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Alphanumeric Hand-Prints Classification: Similarity Analysis between Local Decisions

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***Abstract*-**This paper presents the analysis of similarity between local decisions, in the process of alphanumeric hand-prints classification. From the analysis of local characteristics of hand-printed numerals and characters, extracted by a zoning method, the set of classification decisions is obtained and the similarity among them is investigated. For this purpose the Similarity Index is used, which is an estimator of similarity between classifiers, based on the analysis of agreements between their decisions. The experimental tests, carried out using numerals and characters from the CEDAR and ETL database, respectively, show to what extent different parts of the patterns provide similar classification decisions.

Keywords **-** Handwriting Recognition, Optical Character Recognition, Similarity Index, Zoning.

I. INTRODUCTION

Classification by parts has rightly been considered as one of the most effective strategies for alphanumeric hand-prints classification [1]. In fact, local information is decisive to overcome difficulties due to different writing styles and changeable writing conditions [2].

So far, many systems have been proposed which perform hand-printed digit classification by combining local decisions obtained from the analysis of different parts of the pattern. In this case, the degree of similarity among the local decisions is very important since it is well known that the higher the similarity degree of local decisions the more effective the process of decision combination can be [3,4].

This paper presents the analysis of similarity between local classification decisions, in a process of isolated hand-printed digit recognition. Local classification decisions are obtained from the information extracted by a zoning method: the pattern image is split into sub-images, named zones, each one providing information about a specific part of the pattern [3]. The degree of similarity between local decisions is measured by the *Similarity Index*, which is an estimator of similarity between classifiers, based on the analysis of their agreements [5]. This paper is organized as follows: Section 2 presents the zoning technique for local classification. Section 3 describes the *Similarity Index*, used to estimate the degree of similarity between classifiers. Section 4 shows the experimental results, which have been carried out on hand-printed numerals and characters, extracted from the CEDAR and ETL database, respectively.

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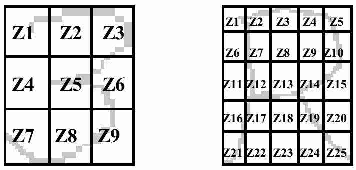
II. LOCAL CLASSIFICATION DECISIONS BY ZONING

Zoning is a diffuse strategy for local analysis of patterns. So far, several zoning methods have been designed by superimposing a r x s regular grid on the pattern image, creating the zones $z_1, z_2, \dots, z_j, \dots, z_M$, M= r·s [6,7,8]. Figure 1 shows the zoning Z^{3x3} and Z^{5x5} , which have been successfully used for the classification of handwritten numerals and characters, respectively.



(a) Z^{3x3} **(b) Z^{5x5}**

Figure 1. Standard Zonings

Let $C=\{C_1, C_2, \dots, C_k, \dots, C_K\}$ be the set of pattern classes and $F=\{f_1, f_2, \dots, f_i, \dots, f_L\}$ the feature set. When zoning $Z=\{z_1, z_2, \dots, z_j, \dots, z_M\}$ is used, for each zone z_j, j=1,2,…,M, the function $\Omega^{C_k}(f_i,z_j)$ can be defined, which denotes the probability that f_i is detected in z_j, for patterns belonging to the class C_k. $\Omega^{C_k}(f_i,z_j)$ can be estimated by using the set of training patterns $P=\{p_1, p_2, \dots, p_N\}$:

$$\Omega^{C_k}(f_i,z_j)=\frac{\Gamma^{C_k}(f_i,z_j)}{\sum_{k=1}^{K}\Gamma^{C_k}(f_i,z_j)} \quad \text{if} \quad \sum_{k=1}^{K}\Gamma^{C_{k}}(f_i,z_j)>0 \ ; \qquad (1a)$$

$$\Omega^{C_k}(f_i,z_j)=0, \qquad \text{otherwise.} \qquad (1b)$$

where

$$\Gamma^{C_k}(f_i,z_j)=\frac{N^{C_k}(f_i,z_j)}{N_{C_k}} \qquad (2)$$

and

- $N^{C_k}(f_i,z_j)=card\{P_t \in P \mid P_t \in C_k \text{ and } P_t \text{ contains } f_i \text{ in zone } z_j\}$
- $N_{C_k} = card\ \{P_t \in P \mid P_t \in C_k\}$.

