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AIVP ADVANCES IN IMAGE AND VIDEO PROCESSING

Processing the Images of Dispersive Structures by Irregular Pyramid

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ABSTRACT

The paper deals with the improvement of irregular pyramid method for processing images of dispersed formations and other microscopic objects. The method is based on the natural aggregation of adjacent image areas from one pyramid level to another and can process noisy images of different sized objects with non-uniform brightness. The developed method combines image segmentation, filtration and binarization operations.

There is made analysis of topological problems caused by applying the different types of pixels connectivity. Algorithms determining the adjacent image areas and internal hollows in connected pixel sets are designed on the basis of analysis. Proposed algorithms may be applied to local image segmentation. Using algorithms for constructing different hierarchical levels of Meer pyramid and dispersed formations images segmentation will provide more precise objects structure and avoid over-detailing. There is proposed method for sliding window size evaluation for local segmentation methods applied to processing dispersion environments images by irregular pyramids method.

Keywords: segmentation, filtration, video images, dispersed formations, irregular pyramid.

1. INTRODUCTION

Object segmentation is one of the main and perhaps the most difficult stages of image processing. The complexity of this problem lies in the possibility of changing the whole spectrum of image parameters in a wide range. The images may be of different brightness, background noisiness etc. Besides, these differences may occur within the same image set, and even more – in the same image. Images of real objects have inhomogeneous background; this feature also should be considered. On the other hand, there is no uniform standard of image quality. Therefore, despite the large number of image processing methods and algorithms [1-4],

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the problems of images filtration, segmentation and binarization (especially for dispersed formations images), do not lose their actuality and do not have a universal solution.

Even such well-known methods as a threshold global segmentation are often inefficient due to the impossibility of determining single threshold for entire image. The method of histogram shape analyzing does not always lead to satisfactory results because of image noise, which causes multimodal histograms. Otsu method [5] is based on the calculating the statistical characteristics of the image pixels. This method also is also reduced to calculating entire image threshold, separating sets of object and background pixels in the most effective way. This method is effective in the case of image uniform illumination.

Methods of local segmentation are more flexible. They are based on evaluating threshold value for each part of the image (window), which size is predetermined [6]. However, for adaptation them to the images of other dispersed environments some reconfiguration of these methods consisting in refining threshold function coefficients and window size is required.

The purpose of investigation is to develop a method providing determination of objects varying in size and brightness, and combining image segmentation, filtration and binarization operations. This problem can be efficiently solved by using irregular pyramids structure.

2. CONSTRUCTION OF AN IRREGULAR PYRAMID FOR DISPERSED FORMATIONS IMAGES

2.1 Irregular pyramid structure

The proposed method uses the irregular pyramids structure and is based on the natural aggregation of adjacent image areas from one pyramid level to another.

Irregular pyramids method by Meer [7] is based on graph theory. Irregular pyramid is a sequence of nodes set R_0, …, R_N restricting at each level. Zero or base pyramid level R_0 is the original image. Each node of the next, decimated pyramid level corresponds to connected set of nodes of the previous level. That is

$$P_{\iota+1}=T(P_\iota), \text{ where } |R_{i+1}|<|R_i|, \quad R_{i+1}\subset R_i, \quad i=\overline{0,N}. \quad (1)$$

So, if the algorithm is applied to original image, at the output we obtain a set of nodes, each of them corresponds to the specified object in the image. Irregular pyramid structure is shown in Figure 1.

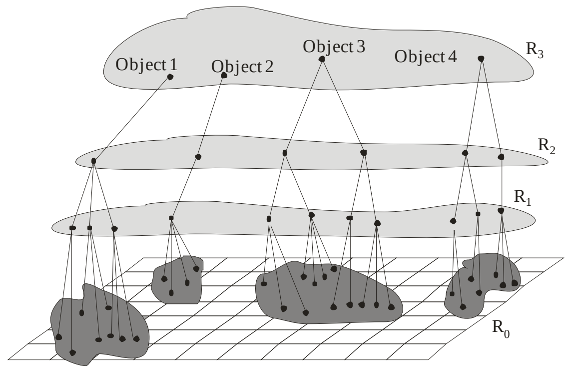


Figure 1: Irregular pyramid structure

From expression (1) it is clear that the key point in algorithm designing is the choice of the transforming function *T*, providing to obtain subset R_{i+1} from R_i nodes set. Function *T* is the criterion for moving from one pyramid level to another. It selects supporting (also mentioned as survivors) nodes among the previous level nodes for making the next level. Function *T* is also known as the decimation function. Child nodes of *i+1* level are formed from the non-survivors (not included in the next *i+1* level) nodes. This technique provides the relationship from any pyramid level down to its base.

