ZONING DESIGN FOR HAND-WRITTEN NUMERAL RECOGNITION

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In the field of Optical Character Recognition (OCR), zoning is used to extract topological information from patterns. In this paper zoning is considered as the result of an optimization problem and a new technique is presented for automatic zoning. More precisely, local analysis of feature distribution based on Shannon’s entropy estimation is performed to determine “core” zones of patterns. An iterative region-growing procedure is applied on the “core” zones to determine the final zoning.

1 Introduction

Notwithstanding hundreds of good recognition algorithms have been proposed so far, machines are still far from achieve the performance of human beings in context-free handwritten character recognition, since different writing styles and changeable writing conditions make hand-written characters extremely variable [1].

In order to improve the recognition capability of reading machines, many efforts have been devoted to the analysis of local characteristics in hand-written characters [2,3,4,]. A simple way to obtain local information is through zoning [5]. A zoning is a partition of the control box of the pattern (i.e. the smallest rectangle containing the pattern); the elements of such partition are used to identify the position in which features of the pattern are detected. In other word, a handwritten characters are first normalized and included into a control box, successively, according to the zones of the control box, each feature is labeled with the name of the zone in which it has been detected. So far, the zoning design, that is the way in which the partition of the control box is defined, was carried out exclusively on the basis of intuitive motivations or personal experiences on the domain of application. In some cases the control box is divided into zones of equal size [5,6,7,8,9]; in other cases the control box is non-uniformly divided according to pattern density [10,11].

In this paper a new technique for zoning design is presented. The technique first determines the statistical distributions of local features using the set of training patterns. Successively the Shannon’s entropy is used to determine “core” zones of the control-box showing high-discrimination capability. An iterative zone-growing process is used to design the final zoning.
2 Notation

In this paper the following definitions are used:

- \( X = \{x_1, x_2, \ldots, x_N\} \) : set of patterns;
- \( F = \{f_1, \ldots, f_n\} \) : set of features;
- \( C = \{C_1, \ldots, C_m\} \) : set of pattern classes;
- \( B \) : control-box of a pattern, i.e. smallest rectangular image including the pattern;
- \( b_j \) : a pixel of the control-box, i.e. \( b_j \in B \);
- \( I(b_j) \) : set of neighbour pixels of \( b_j \) (see Figure 1a);
- \( z_i \) : a sub-image of the control box, i.e. \( z_i \) connected component, \( i=1,2,\ldots,M \);
- \( I(z_i) \) : set of neighbour pixels of \( z_i \) (see Figure 1b);
- \( z^*_i \) : extended zone of \( z_i \), i.e. \( z^*_i = z_i \cup \{b_j\} \), being \( b_j \in I(z_i) \) (see Figure 1c);
- \( Z = \{z_1, z_2, \ldots, z_M\} \) : zoning of a control box, i.e. \( Z \) is a partition of \( B \);

3 Shannon’s entropy for pattern discrimination.

Shannon’s entropy has been widely used in Pattern Recognition for decision tree construction, image thresholding and segmentation [12,13,14,15]. Shannon’s entropy is defined as [16]:

\[
H(P) = \sum_{k=1}^{m} p_k \log_2 \frac{1}{p_k}
\]

(1)

where \( P = (p_1, p_2, \ldots, p_m) \) is a probability distribution.

Now, if each element \( p_i \) of the vector \( P \) represents the probability that feature \( f_i \) is detected in the image zone \( z_j \) for the patterns belonging to \( C_k \), \( k=1,2,\ldots,m \), the
Shannon’s entropy can also be used to estimate the discrimination capability of each zone $z_j$. In fact, it is easy to verify that:

- $\min H(P)$ if $\exists k=1,2,\ldots,m$ s.t. $p_k = 1 \quad p_k = 0 \quad k \neq k$
- $\max H(P)$ if $\forall k=1,2,\ldots,m : p_k = \frac{1}{m}$.

For instance, let be $P=\{p_1, p_2\}$, the behaviour of the Shannon’s entropy is provided in Figure 2 ($p_1=1-p_2$).

Figure 2: Shannon’s entropy

Figure 2 shows as the Shannon’s entropy can be used to estimate the discrimination capability of a zone: if the presence of feature $f_i$ in the image zone $z_i$ is equally probable for patterns belonging to $C_1$ and $C_2$, it results $P=\{0.5, 0.5\}$ and therefore $H(P)=1$ (eq. 1); if the presence of feature $f_i$ in the image zone $z_i$ occurs exclusively for patterns belonging to $C_1$, in this case $P=\{1, 0\}$ and $H(P)=0$ (eq. 1); similarly, if the presence of feature $f_i$ in the image zone $z_i$ occurs exclusively for patterns belonging to $C_2$, it results $P=\{0, 1\}$ and $H(P)=0$ (eq. 1).

