ON-LINE WRITER RECOGNITION FOR THAI BASED ON VELOCITY OF BARYCENTER OF PEN-POINT MOVEMENT

Pitak Thumwarin and Takenobu Matsuura

Department of Communications Engineering,
Tokai University,
Hiratsuka-shi, 259-1292 Japan
pitak@dt.u-tokai.ac.jp, matsuura@dt.u-tokai.ac.jp

ABSTRACT

We propose an on-line writer recognition method for Thai based on velocity of barycenter of pen-point movement. The barycenter is determined from the center point of script and two adjacent pen-point positions with respect to time in handwriting process. In this paper, the Fourier coefficients of the velocity and trajectory of the barycenter are considered as the input and output of FIR(finite impulse response) system, respectively. In this case, the impulse response of the FIR system is interpreted as the feature of handwriting. The K-L expansion of the impulse response is used for writer recognition. Writer recognition experiments are performed on database consisting of 6,642 Thai scripts written by 81 writers. As the result, Type I(false rejection) and Type II(false acceptance) error rates were 1.50% and 0.65%, respectively.

1. INTRODUCTION

As development of an information technology, the necessity of personal identification is increasing. Writer recognition is one of the personal identification which recognizes writer using a handwriting. In Thailand, handwriting is the customary way to recognize the individual in daily operations such as withdrawing cash from bank account. In order to recognize writer using the handwriting, visual examination is popular method for writer recognition in Thailand because of its simplicity. However, it usually takes time for operation and there are occasions for the examiners to make some mistakes by visual examination. In order to recognize writer effectively, an automatic system for writer recognition is required in Thailand.

Many methods for on-line writer recognition have been reported [1]–[6]. In those methods, dynamic features of handwriting have been used such as x, y coordinates of pen-point movement, pen-point pressure, pen-point direction, pen-point velocity and its acceleration. The features of handwriting related to the pen-point velocity have been used and showed the effectiveness in comparison with the pen-point position and acceleration [2]. The work [3] concluded that either pen-point position or pen-point velocity should be considered for signature verification. However, the work [4] tried to incorporate the velocity vector into dissimilarity measure and reported that the improvement due to it was not remarkable. The possibility of an effective incorporation of the velocity into dissimilarity measure is as yet an open problem to be answered [4]. To overcome the above problems, we propose an on-line writer recognition method for Thai based on velocity of barycenter of pen-point movement.

In this paper, a barycenter determined from the center point of script and two adjacent pen-point positions with respect to time in handwriting process is used to reduce fluctuation of pen-point movement. It is considered here that the handwriting motion can be described by the velocity and trajectory of the barycenter. Then in order to extract the feature of handwriting and reduce the fluctuation of the individual handwriting motion, the velocity and trajectory of the barycenter are expanded into Fourier series. Furthermore, it is considered that the difference between the handwriting motions can be represented by that between FIR systems. Then the FIR system characterizing the handwriting motion is realized by considering the Fourier coefficients of the velocity and trajectory of the barycenter as the input and output of the FIR system, respectively. In order to represent the difference between the handwriting motions, the impulse response of the FIR system is used. Because it can be seen that the FIR system can be completely characterized by its impulse response [7]. In this case, the obtained impulse response is used as the feature of handwriting. Finally, the K-L expansion of the impulse response of the FIR system is used for writer recognition.

2. PREPROCESSING

It is assumed here that Thai script is written on a graphical tablet to recognize the writer. The horizontal and vertical components of pen-point movement at a time, $t = n\tau(\equiv t_n)$, in handwriting process are denoted here as $x(t_n)$ and $y(t_n)$, respectively, where τ is a constant sampling rate. In this section, in order to reduce fluctuation of handwriting, three kinds of normalization with respect to the size, location and duration time in handwriting process of script are performed as follows:

First, in order to make a standard size of script, the horizontal and vertical components, $x(t_n)$ and $y(t_n)$ are normalized as

$$\hat{p}(t_n) = \frac{p(t_n) - p_{\min}}{p_{\max} - p_{\min}}, \qquad (p = x, y) \tag{1}$$

$$where \qquad p_{\min} = \min_{0 \le n \le N-1} p(t_n), \quad p_{\max} = \max_{0 \le n \le N-1} p(t_n)$$

where N is a total number of sampled points of pen-point position. In the following $p(t_n)(p = x, y)$ are used to represent the normalized components of pen-point position.

