A Study of Offline Calligraphy Learning System

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Abstract

Japanese elementary and junior high schools have traditionally provided calligraphy classes to students. However, as the number of teachers decreases, so too does the number of calligraphy classes, making it difficult for students to improve their skills due to an inadequate amount of class time. Hence, a system capable of automatically evaluating students’ progress on writing characters would enable them to independently bolster their calligraphy skills.

Many methods of teaching calligraphy have already been proposed [1]-[3]. However, these require special devices which prove difficult to use. Therefore, we suggest an offline system is best as it is easy to use. In this study, ‘offline’ means easily digitized visualization with the use of a smartphone or scanner. This study’s participants were elementary school students capable of writing correctly.

1. Introduction

Calligraphy, or ‘Shodo’ in Japanese, can be defined as the act of writing beautifully. Shodo classes are provided to elementary and junior high school students to teach them to write well. Additionally, many children attend private calligraphy schools to further improve their writing skills. However, in recent years, the number of calligraphy teachers has declined as have opportunities for students to improve their character writing. The spread of smartphones has further decreased incentive to write beautiful characters as analogue forms of writing become less common.

Foreigners face two additional challenges as they learn to write Japanese characters: balance of character, and stroke order. As students rarely learn the stroke order of Chinese characters outside of school, foreigners have few opportunities to learn it. Therefore, it is easier for us to build an offline system than an online system. This system focuses on balance of characters as our study aims to make learning characters easier for students. We chose not to use many of the systems suggested to us as they were too complex and required special devices (e.g., writing brushes incorporated into circuits). Additionally, many of the methods recommended to us require students to trace models, however there are no longer means of evaluating written characters.

We ultimately decided to use a smartphone application since smartphones are widely available. Our proposed system analyses pictures of students’ characters taken by smartphone cameras.

For this study, we built a system to detect students’ writing habits and weak points by determining the figure and ratio of a written character’s eigenvalue. Generally, a character’s outline is provided by joining its outside points, but for beginners it is necessary to reduce the influence of a point and the stroke of the character as they are extremely far from the centre of a character. Therefore, for this study we extracted a smooth outline by using an iterative operation. This allowed us to compare a person with advanced skills to a beginner by analysing the ratio of a character’s eigenvalue with the outline.

2. Image of calligraphy

Figure 1 depicts a sample calligraphic image. The strokes of this sample were composed by a beginner and are far from ideal. However, the purpose of this study is to demonstrate an objective index of written characters instead of...
evaluating them subjectively. Figure 1 is written in Japanese and translates as ‘carp in a pond’. Figure 1 is 120x460 and 256 grey levels.

Figure 2’s flowchart outlines extraction. We will now elaborate on each process below.

3-1. Data Capture
First, we must digitize characters written on Japanese writing paper. There are many ways to digitize characters, but for this study we used a scanner (Product name: Scan Snap ix100, Model name: FL-100A, Fujitsu) since camera functions on smartphones necessitate removing backgrounds behind the characters. The use of scanners made for less processing time.

3-2. Binarization of an Image
Because characters are written on Japanese writing paper with Indian ink, calligraphy is only comprised of black (the ink) and white (the writing paper). However, liquid ink from inksticks rather than India ink make for grey levels. For the purposes of this study, we do not consider grey level images; we only extract character domain. This study defines 128 as the threshold between white and black.

3-3. Morphology Processing
Figure 4 (a) displays an original image containing extra black marks. While this is undoubtedly an extreme example, one can see that Indian ink splashed from the brush, making many small black points on the paper when we wrote the character.

This ‘splatter effect’ makes it difficult to get a definite outline, so we removed these by conducting a morphology operation beforehand. In addition, the structural element is 3 pixels wide. We show an image after the Morphology operation in figure 4 (b).
3-4. Division of Characters
We then divided the characters to extract outlines of each. We detected continuous white pixels from one end to another of Japanese writing paper as border.

The lines reveal borders. There are four characters in figure 5 (a) but they have been divided into five parts. In this case, there is too much division, so we must reduce one division. To do so, we found the shortest distance between the character (domain of \( \text{③} \)) after which we checked distance of the upper (domain of \( \text{②} \)) and lower (domain of \( \text{④} \)) and added a short one. We will report our results in figure 5 (b).

