MVA '96 IAPR Workshop on Machine Vision Applications, November. 12-14, 1996, Tokyo, Japan

A Restoration Method for Broken Handwritten Line-figures with Connecting Terminal Points

Kazuki NAKASHIMA[†], Masashi KOGA[†], Katsumi MARUKAWA[†], Yoshihiro SHIMA[†].

Central Research Laboratory, Hitachi, Ltd.

Abstract

In some pattern recognition processes based on recognizing structural features, a serious problem is poorly-drawn lines which cause broken parts when a digital bitmap (a binary image) is made of the line-figure. This broken pattern changes the pattern structure, and increases the likelihood of rejection or misreading during the recognition process. Therefore, we have developed a restoration method for broken handwritten line-figures. In the restoration, broken parts are selected and connected smoothly. In an experiment using handwritten numerals, about 70 % of the patterns that were restored were recognized correctly.

1. Introduction

In some handwritten line-figure recognition methods, which are also called structural analysis methods, a serious problem is poorly-drawn lines. When figures written with a ball-point pen or pencil are subject to image threshold processing (which consists of making a bitmap), poorly drawn lines often do not from a complete pattern, as shown in Fig. 1. In some pattern recognition processes based on recognizing structural features[1][2][3], these line-figures are rejected because the figures do not match the standard figure patterns that make up the recognition dictionary.

A conventional method used to restore poorly drawn line-figures is the "expanding" and "shrinking" method[4]. This type of method considers the entire figure equally and does not focus on only the badly drawn parts, so inappropriate parts may be restored and a misreading or rejected pattern occur as shown in Fig. 2. For the pattern shown in Fig. 2(a), which is broken in the lower right, not only the broken part is connected but also a not-broken-part in the upper right, as shown in Fig. 2(b). Figure 2(b) shows that an extra hole is formed at the top of the pattern, and as a result, the structure of the pattern differs from the standard pattern in the recognition dictionary. Therefore, in structural analysis recognition, changing the pattern structure can seriously reduce the probability of recognition. To solve this problem, a restoration method that can be focused on selected broken-parts is needed.

This paper proposes a restoration method where only the broken part is selected by using the direction and length of the broken part. The effectiveness of this method when applied to a handwritten line-figure is demonstrated.

2. Detailed broken pattern problem

2.1 How to cope with broken pattern

To solve the broken pattern problem, the following approaches have been taken:

1) making the recognition method more robust against broken pattern,
2) an improved input device,

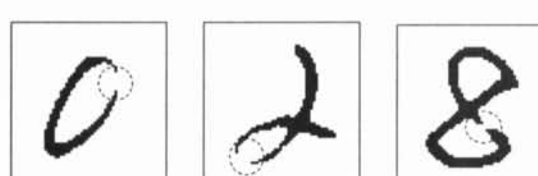
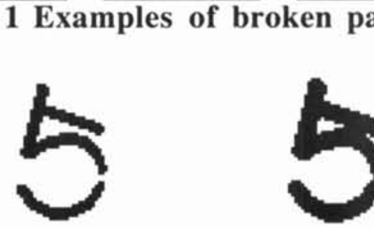


Fig. 1 Examples of broken pattern



(a) broken pattern (b) after expansion

Fig. 2 Problem with the conventional method

[†] Address : 1-280 Higashi-koigakubo, Kokubunji-shi, Tokyo 185, Japan
E-mail : nakasima@crl.hitachi.co.jp

3) an improved image threshold process,
4) addition of standard patterns which are broken,
5) restoration of broken pattern.

The first approach uses a kind of pattern-matching recognition method[5][6]. However, this method cannot cope with hand-written characters very well because of the great variety. Alternatively, another recent method uses gray-scale images in this approach[7][8], but the effectiveness of this new method is still undetermined.

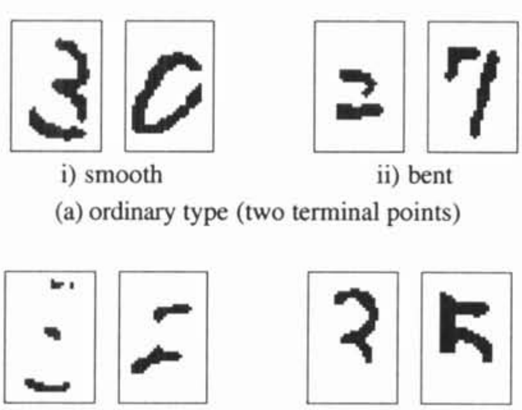
The second and third approaches are to use pre-processing for recognition, where the input pattern images are changed. Thus, both approaches the result of the recognition process is changed greatly, possibly in a negative way.

