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STRUCTURALLY-CONNECTED MODEL OF THE IMAGE: CONTOUR ALLOCATION AND SIGNS FORMATION

The paper suggests structurally-connected model of half-tone and binary image for its usage in the problems dealing with allocation of contour and formation of connectivity centre.

Key words: *image, recognition, connectivity, geometric signs, image contour, centers of gravity and connectivity.*

Introduction

One of the main problem in digital processing is images recognition. There exist various methods of images recognition. One of them is structural recognition, assuming the creation of information space of geometric signs [1].

The most known geometric signs, such as perimeter, area of the figure without holes, area of the hole, maximum distance between external equally inclined tangent lines and boundaries, distance in the direction between external equally inclined tangent lines – Fere diameter, Euler number, do not always provide necessary validity of recognition. Especially this concerns the processing of spot half tone images, which, being processed, are transformed in binary images and have complex form. Thus, the task aimed at creation of binary image model is of great importance since such a model enables to define signs, corresponding to simplicity and information content criteria, and along with already known signs increase the validity of recognition.

The given paper suggests new generalized approach to determination of signs of large class of 2D binary images, based on analysis of contour points.

Connectivity of geometric sign of binary half-tone image

For quantitative evaluation of connectivity sign we may use the notion of “neighbourhood” already known in literature [2, 3]. It is known that in square raster four-connectivity is possible, where elements which are tangential in the angles are considered to be “neighbours”.

Further we will apply the principle of eight-connectivity.

Single elements $b(m,n)$ of binary matrix $B(M,N)$ is connected if at least one of the neighbouring elements $b(m,n+1)$, $b(m+1,n)$, $b(m+1,n+1)$, $b(m-1,n)$, $b(m,n-1)$, $b(m-1,n-1)$, $b(m+1,n-1)$, $b(m-1,n+1)$ is also single, where m, n –are coordinates of element b by columns and rows, M – is number of rows, and N – is a number of columns.

Connectivity $\delta^k(m,n)$ of a single element $b^k(m,n)$ within the frame of the given binary image of k th number is defined by the sum of the single elements, it is connected with, i. e.:

$$\delta^k(m,n) = b^k(m+1,n) + b^k(m-1,n) + b^k(m,n+1) + b^k(m,n-1) +$$
$$b^k(m+1,n+1) + b^k(m-1,n-1) + b^k(m+1,n-1) + b^k(m-1,n+1),$$

$$\forall b^k(m,n) = 1 .$$

Connectivity Δ^k of binary image of k th number is sum of connectivities of its elements (or half of the sum) is defined by the formula:

$$\Delta^k = \sum_{m=1}^{M}\sum_{n=1}^{N} \delta^k(m,n)/2 .$$

This integral quantity characterizes binary image and is not inferior to other geometric signs and taken in combination with them, can be used to increase the validity of recognition.

Let us present the half tone image in the form of matrix A^0, consisting of the set of elements (or pixels) of the image *a(m,n),* where *m*=1, ..., *M*, a *n*=1, ... ,*N* :

$$A^0 = \begin{pmatrix} a(1,1) & a(1,2) & \dots & a(1,N) \\ a(2,1) & a(2,2) & \dots & a(2,N) \\ \vdots & \vdots & \vdots & \vdots \\ a(M,1) & a(M,2) & \dots & a(M,N) \end{pmatrix}.$$

Values of elements *a(m,n)* are limited by the condition: $0 < a(m,n) < C$, where C – maximum possible brightness, and belong to the area of positive integer.

