On-Line Writer Recognition Based on Pen-point Pressure for Thai Numerals

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Abstract — This paper discusses an on-line writer recognition based on pen-point pressure in handwriting process for Thai numerals. First, the fluctuation of pen-point pressure in handwriting process is reduced by using a suitable normalization. Secondly, the pen-point pressure is expanded into Fourier series. Then the features of pen-point pressure can be represented by the Fourier coefficients. Thirdly, in order to describe the feature of handwriting process, a finite impulse response (FIR) system having the above coefficients as the step response is introduced. Then the impulse response of the FIR system is used as the feature of handwriting process. In the writer recognition experiments Type I (false rejection) and Type II (false acceptance) error rates were 0 – 6% and 0 – 2%, respectively.

1 Introduction

Writer recognition problem is largely classified into two classes. One is off-line method based on only static visual information, the other is on-line method based on dynamics of the handwriting process. A major advantage of the latter method is very difficult to forge or copy the invisible dynamics. Many methods for on-line writer recognition have been reported [1]-[6]. However there have been a few methods for on-line writer recognition for Thai numeral or character [6]. In the paper [6], wavelet series expansion of the horizontal and vertical components of pen-point movement in handwriting process of Thai character are used to extract the features.

In this paper an on-line writer recognition method based on the pen-point pressure in handwriting process for Thai numerals is proposed. First, the fluctuation of pen-point pressure in handwriting process is reduced using a suitable normalization. Secondly the pen-point pressure is expanded into Fourier series. Then the features of pen-point pressure is represented in terms of the Fourier coefficients. In order to describe the feature of handwriting process, FIR system having the above coefficients as the step response is introduced. Then the impulse response of the FIR system is used as the feature of the handwriting process. Therefore it can be considered that the resulting impulse response represents the relation between a constant pressure and the individual pressure. With the impulse response writers can be recognized by evaluating the difference between the impulse responses obtained from the writers for particular Thai numerals.

2 Preprocessing

It is assumed here that in order to recognize the writer, Thai numerals (Fig.1) are written on a graphical tablet. The pen-point pressure at a time, \( t = t_n \), in handwriting process is denoted here as \( p(t_n) \). Then a piecewise-linear function (PLF), \( p(t) \) is determined by connecting the components \( \{p(t_n)\} \) with a straight line (Fig.2).

The PLF can be described [6] as

\[
p(t) = a_0 + a_1 + \sum_{n=1}^{N} b_n | t - t_n |, \quad t \in T \quad (1)
\]

where \( a_0 = p(t_0) - \sum_{n=1}^{N} t_n b_n \), \( a_1 = \frac{1}{2}(v_0 + v_N) \),

\[
b_n = \frac{1}{2}(v_n - v_{n-1}), \quad v_n = p(t_{n+1}) - p(t_n),
\]

\( n = 0, 1, ..., N \)

Furthermore the pen-point pressure \( p(t) \) is normalized as

\[
\hat{p}(t) = \frac{p(t) - p_{\min}}{p_{\max} - p_{\min}} \quad (2)
\]
where
\[
\begin{align*}
  p_{\min} &= \min_{0 \leq n \leq N} p(t_n), \\
  p_{\max} &= \max_{0 \leq n \leq N} p(t_n) \quad (3)
\end{align*}
\]

In the following it is assumed that pen-point pressure is normalized and denoted as \( p(t) \). And the duration time \( T \) for a Thai numeral is also normalized as \( T = 1 \). It can be seen from Fig.2 that the proposed normalization reduces the fluctuation of pen-point pressure in handwriting process.

3 Feature Extraction

In this section, it is assumed that the pen-point pressure \( p(t) \) is normalized and even function of time, respectively. Then the \( p(t) \) is expanded into Fourier series as
\[
  p(t) = \sum_{k=0}^{N} a_k \cos k\pi t \quad (4)
\]
where the coefficients \( a_k \) in above Fourier series are calculated by
\[
  a_k = 2 \int_0^1 p(t) \cos k\pi t dt \quad (5)
\]

Then handwriting process is represented by FIR system. That is, constant pressure sequence \( s(n) = \{1, 1, \cdots, 1\} \) and the Fourier coefficients \( a_n \) for pen-point pressure are considered as the input \( f(n) \) and the output \( g(n) \) of the FIR system, respectively.

\[
  f(n) = s(n), \quad g(n) = a_n \quad (6)
\]

Furthermore it is assumed that the FIR system can be described by
\[
  g(n; h) = \sum_{m=0}^{M} h(m)f(n - m), \quad (n = 0, 1, \cdots, N) \quad (7)
\]

where \( h = [h(0), h(1), \cdots, h(M)] \) is the impulse response vector. \( h' \) means the transposition of \( h \) and \( g(n; h) \) is the output and \( M \) is the order of the FIR system. The impulse response vector \( h \) can be obtained by minimizing the least-square error at \( M \), that is,
\[
  E = \sum_{n=0}^{N} [g(n) - g(n; h)]^2 \to \min. \quad (8)
\]
The optimal solution vector \( h \) can be obtained by solving the following equation:
\[
  \Lambda h = w \quad (9)
\]
where
\[
  w = [w_0, w_1, \cdots, w_M]' \quad (10)
\]
\[
  w_k = \sum_{n=0}^{N} g(n)f(n - k), \quad (k = 0, 1, \cdots, M) \quad (11)
\]
\[
  \Lambda = (\lambda_{km}), \quad (k, m = 0, 1, \cdots, M) \quad (12)
\]
\[
  \lambda_{km} = \sum_{n=0}^{N} f(n - m)f(n - k), \quad (k, m = 0, 1, \cdots, M) \quad (13)
\]
Thus if \( \Lambda \) is nonsingular, then the optimal impulse response vector \( h \) is given by
\[
  h = \Lambda^{-1} w. \quad (14)
\]