The fourth approach is a practical and actuality 'symptomatic therapy'. Many broken-patterns can be recognized correctly by adding some standard patterns for typical broken patterns. However, to add patterns for all types of broken pattern, the memory capacity needed for the standard patterns would increase explosively.

The fifth approach involves the "expanding" and "shrinking" method described in the Introduction and the another restoration method described in detail in this paper.

2.2 Classification of broken types

Broken-patterns have various causes. Nevertheless, if the patterns are classified by examining a number of terminal-points, the broken patterns can be classified into three types (one, two, and many terminal-points) as shown in Fig. 3. A terminal-point is a point where the maximum curvature occurs on a local contour line. If broken parts occur in patterns, each broken part will have one or two terminal-points that can be identified.



i) smooth ii) bent
(a) ordinary type (two terminal points)
(b) heavy type (many terminal points)
(c) tip type (one terminal point)

Fig. 3 Classification of broken types

The ordinary broken type can be either smooth or bent, as shown in Fig. 3(a). In either case, there will be a pair of terminal-points. However, the curve of the line at the broken-part will be bent more sharply in the bent type than in the smooth type. Figure 3(b) is a heavy broken type that is a strongly but poorly drawn line. Figure 3(c) is a tip broken type, which have only one terminal-point.

Table 1 shows the occurrence rate of broken type in 1,449 pieces of broken patterns from 7,616 patterns which were rejected by the structural analysis method[1]. (The values in Table 1 are based on the author's subjectivity.) We found that 50.2% of the broken patterns belong to the smooth type. Therefore, it is most important to ensure that the patterns with a smooth-broken-type are restored correctly. In this paper, we focus on the smooth-broken-type. The bent-broken-type is ignored, however, because its occurrence rate is very small and restoration is difficult.

3. A restoration method for broken pattern

3.1 Judgment process

In a broken part, a pair of terminal points that has the maximum curvature of the local contour line can be detected. However, other terminal points may also be detected that are not part of the broken part. The number of pairs will be equal to the number of terminal-point combinations, so we introduced the two features (the broken-stroke-direction and the broken-stroke-distance) shown in Fig. 4(a) which can be used to select the only appropriate pair of terminal points from among all possible pairs of terminal points.

The broken-stroke-direction is defined as the bend-state, which is multiplied symmetrically in the

Table 1. Rate of broken-type occurrence

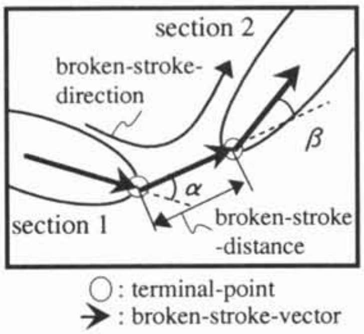
type	rate [%]
smooth	50.2
bent	1.4
heavy	21.4
tip	27.0

direction ($|\beta - \alpha|$), and the amount of displacement in the direction ($|\beta + \alpha|$). If the value of the bend-state is small, the broken stroke can be regarded as a smooth-broken-type. Both the starting point of the broken-stroke-vector that passes through a terminal-point in section 1 and the end-point of the broken-stroke-vector that starts at a terminal-point in section 2 are mid-points of segments that cross the figure line. The broken-stroke-distance (d) is defined as the distance between the pair of terminal points.

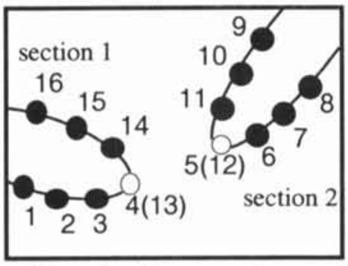
The broken stroke is classified according to the following inequality.

$$|\beta-\alpha| \times (\beta+\alpha) + k_1 \times d \leqq k_2, \quad (1)$$

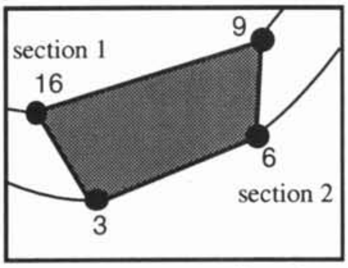
where k_1 and k_2 are constants. Equation(1) dictates that if a broken stroke is smooth, the broken-stroke-distance will be long, and if the value of the bend-state is large, the broken-stroke-distance will be short.



