Structure Extraction from Decorated Characters Using Multiscale Images

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Abstract—Decorated characters are widely used in various documents. Practical optical character reader is required to deal with not only common fonts but also complex designed fonts. However, since the appearances of decorated characters are complicated, most general character recognition systems cannot give good performances on decorated characters. In this paper, an algorithm that can extract character's essential structure from a decorated character is proposed. This algorithm is applied in preprocessing of character recognition. The proposed algorithm consists of three procedures: global structure extraction, interpolation of structure, and smoothing. By using multiscale images, topographical features, such as ridges and ravines are detected for structure extraction. Ridges are used for extracting global structure and ravines are used for interpolation. Experimental results show character structures are clearly extracted from very complex decorated characters.

Index Terms—Character recognition, OCR, decorated character, structure extraction.

1 Introduction

DECORATED characters are widely used in various documents. Practical optical character reader (OCR) is required to deal with not only common fonts but also complex designed fonts. Usually, decorated characters are used for special purpose, for example, attracting readers attention or designing page layout, so that they are constructed by using some special techniques like using texture images or shading original character.

A lot of approaches of character recognition have been developed [1], [2], [3]. The approaches can be classified into two categories: structural analysis [4], [5], [6], [7] and pattern matching [8], [9], [10], [11]. In both structural analysis and pattern matching approaches, features of character images are extracted using information of connected components of black pixels. However, appearances of decorated characters are so complicated and strange that there is no guarantee that the connected components of black pixels represent the essential structure of character. Moreover, it is difficult to construct standard patterns for decorated characters since there are various kinds of fonts that are specially designed. Therefore, most general character recognition systems cannot give good performances on decorated characters.

Usually, decorated characters are constructed by one or combination of the following four procedures:

- using texture images,
- transforming the structure of the original character,
- adding some decorations, and
- deleting some parts of a character.

Therefore, it is necessary for character structure extraction to erase the texture, to delete the additional decoration, and to interpolate the deleted parts.

By investigating the peculiarities of decorated characters, in this paper, an algorithm that can extract character's essential structure from a decorated character is proposed. General character recognition algorithm consists of four major procedures: preprocessing, feature extraction, classification, and postprocessing [3]. The proposed algorithm is applied in preprocessing. After extracting an essential structure that represents the character, existing algorithms for feature extraction, classification, and postprocessing can be applied.

The algorithm consists of three procedures: global structure extraction, interpolation of structure, and smoothing. In the proposed algorithm, topographical features, such as ridges and ravines obtained from *intensity surface* [12], [13], [14], [15], are extracted from multiscale images. Ridges are used for global structure extraction and ravines are used for interpolation. Experimental results show clear character structures are extracted from very complex decorated characters. Moreover, the effectiveness of the algorithm is shown by recognition experiments with decorated characters.

2 Related Work

Some methods for dealing with decorated characters that are used in headlines are proposed [16], [17], [18]. Ozawa and Nakagawa [16] proposed a method for extracting character images printed on complex backgrounds. They enhanced character images by converting spatial gray-level images into actual gray-level images. They also converted outline characters into readable characters. Liang et al. [17] used a morphological approach to extract character strings from text with an overlapping background. In their method, first a background image is extracted by iterative erosion operations. Then, the background image is removed and the character images are reconstructed by closing and dilation operations. Sawaki and Hagita [18] proposed the complementary similarity measure and applied it for headline recognition. They showed that the proposed measure is useful for recognition of characters with graphical designs and degraded characters. However, all of these methods only deal with characters represented by texture images or characters with textured backgrounds. Many other kinds of decorations still need to be considered.

Broken or degraded character recognition [19], [20], [21] sometimes requires the same kinds of techniques as decorated character recognition since the broken or degraded parts of a character may be regarded as decorations. Hobby and Ho [19] developed a method to enhance degraded document images by finding and averaging bitmaps of the same kind of symbols. It improves the display appearance and recognition accuracy. Rodríguez et al. exploited a two-stage classifier [20]. First, a multifont classifier is applied and then a specialized classifier rerecognizes the ambiguous patterns using the patterns whose certainty of correct classification is high. Chou and Chang proposed a flexible matching method between template images and unknown character images [21]. A vector field, called character deformation field, is used to represent deformation. Although the above methods have some effectiveness on a few kinds of decorations, methods still need to be developed to deal with various and complicated decorated characters.

