http://doi.org/10.35784/iapgos.5352

received: 26.07.2023 | revised: 10.09.2023 | accepted: 23.09.2023 | available online: 30.06.2023

SEGMENTATION OF MULTIGRADATION IMAGES BASED ON SPATIAL CONNECTIVITY FEATURES

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Abstract. *The article aims to study the multi-level segmentation process of images of arbitrary configuration and placement based on features of spatial connectivity. Existing image processing algorithms are analyzed, and their advantages and disadvantages are determined. A method of organizing the process of segmentation of multi-gradation halftone images is developed and an algorithm of actions according to the described method is given.*

Keywords: image segmentation, image processing, halftone images, spatial connectivity

SEGMENTACJA OBRAZÓW WIELOGRADACYJNYCH NA PODSTAWIE CECH ŁĄCZNOŚCI PRZESTRZENNEJ

Streszczenie. *Artykuł ma na celu zbadanie procesu wielopoziomowego segmentacji obrazów o dowolnej konfiguracji i rozmieszczeniu w oparciu o cechy łączności przestrzennej. Przeanalizowano istniejące algorytmy przetwarzania obrazu oraz określono ich zalety i wady. Opracowano metodę organizacji procesu segmentacji wielogradacyjnych obrazów półtonowych i przedstawiono algorytm działań zgodnie z opisaną metodą.*

Słowa kluczowe: segmentacja obrazu, przetwarzanie obrazu, obrazy półtonowe, łączność przestrzenna

Introduction

Image recognition is a relevant and promising direction in the information technologies field; its application scope is expanding every year. The recognition process includes several tasks to obtain the most accurate result, one of which is segmentation. Segmentation is the division of an image into regions based on certain features that characterize these regions or the image in general. Depending on the type of image, brightness segmentation, contour segmentation, shape or texture segmentation is used. Existing algorithms have several disadvantages, leading to the necessity of creating new learning methods [5, 6, 9]. Thus, the region augmentation method provides fairly accurate segmentation of simple scenes with a small number of objects and without texture. However, for more complex scenes, this method does not give good results. The development of methods that allow the segmentation of halftone images of arbitrary configuration and placement, considering their spatial relationships, is an urgent task. This article covers information about the developed method that allows performing effective segmentation in an algorithmically convenient way [1, 13, 15].

Purpose and tasks of the study. The article describes the algorithm of the developed method of multigradation image segmentation based on features of spatial connectivity and gives examples of its operation.

1. Materials and methods

Consider the mathematical model of the proposed segmentation method. We present the initial image in the form of a matrix A (1), which forms a set of image elements $a(m,n)$, where $m = 1..M, n = 1..N$.

$$A = \begin{bmatrix} a(1,1) & \cdots & a(1,M) \\ \vdots & \ddots & \vdots \\ a(N,1) & \cdots & a(N,M) \end{bmatrix} \tag{1}$$

This matrix represents the input data for the segmentation problem. The value of the elements $a(m,n)$, limited by condition: $0 < a(m,n) < C$, and belongs to the domain of non-negative integers, where C – maximum brightness value. At the output, it is necessary to obtain several areas that correspond to individual segments of the object, their combination, or the entire object. They can be represented by the corresponding output matrices in halftone

$$V_{1..L} = \begin{bmatrix} v(1,1) & \cdots & v(1,M) \\ \vdots & \ddots & \vdots \\ v(N,1) & \cdots & v(N,M) \end{bmatrix} \tag{2}$$

or binary form (2). They have the same dimension as the original matrix A and are subject to the same conditions. Thus, the domain of feasible solutions is described by an inequality $0 < v(m,n) < C$ and belongs to the domain of non-negative integers [2, 4, 10].

