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IDENTIFICATION OF STRUCTURED SYMBOLS ON THE BASIS OF MORPHOLOGICAL ANALYSIS METHODS

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Identification technique of structured symbols on the basis of morphological analysis methods has been considered. The developed method allows increasing identification reliability in the conditions of change of scaling, orientation and symbol collineation.

Identification of images of structured (printed) symbols supports solution of a number of scientific and applied tasks identifying objects of different nature. Modern methods of symbol identification are used for solving a wide range of tasks both office (electronic signature, massage decipher, text identification etc.) and special-purpose ones, designation image identification on various object surface etc. Affine and projective noises introduce the largest distortions influencing the identification result while recording images. They decrease significantly identification reliability by the methods used in modern recognition systems of printed symbols (for example, FineReader, Readiris, OmniPage, CuneiForm etc.). By the moment three main approaches for solving symbol identification problem are singled out: structural, feature and pattern [1–6]. Each of these methods has its advantages and disadvantages.

Pattern methods [1] compare symbol image with all patterns existing in a system base. The most suitable pattern is that which has the least points different from the studied image. Pattern methods recognize well defective symbols (torn, glued) but the main disadvantage of these methods is impossibility to identify a type differing a bit from that which is put into system (in size, slop or tracing).

Feature methods [2–4] are the most widespread. Simplifying assumption that not the whole symbol image but only a number of features calculated by the image may be analyzed is taken as their principle. It is implied that feature values bear enough information on a symbol. However, the weak point of the feature approach is the fact that not a symbol itself but a certain set of features is recognized that may results in wrong symbol identification.

Structural methods [5, 6] store information on symbol topology (sample contains information on positional relationship of symbol structural elements) but not on its pointwise shape. In this case a size of identified letter-image and a type of its print is not important. But the main disadvantage in this case is large resort costs. They are required for implementation of this method as skeleton is constructed, certain shapes of rotundity, angular and linear ratios, proportions between longitudinal and diametral lines are computed as well as gaps are determined at structural approach to symbol imaging.

Incompleteness and boundedness of application conditions is typical for all three methods. In this connection it is necessary to develop the method of symbol recognition based on application of features invariant to affine and projective transformation. Topological peculiarities of symbols which are extracted by the methods of morphological analysis of image shape are suggested to be used as invariant features.

Morphological analysis of image shape based on set theory, integral geometry, convex function analysis, stereology and geometry probability theory was developed by J. Serra and Yu. P. Pytiev in 60-s of XX c. [7, 8]. It allows giving quantitative description of geometric structure features.

Let us examine binary signal in Fig. 1. Binary signals may be presented by sets. For example, image in Fig. 1 represents binary signal in which white background region is expressed through 0 and shaded area through 1. This signal may be presented by a set of X points corresponding to a shaded area.

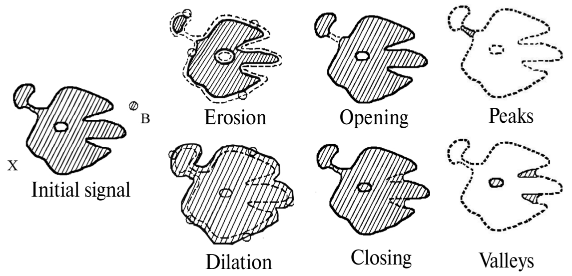


Fig. 1. *Erosion, dilation, disconnection and closing, generation of peaks and valleys of points X set by a structure element B*

Let $X \subseteq E$ be multiple presentation of binary input signal and let $B \subseteq E$ be compact set of small size and simple shape (for example, d-dimensional sphere). Set B is called a structure element (SE). Let $X \pm b = \{x \pm b : x \in X\}$ express vector transfer X to $\pm b \in E$. Basic morphological operators for sets are dilation $\oplus$ and erosion $O \bigcirc X$ with B [7], which are determined as

$$X \oplus B = \bigcup_{b \in B} X + b = \{x + b : x \in X \text{ and } b \in B\},$$

$$X \mathrm{O} B = \bigcap_{b \in B} X - b = \{z : (B + z) \subseteq X\}.$$

Other operators may be determined as combinations of erosion and dilation. For example, two additional basic operators – opening $\circ$ and closing $\bullet X$ with B [7] are determined as

$$X \circ B = (X \mathrm{O} B) \oplus B,$$

$$X \bullet B = (X \oplus B) \mathrm{O} B. \qquad (1)$$

To illustrate geometric behavior of these operators such two-dimensional sets as set X and SE B, showed in Fig. 1 should be examined; shaded areas correspond to set interior, solid black line means boundaries of converted sets and dashed line means a boundary of initial set of points X. This Figure illustrates that SE centre is on the boundary of converted set, erosion results in decrease of set X and dilation results in its increase. Opening suppresses spurs and slots narrow isthmus in X while closing fills narrow bays and small holes and so $X \circ B \subseteq X \subseteq X \bullet B$.

