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GRAINS SEGMENTATION ON URANIUM DIOXIDE THIN SECTION IMAGES

Dmitry Potapov[1, 2], Alexey Modyaev[1] and Natalia Leonova[1]
[1]Department of Informatics and Control Processes, National Research Nuclear University "MEPHI", Kashirskoe highway, Moscow, Russia
[2]Advanced Information Systems group, the European Laboratory for Nuclear Research, CERN, Route de Meyrin, Geneva, Switzerland
E-Mail: div-x15@yandex.ru

ABSTRACT

A technique of computer grains segmentation on uranium dioxide thin section images is described. An algorithm of image preprocessing is developed, allowing to achieve more accurate results in grains boundary detection when using the watersheds marker method. The usage of grey-level morphological operations instead of binary results in information losses reduction on image processing. The developed algorithm can be used for quality control processes automation in metallurgy industrial organizations.

Keywords: grains segmentation, marker watersheds, uranium dioxide, morphological operations, image recognition.

1. INTRODUCTION

Grains size analysis is an important field of metallography, which is used at the phase of metallurgy industry products' quality control. Direct methods for finding grains' volume do not exist, so grains' areas on metal thin sections (cut in several planes) are used to obtain the estimates (State standard specification 5639-82, 1983).

For grains boundaries visualization on thin sections various techniques can be used. In the case of uranium dioxide - the material concerned by this study, thin sections are etched with acids mixture. Grains oriented in different directions have different etching rate, which results in steps formation on the section, which can be observed with an optical microscope (Saltykov, 1970).

Metallography specialists are interested in the development of equipment, allowing to measure grains area on the metallic thin sections images. Currently image processing computer platforms are used for such measurements. In such systems the image of thin section is registered by a microscope-mounted digital camera, and is processed afterwards by specialized software. As it was shown (Mavrin *et al*., 2000), markers watersheds method can be used for automated grains boundary detection. This algorithm was implemented by the authors of the mentioned paper in the "ImageScope" software. It consists of the following steps:

a) pore deletion;
b) image binarization;
c) search for grains markers using the ultimate binary erosion operation;
d) markers watersheds.

Because of inherent characteristics of uranium dioxide section images (Figure-1. In this figure grains are light-colored convex polygons, dark lines are grains' boundaries, dark spots are pores) the result of algorithmic grains' boundaries detection differs significantly from the results of expert's analysis. Some clearly seen boundaries are not detected, whereas in other cases the algorithm detects non-existent ones. This happens for several reasons: some boundaries in the image are not seen at all due to the fact that the etching rates of the adjacent grains proved to be very close; since there are steps on the section, some boundaries are out of focus and their image is blurred; and even distinctly visible boundaries often have gaps. Also many pores of various sizes are present in the image, which complicates the processing.

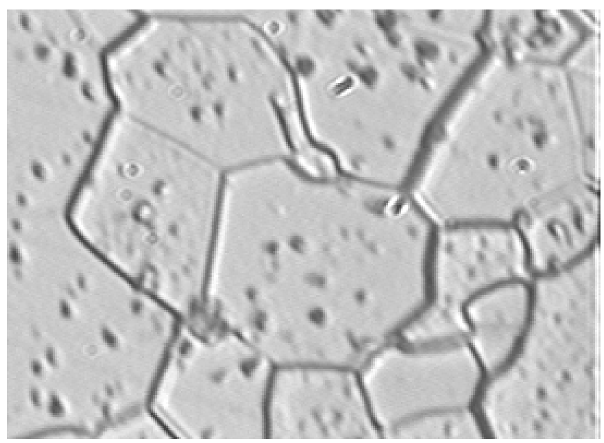

Figure-1. The image of uranium dioxide thin section.

Considering the fact that threshold binarization used in the existing software application inevitably leads to information losses, this study concentrates on applying grey-level morphological operations of erosion and dilation. The developed algorithm of image pre-processing using these operations allows increasing the grains boundaries detection accuracy of markers watersheds method.

