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# IMAGE PROCESSING METHODS FOR SEGMENTATION OF MICROSCOPIC PICTURES OF THE MgCa ALLOYS

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**Abstract**

The paper addresses the problem of image processing of MgCa alloys microstructures. The main objective of the paper is focused on segmentation of images obtained from optical microscope. For this purpose three methods were selected, which offers high reliability in application to noised and highly diversified pictures. These approaches are based on Voronoi tessellation, superpixel regions and multi-filter thresholding with the Bresenham algorithm. The paper contains detailed description of the methods as well as comparison of obtained results.

**Key words**: image processing, segmentation, digital material representation

## 1. INTRODUCTION

Segmentation of microscopic pictures obtained from optical microscope is often used for metallographic purposes or during creation of virtual material representation (Rauch & Madej, 2008; Rauch & Madej, 2010). In this paper, the methods of image segmentation are used for the second purpose for MgCa alloy microstructures. The magnesium alloys with raising biocompatibility are widely used in medicine. One of the new applications of this material is production of surgery threads with small diameter between 0.1 and 2.0 mm. However, a drawing process of such products is highly demanding, because of poor formability and limited ductility of magnesium alloys in room temperature (Milenin & Kustra, 2008). Therefore, new models for simulation of magnesium alloys behavior are developed (Milenin & Kustra, 2010; Milenin et al., 2010; Kustra et al., 2009). One of the most important information, which is passed as an input data to performed simulations, is explicit description of material microstructure. This information can be obtained directly from an analysis of microscopic pictures of the alloys. Manual analysis presents difficulties, because of huge amount of grains on a single picture. On the other hand, usually applied algorithms for edge detection purposes do not cope well with pictures of microstructures, which in many cases are noised and full of distortions. Therefore, automatic segmentation is usually very complex. It requires several algorithms to be composed together as one sophisticated method. These advanced approaches includes procedures of smoothing, denoising, colour quatization, grain borders detection, tracing, classification and clustering, and many others. However, one universal method of segmentation, which could be used for different types of materials, does not exist. Thus, in most cases the method is composed individually, dependently on the grade of material, image scale and quality. For the purposes of this paper the group of various methods was analyzed. Three of them, giving the best results of segmentation, are presented in details:

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1. Segmentation based on generalized Voronoi tessellation and clustering.
2. Multi-class image segmentation defining continuous image regions called superpixels,
3. Multi-filter based processing with the Otsu thresholding and the Bresenham algorithm dedicated to straight line drawing.

The obtained results are compared and concluded in the paper as well.

## 2. SEGMENTATION REVIEW

Segmentation of images has been developed for couple of decades starting from the first edge detection algorithms based on convolution filters with their further modifications, which dominated late 90's. The most important and widely known detectors applied at that time can be enumerated as follows (Heath et al., 1998): Sobel, Canny, Nalwa-Binford and Sarkar-Boyer. The comparison of mentioned methods proved that characteristic features of these solutions predestine them to processing of various types of images. However, in most cases the methods were designed to determine well visible edges without any noise and blur effects. Otherwise, the borders of separated areas remained unrecognized.

Improvements of mentioned methods (Hou et al., 2002), which were able to avoid problems with noisy or damaged data, quickly proved that development direction based on simple convolution filters cannot be further taken into consideration. New ideas were implemented using nature inspired techniques of optimization and artificial intelligence. One of such proposition (Nezamabadi-pour et al., 2006) is designed with application of ant colony search algorithm. Ants communicate by using pheromone trails, where each ant leaves certain amount of pheromone. Thus, the trail becomes more attractive while ants keep following the same path. The application of this idea to edge localization offered unexpected results – ants minimized their efforts during walking and determined local minima leaving edges exposed. Recently, many solutions based on Neural Networks (NN) have been also created (Basturk & Gunay, 2009). Nevertheless, even these algorithms' efficiency is quite low in case of fuzzy borders, gradients and noisy colour patterns. Occurrence of fuzzy borders requires dedicated methods, which are often based on traditional convolution methods or some other algorithms (Kim et al., 2004).