3-5. Coordinate Transformation
We transformed the x-y coordinate system to an r-θ coordinate system to calculate an outline by Fourier series. The origin of the coordinate axes were calculated as the centre of the upper end, the bottom end, and the right-and left sides of each character. Figure 6 shows before and after transformation images. Figure 6 (a) shows an x-y coordinate image and figure 6 (b) shows an r-θ coordinate image.

3-6. Detection of Candidate points of Outline
To estimate an outline, we must determine its candidate point. The black pixel furthest from the outline’s centre serves as its candidate point since the outline connects the outside points. The candidate points on the r-θ coordinate is biggest r each θ. Figure 7 shows the result of extracted candidate points and are printed in red.

3-7. Estimation of Outline
While an outline’s candidate points help us to estimate it, we may not be able to determine the candidate points of the outline in all θ shown in figure 7. Candidate points are not given at 0 <θ<30 and around 180 degrees of figure. Even if this is only one character, candidate points have missing parts in cases where characters are made by few strokes. Therefore, it is difficult to get an outline in simple Fourier series using candidate points. So, in this study, we estimated an outline by the iterative solution using projection operator [4] in figure 8.

3-7-1. Outline estimation principal
In figure 8, \( M \) represents a proper subspace of Hilbert space \( H \), and consists of an ideally band-limited signal \( x(t) \). \( N \) is
observation space that contains \( y(t) \). \( y(t) \) is an observation signal partially lost an amplitude information of \( x(t) \). Missing operator \( w(t) \) mapped \( x(t) \) to \( y(t) \) in equation (1).

\[
y = wx \tag{1}
\]

where, \( w(t) = 0 \) implies loss of amplitude of \( x \) at \( t \), and \( w(t) = 1 \) implies no loss of \( x \) at \( t \), respectively in equation (2) (3).

\[
w x = w^k x, \quad (k = 1,2,\cdots) \tag{2}
\]

\[
w(ax_1 + bx_2) = av_1 + by_2 \tag{3}
\]

\( w(t) \) is a projection operator and \( N \) is apparently proper subspace of \( H \). Band-limiting operator \( p \) mapped \( y \) to \( x \) in equation (4).

\[
x = py \tag{4}
\]

Clearly, \( p \) is also a projection operator. Operator \( w \) and \( p \) are realized using a window function and DFT, respectively.

At first, we observe the signal \( y_1 \) in \( N \), and project it to \( M \) in equation (5). Furthermore, we get equation (6)(7).

\[
x_1 = py_1 \quad \in M \tag{5}
\]

\[
y_2 = wx_1 \quad \in N \tag{6}
\]

\[
x_n = x_{n-1} + p(y_1 - y_n) = (I - pw)x_{n-1} + py_1 \tag{7}
\]

These mappings are clearly contractive. Finally, we obtain the required signal as equation (8).

\[
x^* = \lim_{n \to \infty} x_n = \lim_{n \to \infty} (pw)^{-1}(I - (I - pw)^n)py_1
\]

\[
= (pw)^{-1}py_1 \tag{8}
\]

where, \( I \) represents identity operator.

(1) The outline is representable as a smooth curve \( x(\theta) \).

(2) The outline is similar to an oval.

The candidate points determine the signal \( y_1(\theta) \), configure operator \( w(\theta) = 1 \), and missed points configure operator \( w(\theta) = 0 \), at the same time. According to the assumption (1), subspace \( M \) is spanned with bases \( \{\sin(\frac{n\theta}{360}), \cos(\frac{n\theta}{360})\} \) (\( n = 1,2 \)) for assumption (2). Because the oval expanded circle. Therefore, there is an expanding area symmetrically. When we express this in Fourier series, we can express circle only in a direct current, in the case of an oval, there are two peaks expanding out longer than the diameter of circle. So we used second Fourier series.

Applying the estimation principle, the outline is obtained as the signal \( x^*(\theta) \). The results of estimated outlines are shown in figures 9 and 10.

\[
\begin{array}{c}
\text{(a) Iterative result} \\
\text{(b)Final result}
\end{array}
\]

3-7-2. Outline estimation

Next assumptions are used for outline estimation.