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Fig. 1. Examples of decorated characters. (a) A logotype. (b) Various fonts of character "A."

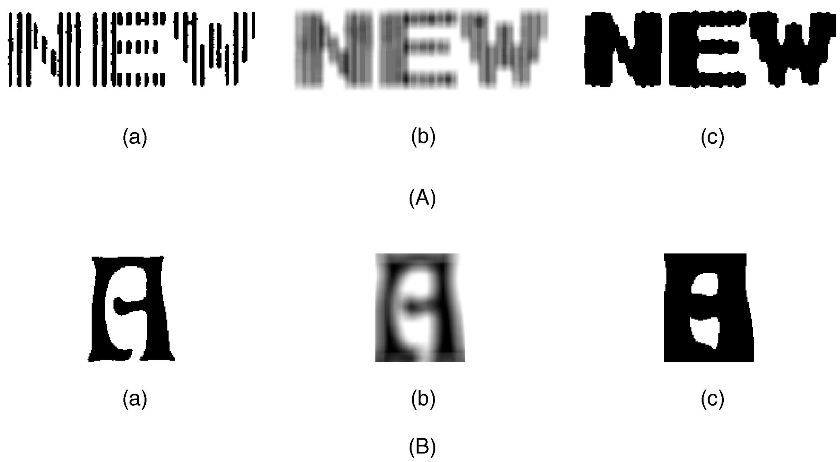


Fig. 2. Structure extraction by blurring and binarization. (A) A logotype. (B) Character "A." (a) Original image. (b) Blurred image. (c) Binarized image.

3 Structure Extraction from Decorated Characters

3.1 Structure of Decorated Characters

Fig. 1 gives some kinds of decorated characters. Fig. 1a shows a logotype and Fig. 1b shows four different kinds of character "A." These A's are some examples of decorated characters discussed in [22]. By investigating these characters, it is thought that global structures represent the outward forms of the characters, while local structures are decorations. The characters' essential structures can be obtained by extracting the global structures.

One considerable method for extracting global structure of an image is blurring. Examples are displayed in Fig. 2. Fig. 2.A displays a string and Fig. 2.B displays a character image of "A." In both figures, (a) is an original image, (b) is a blurred image, and (c) is a binarized image by a certain threshold. In the case of Fig. 2.A, structure of string is successfully extracted. However, the degree of blur or threshold of binarization must be determined by a human. In the case of Fig. 2.B, the structure of the lower part of the character is changed by blurring. Therefore, it is difficult to extract character structures from decorated characters using simple blurring without human operations.

In the proposed algorithm, images are blurred with various values of parameter to get multiscale images. Furthermore, from the multiscale images, the necessary information of topographical features for extracting global and local character structures are obtained.

3.2 Multiscale Images

In the proposed algorithm, the intensity surfaces of multiscale images are used to extract a character's structure. If an image is blurred by Gaussian filter, the brightness of each pixel is changed according to *scale*. Here, scale means the variance of the Gaussian filter. Scale-space describes the information of the thickness of each part of an image at each scale [23]. Scale-space $L(x, y; t)$ of an image $f(x, y)$ is the convolution of $f(x, y)$ and Gaussian function $g(x, y; t)$ with scale t and it is given by the following function:

$$L(x, y; t) = g(x, y; t) * f(x, y), \tag{1}$$

where

$$g(x, y; t) = \frac{1}{\sqrt{2\pi t}} e^{-\frac{x^2+y^2}{2t}}. \tag{2}$$

By blurring the original image at various scales, multiscale images are obtained. Multiscale images of character "N" in Fig. 1a are displayed in Fig. 3. In this figure, (a) is the original image and (b), (c), and (d) are the images blurred at different scales. Fig. 4 shows the intensity surface of each case in Fig. 3. Global and local structure are extracted based on these intensity surfaces of the multiscale images.