In the first step, the value of all elements of the original image is reduced by a defined discrete value. Find $A^1 = A - D$, where all elements of D have the same values d:

$$A^1 = A - D = \begin{bmatrix} a(1,1) - d & \cdots & a(1,M) - d \\ \vdots & \ddots & \vdots \\ a(N,1) - d & \cdots & a(N,M) - d \end{bmatrix} \tag{3}$$

Based on the obtained matrix A^1, which is a truncated image, a slice is formed (binary matrix):

$$B^1 = \begin{bmatrix} b(1,1) & \cdots & b(1,M) \\ \vdots & \ddots & \vdots \\ b(N,1) & \cdots & b(N,M) \end{bmatrix} \tag{4}$$

by:

$$b^k(m,n) = \begin{cases} 1, & a^k(m,n) = 0 \\ 0, & a^k(m,n) \neq 0 \end{cases} \tag{5}$$

These actions are repeated for the matrix A^1 and for all subsequent matrices A^k until all the elements of their respective slices B^k take zero values. Thus, a set of matrices is formed $A^1 \dots A^k$ and their corresponding sections $B^1 \dots B^k$, and the number of slices K is determined by the formula $k = \frac{C}{d}$.

An example of creating slices for 5×5 image fragment and quantization step 1 is shown in figure 1 [8].

Let's determine the value of the intra-slice connectivity for each binary slice from the obtained set as

$$\Delta^k = \sum_{\substack{m=1,\\ n=1}}^{M,N} \sum_{\substack{i=-1,\\ j=-1}}^{1,1} b^k(m,n) \cap b^k(m+i,n+j) \tag{6}$$

This function can be represented by the spectrum of intra-slice connectivity. The next step is to study the obtained connectivity spectrum, namely [6, 12, 14]:

- determination of the global maximum of the function,
- determination of local maxima of the function.

Determining the global maximum is not difficult and can be given by the function:

$$\Delta'(K) = \max(\Delta^k) \tag{7}$$

where $\Delta'(K)$ – the maximum value of the intra-slice connectivity for the slice with the number K. Determining the mentioned local maxima is often complicated due to the "truncated" and stepped spectrum of the function. In this case, it will be logical to approximate the entire histogram or its section with some analytical function and determine the critical points by calculating the derivatives. The value of the maxima of the function of intra-slice connectivity can be represented [3, 7]

$$\Delta'(K) \geq \max\Delta(l_1) \dots \geq \max\Delta(L) \tag{8}$$

where $\max\Delta(l_1) \dots \geq \max\Delta(L)$ – the value of the local maxima of the function of the intra-slice connectivity of the slices$l_1, \dots L$ respectively [5, 9].

1	3	7	5	4
2	7	7	7	3
10	8	7	6	3
11	8	6	6	9
2	2	6	10	11

1

0	2	6	4	3
1	6	6	6	2
9	7	6	5	2
10	7	5	5	8
1	1	5	9	10

2

X	1	5	3	2
0	5	5	5	1
8	6	5	4	1
9	6	4	4	7
0	0	4	8	9

3

X	0	4	2	1
X	4	4	4	0
7	5	4	3	0
8	5	3	3	6
X	X	3	7	8

4

X	X	3	1	0
X	3	3	3	X
6	4	3	2	X
7	4	2	2	5
X	X	2	6	7

5

X	X	2	0	X
X	2	2	2	X
5	3	2	1	X
6	3	1	1	4
X	X	1	5	6

6

X	X	1	X	X
X	1	1	1	X
4	2	1	0	X
5	2	0	0	3
X	X	0	4	5

7

X	X	0	X	X
X	0	0	0	X
3	1	0	X	X
4	1	X	X	2
X	X	X	3	4

8

X	X	X	X	X
X	X	X	X	X
2	0	X	X	X
3	0	X	X	1
X	X	X	2	3

9

X	X	X	X	X
X	X	X	X	X
1	X	X	X	X
2	X	X	X	0
X	X	X	1	2

10

X	X	X	X	X
X	X	X	X	X
0	X	X	X	X
1	X	X	X	X
X	X	X	0	1

11

X	X	X	X	X
X	X	X	X	X
X	X	X	X	X
0	X	X	X	X
X	X	X	X	0

12

0	0	7	0	0
0	7	7	7	0
0	8	7	6	0
0	8	6	6	0
0	0	6	0	0

13

Fig. 1. An example of forming slices

For further analysis, the numbers of sections to which the maximum values belong are of interest. The mathematical description of this procedure looks like this:

$$N(\max\Delta(K)) = \begin{cases} K, \max\Delta(K) = \Delta'(K) \\ 0, \max\Delta(K) \neq \Delta'(K) \end{cases} \tag{9}$$

At the same time, the level of brightness corresponding to the slice with the number K is determined as

$$C^k = d \times K \tag{10}$$

Thus, the element of the binary slice $B(K)$, which has the brightness level C^k, will form the region maximally connected in the given image. These elements belong to the selected area, that is, they belong to one of the output functions [18, 19].

