# DEVELOPMENT AND IMPLEMENTATION OF GRAIN BOUNDARY IDENTIFICATION ALGORITHMS

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**Abstract**

Current approach for microstructure images recognition and image-based properties measurement utilized manual iterative image filtering and threshold-binarization process until image areas, corresponding to desired structure elements, were extracted. This approach, however, led to information loss and inaccurate results, due to extensive filtering required to remove noise and extract features. Results were very sensitive to scanning method used to obtain images, image quality and coloring. Also, manual binarization process assumes that desired structure features are already known.

In this article, we present and describe implementation and results of new approach, where image is segmented using algorithms based on Watershed [1], Morphological Geodesic Active Contours (MorphGAC), and Morphological Active Contours without Edges (MorphACWE) [2-3] algorithms, providing context-independent image partitioning. After image is segmented, obtained segments are classified and then measurements are taken for desired classes. This approach allows to find more features than binarization approach with higher accuracy, as minimal filtering is required, and MorphGAC/ACWE algorithms tend to be more accurate in edge and contour detection than simple thresholding or linear filters.

Our program is written in Python, with use of OpenCV and Scikit-image libraries. It implements mentioned algorithm and provides tools for image filtering, and also analysis and measurements tools including features size and distribution statistics are available. For optimization enhancements, Python C-extensions and OpenCL-based GPU processing will be used if needed.

Future enhancements include graph theory structure analysis, as image partitioned into segments corresponding to structure elements can be easily represented in a graph form. Our goal is also to utilize neural network for microstructure recognition, segmentation and property analysis.

**Keywords:** Microstructure images recognition, grain boundary, images recognition algorithms, Python

## 1. INTRODUCTION

In the age of digitization, automated and semi-automated processing and analysis of images is widely used in many fields of science and technology, among others, in medicine (including the analysis of images from USG or CT), geology (recognition of rocks in petroleum geology) or criminology (face recognition).

The intensive deployment of vision systems in the various fields of our lives has an obvious cause. Human perception has often limited possibilities. By using appropriate image processing operations, information that is not normally recognized by the human visual system [4] can be obtained.

There is a general algorithm whose implementation is a necessary and fundamental requirement in image processing and analysis. In order to process the image and use it as a source of information, the first step is to transform it into a digital image (image acquisition). In the next step the analysis should be performed which includes filtering, segmentation, object localization and determines their characteristics [4]. **Figure 1** shows a diagram of a standard procedure in the analysis and image processing.


**Figure 1** Image processing and analysis algorithm [5]

The first step of image processing and analysis according to the above scheme (**Figure 1**) is to digitize the image. Briefly, image digitization can be described as the processing of analog signals into digital signals, which are signals whose domain and codomain are discrete.

The next step is filtration (**Figure 2**). Filtration is a pixel operation. Based on the appropriate mathematical transformation, it changes the source pixel parameters to the new one, taking into account neighboring pixels. The main purpose of filtration in this paper was to reduce noises of metallic microstructure and to minimize the effects of image compression.

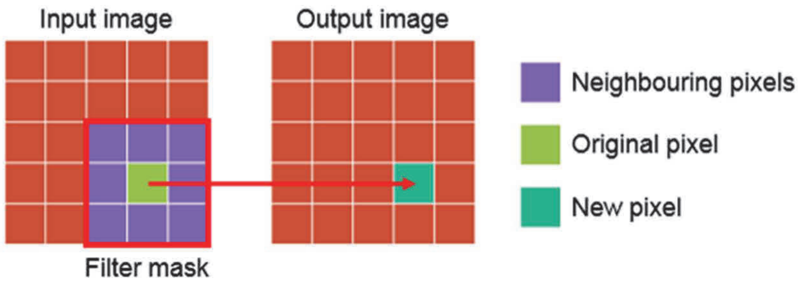


**Figure 2** Image filtering scheme

In the next step of processing and analysis of images, segmentation is realized. Due to the needs of the present work this is a priority step. Segmentation is the process of dividing an image area into certain zones, which are defined by specific properties, often based on color homogeneity. The main advantages of image segmentation tend to be in two directions. First, they give the user the freedom to access individual data. Secondly, they provide accurate information about the processed data, while providing the user ability to modify individual regions [6].