All mentioned algorithms are still developed to process more sophisticated images to determine and enhance edges even out of highly illegible data. Detected straight and curved lines are finally joined together to form borders of separated areas inside analyzed pictures. This approach can be treated as pre-processing to image segmentation, which is often called edge-based segmentation. It is widely used despite of some problems with border completion and blobs processing during analysis of natural images. Nevertheless, this approach is sometimes reversed, started with image segmentation and context analysis aiming to determine visible edges (Yu & Chang, 2006). During recent years lot of research has been done in the area of image segmentation, resulting in many powerful approaches. However, this field of science still remains under intensive investigation to improve reliability of created methods. As well as in case of edge detection in last decade the usage of nature inspired algorithms had huge influence on the direction of development of segmentation methods. The main advantage of these methods is the possibility of searching numerous minima at the same time allowing to determine not only global objects, but also smaller independent areas characterized by certain features. Other implementations include also graph analysis, Gaussian Markov random field (GMRF), wavelet decomposition, Voronoi polygons, Gabor filters and Fractal Dimension. However, FD technique can be applied not only to segmentation of different areas of image. It is also used to assess the complexity of image during and after segmentation process. Unfortunately, evaluation of image quality after segmentation can be ambiguous and in most cases the assessment of obtained results is subjective based on so called ground truth defined by human. One of the objective methods of results evaluation is proposed by Shah (2008). Presented approach inherits the functionality from Bayesian probabilistic framework aiming to find optimal segmentation algorithm for the given input image. Thus, this solution, similarly to other evaluation methods, is unable to assess directly the quality of obtained results. Instead of this, by using special comparison methods it can determine the best algorithm for the processing of selected image. To avoid the problem with assessment of results, the multi scale segmentation methods are designed to obtain several different propositions of images segmented into smaller and larger areas. The final result is then composed from couple of previously obtained images.

## 3. PROPOSED METHODS

For the purposes of this paper three methods were selected, modified and analyzed. The first one is based on Voronoi tessellation originally published by Arbelaez and Cohoen (2006). The second approach is based on the idea of superpixels creation (Gould et al., 2008) with additional post-processing. The last method uses Bresenham algorithm to create straight lines over undetected edges. The details of mentioned algorithms are described in the following subsections.

### 3.1. Segmentation based on voronoi tessellation

The algorithm created by Arbelaez and Cohen starts with generation of initial points of Voronoi regions, aiming to cover an image with a mesh of regular hexagons. A side of a single hexagon is usually 10px long, what gives couple of thousands of Voronoi regions for medium size image in initial step of calculations. Each generated region receives initial color, which is average of all of the pixels' colors inside. All the pictures analyzed in this work were stored in the greyscale, thus, the color of any pixel was described within the range of [0;255]. It is obvious that segmentation based on regular Voronoi regions is not satisfactory enough, generating huge error and oversegmentation. Therefore, the following steps of segmentation are focused on optimization of Voronoi regions shapes. Then, to avoid oversegmentation, particular regions are connected together to form bigger clusters of regions to fit the real segments on the original image.

The optimization of regions is divided into two parts i.e. global and local optimization. The global optimization is composed of the steps, which are performed in iterative way until the value of global error does not improve:

1. **Directions' calculation** – each region defines the direction of its move in the next step. The move is calculated on the basis of error function (the function is defined as a sum of differences between color of pixels inside the segment and the color assigned to this segment). The direction of the move is determined by the lowest value of error function.
2. **Segments' move** – the move is made only if the calculated value of error function in new position is lower than the value of error function in current position.

After the global optimization stops, the procedure of local optimization is performed. The algorithm of local adjustment of segments is very similar to algorithm of global optimization. Each region defines its move into the new position. However, the move is voted with the neighboring regions. Finally, the region, which affects the biggest changes on its error function value is moved. The move is performed even if the global value of error function is worse than the value in previous step. Such solution allows to avoid stacking in local minima after global optimization and to precise the initial segmentation near borders of neighboring areas in original image. The optimization is followed by clustering of regions according to the rules of hierarchical agglomerative clustering methods. The neighboring regions with the smallest difference between their colors are connected together in one complex region. The procedure is repeated until only one region remains. Such approach allows to analyze the process of image segmentation at multilevel decomposition and to select the best result of segmentation according to particular criterion.

### 3.2. Segmentation based on superpixels approach

The segmentation based on connections of pixels into superpixels was proposed on the purposes of more sophisticated method used for classification (Gould et al., 2008). The basic assumption of this algorithm is different definition of an edge between two pixels. Similarly to the graph theory an edge is not defined as a border, but as connection between the neighboring pixels. The main algorithm is defined as follows:

1. **Conversion** – an analyzed image is converted into an undirected graph of pixels, where each edge has assigned weight.
2. **Weights' calculation** – the weights are calculated using information about colors of neighboring pixels. The bigger difference between the colors results in bigger weight, thus usually, it is defined as typical Mean Square Error (MSE). The list of edges with weights is sorted in ascending order to select the smallest value in each iteration of segmentation procedure.
3. **Superpixels' connection** – segmentation procedure is based on agglomerative approach i.e. initially each pixel is treated as a superpixel. In the following steps the superpixels are connected

together according to previously defined weights and threshold function. The simplest form of threshold function is linear, which means that superpixels are connected if the weight of the edge between them is smaller than the value of initial threshold. The threshold function can be formulated nonlinearly dependently on segments' shape, color and other features. However, it is used only for specific purposes.