The pre-processing of the image consisted of the following steps:

a) pores deletion (modified method);
b) morphological image smoothing;
c) image sharpening;

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d) finding markers using grey-level ultimate erosion (in the original algorithm binary erosion is used).

After performing these steps, the set of markers obtained and the pre-processed image were passed as input to ImageScope application for running the watersheds algorithm. The results of boundaries detection have proved to be more accurate than that of the original algorithm.

2. MATERIALS AND METHODS

2.1. Watersheds algorithm

In this section the watersheds algorithm used for grains boundaries detection is described. In geodesy the watershed is defined as a dividing line on the surface between two river basins. The idea behind the watersheds image segmentation is that the original grey-level image can be seen as a topographic map where the image point's height above sea level equals to its color tone intensity (on a grayscale [0-255]).

Usually immersion simulation is used for finding the watershed. If the terrain is consequently submerged in water by one level, gradually the basins will be formed on it. To avoid the interflow of two basins, a dyke is built between them. When the water reaches the maximal level, the built dykes will form the watersheds, i.e. the objects' boundaries.

Consider the following one-dimensional example (IEEE, 1991). Assume that the original relief looks as shown in Figure-2.

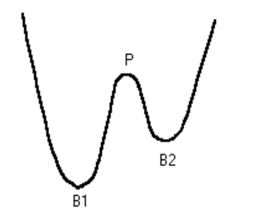

Figure-2. Original relief

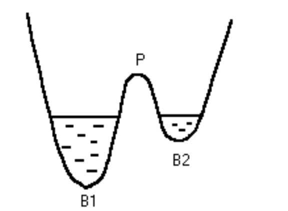

Figure-3. Formation of basins.

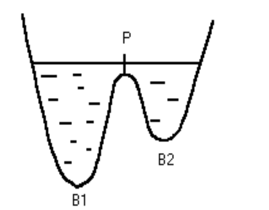

Figure-4. Dyke construction.

Points B1 and B2 are local minima. Now we gradually submerge the relief in water. When water reaches the level of point B1, the first basin will be formed and it will grow with subsequent submerging. After water reaches the level of point B2, the second basin will be formed and the terrain will look as shown in Figure-3. The basins B1 and B2 will expand until they reach point P, where they will meet. To prevent them from interflowing, a dyke is built in the point P (Figure-4) Thus for this case point P is the watershed. When applying this method to two-dimensional image, the boundary detection is more complex, but the idea is the same.

Given the fact that the algorithm considers even the smallest and insignificant objects, for example the noise or slight fluctuations of color intensity in the image, to be basins, application of this method in its original form results in oversegmentation.

To prevent oversegmentation markers watersheds algorithm is used (IEEE, 1996). In this case markers designate the initializing basins, and no additional basins are created during further iterations.

Automated markers search uses the fact that grains have form of convex polygons and most of the boundaries between them are present in the image. Finding centers of convex objects in an image is a known characteristic of ultimate erosion operation, and it is its binary implementation that is used in Image Scope application. The definition of erosion and dilation operations on a binary and gray-level image is given in the next section.

2.2. Morphological operations on binary images

Morphological approach regards images as sets. For example, a binary image can be defined as a set of coordinates of black (or white) pixels. In this case such set will be a subset of Z^2. Assuming that sets A and B belong to space Z^2, dilation of set A by set B is denoted by $A\oplus B$ and is defined as:

$$A\oplus B=\{z|(B)|z\cap A\neq\varnothing\} \tag{1}$$

This equation describes the realization of central reflection of set B in the origin (which we will call center of B) and subsequent shift of the set obtained to point z. Thus dilation of set A by B is a set of all shifts z such that sets B and A have at least one common element. Set B is called primitive of dilation as well as of other morphological operations, discussed below.

For two sets A and B from space Z^2, erosion of A by B, denoted as $A\ominus B$, is defined as:

$$A\ominus B=\{z|(B)|z\subseteq A\} \tag{2}$$

Set A is shown in Figure-5 with dashed line. The solid line corresponds to extreme values of z, after which the shift of the center of B does not meet the requirement of A and B intersection. Thus, the locus inside this solid line (filled with gray in Figure-5) is the result of erosion of set A by the primitive B (Gonsalez, Woods, 2006).