3.3 Global Structure Extraction

Using the intensity surfaces, a method of extracting global structure by detecting ridges is proposed. By observing Fig. 4, it is thought if the ridges of intensity surface at a certain scale given

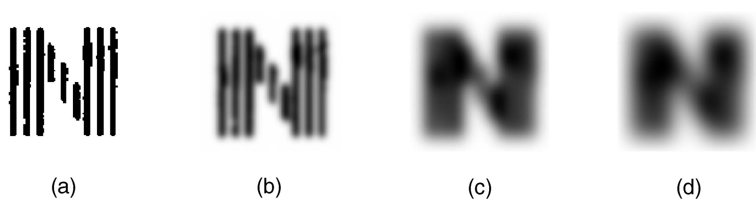


Fig. 3. Multiscale images. (a) $t = 0$, (b) $t = 10$, (c) $t = 50$, and (d) $t = 100$.

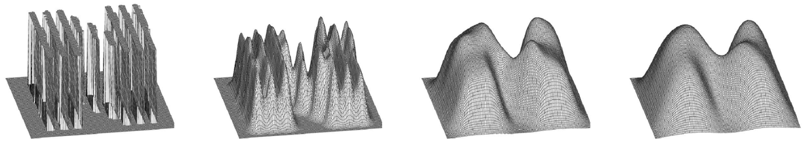


Fig. 4. Intensity surfaces. (a) $t = 0$, (b) $t = 10$, (c) $t = 50$, and (d) $t = 100$.

the global structure, the global structure can be extracted by detecting ridges at that scale. For each pixel of image, denote the direction that the absolute value of quadratic differential is maximum as p and its orthogonal direction as q. The condition that (x, y) is a pixel on the ridge at scale t is

$$\begin{cases} \dfrac{\partial L(x,y;t)}{\partial p} = 0, \\ \dfrac{\partial^2 L(x,y;t)}{\partial p^2} < 0. \end{cases} \tag{3}$$

For simplicity, p and q are quantized to one of the eight kinds of directions $(45° \times n, 0 \leq n \leq 7)$.

For structure extraction, appropriate pixels that represent the character structure need to be selected among the pixels that satisfy (3). In this paper, ridge strength is defined as (4) and the ridge pixels are selected by choosing the scale t at which the strength is the local maximum.

$$S(x,y;t) = \left\{ \frac{\partial^2 L(x,y;t)}{\partial p^2} - \frac{\partial^2 L(x,y;t)}{\partial q^2} \right\}^2. \tag{4}$$

If the following conditions are satisfied, the ridge strength will be the local maximum at (x, y).

$$\begin{cases} \dfrac{\partial S(x,y;t)}{\partial t} = 0, \\ \dfrac{\partial^2 S(x,y;t)}{\partial t^2} < 0. \end{cases} \tag{5}$$

However, if the above processing is applied directly to decorated character images, local structures are extracted simultaneously and it makes the essential structure extraction impossible. An example of this problem is shown in Fig. 5. Fig. 5a is the original image and Fig.5b shows all the black pixels of Fig. 5a that satisfy (3) and (5). Fig. 5b shows that although the global structure of character "A" is extracted, the local structures of decorations are also extracted simultaneously. It is obvious that how to avoid extracting local structures is a big problem.

To choose the ridges that represent the global structure, there are some considerable choices. For example,

- Using the images blurred at large scales.
- Using the pixels whose ridge strength (4) is large.

Fig. 5. Ridge detection. (a) Original image. (b) All the ridges are detected.

In order to verify these methods, two experiments have been carried out. One is extracting ridges at various scales and the other is extracting ridge pixels at various ridge strength. The results are shown in Fig. 6. Fig. 6.A is the results of various scales. Scales are divided into ten levels ($t = 1 \sim 10$, $t = 11 \sim 20, \ldots, t = 91 \sim 100$) and the pixels that satisfy (3) and (5) are extracted at each set of scales. The figures have shown the tendency that local structures are extracted at small scale and global structure is extracted at large scale, however, some local structures are also extracted at large scale. Fig. 6.B is the results of various ridge strength. First, the original image is blurred at scale $t = 1 \sim 100$ and all the pixels that satisfy (3) and (5) at any scale are extracted. Denote the number of extracted pixels be N and the pixels are sorted by descending order of the ridge strength. These are divided into ten sets of $N/10$ pixels and the pixels included in each set is plotted. The set that has the largest ridge strength is denoted as the "first 10 percent" and the set that has the smallest ridge strength is denoted as "10th 10 percent." Fig. 6.B shows strikingly that the global structure is represented by the pixels whose ridge strength is large and local structures are represented by the pixels whose ridge strength is small. These results clarifies that it is proper to extract the pixels whose ridge strength is large to obtain global structure.