4. **Threshold function modification** – even if the superpixel consists of two or more pixels the edges between them do not agglomerate. Thus, two superpixels can be connected by many edges with original weights. The weight are not recalculated, which decrease computational time. However, the threshold function is always recalculated after each connection and it is established for a new superpixel using the following equation:

$$s.k = w + \frac{k}{s.count} \tag{1}$$

where, $s.k$ is a threshold for the new superpixel, $w$ is the weight of connection, $k$ is the initial global threshold and $s.count$ is the number of pixels in a new superpixel. This modification means that if a superpixel is bigger it requires much more similar second superpixel to make connection. This assumption is justified especially in case of natural pictures e.g. to avoid connection of two large segments representing a water and a sky.

The obtained results strongly depend on assumed value of the threshold, which has to be established empirically according to human assessment. Therefore, it is hard to apply this method automatically, however, threshold around 100 very often offers satisfactory results of segmentation. Sometimes, the post-processing algorithms are applied, mainly in form of blob removing procedures to incorporate some small segments of pixels into larger objects.

### 3.3. Segmentation based on multi-filtering and bresenham algorithm

This approach was proposed by Authors mainly for the purposes of this work. This method is composed of four main steps which include multistage filtering preceding edges and glitches detection. The final stage is focused on closing of segments into the separated areas. The detailed description of the main steps of this approach can be enumerated as follows:

1. **Multi-filtering** – before processing of metallographic images the conversion to greyscale is performed, which is sometimes followed by inverse of colors. The inverse stage depends on the content of an image. Afterwards, selected algorithms of smoothing are applied to level the distortions within a picture and to prepare data for the proper thresholding. The median filter is usually applied in this stage. However, the appropriate selection of the smoothing filters has huge influence on obtained results by vanishing of existing borders between grains of a material. Then, the image is binarized using Otsu filtering method.
2. **Edge detection** – the main aim of this step is to obtain as many continuous lines (paths) as possible. Among several tested algorithms (e.g. Canny, Shen-Castan, Sobel, Laplace), the best results were obtained after Canny's method. The main parameters of this algorithm (high and low thresholds) in most cases have to be established according to human assessment, which precludes automatic application of this approach. Nevertheless, for specific group of images the good practice guides are proposed, suggesting values of algorithm's parameters.
3. **Glitch detection** – as a result of the previous step, a bicolor image is created, containing large number of short separated paths which are called 'glitches'. These short paths have to be removed to avoid misclassification of end-points in the following stage. Some of these paths may be deleted by using Connected Components Labeling Algorithm or by counting the number of pixels forming a continuous path. The latter solution allows to delete the paths shorter than assumed threshold.
4. **Segments completion** – the step of glitches removing gives the possibility to detect the end-points of interrupted grain borders properly. This leads to the process of separation of single grain areas. The separation can be done twofold i.e. by direct connection of two endpoints or by extension of an endpoint towards the nearest grain border. Both cases can be solved by application of the Bresenham algorithm dedicated to drawing of a straight line. Both depend on the end-point features and distance to other nearest end-point as well.

## 4. RESULTS

Several different images of MgCa alloy microstructure were analyzed. Two of them are presented in figure 1. The results obtained by using three segmentation methods presented in previous section are shown in figures 2-4. The performance of these algorithms depends mainly on the size of input images, but in all cases the approach based on superpixels was the most efficient. However, the quality of the results according to assessment based on human ground truth is the best in case of multi-filtering approach.

creation and multi-filtering methods with Bresenham algorithm. The selected methods were tested using images of MgCa alloy microstructure and the obtained results were compared according to three different criteria focused on coherence of segments, performance and quality. The approach based on Voronoi tessellation offers the highest coherence of the segments, but their shape is usually not fitted well with the shape of grains in original picture. Nevertheless, these results can be used as input data for creation of digital material representation, because of the simplicity of geometrical description of grains' areas. The method based on superpixels is

a) b)