Fig.8: Principle of estimation

\[
\begin{array}{c}
\text{Fig.9 Iterative result of 3rd Character on r-} \\
\theta \text{ coordinate using principal}
\end{array}
\]

\[
\begin{array}{c}
\text{Fig.10 Estimation result on x-y coordinate}
\end{array}
\]
4. Calculation of eigenvalue

As an index of evaluating each character, we must calculate their respective eigenvalues. We calculated eigenvalue and eigenvector using equations (9) and (10). We show the results that we calculated using these equations in table 1. Furthermore, we show the eigenvector was written in figure 11. The equation $f(\theta)$ is an outline which is an approximation by Fourier series. $A$ is eigenvalue and $u$ is eigenvector.

$$Au = \lambda u$$  \hspace{1cm} (9)  

$$A = \begin{bmatrix} 
\sum_{\theta=0}^{359} (f(\theta) \cos \theta)^2 & \sum_{\theta=0}^{359} (f(\theta) \cos \theta)(f(\theta) \sin \theta) \\
\sum_{\theta=0}^{359} (f(\theta) \cos \theta)(f(\theta) \sin \theta) & \sum_{\theta=0}^{359} (f(\theta) \sin \theta)^2 
\end{bmatrix}$$  \hspace{1cm} (10)

| Characters | Eigenvalue | Eigenvector |
|------------|------------|-------------|
|            | Max | Min | (-1.0,0.07) |
| 1st        | 23  | 20  |
| 2nd        | 23  | 21  | (-0.21,-0.98) |
| 3rd        | 24  | 23  | (-0.91,0.41) |
| 4th        | 26  | 21  | (-0.82,0.58) |

In this way, we were given a lot of information. If the ratio of the character is large, for example, the writer must make shorter vertical strokes. We would like to automatically generate comments from information such as eigenvalue.

5. Evaluation of character

For the purposes of this study, we calculated eigenvalue and eigenvector. We then evaluated these values, comparing characters to those written by teachers of advanced skill. This character is shown in figure 12.

We show eigenvalue which was calculated from outline in table 2. We show the ratio of the eigenvalue of tables 1, 2, and 3.

Figure 11 Eigenvector of each characters

| Characters | Eigenvalue | Eigenvector |
|------------|------------|-------------|
|            | Max | Min | (-0.31,1,05) |
| 1st        | 27  | 26  |
| 2nd        | 24  | 23  | (-0.53,0.85) |
| 3rd        | 26  | 24  | (-0.81,-0.61) |
| 4th        | 29  | 26  | (0.55,0.83) |

| Characters | Beginner (table 1) | Teacher (table 3) |
|------------|---------------------|-------------------|
|            | 1.15 | 1.04 |
|            | 1.10 | 1.04 |
|            | 1.04 | 1.08 |
|            | 1.24 | 1.12 |

From table 3, we can understand the following: teachers of advanced skill’s characters ratio of eigenvalue are approximately 1.0, and a good balance of
characters is shown. On the other hand, the ratio of eigenvalue of the beginners’ characters are over 1.1, characters tend to be slender. Therefore, the outline of beginners’ characters is not a circle, but ovular. Hence, when we get a ratio of eigenvalue over 1.2, we can deem it to be a bad balance of characters.

Furthermore, from a result of the eigenvalue in table 2, we understood that teachers wrote slightly larger Chinese characters (1st character) and slightly smaller Japanese words. On the other hand, the beginner wrote characters without considering its size from the eigenvalue in table 1 since the white space of characters stands out if Japanese words are written using fewer strokes in larger sizes. Therefore the teacher of advanced skill wrote that it is not only each character but also includes consideration of the whole balance.

6. Conclusion

In this study, we developed an index to write beautiful characters by calculating their eigenvalue. In addition, by using this method we can not only determine each character’s ratio of eigenvalue but also the outline size and character balance. Our goal is to create a system that automatically provides comments to improve this information’s use.

Additionally, we provided results, not only about one product in this article, but several. Lastly, we expect that smartphone users will be able to analyse their own written characters using this application.

Reference

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