Two types of image segmentation were used. Watershed [1] and Morphological Geodesic Active Contours (MorphGAC) [2-3].

The name Watershed comes from the name of the boundary separating the river basin or water basins. Watershed is implemented for grayscale images. Watershed algorithms use region and contour information to split the image, presenting it as a topographical 3D relief, comprising two spatial dimensions, and a third being information about a specific attribute [6].

MorphGAC belongs to a group of algorithms called Morphological Snakes. MorphGAC is one of the best known examples of contour evolution methods. The operation of the algorithm is to find a contour that serves as the boundary of the image separation in two areas based on the content of the image. The method works by solving partial differential equations (PDE's) on an embedding function that has a contour defined as zero. Morphological snakes are designed to provide a quick, simple and stable approximation to PDE's. This accomplishes this task by replacing the PDE conditions with the multiple use of morphological operators over the binary embedding [2-3].

## 2. METHODOLOGY

For the purpose of the article the author's program *Structure Processor* for processing and analysis of images, especially photos of metallic materials structures, was created. The paper presents results of analyzes carried out on photos of the Inconel 718 microstructure in the delivery state and after high temperature flow-forming process.

### 2.1. Acquisition

Acquisition of a microstructure images was made using a scanning electron microscope. The device was connected to a computer, which allowed the images to be digitized. The structure pictures are shown in **Figure 3**.

a) b)

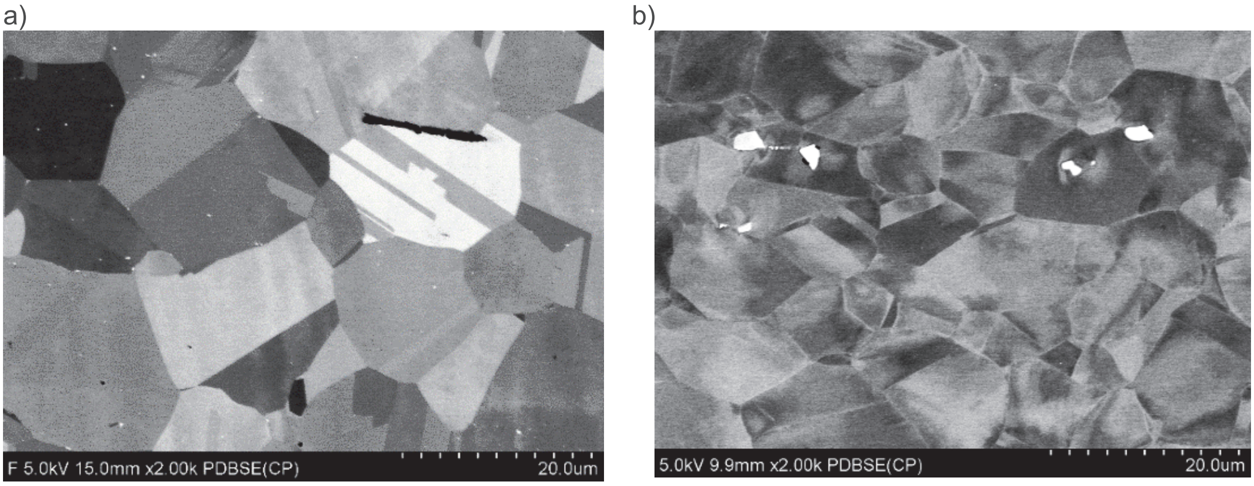


**Figure 3** Pictures from SEM, Inconel 718 in delivery conditions (a) and after plastic deformation in high temperature (b)

### 2.2. Filtering

In the next stage of the work, the image was filtered. The main objective was to achieve a maximum homogeneous color in each grain of material while maintaining grain boundaries. The Chambolle noise reduction algorithm was used for this purpose [8]. The results are shown in **Figure 4**.

a) b)

