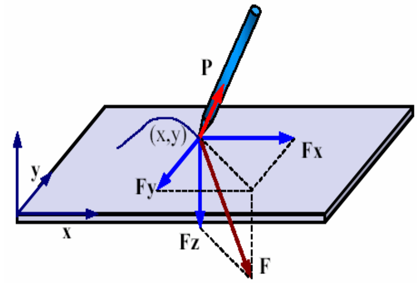

Fig. 2. Coordinate of the F_Tablet

2.2 Signature Database Construction

The database is constructed with 30 persons involved over a one-month period. Each subject donated 40 signatures with 10 ones every week. At the same time, each subject is told to practice and imitate other subject's signature as simple forgeries after the static signature. And 10 persons are recruited to make skilled forgeries. Before the skilled forgeries were collected, each subject can view the signing process of the signature to be imitated with a special program and practice for a period of time what ever long he wants. And a signature database with 1200 genuine signatures, 600 simple forgeries and 300 skilled forgeries is constructed.

2.3 Signature Preprocessing

To improve the classification result, signatures are preprocessed before calculation. The preprocessing methods taken here are filtering, direction adjustment and dehooking.

1) *Filtering.* To remove the noise in the signature data, the Gaussian filter is applied to filter the three dimension forces respectively.
2) *Direction Adjustment.* The posing of the writer or the position of the F Tablet may change when the signatures are collected in several batches, which results in the inconsistency of the signature direction. So force direction adjustment is introduced to adjust the force direction in X and Y direction.
3) *Dehooking.* As the writing surface of the F Tablet is a little smoother than the general paper, so a jerk may occur when a pen collide with the tablet, which will cause the wrong judgement of the pen-down or pen-up status. So dehooking is taken to remove the jerk.

3 Improved DTW Algorithm

Compared to the general DTW algorithm, this improved one takes the varying consistency of different signature point, the signing duration and weights of writing forces in different direction into account. First, weighted multiple signature templates are generated with general DTW algorithm. Then weights of different signature points and stroke signing duration are used to calculate distance. The weights of writing forces in different and classification threshold are decided with iterative experiment.

3.1 Distance Calculation

The difference between the general DTW algorithm and this one lies on the distance calculation. This one takes weight of writing forces in different direction, weight of different signature point and signing duration into account. Euclidean distance is used to measure the difference of the aligned point pair, and it can be expressed as (1):

$$d(T_i, S_j) = \left[w_x (F^{(i)}{}_x - F_x^{(j)})^2 + w_y (F^{(i)}{}_y - F_y^{(j)})^2 + w_z (F^{(i)}{}_z - F_z^{(j)})^2 \right]^{1/2} \tag{1}$$

where w_x, w_y and w_z are weights of F_x, F_y and F_z respectively. Distance between corresponding strokes can be expressed as (3):

$$D_k(T_i, S_j) = \min \begin{cases} D_k(T_{i-2}, S_{j-1}) + \frac{1}{2}\left[w_{i-1} d(T_{i-1}, S_j) + w_i d(T_i, S_j) \right] \\ D_k(T_{i-1}, S_{j-1}) + w_i d(T_i, S_j) \\ D_k(T_{i-1}, S_{j-2}) + \frac{1}{2}\left[w_i d(T_i, S_{j-1}) + w_i d(T_i, S_j) \right] \end{cases} \tag{2}$$

$$D_k^{'}(T, S) = D_k(T, S) \frac{t_s}{t_t} \tag{3}$$

where $D_k(T, S)$ is the k th stroke distance between the sample and weighted template and $D_k^{'}(T, S)$ is the distance which take signing duration into account; t_s is the stroke point number of the sample before being resampled and t_t is that of the template. Only the pen-down points are used here, but the pen-up points can also be regarded as that of the pen-down stroke followed. Then, the distance between the sample and the template can be expressed as (4):

$$D(T, S) = \sum_k D_k^{'}(T, S) \tag{4}$$

3.2 Threshold Setting

Because the consistencies of signing of different subjects are sure to be different, so the threshold is set to reflect both personal and global signing characteristics. The threshold D_i^{th} of subject i is expressed as:

$$D_i^{th} = \mu_i + f\sigma_i \tag{5}$$

where μ_i and σ_i are the average value and standard deviation of the distances between registered signatures and templates; while f is the global coefficient to make sure that all subjects have an optimistic classification performance.