Now, let p'$_t$ be a test pattern described by the set

$$S(p'_t) =\{(f_{t_q}, z_{t_q}) \mid q=1,2,\dots,Q\} \qquad (3)$$

where (f_{t_q}, z_{t_q}) means that f_{t_q} has been detected in the zone z_{t_q} of p'$_t$. A local classification decision is obtained for each zone z_j, j=1,2,…,M. Let

$$D_{z_j}^{C_k}(p'_t)=\sum_{(f_i,z_j)\in S(p'_t)}\Omega^{C_k}(f_i,z_j) \quad k=1,2,\dots,K, \qquad (4)$$

the pattern p'$_t$ is assigned to the class C_m for which it results:

❖ $z_j(p'_t)=C^m$ *iff* $D_{z_j}^{C_m}(p'_t)=\max_{k} D_{z_j}^{C_k}(p'_t)$ (5)

$$\text{and } D_{z_j}^{C_m}(p'_t)-D_{z_j}^{C_{m'}}(p'_t)>0$$

$$\text{(where } D_{z_j}^{C_{m'}}\left(p_t^{'}\right)=\max_{k}\left\{D_{z_j}^{C_k}\left(p_t^{'}\right) \mid k=1,..,K, k\neq m\right\}\text{);}$$

- $z_j(p_t^{'})$=Reject *otherwise*.

III. The Similarity Index

The *Similarity Index*, which is an estimator of similarity among *abstract-level* classifiers [5], is here used to measure the degree of similarity between local decisions obtained from specific pattern zones.

Let $Z=\{z_1, z_2, ..., z_j, ..., z_M\}$ a zoning method and P = $\{p_t \mid t=1,2,...,N\}$ a set of patterns. Let $z_i(p_t)$ be the classification decision (cass label) for the input pattern p_t , obtained from z_i by eq.(5) (we also assume that $z_i(p_t)=Rej$ means that z_j rejects p_t). The *Similarity Index* $\rho_{\{z_i,z_j\}}$ between z_1 and z_2 can be defined as:

$$\rho_{\{z_i,z_j\}}=\frac{1}{C(P_{ij})}\sum_{P_t\in P_{ij}} Q(z_i(p_t),z_j(p_t)) \quad (6)$$

where $P_{ij}=\{p_t\in P \mid z_i(p_t)\neq Rej, z_j(p_t)\neq Rej\}$,$C(P_{ij})$=Card($(P_{ij})$) and

$$Q(z_i(p_t),z_j(p_t))=\begin{cases}1 & \text{if } z_i(p_t)=z_j(p_t)\\ 0 & \text{otherwise}\end{cases} . \quad (7)$$

	$p_1\in$'3'	$p_2\in$'6'	$p_3\in$'7'	$p_4\in$'2'	$p_5\in$'0'	$p_6\in$'1'	$p_7\in$'9'	$p_8\in$'8'	$p_9\in$'5'	$p_{10}\in$'0'
z_i	3	6	7	2	0	1	9	9	5	0
z_j	3	6	1	2	0	1	0	9	5	8

Figure 2. Local decisions from the zones z_1, z_2

In the example of Figure 2, the local decisions obtained from the zones z_i and z_j are reported, when ten patterns $p_1,p_2,\ldots,p_{10}$ are considered. Correct decisions are reported in white cells, wrong decisions in grey cells. In this case z_i provides correct decisions 9 times out of 10, whereas z_j provides correct decisions 6 times out of 10. Decisions from z_i and z_j are the same 7 times out of 10, thus the *Similarity Index* is equal to $\rho_{\{z_i,z_j\}}$=0.7.