Let us form an auxiliary matrix function R^k, of dimension $M \times N$, corresponding to the binary slice $B(K)$, whose elements have the values

$$r^k(m,n) = \begin{cases} a(m,n),\ b^k(m,n) = 1 \\ \quad 0,\ b(m,n) = 0 \end{cases} \tag{11}$$

Then $R^k(M,N)$ belongs V, if the initial image can be represented in halftone form and $B^k(M,N)$ belongs to V if a binary representation is desired. The formation of the inter-slice connectivity function is carried out for each slice with the next slice adjacent to it and has the form:

$$\Delta(k,k+1) = \sum_{\substack{m=1,\\ n=1}}^{M,N} \sum_{\substack{i=-1,\\ j=-1}}^{1,1} b^k(m,n) \cap b^{k+1}(m+i,n+j) \tag{12}$$

However, in contrast to the intra-slice connectivity function, the interest is not the entire spectrum, but its individual sections. The process of selecting these areas is as follows. The slices adjacent to the slice with the maximum intra-slice connectivity, i.e., $K+1$ and $K-1$., are selected as initial slices. The values of the cross-sectional connectivity functions $\Delta(K,K+1)$ and $\Delta(K,K+1))$ are compared with the determined threshold. Based on this, the question of whether the elements of the investigated sections belong to the original function is resolved.

If $\Delta(K,K+1) > P$, then $R(K+1)$ belongs V_l or $B(K+1)$ belongs V_l, respectively, if $\Delta(K,K+1) > P$, then $R(K-1)$ belongs V_l or $B(K+1)$ belongs V_l, where P – is the limit value of the intersection connectivity for selected segments. The process of comparing the values of the intersection connectivity with each adjacent next value takes place until this condition is fulfilled. The process is carried out "to the left" and "to the right" (or "up"-"down") from the slice with the maximum value of intra-slice connectivity. The selected area will form a set of elements whose coordinates are determined by the coordinates of the single elements of the selected binary slices for the binary view (12) or halftone view (13).

$$V_l = \dots \wedge B(K-1) \wedge B(K) \wedge B(K+1) \wedge \dots \tag{13}$$

$$R_l = \dots \wedge R(K-1) \wedge R(K) \wedge R(K+1) \wedge \dots \tag{14}$$

The same operations (12) ~ (14) can be used for slices with local maxima of intra-slice connectivity. As a result, a set of images is generated, which forms separate segments of the input image A. Within the boundaries of these areas, the brightness changes smoothly.

The obtained segments $V_1, .., V_L$ can be used for further research on the connection of one with the other. This makes sense if the segmentation task includes selection of an object formed from several segments [11, 20]:

$$\Delta(V_l, V_{l+1}) = \sum_{\substack{m=1,\\ n=1}}^{M,N} \sum_{\substack{i=-1,\\ j=-1}}^{1,1} v^l(m,n) \cap v^{l+1}(m+i,n+j) \tag{15}$$

where $\Delta(V_l, V_{l+1})$ – the function of cross-sectional connectivity between regions V_l and V_{l+1}.

At the same time, not only the contours of the studied areas are analyzed, but possible "holes" formed in the image from its individual elements are also considered. A software model of the image segmentation method based on features of spatial connectivity was also developed [16, 17].

2. Research results

In summary, we will describe the steps of the general segmentation algorithm, based on the described mathematical model:

1. Image quantization by brightness level.
2. Formation of the intra-slice connectivity function.
3. Determination of the global maximum of the intraslice connectivity function and its slice number.
4. Determination of the slice number with the global maximum connectivity value.
5. Formation of the function of inter-sectional connectivity.
6. Definition of the inter-slice connectivity function for the slice defined in point 4 and adjacent to it.
7. Comparison of the values of cross-sectional connectivity obtained in point 6 with the threshold.
8. Combining the selected sections.