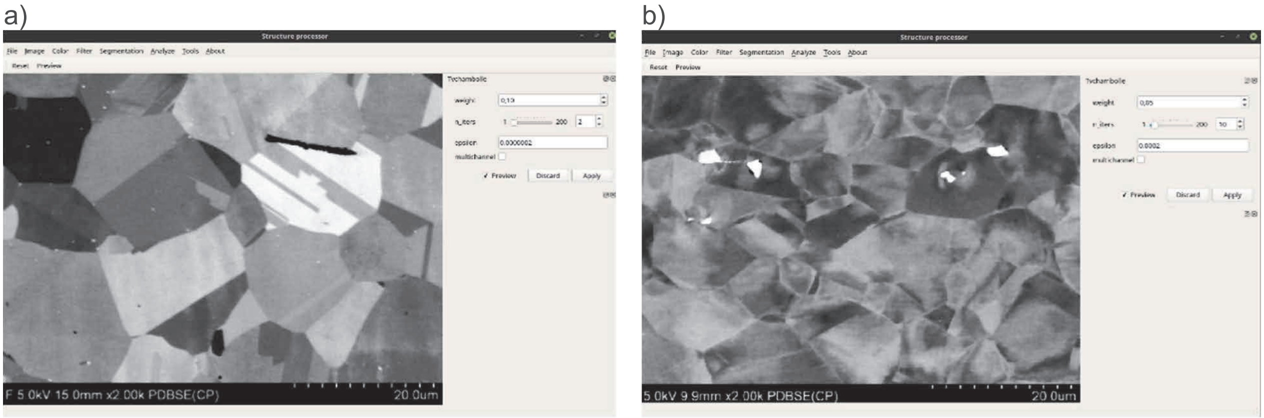

**Figure 4** Noise reduction on the microstructure pictures by Chambolle method

### 2.3. Segmentation

In order to achieve image segmentation, a grid of markers was generated (**Figure 5**). The marking grid is prepared for this method, due to the Watershed segmentation requirement: the algorithm starts with starting points, markers. Then it searches the adjacent points, expanding the area (still containing the starting point). If two areas are merged, the boundary is generated. If the grain did not contain a starting point, it could be incorporated into another.

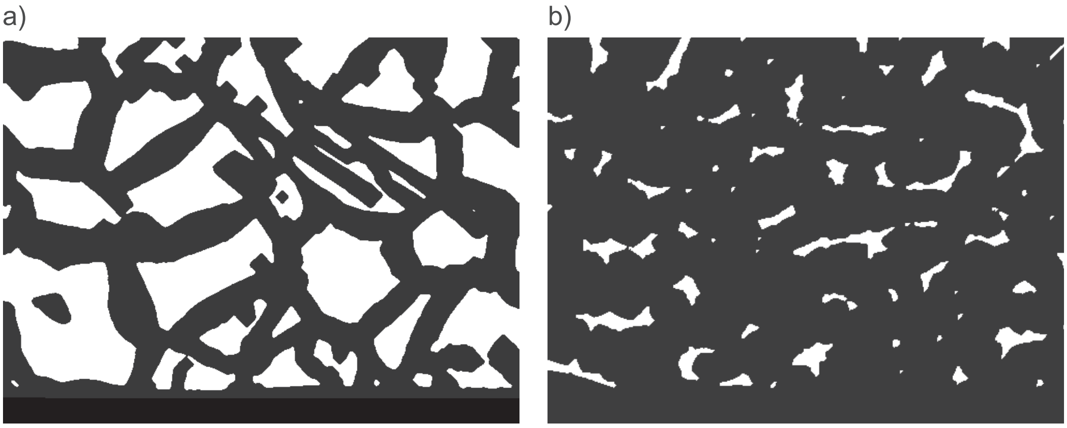

**Figure 5** Marker grid generated for Inconel 718 in delivery conditions (a) for Inconel 718 after plastic deformation (b)

### 2.4. Localization

In the next step, the marker grid is applied on the filtered image to locate the objects and mark the grain boundaries. The grain location result is shown in **Figure 6**.