(a) direction and distance of broken part



(b) apex candidates for the restoration-quadrilateral



(c) restoration-quadrilateral

Fig. 4 Principle of restoration

3.2 Connection process

To reduce misreading influences in the restoration, the broken area must be connected smoothly regardless of the line-width. Therefore, four apexes of a restoration-quadrilateral must be determined as shown in Fig. 4(c).

Figure 4(b) shows black circles and white circles that represent neighboring pixels on the contour line. The number of pairs of pixels on the either side of the terminal pixel on each contour line should be determined by the figure line-width, and in this case, the value of three is selected from experience.

These 14 pixels are candidates to become the apexes of the restoration-quadrilateral and are numbered as shown. Pixels 1, 2, 3, 6, 7, 8, 9, and 16 are the outermost pixels. (If an imaginary rubber band was used to enclose all the pixels as if the pixels were protruding nails, the outermost pixels are defined as the pixels that the band would touch.)

When the candidate pixels are being searched in order, the apexes of the restoration-quadrilateral are the outer-most pixels related to a crossing section. A discontinuous section can be smoothly connected by filling in the restoration-quadrilateral and fitting it into the broken part, as shown in Fig. 4(c).

3.3 Recognition process

The judgment process can be applied to patterns rejected in the recognition process, as shown in Fig. 5. If the recognition is based on a structural analysis, broken

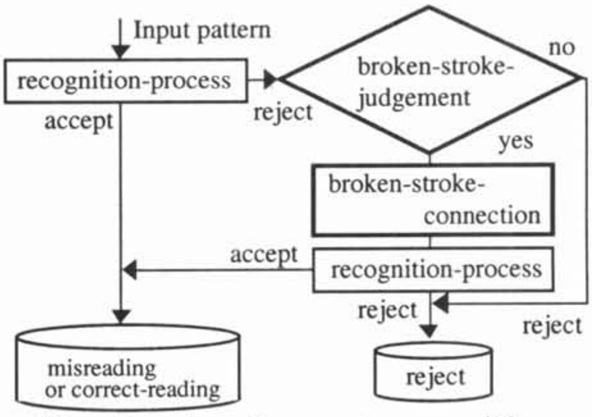


Fig. 5 restoration and recognition process

patterns are included among the rejected patterns, because they do not match the standard pattern for recognition. By trying to correct rejected patterns, although the total processing time is slightly increased, the misreading influences can be greatly reduced.

The patterns that are judged as broken patterns during the judgment go through the restoration process then return to the same recognition process. If the restoration is done correctly, the patterns will be accepted as correctly read.

4. Experimental results and discussion

We used the figure verification method[1], which is a general structural analysis method, as a recognition method. The restoration method described in this paper was programmed in C-language and executed on a workstation. We used 7,616 handwritten numeric patterns that were rejected by the recognition process as experimental samples of line-figure patterns.

From the 7,616 rejected patterns, 509 patterns were judged to be broken patterns by the judgment process. All 509 patterns were restored and went through the recognition process again. Of these, 354 patterns (69.5%) were recognized correctly, and ten patterns were misread.

Typical patterns that were restored correctly are shown in Fig. 6. These patterns are the numbers zero, two, and eight. The restoration of the number eight was especially impressive since the broken area was near the intersection of lines and could be restored smoothly without changing the line-width of the pattern.

The remaining 145 patterns were rejected again by the recognition process in spite of the restoration, because the patterns were changed into figures that did not match any of the character patterns.

5. Conclusion and future work

The restoration method for broken handwritten line-figures that we have proposed judges broken parts by specifying the direction and length of the broken stroke. This method connects broken strokes smoothly, and only patterns rejected in the recognition process are executed. In an experiment, almost 70% of the broken-patterns were correctly restored and recognized. About 2% of the patterns were badly restored and misread, but this is an acceptably small proportion.

The restoration method is only effective, however, if a pair of terminal-points can be found in a smooth-broken-type. Thus, our next step is to develop a robust recognition method for all types of broken patterns.

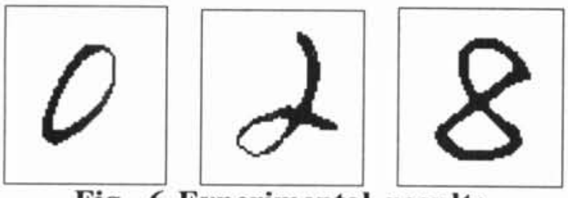


Fig. 6 Experimental results

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