To detect peaks and valleys, Fig. 1, morphological transformations, generation of peaks $P(X)$ and generation of valleys $D(X)$ [7] which are determined in the following way

$$P(X) = X - (X \circ B),$$
$$D(X) = (X \bullet B) - X. \qquad (2)$$

are used.

Fig. 1 illustrates operation of these transformations.

Let us present symbol image in the form of set of X points corresponding to shaded area Fig. 2. Let a be the width of symbol, b be the heights of symbol.

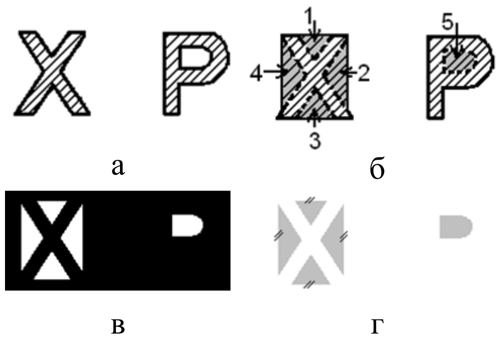


Fig. 2. *Extraction of Выделение «bays» and «lakes»: a) initial symbol image, б) result of closing operation with B with dimension [⅔a,⅔b], в) result of valley generation operation with B with dimension [⅔a,⅔b], г) «bays» and «lake»*

Let us use closing operation (1) to set X in Fig. 2, *a*, with SE B with dimension [⅔*a*,⅔*b*] and examine result in Fig. 2, *б*. Let us call areas marked out grey respectively area 1 is the «upper bay» (UB), 2 is the «right bay» (RB), 3 is the «bottom bay» (BB), 4 is the «left bay» (LB), 5 – is the «lake» (L). Then let us apply operation of valley generation (2) to initial set X Fig. 2, *a*. Thus, areas marked out grey in Fig. 2, *б*, are nothing other than the result of valley generation operation (Fig. 2, *в*). Let us indicate «bays» by two dashes on a part of bay outline which does not border with symbol (Fig. 2, *г*) (it is obvious that there are no dashes on outline «lakes»). Let us introduce as well definition «channel» (C) as regions which have outlines not bordering with symbol in several sides. Thus, for UB dashes are up, for RB – right, for BB – down, for LB – left, Fig. 2, *г*, for C – from several sides.

To formalize this notation let us introduce attribute vector **x** consisting of features characterizing quantity: x_1 – UB, x_2 – RB, x_3 – BB, x_4 – LB, x_5 – L, x_6 – C which call further a vector of primary features.

Let us examine a class of undistorted symbols F_1 (Fig. 3, *a*) and image corresponding to them with «bays», «lakes» and «channels» (Fig. 3, *б*), obtained as a result of applying valley generation (2) to Fig. 3, *a*. Attribute vector **x** divides a set of symbols of class F_1 into subclasses given in Table 1.

Fig. 3. *«Bays» and «lakes» of capital letter in Russian alphabet: a) original image, b) «bays» and «lakes»*

It is seen from Table 1 that quantity of valleys, «bays», «lakes» and «channels» obtained as a result of generation operations, their positional relationship and ratios are the unique feature for each symbol. Therefore, this symbol description may be used as features at symbol recognition.

On the basis of technological conditions of recording rotation angle at image fixing does not exceed 25° (relative to vertical). In this connection let us introduce two more classes of image. Classes F_2, F_3 are the symbol images rotated by 25° to the right and to the left respectively relative to vertical position (Table 1). Rotating image from 0 to 10 and from 10 to 25° both to the left and to the right features **x** for classes F_1 and F_2, F_3, respectively, stay constant.

Let us determine class F_4 for unknown orientation of symbol image in the following way. Let us rewrite all attribute vectors **x** from classes F_1, F_2, F_3 and subclasses corresponding to them into class F_4, then let us combine subclasses having identical attribute vectors **x** in class F_4 (Table 1).

It is seen from Table 1 that using the above mentioned features some symbols get into subclasses F_4 being on lines numbered 1,3,4,6,7,12,13,14,23; let us denote the obtained subclasses respectively F_1', F_3', F_4', F_6', F_7', F_{12}', F_{13}', F_{14}', F_{23}'.