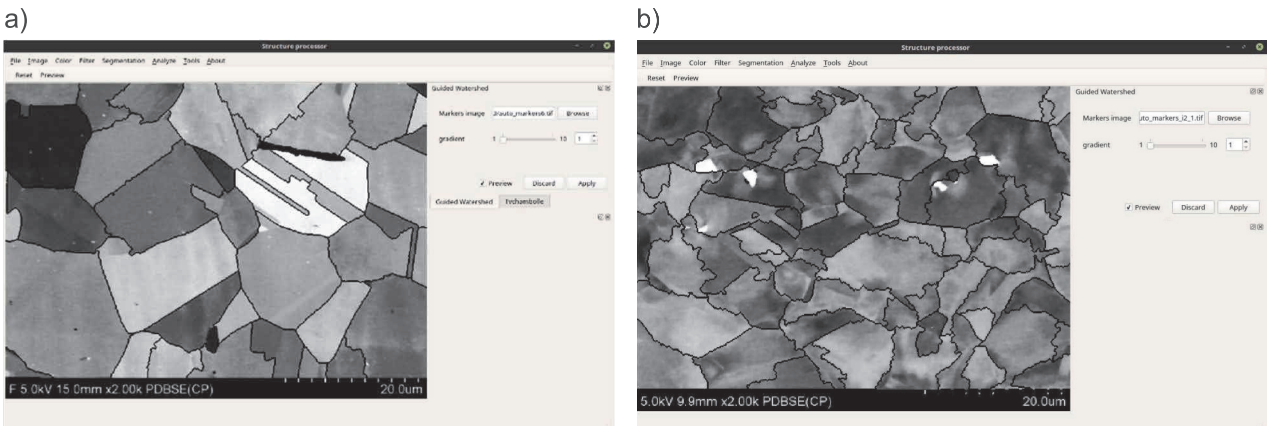

**Figure 6** Grain boundaries determined by the Watershed method

Locations of objects were also obtained using the MorphGAC algorithm. Exemplary results are shown in **Figure 7**.

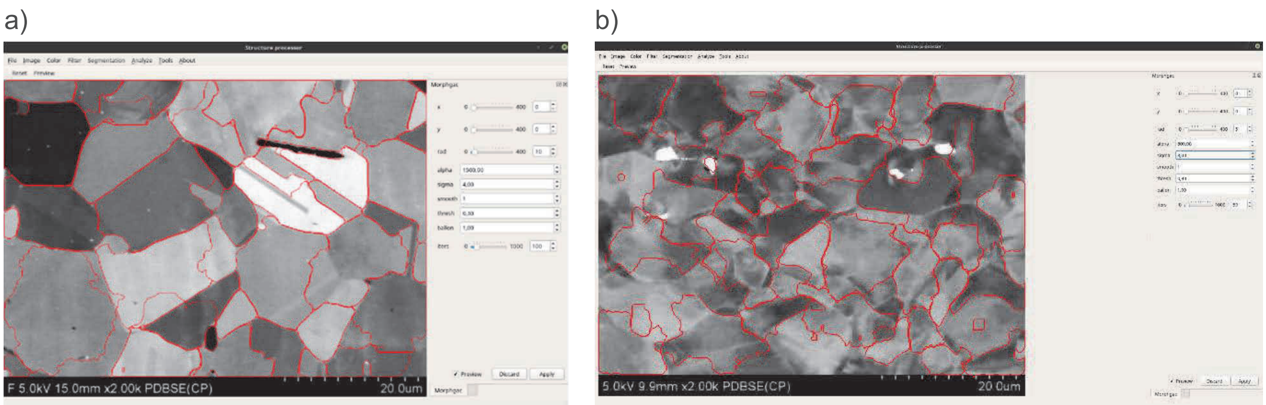

**Figure 7** Location of objects using the MorphGAC method. Inconel 718 in delivery conditions (a) and after plastic deformation (b)

## 2.5. Characterization

This is the last step in working on an image. The *Structure Processor* is equipped with a report and has several report options available to choose from. A base or extended report can be generated. A file obtained from the program contains information about the geometry of the counted objects and image files, each with a single grain. In **Figure 8**, a sample .csv file of the report is given.

