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Research Paper

Development of New Technique for Reverse Engineering by Microstructure Features Detection

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Abstract

Reverse Engineering in the field of material science is considered one of the most important topics, The process is very complicated and depends on different factors. In this work, new software was developed to calculate the microstructure features of metals and alloys such as grain size number, the average diameter of grain, number of particles per unit area, and number of particles per unit volume. The volume fraction and the terms related to volume fraction such as shape factor, edge-to-edge spacing, and distribution of secondary phases were detected by the point count technique. Both quantitative and qualitative analyses were done. The microstructure features were calculated for the selected samples and compared with the standard photos stored in the program, The comparison depends mainly on comparing each constituent characteristic. The chemical composition comparison was taken into account, The C++ and MATLAB environment were used as a tool in this work which can work under Windows or Linux. The new technique has different applications in metallurgy, industry, medicine, and alloy design.

Keywords

Detection, Software, Microstructure, Qualitative, Quantitative, Reverse Engineering

1. Introduction

1.1 Quantitative metallography

Several techniques exist to quantitatively analyze metallographic specimens. These techniques are valuable in the research and production of all metals and alloys and non-metallic or composite materials [1-5]. Microstructural quantification is performed on a prepared, two-dimensional plane through the three-dimensional part or component. Measurements may involve simple metrology techniques, e.g., the measurement of the thickness of a surface coating, or the apparent diameter of a discrete second-phase particle, (for example, spheroidal graphite in ductile iron) [5-7]. Measurement may also require the application of stereology to assess matrix and second-phase structures [8, 9].

Stereology is the field of taking dimensional measurements on the two-dimensional sectioning plane and estimating the amount, size, shape, or distribution of the microstructure in three dimensions[10-13]. These measurements may be made using manual procedures with the aid of templates overlaying the microstructure, or with automated image analyzers. In all cases, adequate sampling must be made to obtain a proper statistical basis for the measurement. Efforts to eliminate bias are required. Some of the most basic measurements include the determination of the volume fraction of a phase or constituent, measurement of the grain size in polycrystalline metals and alloys, measurement of the size and size distribution of particles, assessment of the shape of particles, and spacing between particles.

Standards organizations, including ASTM International's Committee on Metallography and some other national and international organizations, have developed standard test methods describing how to characterize microstructure quantitatively. For example, the amount of a phase or constituent is defined in ASTM E 562; manual grain size measurements are described in ASTM E 112 (equiaxed grain structures with a single size distribution) and E 1182 (specimens with grain size distribution); while ASTM E 1382 describes how any grain size type or condition can be measured using image analysis methods.

Characterization of nonmetallic inclusions using standard charts is described in ASTM E 45 (historically, E 45 covered only manual chart methods and an image analysis method for making such chart measurements as described in ASTM E 1122. The image analysis methods are currently being incorporated into E 45). A stereological method for characterizing discrete second-phase particles, such as nonmetallic inclusions, carbides, graphite, etc., is presented in ASTM E 1245.

Stereology is used to quantify matrix microstructures, as opposed to standard metrology techniques for measuring case depth, plating thickness, or particle size. Microstructural measurements are made on a two-dimensional plane of polish through a three-dimensional opaque metal. Stereology converts these 2-D measurements into 3-D estimates of microstructural parameters. Most procedures are very simple to use, but there are special considerations for their validity. Figure 1 shows a scan line drawn in a portion of the image with its associated profile and derivative values. They are detected along the derivative profile as shown in Figure 1. The pixels are not treated individually anymore but the relative difference between adjacent pixels is considered, which fits the definition of a transition between two phases [3,11].

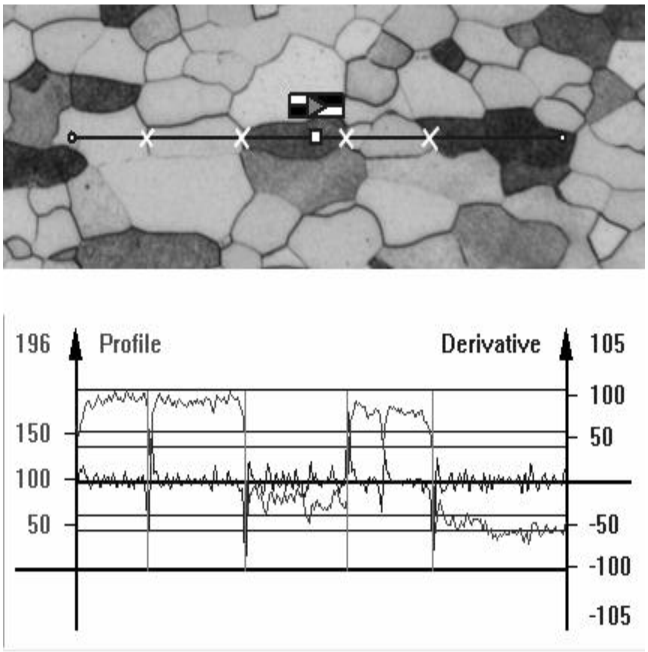


Figure 1. A scan line is drawn in a portion of the image with its associated profile and derivative values