Each stage of algorithm consists of following steps:

- Determination of the neighboring regions;
- Evaluation of *T*-function value ("surviving threshold") for each node of set R_i.
- Nodes of greater "surviving value" than the threshold form supporting nodes subset R_{i+1}, forming the next *i+1* level;
- For each supporting node of set R_{i+1} it is formed connected set of children from R_i nodes neighboring to considered one. Graph nodes at *i* level are considered neighboring if their children are neighbors at the base level.

The process is complete, if $|R_{i+1}| = |R_i|$ there is no further thinning of pyramid levels.

Let's consider algorithm in detail.

2.2 Zero (Basic) Pyramid Level Design

The process starts from analysis of given image. Images of dispersed formations are characterized with non-uniform brightness and noisy background. Objects contours are darker in comparison with background. We propose to put in the pyramid base the pixels corresponding to figures contours after elimination of noise and background elements. To ensure method quality independence, and provide it applicability to images of other environments, filter parameters are not appointed, but evaluated based on the correlation of image parameters. Due to the fact that image brightness and noisiness may be non-uniform, it is advisable to consider each pixel in the context of its surroundings in some neighborhood.

So, the first step is supporting pixels determination. Authors propose to calculate the following global features of the image:

Global average brightness

$$Gab = \frac{\sum\limits_{\substack{x=0,W-1 \\ y=0,H-1}} g(x,y)}{W*H}, \tag{2}$$

Horizontal contrast

$$Gac_h = \frac{\sum\limits_{x=0,W-2} |g(x+1,y)-g(x,y)|}{W*H}, \quad y=\overline{0,H-1}, \tag{3}$$

Vertical contrast

$$Gac_v = \frac{\sum\limits_{y=0,H-2} |g(x,y+1)-g(x,y)|}{W*H}, \quad x=\overline{0,W-1}, \tag{4}$$

Global average contrast

$$Cac = (Gac_v + Cac_h)/2, \tag{5}$$

where *g(x,y)* brightness of *(x,y)* pixel; *W, H* – image width and height.

Local brightness features *Lab* and *Lac* (local average brightness and local average contrast) for each considered pixel *(x, y)* and its neighborhood *(x-w, y-h, x+w, y+h)* should be evaluated in this way. The pixels with high contrast neighborhood only should be taken into consideration, because they are most likely to contain the object. Such neighborhoods (Figure 2, neighborhood A) are characterized by the relationship

$$\frac{Lac}{Gac} >= 1.05, \tag{6}$$

(local contrast is more than the average value). Pixel (x, y) generating such neighborhood will be inserted in supporting nodes list, if it is darker then background in this neighborhood and contrast enough, i.e.

$$Lav - g(x,y) \geq Gac \tag{7}$$

Area B (Figure 2), containing the noise and do not containing any objects of interest, does not satisfy (7) and its pixels will not be included in the supporting nodes set. Thus, we are protected from noise influence.

In the case if the entire neighborhood belongs to object, so it is a low-contrast region (Figure 2, area C)

$$Lac < 0.2\,, \tag{8}$$

which brightness is lower than the average brightness of the image *(g(x,y)<Gav).* Let's introduce following criterion for inclusion its pixels to the supporting points list

$$1 - \frac{g(x,y)}{Gav} > 0.05 \tag{9}$$

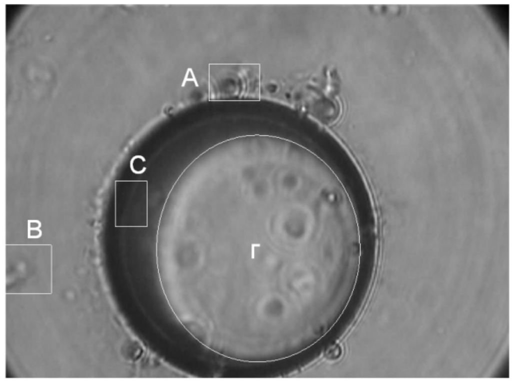


Figure 2: Neighborhoods of different types

This relationship also prevents overdetalizating the contours of objects of non-uniform brightness. Thus, expressions (6) - (9) represent an image self-adjusting filter.