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Id | Label | Color (RGB/Gray) | Mean color | Texture type | Bounding rect | Area | Perimeter | Equivalent diameter | Solidity | Border ratio | Inside image |
| 2 | 1 | 1 | None | None | None | (0, 0, 30, 27) | 563 | 102.734018716 | 26.77375326109316 | 0.918433931485 | 0.671637310236 | None |
| 3 | 2 | 2 | None | None | None | (18, 0, 28, 50) | 1014 | 161.604076401 | 35.93139154501889 | 0.862978723404 | 0.631172197334 | None |
| 4 | 3 | 3 | None | None | None | (119, 0, 102, 97) | 6406 | 391.090403796 | 90.31263767365813 | 0.864390770476 | 0.355416544745 | None |
| 5 | 4 | 4 | None | None | None | (208, 0, 51, 90) | 3750 | 284.787842585 | 69.0988298942671 | 0.936563436563 | 0.544264806366 | None |
| 6 | 5 | 5 | None | None | None | (0, 21, 118, 127) | 8782 | 619.026478659 | 105.74303609157532 | 0.802595503564 | 0.11308078477 | None |
| 7 | 6 | 6 | None | None | None | (177, 39, 79, 121) | 7346 | 383.563491861 | 96.71203490581979 | 0.920320721624 | 0.187713381299 | None |
| 8 | 7 | 7 | None | None | None | (14, 58, 40, 47) | 863 | 140.267027305 | 33.14823867276277 | 0.886947584789 | 0.0641633331292 | None |
| 9 | 8 | 8 | None | None | None | (147, 86, 62, 151) | 3822 | 440.646752982 | 69.7590247923363 | 0.579969650986 | 0.0340408726457 | None |
| 10 | 9 | 9 | None | None | None | (0, 92, 100, 127) | 7613 | 427.462986798 | 98.45391131930104 | 0.891660810494 | 0.23627776701 | None |
| 11 | 10 | 10 | None | None | None | (283, 106, 25, 15) | 251 | 71.8345237792 | 17.876888032555495 | 0.899641577061 | 0.403705606641 | None |
| 12 | 11 | 11 | None | None | None | (148, 132, 101, 150) | 11602 | 497.960461481 | 121.54063188093667 | 0.930542188001 | 0.18073724113 | None |
| 13 | 12 | 12 | None | None | None | (0, 172, 105, 156) | 10876 | 515.847763109 | 117.67647720993193 | 0.851483598215 | 0.186101417638 | None |
| 14 | 13 | 13 | None | None | None | (137, 195, 67, 87) | 3162 | 274.693434176 | 63.450637825419726 | 0.812435765673 | 0.0291233753875 | None |
| 15 | 14 | 14 | None | None | None | (245, 214, 56, 53) | 1603 | 186.953318806 | 45.177461086369895 | 0.900561797753 | 0.315586801972 | None |
| 16 | 15 | 15 | None | None | None | (210, 226, 129, 88) | 6436 | 373.220346111 | 90.52386265463659 | 0.886135205838 | 0.203633056965 | None |
| 17 | 16 | 16 | None | None | None | (0, 244, 121, 124) | 8786 | 455.889393669 | 105.76711511638739 | 0.852926900301 | 0.214964421987 | None |
| 18 | 17 | 17 | None | None | None | (136, 247, 111, 91) | 6703 | 360.634559673 | 92.38249113527843 | 0.913588660215 | 0.0804138128811 | None |
| 19 | 18 | 18 | None | None | None | (128, 251, 23, 12) | 130 | 61.2132034356 | 12.865501965161373 | 0.702702702703 | 0.375735931288 | None |
| 20 | 19 | 19 | None | None | None | (67, 253, 120, 75) | 4661 | 344.090403796 | 77.03615721212081 | 0.90417070805 | 0.0261559168774 | None |
| 21 | 20 | 20 | None | None | None | (204, 261, 82, 40) | 1740 | 205.923881554 | 47.068426868115985 | 0.90295796575 | 0.131116409599 | None |
| 22 | 21 | 21 | None | None | None | (282, 264, 26, 16) | 170 | 65.0416305603 | 14.712264360219255 | 0.829268292683 | 0.445868280825 | None |
| 23 | 22 | 22 | None | None | None | (0, 275, 27, 13) | 239 | 69.2487373415 | 17.44431859350499 | 0.937254901961 | 0.462102288482 | None |

report_full

**Figure 8** Except from a sample report

## 3. SUMMARY

*Structure Processor* is in development, but based on the results obtained with the Watershed algorithm, it can be said that the method is efficient and allows the structure to be analyzed with satisfactory accuracy. An important aspect is the selection of appropriate parameters for both pre-filtering, filtering, and algorithms.

The application of automatically generated markers shortens the analysis time and allows processing of more data.

The morph type algorithm is extremely sensitive to the parameters. The effects are not fully satisfactory yet. Future work will be conducted to improve the quality of the algorithm results.

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