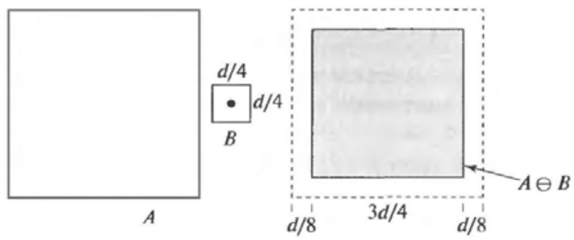

Figure-5. Erosion operation illustration.

Opening of set A by primitive B is denoted A°B and is defined as:

$$A°B = (A\ominus B)\oplus B \quad (3)$$

Thus, opening of set A by primitive B can be obtained as erosion of A by B, and subsequent dilation of the result by the same primitive B.

Similarly, closing of set A by primitive B is denoted A•B and is defined as:

$$A\bullet B = (A\oplus B)\ominus B \quad (4)$$

2.3. Grey-level morphological operations

Grey-level dilation f by b is denoted $f \oplus b$ and is defined as:

$$(f \oplus b)(s,t) = \max\{f(s-x,t-y) + b(x,y) \mid (s-x,t-y)\in D_f;\ (x,y)\in D_b\}; \quad (5)$$

where D_f and D_b are definitional domains of images f and b respectively. Here, unlike the binary case, f and b are functions, not sets.

The condition that coordinates (s-x) and (t-y) must lie in the definitional domain of f, and x and y - in the definitional domain of b, is analogous to the condition in the definition of binary dilation, that the two sets' intersection should not be empty.

Grey-level erosion f by b is denoted $f \oplus b$ and is defined as:

$$(f\ominus b)(s,t) = \min\{f(s+x,t+y) - b(x,y) \mid (s+x,t+y)\in D_f;\ (x,y)\in D_b\}; \quad (6)$$

where D_f and D_b are definitional domains of images f and b respectively. The condition that coordinates (s+x) and (t+y) must lie in the definitional domain of f, and x and y - in the definitional domain of b, is analogous to the condition in the definition of binary erosion, that the primitive should be a subset of the original set.

The expressions for opening and closing operations are the same as in the binary case.

Morphological image smoothing can be achieved but subsequent application of opening and closing operations to the image by the same primitive.

2.4. Ultimate erosion algorithm

Ultimate erosion algorithm is based on iterational erosion of object until the moment when it completely disappears. The object that disappears during the last iteration is considered a marker.

Figure-6. Search for markers using ultimate erosion.

The process of markers search is shown in Figure-6. In the upper row the erosion iterations are shown, in the lower - markers, accumulated by current iteration. A part of grains boundaries image is provided as input (Figure-6a). The eroded objects are the grains (shown in black). After the first erosion iteration (Figure-6b) all objects have become smaller, but none of them has disappeared completely, so no new markers are formed. After the second iteration (figure 6c), applied to the result of the first one, one object has disappeared, thus becoming a marker, etc. Erosion operation is applied until all objects have disappeared from the image (Mavrin *et al.*, 2000).

A similar process can be realized for grey-level erosion using, for example, a unitary matrix as primitive. In this case on each iteration grain boundaries become thicker and finally all objects disappear.

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2.5. Image sharpening

An image can be sharpened by using the following approach: first the result of image filtering by a Laplacian is computed, and afterwards it is subtracted from the original image. In practice these steps can be performed in one run on using a combined primitive (mask). Coefficients of such mask can be obtained from the equation:

$$g(x, y)=f(x, y)-[f(x+1,y)+f(x-1,y)+f(x,y+1)+f(x,y-1)]+4f(x, y)==5f(x, y)-[f(x+1,y)+f(x-1,y)+f(x,y+1)+f(x,y-1)] \quad (7)$$

This equation can be realized with a mask shown in Figure-7.

0	-1	0
-1	5	-1
0	-1	0

Figure-7. Image sharpening mask.