This method can be applied to the segmentation of biomedical images. Below is an example of segmentation based on the method of analyzing connectivity histograms for thermal imaging in figure 2. As can be seen from this example, three main segments were selected (figure 3).

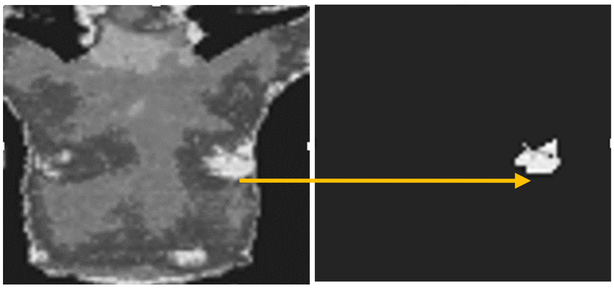

Fig. 2. Input thermal image

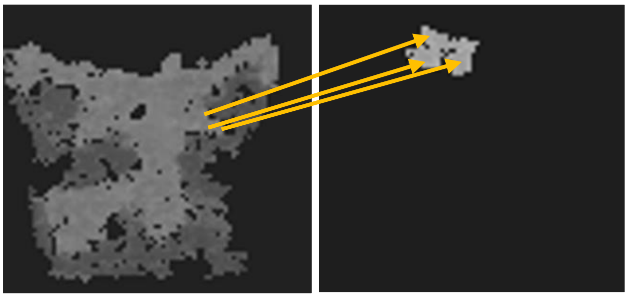

Fig. 3. Selected segments by the described method

Experimental studies included the processing of 500 thermal images. The generalized results of the comparative analysis – correlation comparison of the selected segments based on the proposed segmentation method with known methods, particularly the method of expanding areas and based on the recurrent method of brightness threshold limitation – are presented in table 1.

As a result of the research, a mathematical model is described, which allows the initial image in the form of a matrix A with dimensions $M \times N$ to be presented as a collection of several areas that correspond to individual segments of the object, their combination, or the entire object. They correspond to the original corresponding matrices $V_1, V_2, \dots, V_L$ in halftone or binary form.

Table 1. Segmentation methods comparative analysis results

Segmentation method	Correlation coefficient of segmented areas
Recursive method of limiting brightness	0.85 – 0.90
Segmentation using region augmentation	0.90 – 0.97
The proposed segmentation method	0.95 – 0.99

On its basis, a step-by-step algorithm for segmentation of multigradation images based on spatial connectivity features is presented. The algorithm's result based on the thermal image sample segmentation is demonstrated. The segmentation method is compared with already existing approaches and its effectiveness is shown.

3. Conclusions

In this article, image segmentation was considered. A method of segmentation of multigradation images based on spatial connectivity features has been developed. The proposed method is characterized by a small number of calculations and ease of implementation.

The division of the image into parts can also be considered as a process of clustering image elements. In this case, the elements of the quantum image are displayed in the vector space of the features of inter- and intra-distinct connections. Clusters consist of various sets of feature space vectors. This division of space into clusters allows simpler methods to classify images. Thus, image division is created on a subset consisting of feature space vectors of inter-distinct and intra-distinct connectivity and sets of elements belonging to various classes.

On the one hand, the proposed approach to the segmentation of multigradation images is considered a method of dividing the image into a set of homogeneous areas. At the same time, the degree of homogeneity determines the change in the level of cross-sectional connectivity, which does not exceed a given threshold.

On the other hand, the proposed approach can be used as a simple method of clustering. At the same time, the formed features, such as intra-slice and inter-slice connectivity, can also be used to assess the degree of similarity and difference of the analyzed images.

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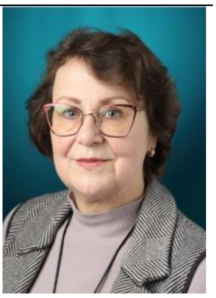

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