Global structure extraction is summarized as follows: First, multiscale images are obtained by blurring the original image by changing the scale from $t = 1$ to $t = 100$. Then, the pixels that satisfy (3) and (5) are extracted. Denote the number of extracted pixels be N. Among these pixels, θN pixels whose ridge strength calculated by (4) is large are chosen. Here, θ is a constant that satisfies $0 < \theta \leq 1$.

Fig. 7 shows the result of extracting global structure from Fig. 5a. Here, $\theta = 0.4$. Compared with Fig. 5b, Fig. 7 shows that the local structures are removed while the global structure of the original image is extracted successfully.

However, Fig. 7 is not a connected structure. To enable the recognition of the decorated character, it is necessary to extract the connected structure that represents the character's essential structure. In the next section, a method for acquisition of the connected structure by interpolating discontinuous line segments is presented.

3.4 Interpolation of Structure by Recursive Ravine Detection

A considerable idea for interpolation is blurring. Some discontinuous line segments can be interpolated by blurring the image with the appropriate parameter and binarization with an appropriate threshold. However, it is not effective for some cases. For example, Fig. 8 shows typical cases that should be interpolated. Fig. 8.A displays discontinuous line segments like Fig. 7. Fig. 8.B displays parallel lines that must be essentially one line, which can often be seen when ridges are detected from characters constructed by using texture images. In each figure, (a) represents the original image, (b) is the blurred image, and (c) is the binarized image with an appropriate threshold. It is necessary to use large scale for