3. RESULTS

In this section all steps of the developed image pre-processing algorithm are described in detail:

a) pore deletion from the original image;
b) morphological smoothing of the image;
c) image sharpening;
d) markers search using grey-level ultimate erosion.

3.1. Pore deletion from the original image

Pores are small dark objects in the image. In ImageScope application pore detection is based on image binarization with subsequent connectivity objects search. For each object found its area is computed (in pixels). If the obtained number is less than threshold, it is considered a pore and is filled with white color. Otherwise, the object is regarded as a grain boundary.

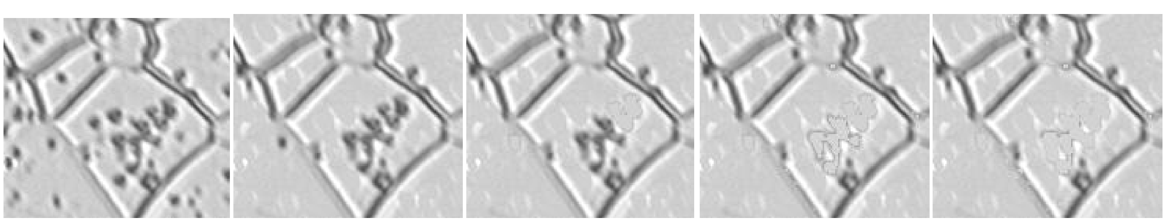
Most pores have a circular form, so a possible approach to their identification can be based on plotting bounding ellipses around them and counting their axes ratios. The size of the object in question should also be taken into account. The original algorithm will identify a long but small object as a pore, whereas the proposed approach will consider it a boundary. Thus it will allow to find smaller grains in the image. Also, an algorithm using the object area as the only criterion is not able to detect and delete big pores.

The algorithm based on the usage of bounding ellipses was implemented in MATLAB language. The pore-deleting function takes four parameters: the image being processed, the threshold ratio of major and minor ellipse axes, intensity threshold and the maximal (threshold) length of the minimal ellipse axis, up to which the object should be regarded as a pore.

The result of pores deletion depends on color intensity threshold. When applying grey-level erosion, it is desirable that the color intensity of pixels located inside the grains is greater than the intensity of boundaries, otherwise false markers can be formed, since, as was mentioned above, dark objects become thicker after erosion. Thus setting a low intensity threshold would leave many pores undeleted, because the dark region around each pore will merge with it on binarization resulting in formation of big pore clusters (wrongly identified as grains) or pore chains (wrongly identified as boundaries). This is why pore deletion is performed in several steps with different color intensity thresholds: (Function Delete Pores (x, ratio, thresh, length) takes the following arguments: x - the image, ratio - bounding ellipse axes ratio, thresh - color intensity threshold, length - length of the minor axis of the ellipse.)

a) x – the original image;
b) y1=DeletePores(x,3.5,200,20);
c) y2=DeletePores(y1,3.5,180,20);
d) y3=DeletePores(y3,1.5,160,30);
e) y4=DeletePores(y4,3.5,190,10).

The result of these operations is shown in Figure-8.



a) b) c) d) e)

Figure-8. The result of subsequent steps of the developed pore deletion algorithm.

3.2. Morphological smoothing

Morphological smoothing consists of consecutive application of closing and opening of the image. A unitary matrix 3x3 was used as a primitive in this study. Using expressions (5) and (6) operations of grey-level erosion and dilation were implemented in C++, as well as opening and closing.

The result of morphological smoothing is shown in Figure-9.

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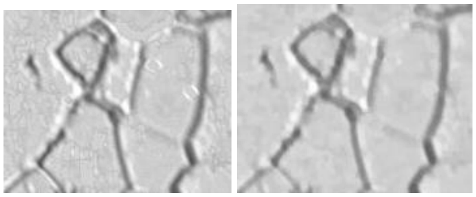
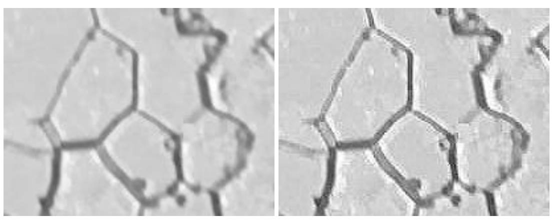


a) b)

Figure-9. a) The image after pores deletion b) Smoothed image.