In general, for the zoning $Z=\{z_1, z_2, ..., z_j, ..., z_M\}$, the *Similarity Index* ρ_Z is defined as [5]:

$$\rho_Z=\frac{\sum_{\substack{i,j=1,...,M\\ i<j}}\rho_{\{z_i,z_j\}}}{\binom{M}{2}} . \quad (8)$$

In the example of Figure 3, the local decisions obtained from the four zones of $Z=\{z_1, z_2, z_3, z_4\}$ are reported, when ten patterns $p_1,p_2,\ldots,p_{10}$ are considered. Figure 4 reports the matrix of *Similarity Index* values for each pair of zones. Of course, since $\rho\{z_i,z_j\}=\rho\{z_j,z_i\}$ $\forall$i,j, only the values $\rho\{z_i,z_j\}$, $i\leq j$, are reported. The *Similarity Index* for $Z=\{z_1, z_2, z_3, z_4\}$ is equal to ρ_Z=0.783.

	$p_1\in$'2'	$p_2\in$'5'	$p_3\in$'5'	$p_4\in$'8'	$p_5\in$'1'	$p_6\in$'0'	$p_7\in$'4'	$p_8\in$'9'	$p_9\in$'0'	$p_{10}\in$'3'
Z_1	2	5	7	8	1	0	4	8	0	3
Z_2	2	5	7	9	1	0	4	8	0	3
Z_3	3	5	5	8	1	0	4	8	0	3
Z_4	2	5	5	8	1	8	4	8	0	3

Figure 3. Local decisions from the zones z_1, z_2, z_3, z_4

	z_1	z_2	z_3	z_4
z_1	100%	90%	80%	80%
z_2		100%	70%	70%
z_3			100%	80%
z_4				100%

Figure 4. Degree of Similarity between local decisions

Of course, the *Similarity Index* ranges in the interval from 0 to 1 (i.e. $\rho_Z\in[0,1]$):

- ρ_Z close to 0 means that local decisions are weakly similar;
- ρ_A close to 1 means that local decisions are strongly similar.

IV. Experimentals results

The experimental tests have been carried out on numerals ($C^N=\{0,1,2,\ldots,9\}$) of the CEDAR database (18467 learning patterns, 2189 test patterns) [9] and characters ($C^C=\{A,B,C,\ldots,Z\}$) of the ETL database (29570 learning patterns, 7800 test patterns) [10]. For the analysis of the numerals the zoning Z^{3x3} of Figure 1a has been considered, whereas the zoning Z^{5x5} of Figure 1b has been used for the analysis of characters. Furthermore, two feature sets, F_1 and F_2, have been extracted from the normalized pattern images (72x54 pixel image). The set $F_1=\{f_1,\ldots, f_9\}$ consists of hole, cavity and end-point features [3,11]. The feature set $F_2=\{f_1,\ldots, f_{57}\}$ consists of features extracted from contour profiles, intersections, extrema-points, cross points [3,11]

4.1 Experiments by C^N and F_1. Figure 5 shows the degree of similarity between the local decisions from the different zones of the patterns images, when the set of numeral digits C^N is recognized by the features of the set F_1. Four levels of similarity are considered: *Strongly Similar (*$\rho_Z\in]0.75,1]$*)*, *Similar (*$\rho_Z\in]0.50,75]$*)*, *Weakly Similar (*$\rho_Z\in]0.25,0.50]$*)*and *Not Similar(*$\rho_Z\in[0,0.25]$*)*. In general, the local decisions provided by the different zones are similar. Strongly similar decisions are only provided by the zones z_1 and z_4.