Let us introduce secondary attribute vector **y** (it is computed after determining to what subclass F_4 the identified symbol refers) to determine what letter the obtained feature refer to; this attribute vector consists of the following features:

- y_1 is the ratio of BB to UB, y_1=0 at ratio <0,5, y_1=1 at ratio, →1, y_2=2 at ratio >1;
- y_2 is the ratio of RB to L, y_2=0 at ratio <0,5, y_2=1 at ratio >0,5;
- y_3 is the ratio of BB to LB, y_3=0 at ratio <1, y_3=1 at ratio of BB to LB >1;
- y_4 is the ratio of L height to symbol height, y_4=1 at ratio →0,5, y_4=1 at ratio →1;

Table 1. *Division into subclasses sets of capital letters in Russian alphabet*

№	F_1		F_2		F_3		F_4	
	x	Subclass	*x*	Subclass	*x*	Subclass	*x*	Subclass
1	001010	А, Д	001010	А, Р	001010	А	000000	Г, Т
2	010010	Б	010010	Б, Ь	010010	Б, Р	100000	Ц
3	010020	В	010020	В	010020	В	010000	Г, С
4	000000	Г, Т	001000	Г, П	010000	Г, С	001000	Г, Л, П
5	020000	Е	111110	Д	111110	Д	000100	Э
6	212100	Ж	020000	Е	020000	Е	000010	О, Р, Ь, Ъ
7	010100	З	212100	Ж	212100	Ж	101000	И, Н, Ч, Л
8	101000	И, Н, Ч	010100	З	010100	З	100100	У
9	111000	К	101000	И, Н, Л	101000	И, Н, Ч	100010	Ь
10	001000	Л, П	111000	К	111000	К	011000	Т
11	102000	М	102000	М	001100	Л	010100	З
12	000010	О, Р, Ь, Ъ	000010	О	102000	М	010010	Б, Р, Ь
13	010000	С	010000	С	000010	О	001100	Т, Л
14	100100	У	001100	Т	001000	П	001010	А, Д, Р
15	000020	Ф	100100	У	011000	Т	000011	Ы
16	111100	Х	111120	Ф	100100	У	111000	К
17	100000	Ц	111100	Х	111120	Ф	110100	Ц
18	200000	Ш, Щ	110100	Ц	111100	Х	101010	Ю
19	000100	Э	200000	Ш	201000	Ц	010110	Ъ
20	000011	Ы	210100	Щ	200000	Ш	001110	Я
21	101010	Ю	000100	Э	301000	Щ	111100	Х
22	001110	Я	000011	Ы	000100	Э	111110	Д
23			010110	Ъ	100010	Ь	200000	Ш, Щ
24			101010	Ю	000011	Ы	020000	Е
25			001110	Я	010110	Ъ	000020	Ф
26					101010	Ю	102000	М
27					001110	Я	010020	В
28							201000	Ц
29							111120	Ф
30							210100	Щ
31							212100	Ж
32							301000	Щ

y_5 is the quantity of «bays» and «lakes» after application of valley generation operation to original image using SE in the form of section with the length equals to symbol height related angularly 45 and 135° to abscissa and logical addition with the results of valley generation operation performed earlier (the example is given in Fig. 4), y_5 possesses a value equals to a quantity of «bays» and «lakes»;

y_6 is the ratio in UB of quantity of grey pixels in the first line to a number of grey pixels in the second line, quantity of grey pixels in the second line to a number of grey pixels in the third line and so on up to the last line in which there are grey pixels of UB; y_6=0 at gradual increase of ratios, y_6=1 at sharp jump in ratios or at equal ratios;

y_7 is L position relative to symbol centre, y_7=0 at L position in the upper part of symbol, y_7=1 at L position in bottom part of symbol;

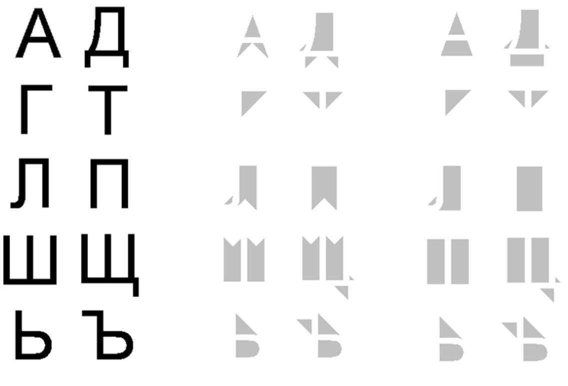
y_8 is the quantity of «bays» and «lakes» after applying valley generation operation to the original image using SE in the form of section with the length equals to symbol height related angularly 45° to abscissa, y_8 possesses the value equals to a number of «bays» and «lakes»;

y_9 is the number of UB after applying valley generation operation to the original image using SE in the form of section with the length equals to symbol height related angularly 135° to abscissa, y_9 possesses value equals to a number of UB;

y_{10} is the ratio of BB area to the area of rectangle describing the symbol, y_{10}=0 at ratio ≤0,5, y_{10}=1 at ratio >0,5;

y_{11} is the ratio of RB area to the area of rectangle describing the symbol, y_{11}=0 at ratio ≤0,5, y_{11}=1 at ratio >0,5.

x is this feature that is not calculated.