The next step is child nodes selection. Let's assign some connected set of child pixels to each supporting node. For this purpose it should be done local segmentation within the smallest (3 x 3) 8-connected neighborhood of supporting pixel. Average brightness value in this neighborhood will be taken as threshold. The pixels which brightness is less than calculated threshold will be considered children. Since the considered supporting pixel is the center of such neighborhood, set connectivity is not violated for any choice of child points. Pixels forming the base level of the pyramid are shown in black in Figure 3.

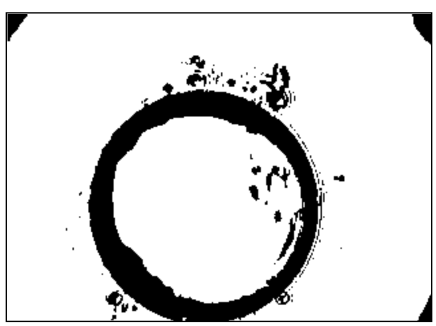


Figure 3: Base level of pyramid

Pyramid base level in this interpretation is monochrome and partially filtered version of the original image. If binarization is the final goal and there is not a segmentation problem in its general formulation implying relationships between the pixels forming specified object, there is no need in making other pyramid levels. Thus, in Figure 3 there is shown selection of entire pixel mass characterizing all objects, but these data cannot be used for analytical determination the objects number, their relative positions and geometric parameters. To determine if the pixel belongs to the particular object one should make higher pyramid levels.

2.3 Higher Pyramid Levels Design

- Determining neighboring supporting nodes for each supporting node.
- Evaluate *T*-function value for each node. This value is the number of neighboring supporting nodes.
- The threshold value of surviving function *T* is defined as an average number of neighboring nodes. Supporting nodes which surviving value is greater than threshold, assign the supporting nodes at the next level.
- Non-surviving neighboring nodes are attached to list of children. Specificity of dispersed structures segmentation consists in the fact that object is a kind of ring, i.e. has dark contour, bounding the light area (which is a part of the object too), this feature is caused by optical effects on the participles surface. Therefore, internal area nodes contained within the selected child sets should be attached as children nodes. Identification of such areas is made by algorithm described below.

At a certain pyramid level there is a situation when the nodes number ceases to decrease due to the impossibility of further merging because of neighborhood absence, each supporting node corresponds to the entire isolated object (for clarity, unique color is assigned to each object), this fact is a criterion for algorithm termination. Figure 4 shows results of method application to the image in Figure 2.

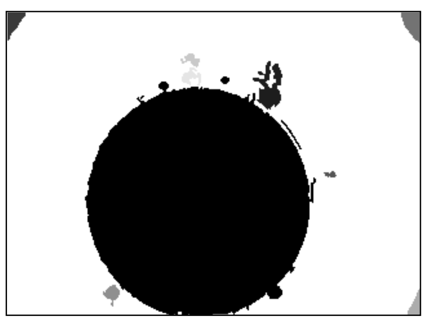
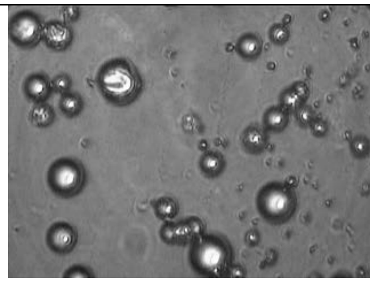
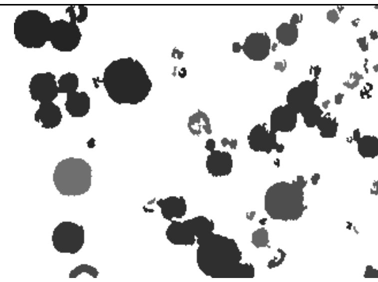
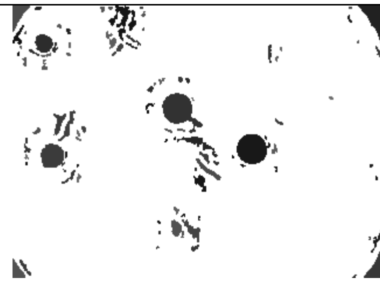
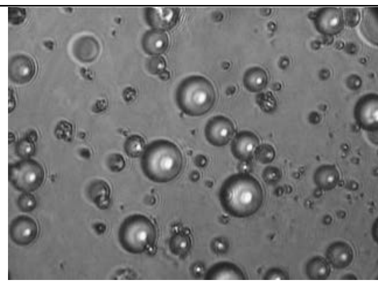
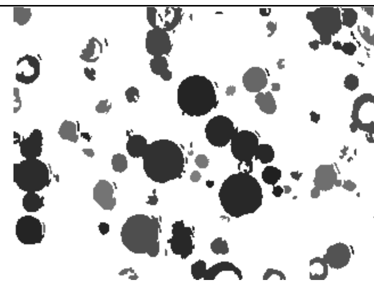