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Z1	**100%**	63.2%	41.4%	77.5%	50.2%	69.2%	44.4%	59.4%	64.4%
Z2		**100%**	29.2%	68.3%	44.9%	64.0%	40.6%	54.4%	57.1%
Z3			**100%**	45.1%	20.4%	43.5%	33.9%	37.0%	40.1%
Z4				**100%**	55.6%	71.9%	46.2%	61.8%	63.4%
Z5					**100%**	47.7%	25.1%	38.9%	40.2%
Z6						**100%**	41.0%	58.7%	63.1%
Z7							**100%**	35.2%	35.2%
Z8								**100%**	61.8%
Z9									**100%**

Strongly Similar Similar Weakly Similar Not Similar

Figure 5. Class Set C^N – Feature Set F_1 : Analysis of Similarity between local decisions

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Z1	**100%**	11.8%	29.5%	6.4%	13.0%	12.7%	0.3%	8.2%	14.2%
Z2		**100%**	12.8%	13.2%	19.7%	24.2%	6.4%	21.7%	7.5%
Z3			**100%**	5.2%	24.6%	11.1%	24.1%	2.7%	1.5%
Z4				**100%**	13.1%	27.0%	14.4%	24.1%	17.2%
Z5					**100%**	11.8%	18.6%	12.2%	5.0%
Z6						**100%**	12.6%	40.6%	32.7%
Z7							**100%**	19.5%	21.0%
Z8								**100%**	37.8%
Z9									**100%**

Strongly Similar Similar Weakly Similar Not Similar

Figure 6. Class Set C^N – Feature Set F_2 : Analysis of Similarity between local decisions

Conversely, several zones provide weakly similar decisions. For instance, decisions from zone z_7 are weakly similar to decisions from any other zone. Decisions from z_3 are weakly similar to decisions from z_1, z_2, z_5, z_6, z_7, z_8, z_9, whereas no significant similarity is measured between decisions from z_3 and z_4. The overall similarity between decision from the different zones is (eq. (8)) 49.83%.

4.2 Experiments by C^N and F_2. Figure 6 shows the degree of similarity between the local decisions from the different zones of the patterns images, when the set of numeral digits C^N is recognized by the features of the set F_2. In this case the local decisions are generally not similar. Weakly similar decisions are provided by z_1 and z_3, z_4 and z_6, z_6 and z_8, z_6 and z_9, z_8 and z_9. The overall similarity between decisions from the different zones is equal to (see eq. (8)) 16.07%.

4.3 Experiments by C^C and F_1. Figure 7 the degree of similarity between the local decisions from the different zones of the patterns images, when the set of characters C^C is recognized by the features of the set F_1. In this case the local decisions are generally strongly similar. Similar decisions are generally provided by decisions from zones z_{13} , z_{21} and z_{25}, with respect to decisions from other zones. The overall similarity between decision from the different zones is equal to (eq. (8)) 80.40%.

4.4 Experiments by C^C and F_2. Figure 8 shows the degree of similarity between the local decisions from the different zones of the patterns, when the set of characters C^C is recognized by the features of F_2. The local decisions are generally not similar. Weakly similar decisions are provided by the zones in the central part of the character (z_7, z_8, z_9, z_{12}, z_{13}, z_{14}, z_{17}, z_{18}, z_{19}).The overall similarity between decision from the different zones is equal to (eq.(8)) 18,81%.

V. CONCLUSION

This paper presents the analysis of similarity between local decisions obtained from different regions of hand-written numerals and characters. Two different zoning methods and feature sets have been considered for the experimental tests. The result show the effectiveness of the proposed analysis in estimating to what extent different pattern regions convey similar information.