We will represent the half tone image in the form of mathematical structural model as the set of *k* binary images of corresponding brightness levels:

$$A(M,N) = \bigcup_{k=1}^{K} B^k(M,N).$$

Elements of each binary matrix are calculated according to the rule:

$$b^k(m,n) = \begin{cases} 1, & якщо \quad a^k(m,n) = c_k \\ 0, & якщо \quad a^k(m,n) \neq c_k \end{cases}.$$

Then, having defined connectivity Δ^k of each binary image we can formulate series of connectivity values, which will characterize the half-tone image. The results obtained can represented in the form of the function:

$$\Delta(k) = \Delta^1, \Delta^2, \dots, \Delta^{k-1}, \Delta^k, \Delta^{k+1}, \dots, \Delta^K .$$

Application of structurally-connected model of binary image for the problems of contour allocation

Some problems of images processing and analysis provide allocation of binary image contour for its further usage in problems of recognition and classification.

We will use the suggested connectivity sign for the solution of the above-mentioned problem.

Let input image be represented by matrix $B^0(M,N)$, elements $b^0(m,n)$ of which take the value of zero (background) or unit (image).

1. Let us represent the elements of binary image $B^0(M,N)$ by the values of their connections with neighbouring elements, i. e., instead of single element of the image, the value of its connectivity is written. We will call such model of the image *Z(M,N)* as connected image:

$$z(m,n) = \begin{cases} \delta^k(m,n), & if \quad b^0(m,n) = 1, \\ 0, & if \quad b^0(m,n) = 0. \end{cases}$$

2. Initial point is defined on connected image. This may be any point, belonging to the contour. It is used as the first non-zero point while serial scanning of the image. This point is assigned the label of the contour. That is: if $z(m,n) \neq 0$, then *z(m,n)* – is initial and matrix contour image $B^1(M,N)$: $b^1(m,n)=1$ is formed.

3. Values of the points which are neighbours of initial point are analyzed. Among these points neighbouring minimal by value non-zero point is chosen.

$$z_{\min} = MIN\{z(m-1,n), z(m+1,n), z(m-1,n-1), z(m,n+1), z(m+1,n-1),$$
$$z(m-1,n+1), z(m,n-1), z(m+1,n+1)\}.$$

This points is assigned the label of the contour and transfer is performed.

4. Further we will consider points bordering on new point. Among these points we select

neighbouring minimal by value non-zero point with the exception of the previous one.

Point 4 is repeated until the initial point enters the neighbouring points. That is, the contour becomes complete. The allocation process is completed. Fig 1 shows the example of this method.

B^0 (10,10)

0	0	0	0	0	0	0	0	0	0
0	0	0	1	1	1	1	0	0	0
0	1	1	1	1	1	1	1	0	0
0	1	1	1	1	1	0	0	0	0
0	1	1	1	0	0	0	0	0	0
1	1	1	1	0	0	0	0	0	0
0	1	1	1	1	1	1	1	0	0
0	1	1	1	1	1	1	0	0	0
0	0	0	1	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Z(10,10)

0	0	0	0	0	0	0	0	0	0
0	0	0	4	5	5	4	0	0	0
0	3	6	7	8	8	5	5	0	0
0	5	8	7	5	4	0	0	0	0
0	6	8	6	0	0	0	0	0	0
3	6	8	6	0	0	0	0	0	0
0	6	8	7	6	5	4	2	0	0
0	3	6	7	8	6	4	0	0	0
0	0	0	4	4	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

B^1(10,10)

0	0	0	0	0	0	0	0	0	0
0	0	0	1	1	1	1	1	0	0
0	1	1	0	0	0	1	1	0	0
0	1	0	0	1	1	0	0	0	0
0	1	0	1	0	0	0	0	0	0
1	0	0	1	0	0	0	0	0	0
0	1	0	1	1	1	1	1	0	0
0	1	1	0	0	1	1	0	0	0
0	0	0	1	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Fig. 1. The example of the method of binary image contour allocation by connectivity sign: B^0(10, 10) – is an input image, Z(10, 10) – is connected image, B^1(10, 10) – is contour image

In such case connected image *Z(M,N),* defined by rule 3, is a structural model of input binary image. The algorithm is developed and the programme, based on C programming language is written for realization of this method.

