ON-LINE HANDWRITTEN CHINESE CHARACTER RECOGNITION USING A RADICAL-BASED AFFINE TRANSFORMATION

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ABSTRACT

On-line handwriting has been shown to be an effective tool for the input of Chinese characters. However, due to the high variabilities of handwriting, the recognition performance is somewhat limited. One approach to resolve this problem is to view the pattern mismatch as composed of two components: natural distortion component and residual discriminative component. By adopting a suitable deformation technique, the residual discriminative component can be extracted, which is then used for character recognition. The stroke-based affine transformation (SAT) is a prominent example of this approach. Although the SAT method proved to be successful, it did not fully exploit the structural nature of Chinese characters. This work extends Wakahara's SAT further by considering a higher-level character element, radical, which is commonly deemed as a true structural entity in Chinese characters. The proposed scheme contains two main parts: fuzzy stroke grouping and radical-based affine transformation (RAT). Simple yet effective fuzzy connectivity and transitivity concepts are adopted to extract pseudo-radicals. After the pseudo-radicals are found, an RAT is employed to deform each pseudo-radical so that the input test pattern can match the desired reference pattern more closely. A small-scale experiment was conducted to examine the feasibility of this approach. The results indicate some improvements of the presented approach over the SAT scheme and verify its applicability. Further performance improvement is expected if a writer has the tendency to write radicals more independently.

1. INTRODUCTION

On-line handwritten Chinese character input has been shown to be an easy-to-use and efficient real-time tool; hence it is currently widely adopted in PDA's and tablet PC's. Due to the variability of handwritten character forms and differences among the writing styles of various writers, on-line handwritten Chinese character recognition manifests itself as a difficult task. To deal with handwriting variation, efficient distortion-tolerant recognition methods should be devised. Some earlier methods include dynamic programming [1], nonlinear shape normalization [2, 3], biomedical handwriting models [4], local affine transformation (LAT) [5], stroke-based affine transformation (SAT) [6], etc. Motivated by Wakahara's recent success of SAT, we focus on certain possible improvements of his method. In view of the composition structures of Chinese characters, it is commonly accepted that radicals (or compound strokes) should be considered as construction units. When performing deformation, is should be beneficial to treat a radical as an entity, instead of a stroke. Although in Wakahara's SAT, two consecutive strokes are treated as a structural unit, they may be sometimes spatially apart. In addition, radicals are not always composed of two consecutive strokes. We thus came up with the idea of a radical-based affine transformation (RAT). By applying the RAT in the deformation process, it is expected that the input test pattern can match the desired reference pattern more closely. The proposed method contains two main parts: fuzzy stroke grouping and radical-based affine transformation. The purpose of fuzzy stroke grouping is to extract pseudo-radicals from the input test character. Since the objective is to find structural units that are suitable for shape deformation, it is not necessary for the extracted pseudo-radicals to be exactly the same as those defined in standard Chinese dictionaries. Simple yet effective methods based on fuzzy connectivity and transitivity concepts are used in the stroke-grouping module to reduce the computational burden. The radical-based affine transformation performs character deformation on the basis of radicals that are extracted from the fuzzy stroke-grouping module. In view of the computational overhead involved in the RAT, it is suggested that the RAT method be used in the fine classification stage of any existing on-line Chinese character recognizer. The RAT provides a guided deformation of the test pattern so that even similarly shaped characters can be more easily recognized.

The rest of this paper is organized as follows. Section 2 gives a short summary of the SAT. Sections 3 and 4

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describe the operations of the fuzzy stroke grouping and the RAT. A short description of the character recognition criterion is given in Section 5. Experimental results are provided in Section 6. Finally, conclusions are given in Section 7.

2. SUMMARY OF THE STROKE-BASED AFFINE TRANSFORMATION (SAT)

In on-line recognition, each character is given in terms of a sequence of points along the trajectories defined by pen movement. By uniform spatial sampling, points separated by constant distances are selected as feature points. A stroke is defined as a pen trajectory between the pen-down and the pen-up states. Because of the different lengths of strokes, each stroke may have different number of feature points. In Wakahara's SAT method [6], a number of consecutive strokes, usually two, are treated as an entity. This entity is used as a basic deformation unit that is passed to the SAT. The SAT is in principle a local affine transformation that deals with scaling, rotation, and translation. Each stroke group goes through the SAT sequentially until all the strokes are scanned. The mathematical form of the SAT is given in Section 4.