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	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15	Z16	Z17	Z18	Z19	Z20	Z21	Z22	Z23	Z24	Z25
Z1	100%	94.2%	91.7%	94.1%	89.9%	91.3%	85.3%	85.0%	89.3%	95.5%	91.1%	87.9%	69.3%	90.7%	96.0%	92.1%	92.7%	84.9%	89.1%	93.3%	70.1%	83.1%	6.6%	85.8%	73.7%
Z2		100%	90.0%	92.3%	88.0%	89.5%	83.5%	83.2%	87.5%	93.6%	89.6%	86.0%	67.4%	88.7%	94.1%	90.4%	90.7%	83.1%	87.2%	92.2%	68.7%	81.2%	85.2%	84.3%	72.1%
Z3			100%	89.5%	85.0%	87.7%	81.4%	80.4%	84.7%	90.8%	89.3%	83.3%	64.6%	86.0%	91.4%	90.0%	88.1%	80.4%	84.7%	90.1%	65.2%	79.8%	83.8%	82.0%	69.4%
Z4				100%	87.4%	89.2%	83.6%	82.9%	87.6%	93.3%	88.8%	85.7%	67.2%	88.6%	93.8%	90.1%	90.5%	82.9%	87.4%	92.0%	68.5%	80.8%	85.3%	84.2%	71.8%
Z5					100%	85.5%	80.2%	78.7%	83.0%	92.1%	84.6%	82.0%	63.3%	84.6%	91.7%	85.7%	86.2%	78.5%	82.7%	86.6%	67.8%	77.5%	80.3%	79.6%	67.7%
Z6						100%	80.6%	80.2%	84.8%	90.8%	86.8%	83.4%	64.9%	85.9%	91.4%	87.4%	89.4%	80.9%	84.5%	89.2%	67.4%	78.1%	82.3%	81.6%	69.9%
Z7							100%	75.9%	80.0%	85.5%	80.3%	78.2%	60.2%	80.1%	85.5%	81.5%	82.1%	74.9%	79.0%	83.1%	71.2%	72.2%	76.2%	76.0%	65.6%
Z8								100%	78.7%	84.4%	80.1%	79.0%	62.0%	80.3%	84.8%	80.9%	81.9%	76.6%	79.4%	83.0%	62.1%	71.9%	76.1%	75.8%	66.1%
Z9									100%	88.7%	84.1%	81.6%	65.7%	84.5%	89.2%	85.2%	86.0%	79.6%	83.6%	86.4%	64.7%	75.6%	79.7%	79.4%	72.6%
Z10										100%	90.1%	87.4%	68.7%	89.9%	95.2%	91.2%	91.9%	84.2%	88.6%	92.4%	70.4%	81.5%	85.6%	85.0%	73.0%
Z11											100%	83.1%	65.2%	85.5%	90.6%	87.3%	88.2%	81.0%	84.0%	87.8%	65.9%	78.2%	82.2%	81.6%	69.9%
Z12												100%	64.1%	82.8%	87.9%	84.0%	85.0%	79.3%	82.0%	84.9%	65.0%	74.7%	78.7%	79.3%	68.9%
Z13													100%	65.6%	69.4%	65.5%	66.8%	61.4%	65.1%	67.1%	47.5%	56.9%	61.2%	62.9%	58.6%
Z14														100%	90.5%	86.6%	87.3%	80.3%	84.3%	87.7%	64.6%	77.2%	81.1%	81.0%	69.5%
Z15															100%	91.8%	92.4%	84.7%	88.9%	92.8%	70.3%	82.0%	86.1%	85.7%	73.5%
Z16																100%	89.0%	81.4%	85.5%	89.0%	66.2%	79.5%	82.9%	82.7%	70.8%
Z17																	100%	82.4%	86.9%	89.8%	67.0%	79.6%	83.5%	84.1%	70.7%
Z18																		100%	80.7%	82.9%	60.2%	71.9%	76.3%	77.6%	66.0%
Z19																			100%	86.5%	64.1%	76.3%	80.8%	81.6%	68.6%
Z20																				100%	66.9%	80.2%	85.2%	84.4%	71.4%
Z21																					100%	56.3%	60.4%	60.6%	53.2%
Z22																						100%	72.7%	73.3%	60.2%
Z23																							100%	77.0%	65.1%
Z24																								100%	64.2%
Z25																									100%

Strongly Similar | Similar | Weakly Similar | Not Similar

Figure 7. Class Set C^C – Feature Set F_1 : Analysis of Similarity between local decisions