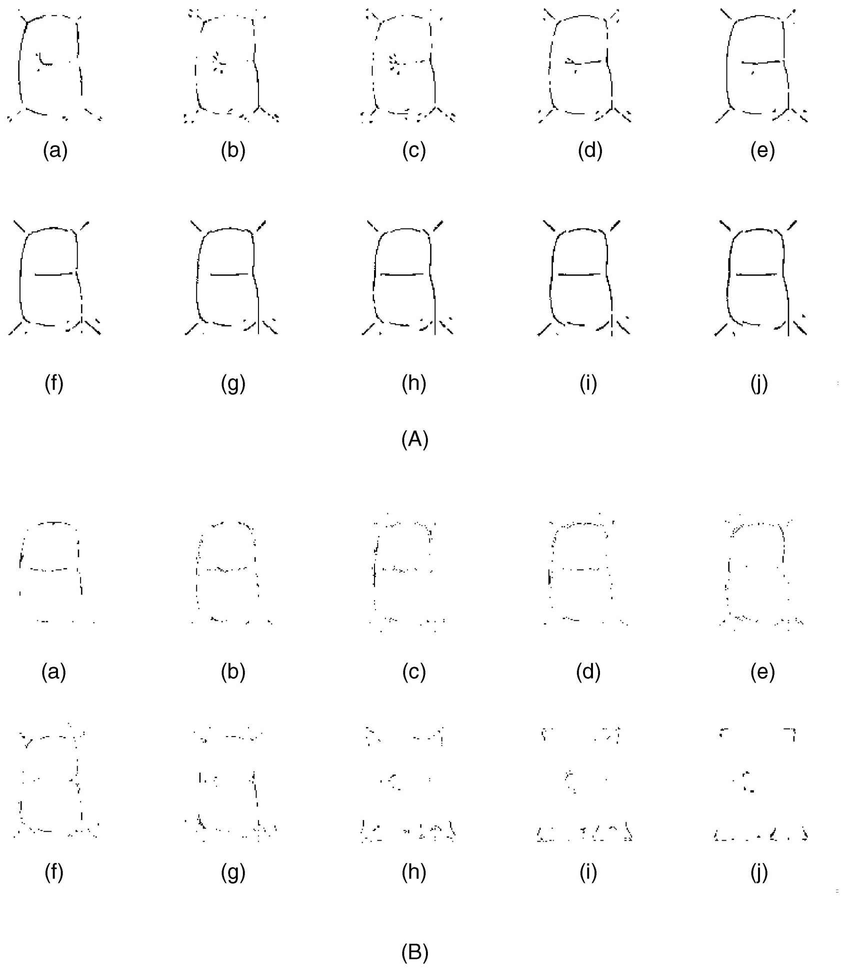


Fig. 6. Change of ridge shape. (A) Ridges extracted at various scales. (a) $t = 1 \sim 10$, (b) $t = 11 \sim 20$, (c) $t = 21 \sim 30$, (d) $t = 31 \sim 40$, (e) $t = 41 \sim 50$, (f) $t = 51 \sim 60$, (g) $t = 61 \sim 70$, (h) $t = 71 \sim 80$, (i) $t = 81 \sim 90$, and (j) $t = 91 \sim 100$. (B) Ridges extracted with various strength. (a) First 10 percent, (b) second 10 percent, (c) third 10 percent, (d) fourth 10 percent, (e) fifth 10 percent, (f) sixth 10 percent, (g) seventh 10 percent, (h) eighth 10 percent, (i) ninth 10 percent, and (j) tenth 10 percent.

interpolation since there are wide intervals between line segments. For this reason, essential purpose that only between line segments must be interpolated cannot be accomplished and the interpolated image is heavily different from the original image. Changing the shape heavily, simple interpolation by blurring may fill up some gaps that are the feature of a character.

For interpolation, a method of interpolating gaps between lines by detecting ravines recursively is proposed. The condition that (x, y) is a pixel on ravine at scale t is,

$$\begin{cases} \dfrac{\partial L(x,y;t)}{\partial p} = 0, \\ \dfrac{\partial^2 L(x,y;t)}{\partial p^2} > 0. \end{cases} \tag{6}$$

Fig. 7. Result of global structure extraction.

If larger scale t is adopted, wider gap between lines can be the interpolated. The interpolation algorithm by recursive ravine detection is as follows:

1. Initial value of scale t_1 is given. $t \leftarrow t_1$.
2. Detect ravines at scale t. Detected ravines are added to the image.
3. $t \leftarrow t/2$.
4. Steps 2 and 3 are repeated for k times.
5. Blur the image at a small scale.

Here, $t_1 = 30$ and $k = 5$.

Fig. 9 shows examples of interpolation. Figs. 9.A and 9.B show the results of Fig. 8.Aa and Fig. 8.Ba obtained by the proposed method. In both figures, (a) is the original image, (b), (c), and (d) show the processes of detecting ravine, (e) is the blurred image of (d), and (f) is the binarized image of (e). Compared with the results shown in Fig. 8, our method only interpolates the gaps between lines without changing the essential shapes of the original image.

3.5 Smoothing by Thinning

The line widths of images obtained by the method described in the previous sections are not uniform. Moreover, there are unevenness on the contours since the decorated structures are partially left. In order to resolve these problems, smoothing is needed. Smoothing is done by thinning, blurring at a small scale, and binarization.

Fig. 10 displays the process of character structure extraction of decorated character "N."

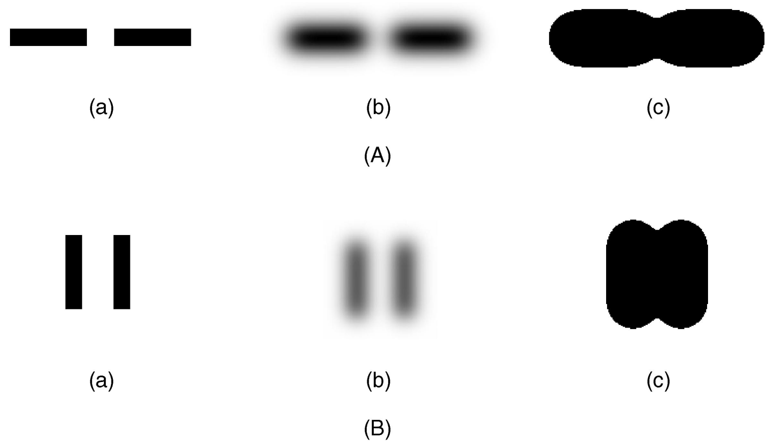


Fig. 8. Interpolation of structure by blurring. (A) Dashed line. (B) Parallel lines. (a) Original image. (b) Blurred image. (c) Binarized image.