Secondly, the location of script is normalized as

$$c_p = \frac{1}{N} \sum_{n=0}^{N-1} p(t_n), (p = x, y), \tag{2}$$

$$\hat{p}(t_n) = p(t_n) - c_p, (\hat{p} = \hat{x}, \hat{y}), (n = 0, \cdots, N-1), \quad (3)$$

where c_p is the center point of script.

Thirdly, in order to reduce a fluctuation of pen-point movement in handwriting process, a trajectory of the barycenter determined from the center point of script and two adjacent pen-point positions with respect to time in handwriting process, is used. The coordinates $(r_x(t_n), r_y(t_n))$ of the barycenter are calculated as

$$\left. \begin{array}{l} r_x(t_n) = \frac{\hat{x}(t_n)+\hat{x}(t_{n+1})+0}{3}, \\ r_y(t_n) = \frac{\hat{y}(t_n)+\hat{y}(t_{n+1})+0}{3}. \end{array} \right\} \quad (4)$$

Then in order to represent the handwriting process, we define the followings

$$z(t_n) = r_x(t_n) + jr_y(t_n), \quad (5)$$

$$v(t_n) = z(t_{n+1}) - z(t_n), \; j \equiv \sqrt{-1}, \quad (6)$$

where $z(t_n)$ represents the barycenter trajectory and $v(t_n)$ corresponds to an average of the velocity between the two adjacent barycenters. Furthermore, in order to reduce another fluctuation such as duration time in a part of handwriting process, a segmentation of handwriting process is performed. The segmentation points $t_i^{(s)}$ of handwriting process are defined as

$$\{t_1^{(s)}, \cdots, t_i^{(s)}, \cdots, t_{L-1}^{(s)}\} \stackrel{\text{def}}{=} \{t_n \mid |v(t_n| > \alpha\}, \quad (7)$$
$$(n = 0, \cdots, N-2)$$

where α, determined by using training data, is a threshold value for segmentation. L is total number of segmentation of handwriting process. Using $t_i^{(s)}$ in Eq.(7), the barycenter trajectory and velocity of the barycenter in Eq.(5) and Eq.(6) are divided into L parts as

$$\mathbf{z} = [\mathbf{z}'_1 \cdots \mathbf{z}'_i \cdots \mathbf{z}'_L]', \quad (8)$$

$$\mathbf{z}_i = [z_i(t_0), \cdots, z_i(t_n), \cdots, z_i(t_{N_i})]', \quad (9)$$

$$\mathbf{v} = [\mathbf{v}'_1 \cdots \mathbf{v}'_i \cdots \mathbf{v}'_L]', \quad (10)$$

$$\mathbf{v}_i = [v_i(t_0), \cdots, v_i(t_n), \cdots, v_i(t_{N_i})]', \quad (11)$$

$$z_i(t_n) = z_i^{(real)}(t_n) + jz_i^{(img)}(t_n) \quad (12)$$

$$v_i(t_n) = v_i^{(real)}(t_n) + jv_i^{(img)}(t_n), (n = 0, \cdots, N_i) \quad (13)$$

where $[\cdot]'$ is the transposition of $[\cdot]$, $\mathbf{z}_i$ and $\mathbf{v}_i$ are vectors defined by $N_i + 1$ sampled points of the barycenter. Then in order to normalize the duration time in the part of handwriting process a piecewise-linear function(PLF) of $z_i^{(real)}(t_n)$, $z_i^{(img)}(t_n)$, $v_i^{(real)}(t_n)$ and $v_i^{(img)}(t_n)$ are determined by connecting their components with a straight line. The PLF can be described as

$$q(t) = a_0 + a_1 t + \sum_{n=1}^{N_i-1} b_n \mid t - t_n \mid, t \in T_i, \quad (14)$$
$$(q = z_i^{(real)}, z_i^{(img)}, v_i^{(real)}, v_i^{(img)}),$$

where

$$a_0 = q(t_0) - \sum_{n=1}^{N_i-1} t_n b_n, \;\; a_1 = \frac{1}{2}(u_0 + u_{N_i-1}),$$
$$b_n = \frac{1}{2}(u_n - u_{n-1}), \;\; u_n = q(t_{n+1}) - q(t_n),$$
$$t_0 = 0, \;\; (n = 0, 1, \cdots, N_i - 1)$$

where T_i is the duration time in the i-th part of handwriting process. Using Eq.(14), the duration time in the i-th part of handwriting process is normalized as T_i^N. The T_i^N is determined by using training data for a particular writer.