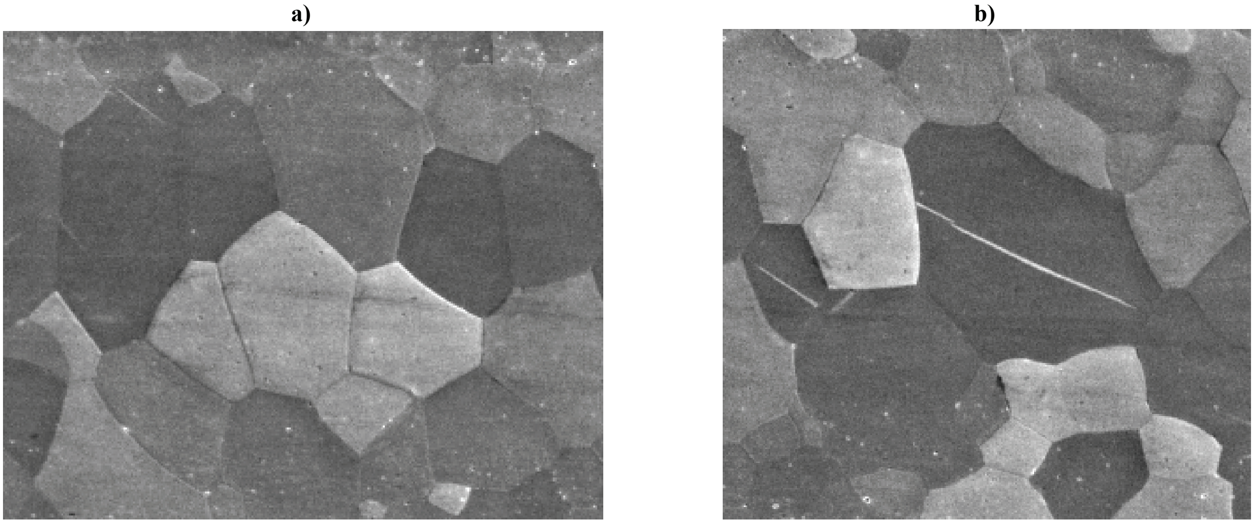

*Fig. 1. Examples of original images of MgCa alloy microstructure.*

a) b)

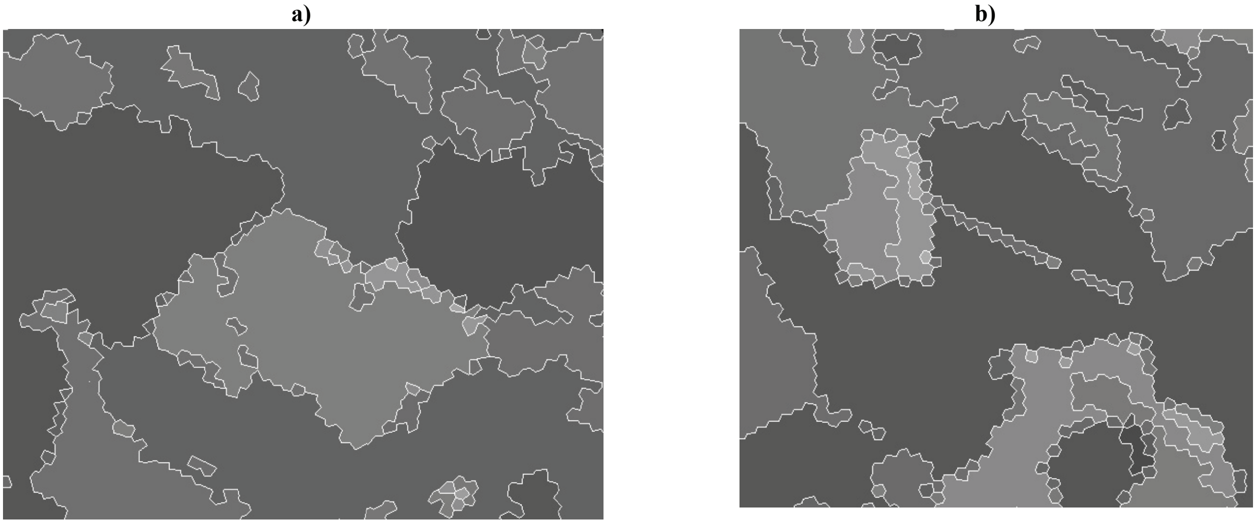

*Fig. 2. Results obtained from segmentation based on Voronoi tessellation.*

## 5. CONCLUSIONS

Three approaches to image segmentation were presented in the paper i.e. segmentation based on Voronoi tessellation, approach based on superpixels

characterized by the best efficiency. The results are returned after millisecond, but they have to be subjected to post-processing methods of smoothing before further usage. The last approach based on multi-filtering gives the highest quality, which is obtained mostly by implementation of the Bresenham algorithm. On the other hand, because of implementation of this algorithm, the efficiency of the third method is worse than in case of the second approach.