3.3. Image sharpening

For image sharpening a function was implemented taking two parameters - the image being processed and the mask. (Function MaskAnImage(x,mask) takes the following arguments: x - the image being processed, mask - the mask). The mask used is provided in Figure-7, the result of the filtering is shown in Figure-10.



a) b)

Figure-10. a) Smoothed image b) Sharpened image.

The reason for which sharpening occurs not immediately, but after smoothing lies in the fact that despite the iterative implementation of pores deletion algorithm, after its execution dark granularity is still present in the image (Figure-9 a). On sharpening of such image these small dark objects will also become sharper and darker, which may lead to false markers formation at the erosion step. As can be seen in Figure-10 b, on smoothed image sharpening the background remains rather homogeneous, whereas the boundaries become darker.

3.4. Markers search using grey-level ultimate erosion

After sharpening, the grey-level ultimate erosion operation can be applied to the image to find the markers. The developed algorithm of grey-level ultimate erosion is similar to the binary one: the image is iteratively eroded (a unitary matrix 11x11 was used as a primitive), which results in boundary thickening; gradually diminishing light-colored fields are considered objects (a threshold value is used for their identification). As with the binary erosion, if an object disappears, it is saved as marker.

As was mentioned in the introduction, since the uranium dioxide grains boundaries correspond to steps on the thin section, they might be out of focus and blurred in the image. In some cases such boundaries can look like two close parallel lines (Figure-11).

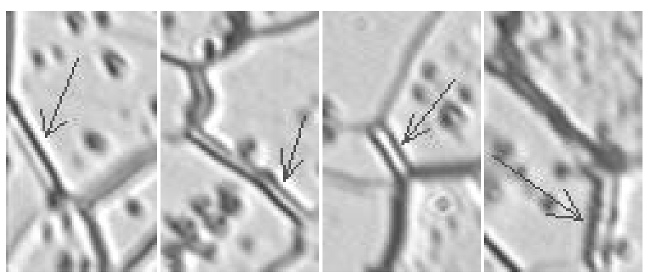
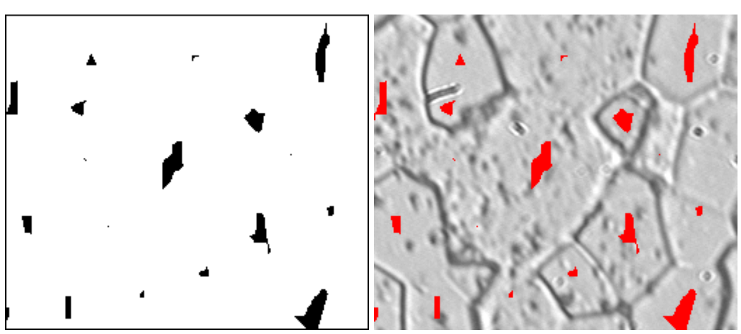


Figure-11. Double boundaries (marked in the original image).

The method described above will consider the inner area between such lines to be a grain. To prevent that, markets obtained on the first iteration of the ultimate erosion are not taken into account; thus all double boundaries disappear after the first algorithm iteration.

The result of markers search is shown in Figure-12.



a) b)

Figure-12. a) Markers; b) Markers imposed on the original image.

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It is worth mentioning that presence of all boundaries in the image is not necessary for correct markers discovery - on certain erosion iteration the visible boundaries will connect forming a convex Figure. Markers' size and form is not important, since they only indicate the location of the initializing basins for markers watersheds method. Thus small markers are equally important as big ones.

After markers discovery, their image was provided as an argument to the corresponding method in ImageScope application.

The results of boundary detection by its original version and by the developed algorithm are shown in Figure-13.