2. Experimental Work

2.1 Metallographic Examinations

Samples preparation:

The specimens were prepared for examination according to the following steps:-

1. grinding on different grades of silicon carbide "SiC" papers coarse grinding followed by fine grinding at 180,240,320,400,600,800,1000 and 1200
2. polishing was conducted with Alumina powder (3µm) size or less depending on the nature of the examined surfaces.
3. The details of the microstructure were revealed after etching by the standard etching solution of the alloy selected.
4. All specimens had to be etched and polished several times to obtain the best results and to produce a uniform level of sample examination.
5. The surfaces of the samples were examined using an optical microscope at selected magnification.
6. The details of the microstructure were revealed after etching in the recommended solution.
7. The etching process was done by emerging the surface of the samples in the etching solution.
8. The specimen must be etched and polished several times to obtain the best results and produce a uniform level of matrix

Steps of reverse engineering method:

1) prepare samples by grinding, polishing, and etching
2) take photos of the sample at different magnifications
3) take the photo at a standard magnification of 100X
4) grain size and grain size number are evaluated
5) the parameters related to grain size such as average grain diameter, number of particles per unit area, number of particles per unit volume, shape factor, and so on
6) the parameters related to secondary phases are evaluated such as volume fraction, shape factor, edge-to-edge spacing, and so on
7) The chemical composition of the sample is recorded
8) the qualitative analysis of the sample is done
9) all values were recorded to make a fingerprint for the standard sample
10) all measurements were done for an unknown sample
11) Compare the recorded values of the standard samples to unknown simple by software to know all details about unknown sample
12) the microstructure features indicate the manufacturing method, treatment, fabrication, and processing
13) comparing the fingerprint of the unknown sample with standard samples indicate all of the characteristics without human error

Using software as a tool to do the above steps give fast and accurate results, for example, an average of 100 reading can be done in no time.

2.2 Image (Micrograph) Preprocessing

MATLAB and its Linux clone Octave to do preliminary algorithms development and concept proving. Figure 2 shows a Case Diagram of the proposed System Used according to the following steps:

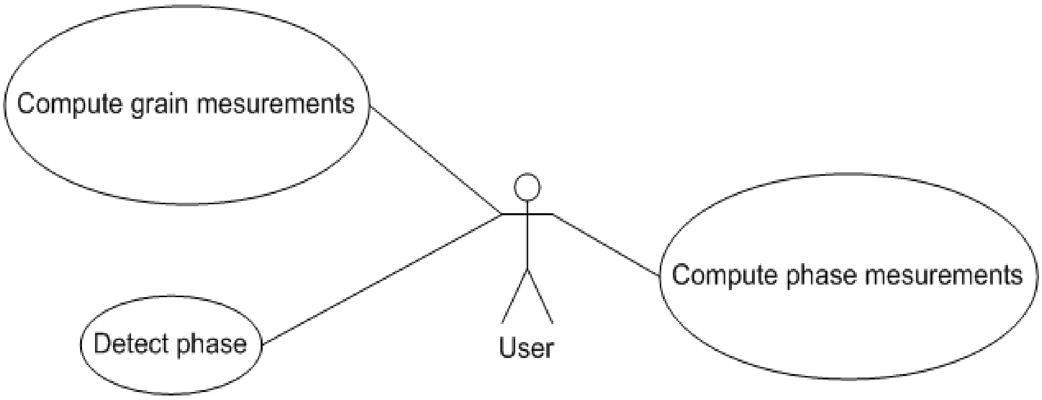


Figure 2. Proposed System Use Case Diagram

Contrast Enhancement:

Contrast Enhancement alters each pixel color value to a new value. This is done through a Look-Up Table (LUT) that holds all the image color values and their final color values that will be shown on screens or saved as the final image colors, the method of Contrast Enhancement is Histogram Equalization.

Image Intensity Enhancement:

In Image Intensity Enhancement, each pixel color value is reassigned to a new value based on the original image histogram. The original image histogram is expanded to cover the entire color scale. This gives better results in some images where image color values are not fully expanded to cover the entire color scale.

The justification for this enhancement is so simple. When the color values are mapped to cover the entire color scale, pixel color values are more separated. Thus, when applying a clustering algorithm like K-Means for the altered color values, some pixels at the decision boundary will be more separable. Therefore, they will fall in their correct clusters. Applying the image intensity enhancement for each of the color layers (such as RGB) results in overall better detection and results.

The function used in Matlab is *imadjust*. Don't worry about performance; use *imadjust* directly even if the image color values cover the entire color scale. Finding the minimum and the maximum color values for the image takes longer than applying *imadjust*.

Histogram Equalization:

Histogram Equalization includes two operations. The first is Image Intensity Enhancement. The second one is the uniformity of color values. The latter is achieved by drawing a cumulative curve over the original image histogram. Then the new histogram and color values are calculated such that the cumulative curve becomes a linear line (Figure 3).