3. FUZZY STROKE GROUPING

In order to extract concrete structural elements, namely pseudo-radicals in this work, the first main part of the proposed scheme is a fuzzy stroke-grouping module. Radicals are themselves sub-characters, and are commonly viewed as indivisible structural elements that Chinese characters are made up of. The radicals defined in our scheme are not necessarily the same as those defined in traditional Chinese dictionaries that are critically analyzed and have exact meanings. The reasons are due to (1) the difficulties in exact extraction of the true radicals and (2) computational consideration. Therefore, the radicals in this work are in fact pseudo-radicals that are formed by a stroke grouping technique. A stroke is basically a consecutive point sequence that lies between the pen-down and the pen-up moments in on-line handwriting. Based on the spatial relations among neighboring strokes, connectivity and transitivity can be defined, and compound strokes (i.e., pseudo-radicals) are thus generated. By connectivity, we mean strokes that are physically connected (or touched) or almost connected. By transitivity, we mean strokes that may not be physically connected but can be transitive to each other through some other strokes. Since these pseudo-radicals are structurally located together, they have the tendency to move together in the handwriting process and then can be treated as the fundamental unit during pattern deformation. Compared to Wakahara's SAT, we use a higher-level object in the character composition hierarchy. The fuzzy stroke-grouping module is composed of four steps: (1) fuzzy connectivity analysis, (2) fuzzy transitivity analysis, (3) stroke grouping, and (4) isolated-strokes merging. In the fuzzy connectivity analysis step, mutual distances between each stroke are calculated for all the strokes where the distance is defined as the minimum distance between the two strokes under consideration. A fuzzy membership function is defined for measuring the connectivity of two strokes. The use of a fuzzy membership function avoids a hard-limiting definition of connectivity and is more appropriate for extracting connected strokes in on-line handwriting. The result of the fuzzy connectivity analysis step can be represented by a connectivity matrix. The operation of connectivity analysis attempts to find those strokes that are directly connected or almost connected. To search for pseudo-radicals, not only those connected strokes should be considered, but also those strokes that are transitive to one another, because they altogether constitute a structural unit. The second step performs transitivity analysis. In the fuzzy transitivity analysis step, a fuzzy-AND operation is applied to the connectivity matrix to find transitive strokes and a fuzzy-OR operation is used to update the transitivity values. For details, refer to [7]. In the third step, strokes with transitivity value 1 are grouped together as candidate pseudo-radicals. After the stroke-grouping step, some groups may contain a single stroke, which are not considered as valid pseudo-radicals. To prevent from such cases, a final merging step is applied to merge those isolated strokes so that each pseudo-radical consists of at least two strokes. The principle is to merge the single stroke with the neighboring group that has the highest membership value. To illustrate the above procedure more clearly, we give an example as follows. A ten-stroke Chinese character 班 (which means *class*) is shown in Fig.1(a). This character contains three radicals. After the fuzzy connectivity analysis step, a connectivity matrix if formed, which is shown in Table 1. The result of the fuzzy transitivity analysis step is given in Table 2. Referring to Table 2, five groups of compound strokes can be generated, which are illustrated in Fig.1(b). We see from Fig.1(b) that Groups 2, 3, and 4 are composed of single strokes. After merging the single strokes with best neighboring stroke groups, the final pseudo-radicals are obtained as desired, which are shown in Fig.1(c).

4. THE RADICAL-BASED AFFINE TRANSFORMATION (RAT)

Compared to the SAT, the radical-based affine transformation (RAT) attempts to exploit the structural

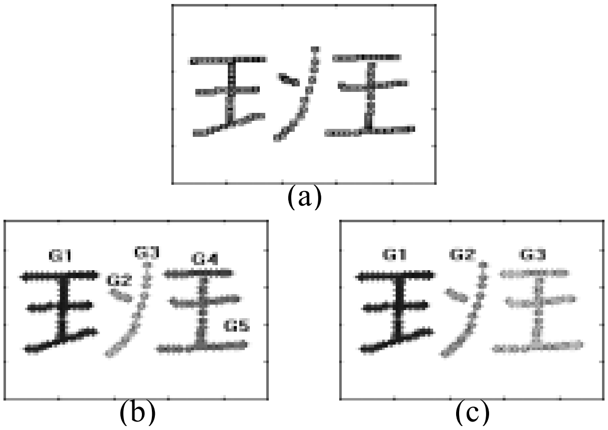

Fig.1. A demonstrating example that shows the results of the fuzzy stroke grouping. (a) The input test character that has a meaning of *class*. (b) Five groups of strokes are obtained after the fuzzy stroke grouping operation is applied. Among the groups, G2, G3, and G4 contain only single strokes. (c) After merging of isolated stokes, the final correct three radicals are obtained.