Figure 4: The top level of the pyramid for the image in Figure 2

The results of application of this method to several images of the water-oil emulsions are shown in Table. 1.

Table 1 Segmentation of water-oil emulsion by irregular pyramids

No	The original image	Resulting image
1		
2		
3		

At the end of algorithm procession, additional filtering of selected objects based on their geometrical or morphological characters may be done. So, in our case, for images containing more or less homogeneous objects (see Table 1), it is advisable to perform filtering to eliminate the drops of low pixel weight (less than 5% of average pixel weight of all identified objects).

3. APPLYING DIFFERENT TYPE OF PIXELS CONNECTIVITY TO IMAGE PROCESSING

Concepts of 4- and 8- connected regions are often used for image recognition. But applying the both types of connectivity causes some topological problems. If the pixels forming the object are considered to be 4-connected, we get the following anomaly: the vertical and horizontal sections of the border will be connected, but the inclined ones – will not. For example, line inclined at 45° to the raster grid lines is presented not as solid object (as it is in fact), but as a set of odd pixels. This fact causes to the multiple breaks in the object contour (Figure 5(a)).

If objects boundaries are considered in terms of 8-connectivity, inclined parts are correctly identified, but background areas will be connected too, so the sloping line shown in Figure 5(b) does not divide the field in two areas and the white pixels are connected in spite of the a black line separating them.

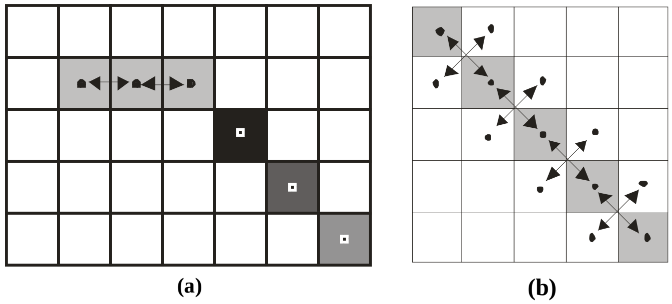


Figure 5: (a) Topological anomalies when using 4-connectivity principle; (b) Topological anomalies when using 8-connectivity principle

To solve this problem, we propose to apply different connectivity types to objects and to background. 8-connectivity is applied to object pixels, and 4-connectivity to background pixels. In this case, the object shown in Figure 6 will be a "ring", dividing the field of the image in two areas – internal and external.

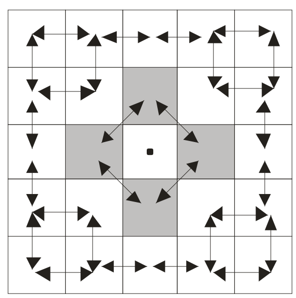


Figure 6: Application of different connectivity types to object and background pixels

In accordance with introduced connectivity criteria algorithm for areas filling [9] is improved to process not only the 4-connected (as in standard case), but the 8-connected regions. Based on this improvement, the algorithms for image segmentation are developed and applied to irregular pyramid method.