Formation of contour images connectivity centre

The method of connectivity determination is based on digital model, obtained on the basis of rectangular raster points, field of continuous image calculation [4]. The method is based on procedure of balanced sums of connectivity [5, 6]. Binary images in the form of flat geometric figures in Cartesian coordinate system are used in the research. Discrete elements of contour image have logic signs, taking values either 1 or 0, and are defined proceeding from the condition of contour line belonging. (Fig. 2).

Connectivity sum of all the elements, having value 1 is defined (Fig. 3), then connectivity of each 0 elements with 1 elements is defined. After that, images are shifted and the sum of all elements is calculated, the elements of binary image are calculated separately horizontally and vertically (Fig. 5). Equality of connectivity sum by verticality and horizontality is defined by balancing method. Two mutually perpendicular lines form the coordinates of connectivity centre (Fig. 6).

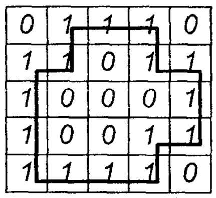


Fig. 2. Contour representation of the image

	3	3	3	
3	4		4	3
3				4
3			4	3
2	3	3	3	

Fig. 3. Connectivity of single elements

	1	1	1	
1	1	5	1	1
1	4	3	5	1
1	5	4	1	1
1	1	1	1	

Fig. 4. Connectivity of zero elements

	3	3	3	
3	4	5	4	3
3	4	3	5	4
3	5	4	4	3
2	3	3	3	

Fig. 5. Connectivity of aligned single and zero elements

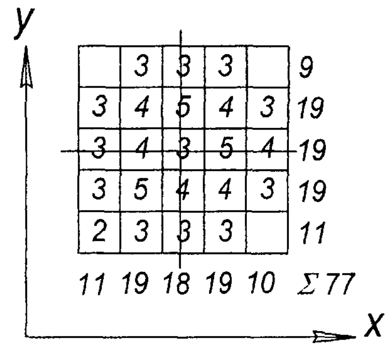


Fig. 6. Formation of image connectivity centre

Proceeding from the above-considered method we constructed mathematical balancing model of thee obtained elements of binary image.

Let us denote $a^1_{i,j}$ – connectivity of a single element i, j, $a^0_{i,j}$ – connectivity of zero element i, j. Balancing of columns and rows must satisfy such system conditions.:

$$\begin{cases} \sum\limits_{i=1}^{u_j^*}\left(a^1_{i,j}+a^0_{i,j}\right)=\sum\limits_{i=u_i^*+1}^{N}\left(a^1_{i,j}+a^0_{i,j}\right), & u_j^*\in\{1,2,\ldots N\} \\ \sum\limits_{j=1}^{u_i^*}\left(a^1_{i,j}+a^0_{i,j}\right)=\sum\limits_{j=u_i^*+1}^{N}\left(a^1_{i,j}+a^0_{i,j}\right), & u_i^*\in\{1,2,\ldots N\} \end{cases}$$

Thus, applying the operation of generalized contour preparation and operation of balancing by columns and rows we can form simple signs, intended for recognition of contour image.

Experimental research and computer modeling of image connectivity centre

Algorithm of connectivity centre determination is based on the method of connectivity sums balancing applying dichotomy principle. Fig 7, 8 show the formation of connectivity centre of spotted images having no axis of symmetry. On the basis of the algorithm obtained, the applied program was elaborated, enabling to study images in the form of random flat contours by means of overlapping on them the rectangular grid with variable step and define the coordinates of connectivity centre of investigated contour [6].

The program has several functional units, such as graphic editor, computational-analytical unit, unit of writing and reading of the formed image. Built-in editor allows to draw, correct image, change the step of coordinate grid on the obtained image and performs some other functions.