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15	Z16	Z17	Z18	Z19	Z20	Z21	Z22	Z23	Z24	Z25
Z1	100%	15.5%	17.8%	12.7%	12.0%	10.7%	20.9%	29.6%	21.4%	7.0%	7.3%	17.3%	17.2%	13.1%	11.8%	4.1%	20.7%	24.1%	17.8%	12.1%	0.3%	12.7%	15.6%	12.8%	13.1%
Z2		100%	26.7%	23.0%	7.4%	12.2%	21.1%	17.0%	17.7%	11.1%	9.1%	13.5%	17.2%	14.4%	15.6%	8.4%	16.0%	15.7%	17.8%	12.6%	2.0%	19.5%	18.5%	16.5%	11.4%
Z3			100%	34.6%	5.1%	9.3%	22.4%	23.7%	15.8%	9.1%	10.9%	20.4%	17.1%	16.9%	19.5%	9.1%	21.6%	21.1%	21.0%	17.6%	0.7%	16.7%	23.5%	24.0%	12.1%
Z4				100%	12.9%	7.2%	20.9%	20.6%	20.7%	6.6%	8.8%	21.8%	20.2%	23.6%	17.9%	11.1%	21.8%	21.0%	23.6%	16.7%	4.6%	13.5%	20.2%	19.3%	15.1%
Z5					100%	3.7%	6.4%	10.1%	9.4%	3.8%	1.2%	3.2%	6.3%	6.0%	4.1%	7.0%	5.2%	7.9%	8.9%	2.6%	4.5%	7.2%	6.3%	6.8%	3.7%
Z6						100%	20.1%	9.0%	10.0%	19.9%	29.3%	17.9%	11.0%	15.1%	23.1%	20.6%	17.7%	13.8%	20.6%	18.4%	2.8%	13.8%	13.5%	19.0%	13.3%
Z7							100%	43.6%	38.4%	21.5%	18.3%	35.6%	35.0%	30.1%	31.5%	15.2%	40.6%	39.4%	38.3%	34.1%	1.0%	14.8%	23.8%	27.2%	25.1%
Z8								100%	41.7%	16.2%	10.8%	35.5%	31.6%	24.5%	23.2%	8.5%	36.6%	40.0%	33.1%	25.3%	5.4%	11.6%	16.2%	20.3%	23.7%
Z9									100%	18.0%	9.3%	30.1%	34.1%	29.0%	19.4%	10.8%	40.6%	39.8%	37.8%	24.9%	1.2%	13.0%	17.8%	20.5%	25.3%
Z10										100%	19.3%	22.0%	18.8%	20.1%	35.9%	16.2%	20.3%	18.1%	24.5%	27.9%	2.7%	12.2%	10.0%	14.4%	12.4%
Z11											100%	20.9%	10.9%	16.1%	25.9%	25.6%	14.7%	10.8%	19.3%	19.9%	2.2%	9.1%	10.6%	17.3%	15.3%
Z12												100%	40.1%	36.3%	32.5%	18.1%	37.5%	32.8%	34.8%	26.7%	7.8%	11.1%	12.1%	20.9%	26.6%
Z13													100%	34.4%	25.8%	10.4%	37.0%	34.8%	31.2%	22.3%	0.6%	9.0%	10.9%	16.1%	21.4%
Z14														100%	30.2%	14.2%	33.1%	30.3%	35.9%	22.3%	7.7%	9.2%	14.8%	18.5%	18.5%
Z15															100%	20.6%	29.1%	23.3%	33.2%	46.1%	8.1%	18.2%	20.1%	27.4%	24.0%
Z16																100%	14.3%	10.4%	18.6%	21.0%	10.1%	8.8%	12.0%	15.9%	19.7%
Z17																	100%	52.5%	45.2%	30.3%	2.6%	19.0%	26.3%	28.3%	26.1%
Z18																		100%	47.2%	24.0%	2.5%	14.5%	24.6%	24.5%	22.4%
Z19																			100%	32.4%	2.5%	17.8%	25.3%	29.5%	23.5%
Z20																				100%	5.3%	19.2%	26.5%	30.6%	33.1%
Z21																					100%	2.5%	3.6%	2.7%	13.8%
Z22																						100%	33.3%	23.4%	14.0%
Z23																							100%	40.5%	19.9%
Z24																								100%	29.8%
Z25																									100%

Strongly Similar | Similar | Weakly Similar | Not Similar

Figure 8. Class Set C^C – Feature Set F_2 : Analysis of Similarity between local decisions