3. FEATURE EXTRACTION

In this section, it is assumed that the functions $\check{z}_i^{(real)}(t)$, $\check{z}_i^{(img)}(t)$, $\check{v}_i^{(real)}(t)$ and $\check{v}_i^{(img)}(t)$ are even periodic function of time with period $2T_i^N$, respectively. And $z_i^{(real)}(t)$, $z_i^{(img)}(t)$, $v_i^{(real)}(t)$ and $v_i^{(img)}(t)$ obtained in the preceding section are the segments of the above functions in the interval $(0, T_i^N)$. Then in order to extract the feature of handwriting and reduce the fluctuation of the individual handwriting motion, they are expanded into Fourier series as

$$l(t) \simeq \frac{1}{2}a_0^{(l)} + \sum_{k=1}^{K_i-1} a_k^{(l)} cos k\omega_0^{(i)} t, \quad (15)$$
$$where \;\; \omega_0^{(i)} = \frac{\pi}{T_i^N}, \; (l = \check{z}_i^{(real)}, \check{z}_i^{(img)}, \check{v}_i^{(real)}, \check{v}_i^{(img)})$$

The coefficients $a_k^{(l)}$ in the Fourier series are given by

$$a_k^{(l)} = \frac{2}{T_i^N} \int_0^{T_i^N} l(t) cos(k\omega_0^{(i)} t) dt, \quad (16)$$
$$(k = 0, 1, \cdots, K_i - 1)$$

where K_i is number of Fourier coefficients and $K_i < N_i + 1$. The fluctuation of the individual handwriting motion can be reduced by selecting a suitable number of Fourier coefficients for each writer. The suitable number of Fourier coefficients is determined by minimizing mean square error in the Fourier approximations of $\check{z}_i^{(real)}(t)$, $\check{z}_i^{(img)}(t)$, $\check{v}_i^{(real)}(t)$ and $\check{v}_i^{(img)}(t)$.

For the simplicity of explanation the following functions:

$$f_i(k) \equiv a_k^{(\check{v}_i^{(real)})} + ja_k^{(\check{v}_i^{(img)})}, g_i(k) \equiv a_k^{(\check{z}_i^{(real)})} + ja_k^{(\check{z}_i^{(img)})} \quad (17)$$

are defined. We consider a handwriting system characterizing the handwriting motion. The handwriting system consists of subsystems describing the dynamics in the corresponding part of handwriting process. The subsystem is realized by considering the Fourier coefficients $f_i(k)$ and $g_i(k)$ as the input and output of the i-th subsystem, respectively. It is assumed that the subsystem can be described by

$$\hat{g}_i(k; \mathbf{h}) = \sum_{m=0}^{M_i} h_i(m) f_i(k-m), (k = 0, 1, \cdots, K_i - 1) \quad (18)$$

where $\mathbf{h}'_i = [h_i(0), h_i(1), \cdots, h_i(M_i)]$ is an impulse response of the subsystem, M_i is order of the subsystem and $\hat{g}_i(k; \mathbf{h}_i)$ is an approximation of $g_i(k)$. $\mathbf{h}'_i$ means the transposition of $\mathbf{h}_i$. The impulse response $\mathbf{h}_i$ can be obtained by minimizing the least-square error at M_i as

$$E_i = \sum_{k=0}^{K_i-1} |e_i(k)|^2 \rightarrow min \quad (19)$$

$$e_i(k) = g_i(k) - \hat{g}_i(k; \mathbf{h}_i), (i = 1, 2, \cdots, L) \quad (20)$$

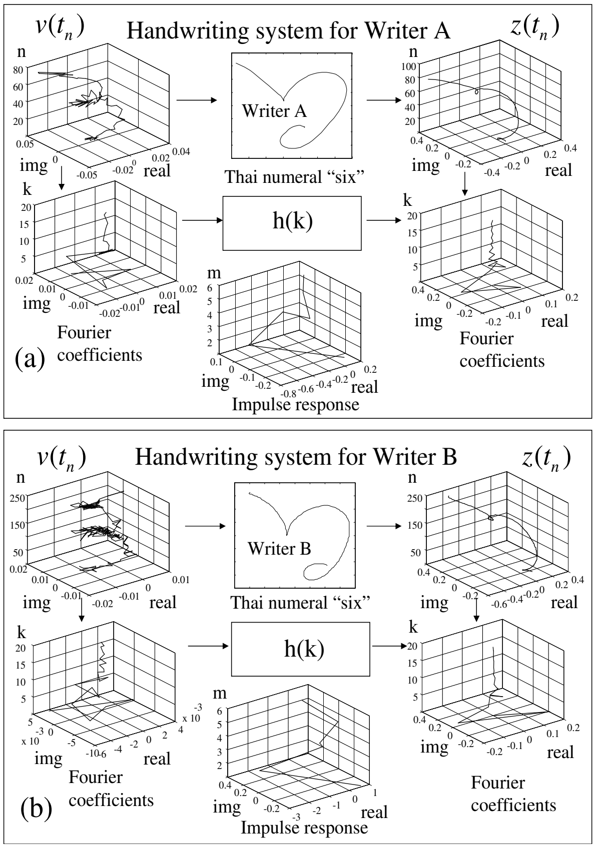

Fig. 1. FIR systems characterizing the handwriting system for Thai numeral "six" (a) for writer A (b) for writer B.