4 The Zoning Design Problem

In this paper, the zoning $\overline{Z} = \{\overline{z_1}, \overline{z_2}, \ldots, \overline{z_M}\}$ is derived by the following optimisation problem in which the Shannon’s entropy $H(P^i)$ is used to evaluate the discrimination capability of zone $z_j$ when feature $f_i$ is considered:

$$\overline{Z} = \min \sum_{j=1}^{M} H(P^j)$$

where $P^i = (p_{i1}, p_{i2}, \ldots, p_{im})$ is the probability distribution of the features $f_i$ in $z_i$, for patterns belonging to the classes $C_1, C_2, \ldots, C_m$. The probability distribution $P^j = (p_{j1}, p_{j2}, \ldots, p_{jm})$ is computed by using the formula:
\[ \forall k = 1, 2, ..., m \quad z_j = \frac{F_{C_k}(z_j)}{\sum_{k=1}^{m} F_{C_k}(z_j)}, \text{if } \sum_{k=1}^{m} F_{C_k}(z_j) > 0; \quad p_k z_j = 0, \text{otherwise.} \]

where \( F_{C_k}(z_j) = X_{C_k}(z_j)/N_{C_k} \), and

- \( X_{C_k}(z_j) = \text{card} \{ \mathbf{t} \in X \mid \mathbf{t} \text{ belongs to } C_k \text{, and } f_i \text{ has been detected in } \mathbf{t} \text{ at zone } z_j \} \);
- \( N_{C_k} = \text{card} \{ \mathbf{t} \in X \mid \mathbf{t} \text{ belongs to } C_k \} \).

## 5 A Technique for Zoning Design

The technique for zoning design, based on eq. (2), is described in the following:

(Preliminary Phase)

- For each one-pixel zone \( z_j \) of the pattern image compute: \( P^j = (p_1^j, p_2^j, ..., p_m^j) \)

(Phase 1: Core zone Definition)

- Detect the \( M \) "core" one-pixel zones of the image \( z_1 = \{b_1\}, z_2 = \{b_2\}, ..., z_j = \{b_j\}, ..., z_M = \{b_M\} \) with the best discrimination capability (the points \( b_i \) are local minima for function \( H \)).

(Phase 2: Iterative zone-growing procedure)

- Repeat until the set of zones \( \{z_1, z_2, ..., z_j, ..., z_M\} \) becomes a partition of the pattern image:
  - For each \( z_p \), \( j = 1, 2, ..., M \), select \( z_{j}^* \) min so that: \( H(P_{j}^{*_{\text{min}}}) = \min \{ H(P_j) \mid z_j^* \text{ is an extended zone of } z_j \} \)
  - Select the zone \( z_{j}^{*_{\text{min}}} \) so that: \( H(P_{j}^{*_{\text{min}}}) = \min \{ H(P_j) \mid j = 1, 2, ..., M \} \).

This zone-growing process continues until the set of zones becomes a zoning, i.e. the set of zones becomes a partition of the control-box.

## 6 Experimental Results

The new technique for zoning design has been applied to handwritten numeral recognition. For this purpose we consider the classes \( \mathcal{C} = \{ C_1 = \emptyset, ..., C_{26} = \{9\} \} \), and the set of features \( F = \{f_1, ..., f_9\} \) \([17, 18]\): \( f_1 : \text{vertical-down cavity}; f_2 : \text{vertical-up cavity}; f_3 : \text{horizontal-right cavity}; f_4 : \text{horizontal-left cavity}; f_5 : \text{vertical-up end-point}; f_6 : \text{horizontal-right end-point}; f_7 : \text{horizontal-left end-point}; f_8 : \text{hole} \). The pattern set \( X \) used for zoning design consists of the 18468 hand-written numerals extracted from the "BR" directory of the CEDAR database \([19]\).

The new technique for zoning design has been evaluated with respect to a traditional zoning based on a 4x4 grid. Numeral recognition has been performed by an holograph-based technique \([20]\). Table 1 reports the results when a 4x4 grid is used (a), and when the new technique is adopted (b). The set of 2671 hand-written numerals from the CEDAR database has been used for the test \([19]\).
This result demonstrates the effectiveness of the new technique even if the recognition rate is not satisfactory for some classes. In fact, several zones provide information useful for the classification of patterns belonging to a restricted subset of classes, while no zone provides information useful for the other classes. In this sense other optimality functions must be considered able to select zones with high-discrimination capability and with complementary behaviour.

Table 1: Experimental Results

<table>
<thead>
<tr>
<th>Pattern Class</th>
<th>Number of Testing Patterns</th>
<th>Recognition rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Zoning (a)</td>
</tr>
<tr>
<td>0</td>
<td>355</td>
<td>68%</td>
</tr>
<tr>
<td>1</td>
<td>288</td>
<td>85%</td>
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<tr>
<td>2</td>
<td>220</td>
<td>88%</td>
</tr>
<tr>
<td>3</td>
<td>206</td>
<td>84%</td>
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<tr>
<td>4</td>
<td>179</td>
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</tr>
<tr>
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<td>56%</td>
</tr>
<tr>
<td>6</td>
<td>243</td>
<td>65%</td>
</tr>
<tr>
<td>7</td>
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</tr>
<tr>
<td>8</td>
<td>189</td>
<td>60%</td>
</tr>
<tr>
<td>9</td>
<td>176</td>
<td>65%</td>
</tr>
</tbody>
</table>

7 Conclusion

In this paper a new technique for the zoning design is presented. Topological distribution of features is used to detect zones of the pattern image with high discrimination capabilities. The experimental results, carried out in the field of hand-written digit recognition, point out the effectiveness of the new approach and make clear promising research directions.

References