It can be considered that the obtained impulse response vector \( h \) can fully characterize the feature of handwriting process. In the present method the difference between systems can be represented by that between impulse responses. In other words, the difference between impulse responses of the above FIR systems means the difference between the feature of handwriting process. It can be seen from Fig.6

Figure 4: FIR system

Figure 3: Pen-point pressures and their Fourier coefficients for two persons

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impulse response can be used as the feature characterizing the handwriting process. It therefore is considered that the above impulse responses for different persons are different. It therefore is considered that the above impulse response can be used as the feature characterizing the handwriting process.

![Figure 5: Impulse responses obtained from the Fourier coefficients of pen-point pressures shown in Fig. 3](image)

that the impulse responses for different persons are different. That is, therefore is considered that the above impulse response can be used as the feature characterizing the handwriting process.

![Figure 6: Impulse responses obtained from four persons](image)

4 Writer Recognition

In this section the coefficients in the K-L expansion of the impulse response vector obtained in the preceding section is used to recognize the writer. Two normalized eigenvectors corresponding to the two largest eigenvalues of the correlation matrix for a particular person of interest are used for writer recognition. The writer recognition procedures are given below.

1) Define the following correlation matrix $R$:

$$R = \frac{1}{N} \sum_{i=1}^{N} (\mathbf{h}_i \mathbf{h}_i^T), \quad \mathbf{h}_i = \mathbf{h}_i - \bar{\mathbf{h}} \quad (15)$$

where $N$ is the total number of training data for a particular person of interest, $\mathbf{h}_i$ is the impulse response of the FIR system and $\bar{\mathbf{h}}$ is the average of impulse response vector determined from the training data.

2) Calculate the eigenvalues $\lambda_k$ and the eigenvectors $\mathbf{u}_k$ of the correlation matrix $R$:

$$R \mathbf{u}_k = \lambda_k \mathbf{u}_k \quad (16)$$

3) The columns of the transformation matrix $U$ are chosen as the two normalized eigenvectors corresponding to the two largest eigenvalues of the correlation matrix $R$.

$$U = [\mathbf{u}_1, \mathbf{u}_2] \quad (17)$$

4) Compute the feature vector $\mathbf{z}_i$ given by

$$\mathbf{z}_i = U^T \mathbf{h}_i \quad (18)$$

5) Determine the decision function

$$g(\mathbf{x}; \mathbf{c}) = \mathbf{c}' \mathbf{x}, \quad (19)$$

satisfying the following inequalities:

$$g(\mathbf{x}_i^{(1)}; \mathbf{c}) > 0 \quad \text{for} \quad \mathbf{x}_i^{(1)} \in \omega_1$$

$$g(\mathbf{x}_i^{(2)}; \mathbf{c}) < 0 \quad \text{for} \quad \mathbf{x}_i^{(2)} \in \omega_2$$

where $\mathbf{c}$ is the parameter vector to be determined,

$$\mathbf{c}' = [c_1, c_2, c_3], \quad \mathbf{x}_i^{(j)} = [x_i^{(1)}, 1], \quad \mathbf{z}_i^{(j)} = [z_i^{(1)}, z_i^{(2)}] \quad (21)$$

where $\omega_1$ is the training data set of a particular person of interest and $\omega_2$ is training data set of the other persons. The vector $\mathbf{c}$ can be determined in the least square sense:

$$\mathbf{c} = (\Omega \Omega')^{-1} \Omega' \mathbf{b} \quad (22)$$

$$\Omega' = [\mathbf{x}_1^{(1)}, \ldots, \mathbf{x}_L^{(1)}, -\mathbf{x}_1^{(2)}, \ldots, -\mathbf{x}_L^{(2)}] \quad (23)$$

$$\mathbf{b}' = [b_1, \ldots, b_{L_1 + L_2}], \quad b_i > 0 \quad (24)$$

5 Experiments

Writer recognition experiments were performed using 2,000 Thai numerals written by ten Thai persons. In our experiments the decision functions(Fig.7) for a Thai numeral for a particular person were determined from five impulse responses selected randomly from the training data set. With the determined decision function, the writer recognition were performed using fifty impulse responses selected randomly from each person. As the results, Type I (false rejection) error rate and type II (false acceptance) error rate were obtained as shown in Fig.7.

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6 Conclusion

We proposed an on-line writer recognition based on pen-point pressure in handwriting process for Thai numerals. A suitable normalization of pen-point pressure in handwriting process was used to reduce the fluctuation. Then Fourier coefficients in the Fourier series expansion of pen-point pressure was considered as the step response of FIR system. The impulse responses of the FIR system was used as the feature of handwriting process. The proposed method has reduced the writer recognition problem to the system identification problem. It was found from the experimental results that the proposed method is useful for on-line writer recognition for Thai numerals. This method is available for not only Thai numerals but also the other scripts such as English, Japanese and so on.

Acknowledgement

The authors would like to thank the Hitachi Scholarship Foundation and KMIT’L staff for the warmest supports.

References