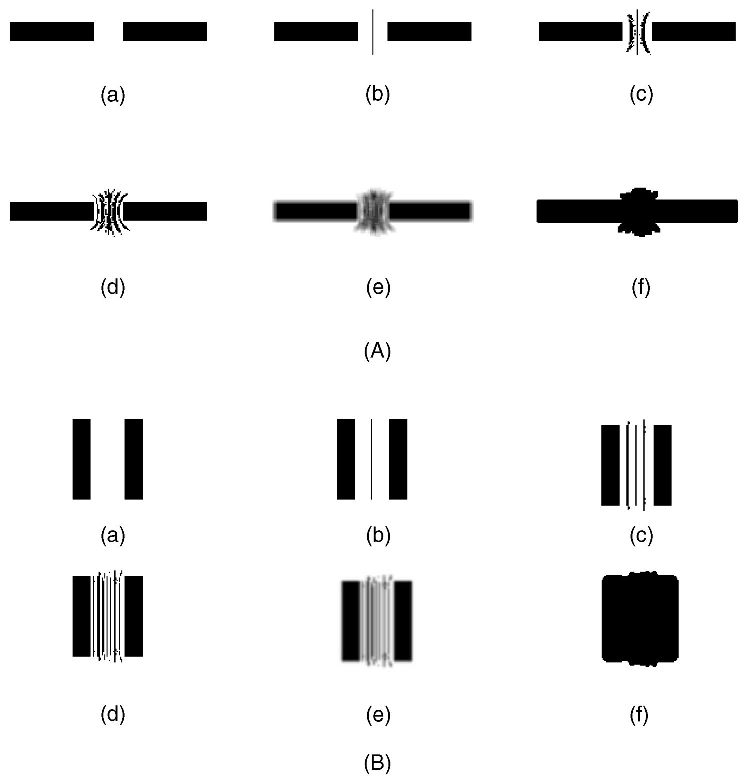


Fig. 9. Interpolation of structure by recursive ravine detection. (A) Dashed line. (B) Parallel lines. (a) Original image. (b) Ravines are detected once. (c) Detected twice. (d) Detected three times. (e) Blurred image. (f) Binarized image.

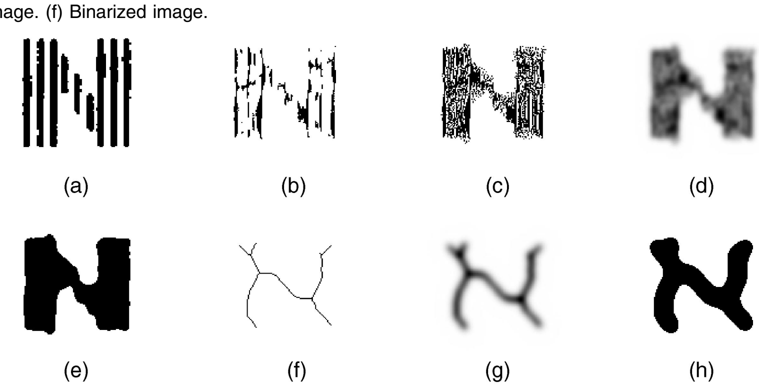
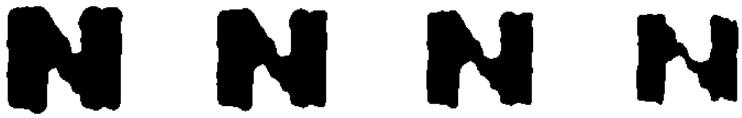


Fig. 10. Structure extraction of a decorated character. (a) Original image. (b) Detected ridges. (c) Ravines are detected recursively and are added to the image of (b). (d) Blurred. (e) Binarized. (f) Skeletonized. (g) Blurred. (h) Result.



(a) (b) (c) (d)

Fig. 11. Binarization with various thresholds. (a) $b = 1$. (b) $b = 10$. (c) $b = 35$. (d) $b = 100$.

The threshold for binarization was determined by human. However, it does not have so much influence on the algorithm. For example, Fig. 11 displays the results of binarization of the image of Fig. 10d with various thresholds b. If the threshold varies, the binarized image will change only a little. These figures show that the threshold is not so susceptible to binarization in the algorithm. In the following experiments, $b = 35$ is used.

4 Experiments

In order to verify the effect of our method, the proposed algorithm is applied for character structure extraction. Furthermore, recognition experiments are carried out.