In order to characterize the handwriting motion in a whole handwriting process, the impulse responses of subsystems are combined as

$$\mathbf{h}^\sharp = [\mathbf{h}_1^{'} \;\; \mathbf{h}_2^{'} \;\; \mathbf{h}_3^{'} \;\; \cdots \;\; \mathbf{h}_L^{'}]' \tag{21}$$

where $\mathbf{h}^\sharp$ is a feature parameter vector used as the feature of handwriting. Figs. 1 (a) and (b) show the FIR systems characterizing the handwriting system of writers A and B for Thai numeral "six." It can be seen from Figs. 1 (a) and (b) that the impulse response of the FIR system obtained from writer A is different from that obtained from writer B. Therefore, it is considered that the obtained impulse response can be used as the feature of handwriting.

4. WRITER RECOGNITION

In this section, the K-L expansion of the feature parameter vector obtained in the preceding section is used to recognize writer. The writer recognition procedures are given below.

1. Calculate the following correlation matrix R:

$$R = \frac{1}{P}\sum_{i=1}^{P}(\tilde{\mathbf{h}}_i^\sharp \tilde{\mathbf{h}}_i^{\sharp\prime}), \tag{22}$$

$$\tilde{\mathbf{h}}_i^\sharp = [\tilde{h}_i^\sharp(1), \tilde{h}_i^\sharp(2), \cdots, \tilde{h}_i^\sharp(\underline{N})]', \tag{23}$$

$$\tilde{h}_i^\sharp(m) = |h_i^\sharp(m) - \bar{h}^\sharp(m)|, \tag{24}$$

$$\bar{\mathbf{h}}^\sharp = \frac{1}{P}\sum_{i=1}^{P}\mathbf{h}^\sharp{}_i, \tag{25}$$

$$\bar{\mathbf{h}}^\sharp = [\bar{h}^\sharp(1), \bar{h}^\sharp(2), \cdots, \bar{h}^\sharp(\underline{N})]', \tag{26}$$

$$\mathbf{h}^\sharp{}_i = [h^\sharp{}_i(1), h^\sharp{}_i(2), \cdots, h^\sharp{}_i(\underline{N})]', \tag{27}$$

$$(m = 1, 2, \cdots, \underline{N}),$$

where $\mathbf{h}^\sharp{}_i$ is the feature parameter vector obtained from training data for a particular writer, $\underline{N}$ is a total number of elements in the feature parameter vector and P is a total number of training data.

2. Calculate the eigenvalues λ_k and the corresponding eigenvectors $\mathbf{u}_k$ of the correlation matrix R:

$$R\mathbf{u}_k = \lambda_k \mathbf{u}_k, \qquad (k = 1, 2, \cdots, \underline{N}). \tag{28}$$

3. Form the transformation matrix U from the N^* eigenvectors corresponding to the largest eigenvalues of R as follows

$$U = [\mathbf{u}_1, \mathbf{u}_2, \cdots, \mathbf{u}_{N^*}], \;\; where \;\; N^* < \underline{N}. \tag{29}$$

4. Compute the K-L coefficients $\mathbf{c}$:

$$\mathbf{c} = U'\tilde{\mathbf{h}}^\dagger \equiv [c_1, c_2, \cdots, c_{N^*}]', \tag{30}$$

$$\tilde{\mathbf{h}}^\dagger = [\tilde{h}^\dagger(1), \tilde{h}^\dagger(2), \cdots, \tilde{h}^\dagger(\underline{N})]', \tag{31}$$

$$\tilde{h}^\dagger(m) = |h^\dagger(m) - \bar{h}^\sharp(m)|, \tag{32}$$

$$(m = 1, 2, \cdots, \underline{N}),$$

where $h^\dagger(m)$ is obtained from the feature parameter vector for writer to be recognized and $\bar{h}^\sharp(m)$ is obtained from Eq. (25).