3.1 Algorithm for adjacent areas determination

To determine whether the two connected pixel sets X_1 and X_2 are adjacent, i.e. if $X_1 \cup X_2$ set is connected, the following algorithm is proposed:

– Make the convex hull for each set.

– Check if the convex hulls are overlapping. If no, X_1 and X_2 are not overlapping too.

– Otherwise paint the areas corresponding to these sets in the same color. Determine the connectivity of $X_1 \cup X_2$ set by pouring it with contrasting color using above mentioned filling algorithm, starting from some point A (Figure 7) of X_1 set. If the sets are adjacent, algorithm automatically fills X_2 area. So, if the color of any X_2 point is changed (in point B, for example) to the given color, X_1 and X_2 are adjacent.

– After merging adjacent regions joint convex hull will be made.

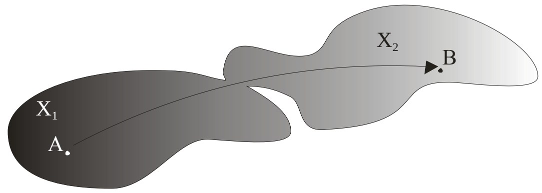


Figure 7: Scheme of $X_1 \cup X_2$ set connectivity definition

3.2 Algorithm for determining internal hollows in connected set

Developed filling algorithm are applied to determinating the internal hollows of connected sets. Area of interest are placed into some rectangle, height and width of it are 2 pixels larger than circumscribed rectangle (Figure 8, a). Then fill an external towards the object part of the rectangle with some contrast color considering it in terms of 4-connectivity. In this case, isolated internal hollows keeps original color (Figure 8, b). The points which have kept original color, will be attached to considered set (Figure 9, c) . This approach provides us to process not only the dark contours of drops, bubbles and other dispersed formations, but the whole "body" of participles containing glares.

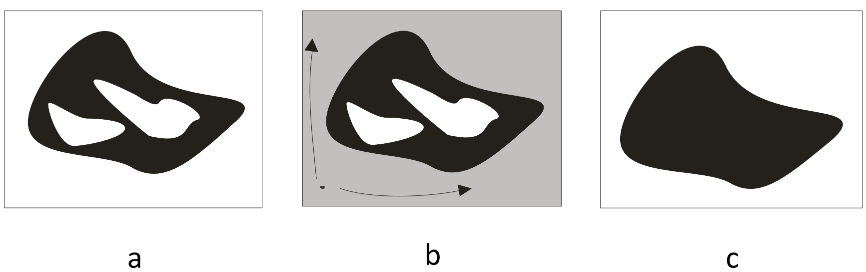


Figure 8: Scheme of internal hollows determination by using the filling algorithm

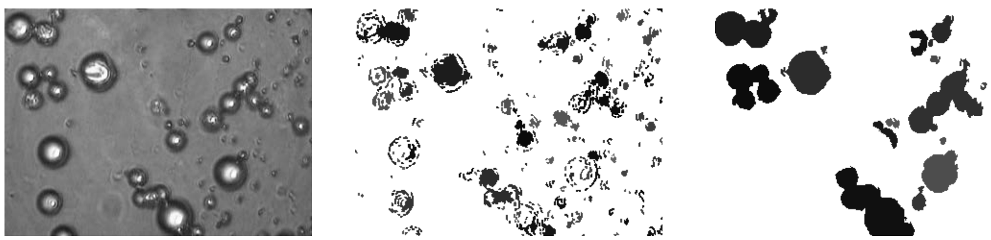
4. EVALUATE SLIDING WINDOW SIZE AT THE BASE PYRAMID LEVEL

The question of choosing sliding window size while constructing of base pyramid level is still open. Experiments on determining the influence of window size on segmentation results show that the small window size causes noise gaining, while too large one leads to brightness and contrast parameters averaging over a large area and cause small objects elimination.