а б в

Fig. 4. *Obtainment of additional features: а) original image; б) the result of valley generation operation; в) the result of logical addition of the results of valley generation operation to the original image, B with the dimension [2⁄3a,2⁄3b] and Fig. 4, б*

Table 2. *Division of symbol set into subclasses by the secondary attribute vector* ***y***

Class	Subclass	y										
F_1'	Г	x	x	x	x	1	x	x	x	x	x	x
	Т	x	x	x	x	2	x	x	x	x	x	x
F_4'	Г	x	x	x	x	x	x	x	x	0	0	x
	Л	x	x	x	x	x	x	x	x	1	x	x
	П	x	x	x	x	x	x	x	x	0	1	x
F_6'	О	x	x	x	1	x	x	x	x	x	x	x
	Р	x	x	x	0	x	x	0	x	x	x	x
	Ь	x	x	x	0	2	x	1	x	x	x	x
	Ъ	x	x	x	0	3	x	1	x	x	x	x
F_7'	И	1	x	x	x	x	0	x	x	x	x	x
	Н	1	x	x	x	x	1	x	x	x	x	x
	Ч	0	x	x	x	x	x	x	x	x	x	x
	Л	2	x	x	x	x	x	x	x	x	x	x

Class	Subclass	y										
F_3'	Г	x	x	x	x	x	x	x	x	x	x	0
	С	x	x	x	x	x	x	x	x	x	x	1
F_{12}'	Б	x	1	x	x	x	x	x	x	x	x	x
	Р	x	0	x	x	x	x	0	x	x	x	x
	Ь	x	0	x	x	x	x	1	x	x	x	x
F_{13}'	Т	x	x	0	x	x	x	x	x	x	x	x
	Л	x	x	1	x	x	x	x	x	x	x	x
F_{14}'	А	x	x	x	x	x	x	x	2	x	x	x
	Д	x	x	x	x	x	x	x	3	x	x	x
	Р	x	x	x	x	x	x	x	1	x	x	x
F_{23}'	Ш	x	x	x	x	2	x	x	x	x	x	x
	Щ	x	x	x	x	4	x	x	x	x	x	x

This attribute vector divides symbol set into subclasses of symbols given in Table 2.

It is seen from Table 2 that having computed the secondary attribute vector **y** it is possible to determine definitely which symbol the identified image refers to.

It is seen from Table 1 and 2 that such attributes as quantity of «bays», «lakes» and «channels» obtained as a result of valley generation operation, their positional relationship are the unique features for each symbol. Therefore, this symbol description may be used as an invariant features to affine and projective transformations at symbol recognition.

Thus, this method uses topological peculiarities of symbols as attributes; in this case less quantity of attributes than in structural recognition methods is computed. The suggested method is not sensitive to scale changes and such symbol deformations as affine and projective transformations till single elements of symbol are not overlapped each other.

The developed method of symbol identification may be used both at recognition of designation images on different objects surface obtained by the systems of automated information input through various types of digital photo- and video cameras and for solving typical office tasks connected with printed symbol recognition.

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REFERENCES

1. Bagdonas A. Reading machine «RUTA 701» // Automation of characters input into computers: report of scientific and technical conference. – Vilnius, 1968. – P. 96–121.
2. Abramov E.S. Simulation of image recognition systems (by the example of printed texts): Thesis ... of candidate of tech. science. – Moscow, 2006. – 234 p.
3. Gorlov D.V. Images identification on the basis of features invariant to shift, rotation, scaling: Author's abstract ... of a candidate of tech. science. – Krasnoyarsk, 2002. – 20 p.
4. Andreev S.V. Algorithmic supply of prototype of device for readout of passports and visas / S.V. Andreev, A.V. Bondarenko, V.I. Goremychkin, A.V. Ermakov, S.Yu. Zheltov. [Electronic resource]: [scientific electronic library of RAS IPM]. Access mode: http://www.keldysh.ru/papers/2003/prep46/prepr2003_46.html.
5. Fu K. Structural methods in image recognition. – Moscow: Mir, 1977. – 319 p.
6. Kotovich N.V. Sceleton image recognition / N.V. Kotovich, O.A. Slavin. [Electronic resource]. Access mode: http://ocrai.narod.ru/skeletrecognize.html.
7. Margos P., Serra J. Morphological systems for processing multidimensional signals // Proceeding of engineering Institute in electrical engineering and radio electronics. – 1990. – V. 78. – № 4. – P. 109–132.
8. Pytiev Yu.P. Problems of image morphological analysis // Mathematical methods of studying natural resources of the Earth from space / Ed. by V.G. Zolotukhin. – Moscow: Nauka, 1984. – P. 41–83.

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