**a)** **b)**

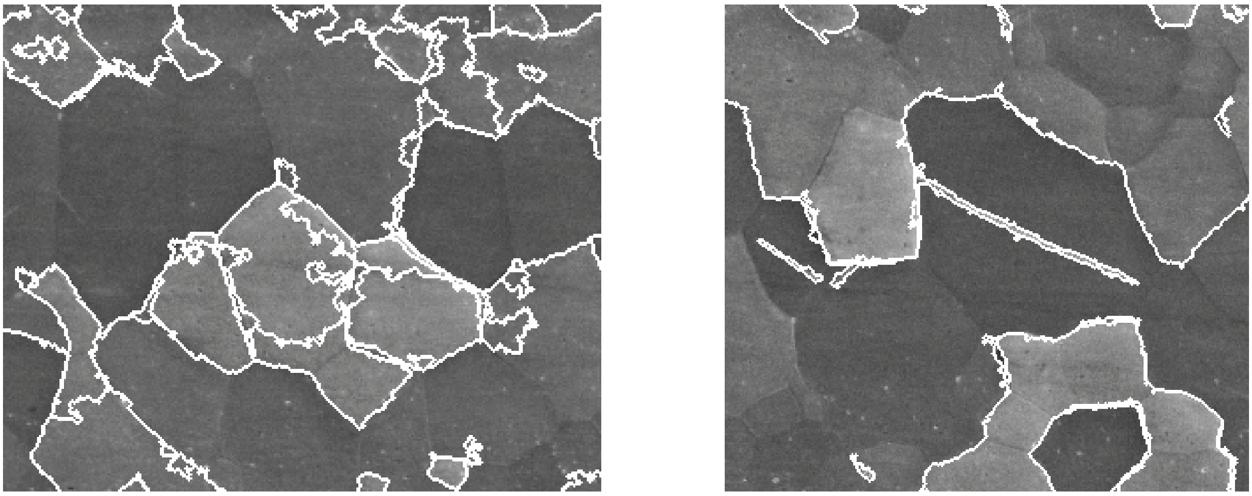

*Fig. 3. Results obtained from segmentation based on superpixels approach.*

**a)** **b)**

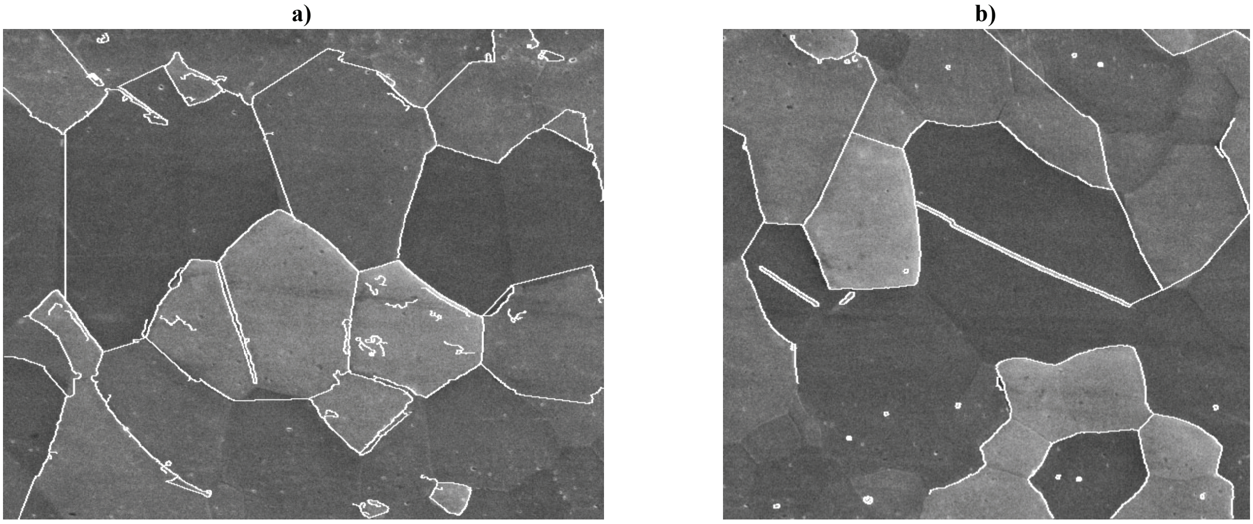

*Fig. 4. Results obtained from segmentation based on multi-filtering and the Bresenham algorithm.*