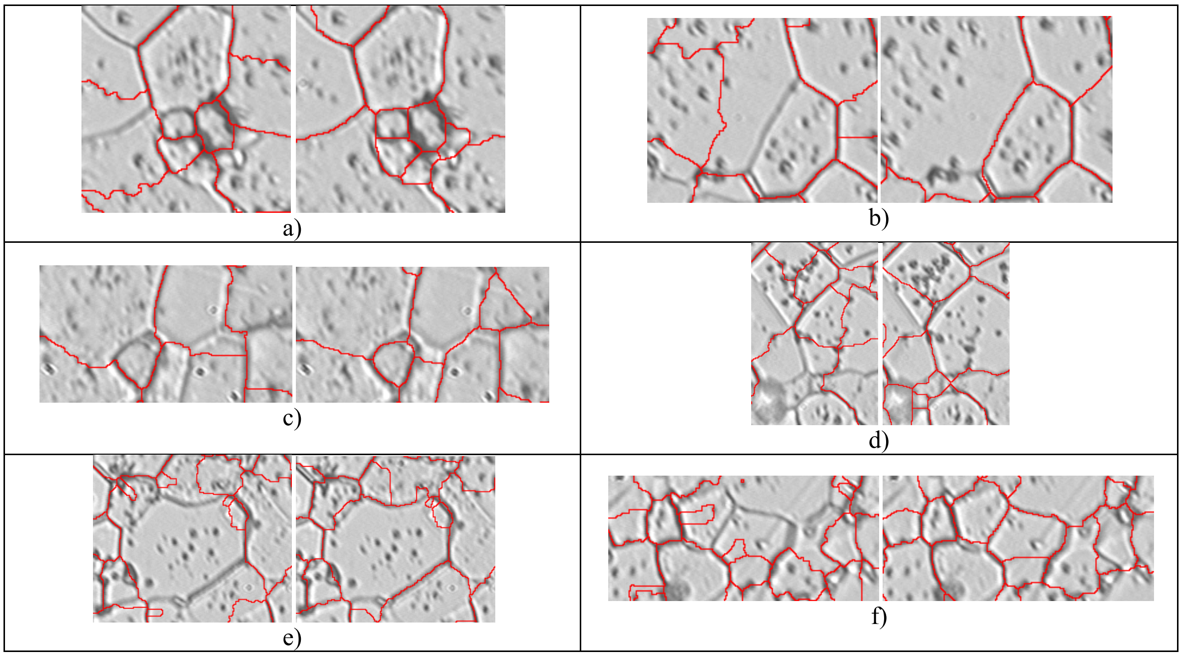

Figure-13. On the left - boundaries detected by original ImageScope application. On the right – boundaries detected using the proposed markers search algorithm.

As can be clearly seen in Figure-13, the results of boundaries detection are better when using the proposed algorithm: the number of false and undetected boundaries is significantly lower comparing to the original approach. However excluding them completely is not possible with the erosion approach, as some boundaries in the image are light-colored (lighter than the background), and also because some pores superimpose on the boundaries and are not deleted (Figure-10 b), which may make the grain look concave thus producing more than one marker.

4. DISCUSSIONS

In this paper a method of image pre-processing using grey-level morphological operations (erosion and dilation) is proposed, which allows to increase markers watersheds algorithm boundaries detection accuracy for uranium dioxide thin section images. The developed algorithm consists of the following steps:

a) pores deletion (an alternative algorithm is proposed, allowing deletion of big pore clusters and chains (Figure-10);
b) morphological image smoothing (used for removing dark residual granularity left after pores deletion);
c) image sharpening (increases the efficiency of markers search);
d) markers search (based on grey-level ultimate erosion as opposed to binary).

All procedures were implemented in MATLAB or C++, in the latter case it was integrated into MATLAB using mex-functions.

The image of discovered markers was provided as an argument to the corresponding method in ImageScope application for running the watersheds algorithm boundaries detection.

The images, processed by the proposed grey-level erosion-based algorithm contained significantly lower number of false or undetected boundaries comparing to the original ImageScope application. Thus the results obtained using the proposed algorithm are closer to the results of manual grains boundary detection by an expert.

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