4.1 Examples of Results of Structure Extraction and Recognition

Three different characters segmented from the logotype in Fig. 1a and four kinds of character "A" in Fig. 1b are used. For recognition, an existing OCR is adopted. The original images and the extracted images are shown in Table 1. In the table, the recognition result of each image using the OCR is shown below the image.

In the table, columns (a), (b), and (c) are the characters constructed using texture images, column (d) is a kind of outline character, and columns (e), (f), and (g) are the ones that have various kinds of decorations. Although totally different kinds of decorated character images are tested, the extracted images in Table 1 show that character structure is clearly obtained in every case. These results clarify the effectiveness of the proposed algorithm.

Original character images are recognized incorrectly except (f). For the cases of (a) and (c), texture images are regarded as a combination of many characters, since decorations are extracted as the important features of characters. For the case of (b), recognition is rejected. Compared with these results, most of the images extracted by the proposed algorithm are correctly recognized. The only failed case is (g) that "A" is recognized as "R." Since the topological features of "A" and "R" are similar, it is thought to be necessary to use the knowledge of natural languages for distinguishing them.

TABLE 1
Results of Structure Extraction and Recognition

	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Original image							
Result	I ',Jt		I Iljll'	j˜	˜	A	El
Extracted image							
Result	N	E	W	A	A	A	R

TABLE 2
Results of Quantitative Evaluation

	Original image		Extracted image			Original image		Extracted image	
(a)		0/26		25/26	(i)		9/26		21/26
(b)		0/26		24/26	(j)		0/26		19/26
(c)		0/26		24/26	(k)		11/26		19/26
(d)		0/26		25/26	(l)		11/26		14/26
(e)		3/26		25/26	(m)		4/26		15/26
(f)		0/26		25/26	(n)		10/26		14/26
(g)		0/26		21/26	(o)		9/26		13/26
(h)		0/26		22/26	(p)		1/26		9/26

TABLE 3
Candidates Selected for Each Character

	Candidates		Candidates
A	A(14), R(1), *failure*(1)	N	N(11), *failure*(5)
B	B(6), 8(4), O(2), S(1), b(1), g(1), *failure*(1)	O	O(13), *failure*(3)
C	C(14), *failure*(2)	P	P(13), *failure*(3)
D	D(13), O(2), u(1)	Q	Q(10), O(3), J(1), *failure*(2)
E	E(11), B(1), C(1), L(1), S(1), e(1)	R	R(14), Q(1), n(1)
F	F(11), r(2), P(1), T(1), *failure*(1)	S	S(16)
G	G(10), C(1), O(1), e(1), 6(1), *failure*(2)	T	T(14), *failure*(2)
H	H(11), X(2), *failure*(3)	U	U(15), *failure*(1)
I	I(8), l(2), a(1), i(1), r(1), t(1), *failure*(2)	V	V(14), Y(1), *failure*(1)
J	J(16)	W	W(12), *failure*(4)
K	K(9), X(2), *failure*(5)	X	X(15), *failure*(1)
L	L(14), *failure*(2)	Y	Y(13), I(1), T(1), r(1)
M	M(7), N(2), *failure*(7)	Z	Z(11), A(1), S(1), X(1), l(1), 7(1)

4.2 Quantitative Evaluation and Discussions

In order to verify the general ability of the method, various kinds of decorated characters are tested. Uppercase alphabetical characters (from A to Z) are used. The proposed algorithm is applied for each decorated character image and then it is recognized by the OCR. Table 2 shows the first five original and extracted character images. The numbers of correctly recognized characters out of 26 characters by the OCR are also shown.[1] The overall rates are 13.9 percent for the original images and 75.7 percent for the extracted images. Through the experiments, the values of t_1 and k in Section 3.4 and the threshold for binarization are not changed. In other words, we do not change these values according to the character image. We fix these values and investigate the effectiveness for various kinds of decorated character images.

These character images are roughly classified into two types. In Table 2, rows (a) through (h) are the decorated characters represented by texture images. The results have shown that the original character images can hardly be recognized correctly. It is shown that clear character images that represent the character's essential structure are obtained by the proposed method. After applying the proposed method, most of the character images are correctly recognized. These results show that the proposed method is extremely effective for character images represented by texture images.