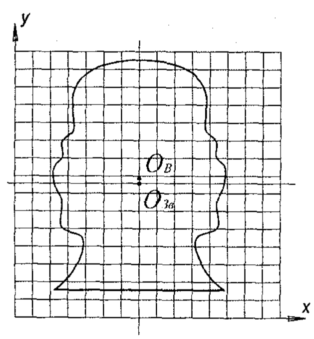
Computational-analytical unit scans the field of flat contour, determining the location of each cell and then defines the connectivity of elements with values 1 and elements with values 0. Then sums of connectivity by verticality and horizontality and, at last, location of connectivity centre relatively contour and its coordinates in the preset system of count are determined. Unit of reading and writing allows to save the obtained image and continue to work with it for some time. By means of elaborated programme 500 flat geometric figures with closed contour are investigated regarding the dependence of connectivity centre location on the step of grid and orientation of flat contour.

Three groups of images were investigated:

1. Images, having no axis of symmetry.
2. Images, having one axis of symmetry.
3. Images, having two axes of symmetry.

In images, having one axis of symmetry, centre of gravity and centre of connectivity are located on the axis of symmetry. Fig 7 shows the example of the image, having coordinates of gravity centre *Og*: x=35, y=39,279; coordinates of connectivity centre O_c: x=35, y=37,8.

In images, having two axes of symmetry, centre of gravity and connectivity centre coincide and are located in the point of intersection of symmetry axes. Fig 8 shows the example of the image, where the coordinates of gravity centre and coordinates of connectivity centre coincide: $Og = O_c$: x=35, y=37,651.



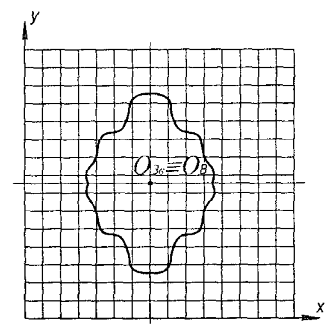


Fig. 7. Image with one axis of symmetry:

Fig. 8. Image with two axes of symmetry:

O_g – centre of gravity,

O_c – centre of connectivity

Fig 9 shows the contours of spot- like images of laser routes with connectivity centres, having no symmetry axis.

Fig. 9. Contours of spot-like images with connectivity centres

Study of spot-like images of laser routes showed that the connectivity centre is inside the images. Experimental research of connectivity centre dependence on the step of the grid showed, that connectivity centre is sensitive to variation of grid step (Fig 10)

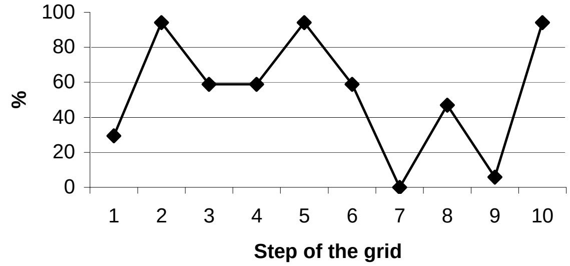


Fig. 10. Graph of connectivity centre dependence on the step of the grid

The graph shows that the highest accuracy of connectivity centre definition is achieved at steps 2, 5 and 10 of the grid.

While random motion, turn and scaling of flat figure the location of connectivity centre of the figure the location of connectivity centre of the figure itself does not change, i. e., the coordinates of connectivity centre are invariant to affine transformations.

In images, having one symmetry axis, centre of gravity and centre of connectivity are located on the symmetry axis. In images, having two axes of symmetry, centre of gravity coincide and are located in the point of intersection of axe.

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Conclusions

1. The suggested model allows to increase the accuracy of contour allocation as compared with already known methods at the expense of approximation of angular elements of the image. It is expedient to use this model for processing of images when half-tone images are represented by the totality of binary images, as well as if the value of connectivity of image elements have already been calculated while preprocessing. Structurally-connected model of binary image can be used for recognition of certain geometric forms of the object and classification.

2. Structurally-connected model allows to form simple contour geometrical signs, namely connectivity centre, located in the centre of the image and sensitive to variation of coordinate grid step. Experimental research showed, that the highest accuracy of connectivity centre definition is achieved if grid step is 2,5 and 10.

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