Table 1. Fuzzy connectivity matrix of the character shown in Fig.1.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
S1	1	0.125	1	0	0.5	0.001	0	0	0	0
S2	0.125	1	1	0.268	0.594	0.008	0	0	0	0
S3	1	1	1	1	0.029	0.005	0	0	0	0
S4	0	0.268	1	1	0	0.479	0	0	0	0
S5	0.5	0.594	0.029	0	1	0.961	0	0.077	0	0
S6	0.001	0.008	0.005	0.479	0.961	1	0.889	0.599	0	0.287
S7	0	0	0	0	0	0.889	1	0.272	0.996	0
S8	0	0	0	0	0.077	0.599	0.272	1	1	0
S9	0	0	0	0	0	0	0.996	1	1	1
S10	0	0	0	0	0	0.287	0	0	1	1

Table 2. Fuzzy transitivity matrix of the character shown in Fig.1.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
S1	1	1	1	1	0.594	0.479	0	0	0	0
S2	1	1	1	1	0.594	0.479	0	0	0	0
S3	1	1	1	1	0.594	0.479	0	0	0	0
S4	1	1	1	1	0.594	0.479	0	0	0	0
S5	0.5	0.594	0.029	0	1	0.961	0	0.077	0	0
S6	0.001	0.008	0.005	0.479	0.961	1	0.889	0.599	0	0.287
S7	0	0	0	0	0	0.889	1	0.272	0.996	0
S8	0	0	0	0	0.077	0.599	0.996	1	1	1
S9	0	0	0	0	0.077	0.599	0.996	1	1	1
S10	0	0	0	0	0.077	0.599	0.996	1	1	1

benefits further that are inherent in Chinese characters. The SAT performs a local affine transformation on each stroke group (composed of two consecutive strokes). However, these two consecutive strokes may not be structurally related; in particular, some of them may be spatially far apart. To tackle this problem, we came up with the idea of a radical-based affine transformation. Since Chinese characters are in principle constructed by radicals, the RAT can be expected to be a more effective deformation unit. The affine transformation is a tool to deal with shape variations in handwriting. The general framework of an affine transformation is given by

$$\tilde{\boldsymbol{r}} = A\boldsymbol{t} + \boldsymbol{b} \qquad (1)$$

where A is the affine transformation matrix that takes care of scaling and rotation, $\boldsymbol{b}$ is the translation vector, $\boldsymbol{t}$ is the test pattern to be recognized, and $\tilde{\boldsymbol{r}}$ is the deformed test pattern that should be matched against the reference pattern, $\boldsymbol{r}$. In the SAT case, $\boldsymbol{t}$ consists of sample points from two consecutive strokes, while in the RAT case, $\boldsymbol{t}$ is composed of sample points from extracted pseudo-radicals. The optimal A's and $\boldsymbol{b}$'s are determined locally by minimizing

$$\| A\boldsymbol{t} + \boldsymbol{b} - \boldsymbol{r} \|_2^2 \qquad (2)$$

To demonstrate the effectiveness of the RAT, compared to the SAT, we give two examples, which are shown in Fig.2. The characters 恐 and 能 in Fig.2 mean *afraid* and *capable*, respectively. From Fig.2, it is seen clearly that the RAT pushes the test patterns more closely toward the reference patterns.