In Table 2, rows (i) to (p) show the characters with various decorations. Some of the original character images can be recognized correctly. By applying the proposed method, character's essential structures are obtained in many cases. Moreover, the recognition accuracy improves in every case. However, the proposed method fails to extract the character structure in some cases. The method is not effective if the original character image includes both very thin lines and very thick lines. For example, in the case of (n), the curves of "C" and "D" are broken. This is because we use ridge strength for global structure extraction. If the line or curve of the original character image is thin, the ridge can be detected, however, the ridge strength is not so large. So, the detected ridge is not selected as the component that represents the global structure. This is the drawback of the proposed method. As we pointed out in Section 3.3, erasing the points whose ridge strength are small is very useful to eliminate decorations. To solve this problem, we must find another criterion to select the points other than ridge strength.

Another drawback of the method is the processing time. If the size of the image is $n \times n$ and if we use m scales, the time complexity for global structure extraction is $O(n^2m)$. In the experiments, the size of the character image is about 128×128. We used 100 scales for global structure extraction and five scales for interpolation. It takes about 15 seconds for one character to be processed when using a Pentium III, 800MHz processor. In order to put the method to practical use, we have to speedup the method by using smaller size images, reducing the number of images, using some approximations, etc.

Table 3 shows candidate categories selected for each character image. The umber of times each category has been selected is also shown. Alphabetical characters and digits selected as candidates are shown. In the table, *failure* is the case that no candidate is selected or the input image is recognized as a combination of several characters. The classification accuracies of "J" and "S" are the highest. All kinds of decorated characters of "J" and "S" in the experiments are correctly recognized. This is because character's essential structure is clearly extracted by the proposed method and they have no similar character. The classification accuracy of "B" is the lowest. This is because "B" has a similar character "8." Since the proposed method changes the shape of characters a little, in some cases, the shape of "B" becomes more similar to "8." The classification accuracy of "M" is the second lowest. Since "M" originally has a complex structure, the decorated character image is much more complex, and it is difficult to extract the essential structure.

Since the proposed algorithm is a preprocessing of a character recognition system, any kind of discriminant process or postprocessing can be applied to it. However, it is effective for applying a discriminant process suitable for the proposed algorithm. The experimental results show that the algorithm changes the shape of characters a little, and some parts of the character may disappear. Some structural analysis methods that can cope with changes in structure and can interpolate missing parts, e.g., [7], may be useful for the proposed algorithm.

1. For characters C, O, P, S, U, V, W, X, Y, and Z, we regard the lowercase character is the same as the uppercase character.

Moreover, since the proposed algorithm is extremely effective for character images represented by texture images, it may be effective to judge whether the input is represented by texture images or has some other decorations. Investigation of these processes is the future work.

5 Conclusions

Decorated characters are widely used in various documents. Practical OCR is required to cope with not only common fonts but also complex designed characters. In the case of recognizing decorated characters, the most important point is to remove decorated parts from character's essential structure.

In this paper, an algorithm for extracting character structures from various kinds of decorated character images was proposed. This algorithm is applied in preprocessing of character recognition. The proposed algorithm consists of three procedures: global structure extraction, interpolation of structure, and smoothing. First, global structure is obtained by detecting strong ridges using multiscale images. Next, gaps are interpolated by recursive ravine detection. Finally, character structure that is appropriate for recognition is made by smoothing.

Various kinds of character images were used to investigate the effectiveness of our algorithm. The results have shown that structures of decorated characters are extracted successfully in many cases. These clear structures make the recognition possible. Especially, it is extremely effective for the fonts represented by texture images. The recognition results have proved that although the original decorated characters are unrecognizable, after applying our algorithm in the preprocessing, many decorated characters can be recognized correctly. Moreover, by simply adding our algorithm to preprocessing, existing character recognition systems are able to cope with decorated characters without changing original recognition algorithm.

Although many of the complex designed characters tested in this paper are recognized successfully, it does not mean our method can deal with any kind of decorated character. From the experimental results, it is shown that the proposed method is not effective for some cases. The method is not effective if the font includes both very thin lines and very thick lines. Moreover, in this paper, the character recognition method has not been considered. Recognition method which is suitable for the images obtained by the proposed algorithm needs to be developed.

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