This work can be developed further as a complex solution with the main direction for nearest future focused on optimization of selected constituent algorithms of presented methods. These studies will be performed on the images of microstructures containing significantly high number of grains, which allow reliable quantitative assessment of grains' sizes and shapes.

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## REFERENCES

Arbelaez, P.A., Cohen, L.D., 2006, A Metric Approach to Vector-Valued Image Segmentation, *International Journal of Computer Vision*, 69, 119-126.

Basturk, A., Gunay, E., 2009, Efficient edge detection in digital images using a cellular neural network optimized by differential evolution algorithm, *Expert Systems with Applications*, 36, 2645-2650.

Gould, S., Rodgers, J., Cohen, D., Elidan, G., Koller, D., 2008, Multi-class Segmentation with Relative Location Prior, *International Journal of Computer Vision*, 80(3), 300-316.

Heath, M., Sarkar, S., Sanocki, T., Bowyer, K., 1998, Comparison of Edge Detectors, *Computer Vision and Image Understanding*, 69(1), 38-54.

Hou, Z.J., Wei, G.W., 2002, A new approach to edge detection, *Pattern Recognition*, 35, 1559-1570.

Kim, D.S., Lee, W.H., Kweon, I.S., 2004, Automatic edge detection using 3x3 ideal binary pixel patterns and fuzzy-based edge thresholding, *Pattern Recognition Letters*, 25, 101-106.

Kustra, P., Milenin, A., Schaper, M., Grydin, O., 2009, Multiscale modeling and interpretation of tensile test of magnesium alloy in microchamber for the SEM, *Computer Methods in Materials Science*, 9(2), 207-214.

Milenin, A., Byrska, D., Kustra, P., Heidenblut, T., Grydin, O., Schaper, M., 2010, A model of ductility phenomena of MgCa0,8 alloy in cold forming process, *Rudy i Metale Nieżelazne*, 55(4), 200-208.

Milenin, A., Kustra, P., 2008, The multiscale FEM simulation of wire fracture phenomena during drawing of Mg alloy, *Steel Research International*, 79, 717-722.

Milenin, A., Kustra, P., 2010, Mathematical model of warm drawing process of magnesium alloys in heated dies, *Steel Research International*, 81(9), 1251-1254.

Nezamabadi-pour, H., Saryazdi, S., Rashedi, E., 2006, Edge detection using ant algorithms, *Soft Computing*, 10, 623-628.

Rauch, L., Madej, L., 2008, Deformation of the dual phase material on the basis of digital representation of microstructure, *Steel Research International*, 79, 247-254.

Rauch, L., Madej, L., 2010, Application of the automatic image processing in modelling of the deformation mechanisms based on the digital representation of microstructure, International *Journal for Multiscale Computational Engineering*, 8(3), 1-14.

Shah, S.K., 2008, Performance Modeling and Algorithm Characterization for Robust Image Segmentation, *International Journal of Computer Vision*, 80, 92-103.

Yu, Y.H., Chang, C.C., 2006, A new edge detection approach based on image context analysis, *Image and Vision Computing*, 24, 1090-1100.

**METODY SEGMENTACJI ZDJĘĆ MIKROSKOPOWYCH STOPÓW MgCa**

Streszczenie

Artykuł porusza problem przetwarzania mikroskopowych zdjęć stopów MgCa pod kątem poprawnej segmentacji i ekstrakcji ziaren. W tym celu wykonany został przegląd literatury z dostępnymi obecnie popularnymi metodami segmentacji, a następnie wybrane zostały trzy metody charakteryzujące się wysoką wiarygodnością w przypadku analizy zdjęć zaszumionych i silnie zróżnicowanych. Metody te opierają się na tesselacji Woronoja, regionach zwanych superpikselami oraz na wielokrotnym filtrowaniu progowym i algorytmie Bresenhama (ostatnia z metod jest rozwiązaniem zaproponowanym przez Autorów). Artykuł zawiera również szczegółowy opis każdego z podejść jak również porównanie otrzymanych wyników segmentacji.

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