3.3 Iterative Experiment

Iterative experiment is introduced to decide the global threshold coefficient f and the ratio between w_x, w_y and w_z. As F_x and F_y are forces parallel to the writing tablet, they have same weight in distance calculation. So in the experiment, the ratio between w_x, w_y and w_z is $w : w : (3-2*w)$. The goal of the experiment is to get the values of w and f where the signature classification result is the best. First initial values are set for them, then parameters w and f are alternatively changed to do experiments on the signature database to find the other one where FAR equals FRR, until the parameter difference between two experiments is small enough.

4 Experimental Results

4.1 The Trajectory and Forces of Signature

The first purpose of our experiment presented here is to verify the F-Tablet™ the forces consistency in writing the same character. The second is to identify the relationship between trajectory and forces. Test software is developed to display the trajectory and draw the three forces at the same time. The time-interval width of the stroke can be obtained from the pressure between the pen-tip and the input tablet or Fz. And because the coordinates of the trajectory are calculated from Fx, Fy, Fz, Mx and My, so the shape of the displayed character implies all the forces and torques of the writing.

Fig.4 shows the shape of the Chinese character and the three forces during writing. From the shape of the character, we can see that not only the trajectory of the pen, but also the writing style of the writer is recorded. And from the force curve and the static shape we can even get the stroke order. The right part of the image represents the three forces to time series. The value of Fz is negative and defined by the multi-force sensor reference frame. How the pen has gone can be figured out combine Fx with Fy. First, the pen wrote the top point. Then it went from left to right. Then it goes from top right to down left. And then wrote the last stroke.

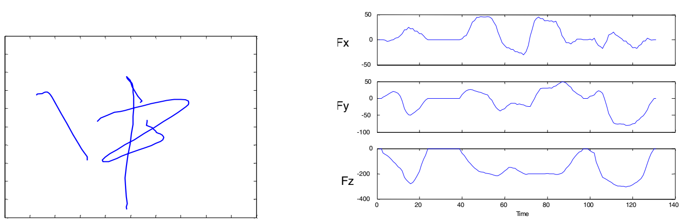

Fig. 3. The trajectory and forces of handwriting (by Wu)

4.2 The Performance of Verification

Experiments are carried out on the constructed signature database. And before experiment, preprocessing such as filtering, dehooking and rotation are applied to the raw signature data. The results of the improved DTW algorithm and the general one without signature point weight setting and signing duration are displayed in Fig.5 and Fig.6 respectively. From the figures, we can see that a great improvement in classification rate has been made. This shows that signature point weight and signing duration are important factors in signature verification. With the iterative experiment, we get the optimum equal error classification rate of zero where the global threshold coefficient f is 2.50 and the ratio between w_x, w_y and w_z is $7:7:1$. But this doesn't imply that F_x and F_y are much more important than F_z, because the amplitude of F_z is much bigger than those of F_x and F_y.

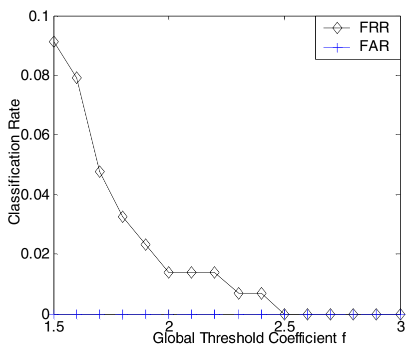

Fig. 4. Performance of the improved DTW

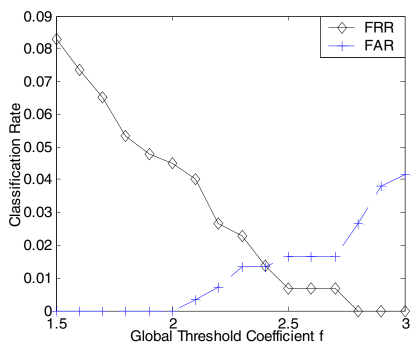

Fig. 5. Performance of the general DTW

5 Conclusion

An improved DTW algorithm is put forward to very online signature based on writing forces. The F_Tablet is used here to capture the three perpendicular writing forces. Compared to the general DTW algorithm, this one deals with the varying consistency of signature point, signing duration and the different weights of writing forces in different direction. And iterative experiment is introduced to decide weights for writing forces in different direction and the classification threshold. With this algorithm, the equal error classification rate of zero is realized base on the constructed signature database.

Although this improved DTW algorithm has better performance, it does have its deficiency.This algorithm consumes more computation time and memory space and these problems are left for the future work.

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