5. The writer is recognized as

$$\left.\begin{array}{ll} true & if \;\; \|\mathbf{c} - \mathbf{c}_r\| < \eta, \\ false & \text{otherwise,} \end{array}\right\} \tag{33}$$

where $\|.\|$ is Euclidean norm, $\mathbf{c}_r$ is K-L coefficients obtained from training data for a particular writer and η is a predetermined threshold value determined using training data set for a particular writer.

5. EXPERIMENTS

Writer recognition experiments were performed on database consisting of 6,642 Thai scripts written by 81 writers for one year. The database contains Thai numeral and Thai scripts for particular writers. In our experiments, 4 digits of Thai numerals selected randomly and some Thai words were used. In the experiments, the training data set of the feature parameter vectors was determined using 5 scripts selected randomly from the database. The numbers of data used for writer recognition experiments and the error rates are shown in Tables 1 and 2, respectively.

Fig. 2 (a) shows the Type I and Type II error rates with segmentation and no segmentation of handwriting process. It can be seen from Fig. 2 (a) that the error rates with segmentation are lower than those with no segmentation. Thus the experimental result shows the effectiveness of the segmentation of handwriting

TABLE 1
Number of set of Thai numeral and error rates

Experiment No.	1	2	3	4	5	6	7	8	9	10
Number of data for particular writers	60	60	60	60	60	60	60	60	60	60
Number of data for other 53 writers	312	312	312	312	312	312	312	312	312	312
Type I error rate(%)	0.00	3.33	3.33	3.33	0.00	0.00	1.66	0.00	1.66	1.66
Type II error rate(%)	0.00	3.20	1.92	0.64	0.00	0.00	0.96	0.00	0.96	0.32

Average Type I = 1.50% Type II = 0.80%

TABLE 2
Number of script in Thai and error rates

Experiment No.	11	12	13	14	15
Number of data for particular writers	95	95	90	70	65
Number of data for other 26 writers	267	267	313	257	257
Type I error rate(%)	1.05	1.05	2.50	1.43	1.45
Type II error rate(%)	0.00	0.37	1.28	0.00	0.78

Average Type I = 1.50% Type II = 0.49%

process. Using the data in Table 1, comparison of the experimental results for the method proposed in this paper and the methods in the works [5], [6] is shown in Fig. 2 (b). It can be seen from Fig. 2 (b) that the proposed method is able to recognize a writer with lower error rate in comparison with the methods in the works [5], [6].

6. CONCLUSIONS

We proposed an on-line writer recognition method for Thai based on velocity of barycenter of pen-point movement. The barycenter determined from the center point of script and two adjacent pen-point positions with respect to time in handwriting process was used to reduce fluctuation of pen-point movement. The velocity and trajectory of the barycenter were calculated to describe the handwriting motion. The FIR system characterizing the handwriting motion was realized by using the Fourier coefficients of the velocity and trajectory of the barycenter as the input and output of the system, respectively. The impulse response of the FIR system was used as the feature of individual handwriting. As the experimental results, the type I and type II error rates were 1.50% and 0.65%, respectively. It was found from the experimental results that the impulse response can characterize the handwriting motion and the impulse responses obtained from different writers are different. Therefore the proposed method is useful for on-line writer recognition for Thai.

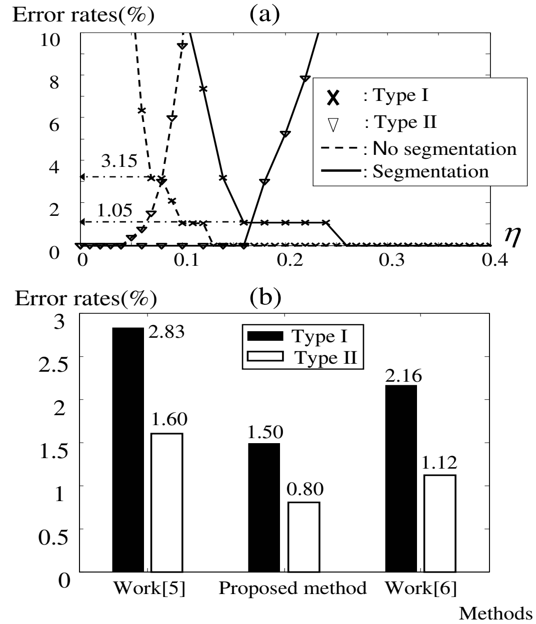

Fig. 2. Comparison of the error rates (a) using segmentation and no segmentation of handwriting process, (b) using the proposed method in this paper and the methods in the works [5], [6].

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