ZONING DESIGN FOR HAND-WRITTEN NUMERAL RECOGNITION

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V.DI LECCE[1], G.DIMAURO[2], A.GUERRIERO[1], S.IMPEDOVO[2], G.PIRLO[2], A.SALZO[2]

(1) Dipartimento di Ing. Elettronica - Politecnico di Bari
Via Re David - 70126 Bari - Italy
(2) Dipartimento di Informatica - Università di Bari
Via Orabona, 4 - 70126 Bari – Italy

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 optimisation 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 hand-written 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*.

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2 Notation

In this paper the following definitions are used:

- $X=\{x_1, x_2, ..., x_N\}$: set of patterns;
- $F=\{f_1,...,f_n\}$: set of features;
- $C=\{ C_1 ,..., C_m\}$: 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,…,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);
- $Z=\{z_1, z_2, ..., z_M\}$: zoning of a control box B, i.e. Z is a partition of B;

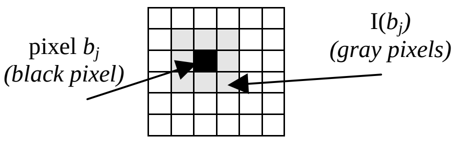

Figure. 1a

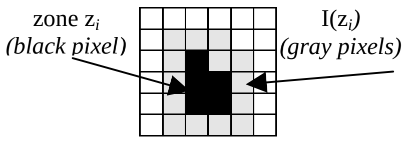

Figure. 1b

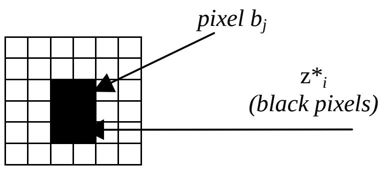

Figure. 1c

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]:

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

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

Now, if each element p_k 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,…,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 $\exists \underline{k}=1,2,\ldots,m$ ∋' $\begin{cases} p_{\underline{k}} = 1 \\ p_k = 0 \quad k \neq \underline{k} \end{cases}$
- max $H(P)$ if $\forall k=1,2,\ldots,m$: $p_k = \dfrac{1}{m}$.

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).

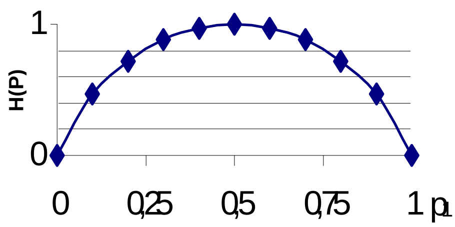

Figure 2: Shannon's entropy

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_j 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_j 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_j 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 $H(P^{z_j})$ is used to evaluate the discrimination capability of zone z_j when feature f_i is considered:

$$\overline{Z} = \min_Z \sum_{j=1}^{M} H(P^{z_j}) \qquad (2)$$

where $P^{z_j} = (p_1^{z_j}, p_2^{z_j}, \ldots, p_m^{z_j})$ is the probability distribution of the features f_i in z_j, for patterns belonging to the classes $C_1, C_2, \ldots, C_m$. The probability distribution $P^{z_j} = (p_1^{z_j}, p_2^{z_j}, \ldots, p_m^{z_j})$ is computed by using the formula:

$$\forall k = 1,2,...,m \quad p_k^{z_j} = \frac{F_{C_k}(z_j)}{\sum_{k=1}^{m} F_{C_k}(z_j)}, \text{if} \ \sum_{k=1}^{m} F_{C_k}(z_j) \rangle 0; \quad p_k^{z_j} = 0, otherwise.$$

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

- $X_{C_k}(z_j)$ = card {t∈ X | t belongs to C_k, and f_i has been detected in t at zone z_j };
- N_{C_k} = card {t∈ X | t 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: $P^{z_j} = (p_1^{z_j}, p_2^{z_j}, \ldots, p_m^{z_j})$

(*Phase 1*: <u>*Core" zone Definition)*</u>

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

(*Phase 2*: <u>*Iterative zone-growing procedure)*</u>)

- Repeat until the set of zones $\{z_1, z_2, \ldots, z_j, \ldots, z_M\}$ becomes a partition of the pattern image:

⇒ For each z_j, j=1,2,…,M, select $z_j{*}_{min}$ so that: $H(P^{z_j^*}{}_{min}) = \min\{H(P^{z_j^*}) \mid z_j^*$ is an extended zone of $z_j\}$

⇒ Select the zone $z_t{*}_{min}$ so that: $H(P^{z_t^*}{}_{min}) = \min \{ H(P^{z_j^*}) \mid j = 1,2,\ldots,M\}$.

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 *C={ C_1 ='0',..., C_{10}='9'}*, and the set of features *F={f_1,...,f_9}* [17,18]: f_1 : *vertical-down* cavity; f_2 : *vertical-up* cavity; f_3 : *horizontal-right* cavity ; f_4 : *horizontal-left* cavity; f_5 : *vertical-down* end-point ; f_6 : *vertical-up* end-point; f_7 : *horizontal-right* end-point ; f_8 : *horizontal-left* end-point; f_9 : 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

Pattern Class	**Number of Testing Patterns**	**Recognition rate**	
		Zoning (a)	**Zoning (b)**
0	355	68%	77%
1	288	85%	93%
2	220	88%	93%
3	206	84%	96%
4	179	77%	88%
5	116	56%	83%
6	243	65%	87%
7	217	63%	76%
8	189	60%	75%
9	176	65%	76%

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.

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