Influence of sliding window size on segmentation quality of water-oil emulsions images (Table 1) is shown in the chart (Figure 10). As conventional criterion K (ordinate) is taken average brightness of supporting pixels ($\overline{g_{sup\,port.}}$) at base level divided by the average image brightness.

$$K = \frac{\overline{g_{sup\,port.}}}{Gav}\ . \qquad (10)$$

As it is shown in the picture, applying sliding window of small area ~ 0.1 % (1p. x 1p. , 3p. x 3p.) of image area, the average brightness of supporting pixels is high, because of capturing the large mass of background elements (noises) that falls as the window area increases and reaches its minimum at a window area ~ 0.3 % - 1.3% of image size, then it increases again due to excessive brightness averaging, leading to the contours roughening and the adjacent areas capture. Thus, sliding window size for water-oil emulsions images segmentation advisable to choose within these limits. The curve corresponding to image in Figure 2, reaches its minimum at a larger window size - 2.21 % due to a significant difference between the structure of this image and other images containing number of objects. One drop in Figure 2 occupied ~ 32 % of image area.



a b c

Figure 9: Segmentation using sliding windows of different sizes: a – original image (320p. x 237p.); b – 1p. x 1p. window; c – 30p. x 30p. window;

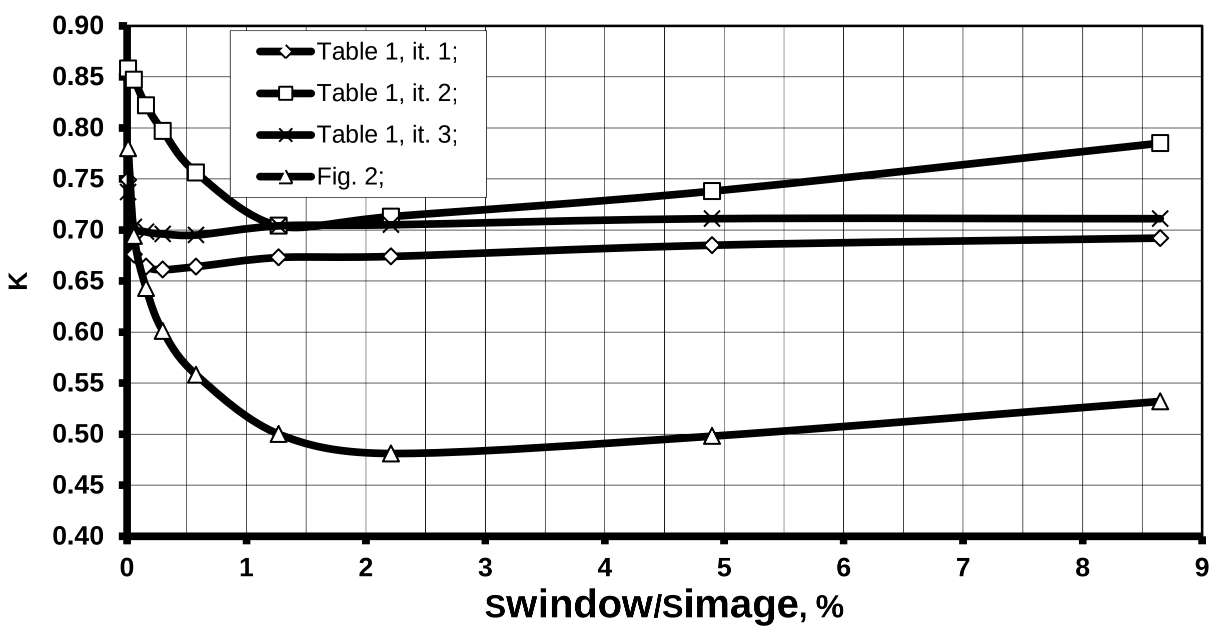


Figure 10: The impact of sliding window size on segmentation quality factor of water-oil emulsions

5. CONCLUSION

There is improved irregular pyramids method for processing the images of dispersed formations and other micro objects. The method is based on the natural aggregation of adjacent areas in the image from one pyramid level to another and can process noisy images of different sized objects with non-uniform brightness.

Algorithms determining the neighboring areas in the image and internal hollows of connected set are designed on the basis of different types of pixels connectivity. Using proposed algorithms for constructing different hierarchical levels of Meer pyramid and dispersed formations images segmentation will provide more precise objects structure and avoid overdetalization. There is proposed method for sliding window size evaluation for local segmentation methods applied to processing dispersion environments images by irregular pyramids method. The software system is designed on the results of investigation.

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