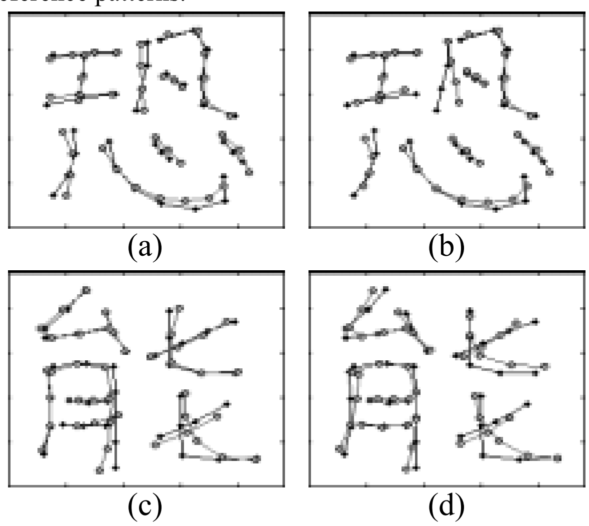

Fig.2. Examples demonstrating the deformating capability of the RAT. The characters in (a) and (c) mean *afraid* and *capable* in Chinese, respectively. The results after applying the RAT to input characters are shown in (a) and (c). The results after applying the SAT to input characters are shown in (b) and (d). In these figures, the deformed input patterns and the reference patterns are overlapped to show the effects of deformation. From these figures, it is clearly seen that the RAT pushes the input test patterns more closely toward the reference patterns.

5. FINE CLASSIFICATION OF ON-LINE HANDWRITTEN CHINESE CHARACTERS

In view of the computations involved in the RAT, it is suggested that the RAT method be used in the fine classification stage of any existing on-line Chinese character recognizer. Typically a coarse classification module is used to search for some number of candidate characters (say, ten), which are then passed to the fine classifier. The RAT provides a guided deformation of the test pattern so that even similarly shaped characters can be more easily recognized. The recognition criterion is based on the residual inter-character distance.

6. EXPERIMENTAL RESULTS

The character database used in our experiment is composed 5401 daily-life Chinese characters. After a simple scaling normalization that retains the original aspect ratio, each character has a size of 240x240 pixels. The test set was collected from ten different persons. Each person wrote 200 characters to generate a 2000-character test collection. Free format writing was assumed. We compare the results of three different schemes: coarse classification without using any deformation technique, the SAT, and the RAT presented in this paper. The resultant recognition performance is shown in Tables 3 through 5. In each table, the first row indicates the number of candidate characters selected after the corresponding operation is applied. The second row represents the number of successfully recognized characters out of the 2000 test characters. The last row gives the recognition rate based on the test character set. Comparing Tables 3, 4, and 5, it is seen that both the RAT and the SAT offer considerable improvements over the coarse classification scheme. The RAT scheme is slightly better than the SAT scheme. Although not demonstrated in this experiment, we believe that the RAT scheme will attain more performance gain if the writer is accustomed to write radicals more independently.

Table 3. The recognition performance of the coarse classifier. (In Tables 3 through 5, "A" represents the number of candidate characters selected, "B" represents the number of successfully recognized characters, and "C" represents the cumulative recognition rate.)

A	1	2	3	4	5	6	7	8	9	10
B	1771	1897	1936	1946	1956	1965	1970	1970	1973	1977
C	88.55	94.85	96.8	97.3	97.8	98.25	98.5	98.5	98.65	98.85

Table 4. The recognition performance of the SAT scheme.

A	1	2	3	4	5	6	7	8	9	10
B	1941	1951	1958	1967	1971	1974	1975	1976	1976	1977
C	97.05	97.55	97.9	98.35	98.55	98.7	98.75	98.8	98.8	98.85

Table 5. The recognition performance of the RAT scheme.

A	1	2	3	4	5	6	7	8	9	10
B	1944	1959	1960	1964	1970	1975	1975	1976	1977	1977
C	97.2	97.95	98	98.2	98.5	98.75	98.75	98.8	98.85	98.85

7. CONCLUSIONS

In this paper, we present a new deformation method for on-line Chinese character recognition. Motivated by the success of Wakahara's stroke-based affine transformation, we extend his idea to a radical-based affine transformation to further exploit the structural nature of Chinese characters. The proposed scheme comprises two main parts: fuzzy stroke grouping, and radical-based affine transformation. Simple yet effective fuzzy connectivity and transitivity concepts are adopted to locate pseudo-radicals. These pseudo-radicals are the results of stroke grouping, based on spatial relations. Since our goal is to extract certain structural units that should be deformed together, they need not be the same as those defined in standard Chinese dictionaries. After the pseudo-radicals are found, a radical-based affine transformation is employed to deform each pseudo-radical so that the input test pattern can match the desired reference pattern more closely. A small-scale experiment was conducted to examine the feasibility of this approach. The results indicate some improvements of the presented approach over the SAT scheme and verify its applicability. Further performance improvement is expected if a writer has the tendency to write radicals more independently. Comparison of computational complexities is another issue that should be considered in the future.

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