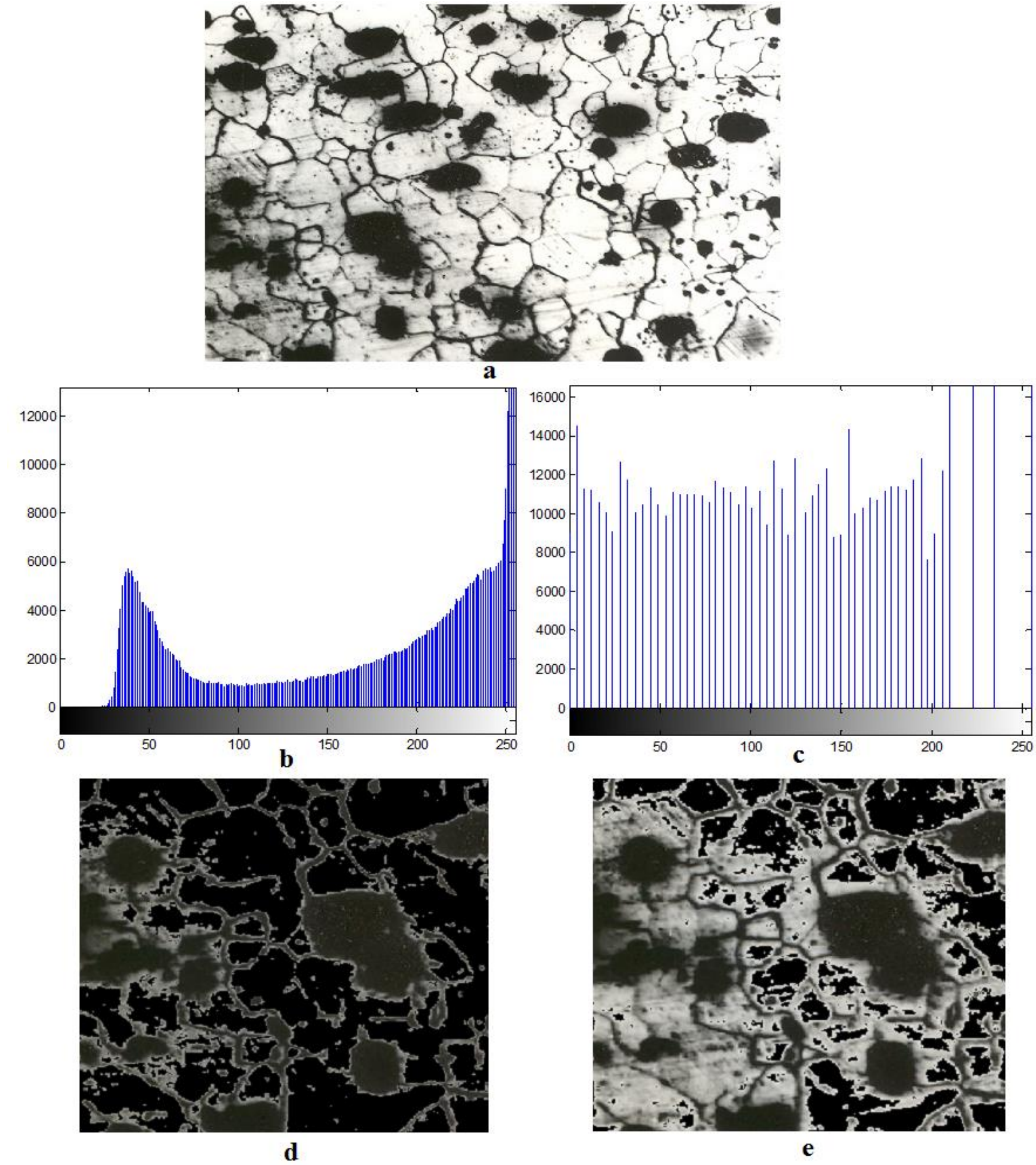


Figure 3. Histogram Equalization a) Original Image b) Original Image Histogram c) The histogram of the histogram equalized image d) The lower left part of the black phase after separation (without applying histogram equalization) e) The lower left part of the black phase after separation (after applying histogram equalization)

This means that histogram equalization changes pixels' color values based on the cumulative curve to change their frequency to obtain the linear curve. This will change the color values unfairly. Figure 3-d shows the black phase coming almost pure, while Figure 3-e shows the black phase with some parts of the white phase both detected as the black phase.

2.3 Proposed System

Deliverables:

The proposed system deliverables are ordered by priority from the most to the least important. Figures 4 and 5 show the activity diagram of the proposed system (Quantilizer) This importance comes from customers' and users' requirements.

- Grain Detection
- Grain-related Measurements
- Phase-related Measurements

Cross-Platform System, initially the system will run under Windows and Linux. End-User Software; installable, documented software, Figure 6 shows the proposed system sequence diagram

2.4 The measurements and outputs of the proposed system

There is a lot of measurement done by the proposed system (Quantilizer), the output windows that appear during the measurements were shown in the following figures, Figure 7 shows the detection of grain size by converting image colors, volume fraction was determined by point count technique as shown in Figure 8. The required magnification of the photos and the measurement units can be adjusted according to the specimen examined as shown in Figure 9. The system can also compare the photo with the ASTM standard photos stored in the software, this help in the identification of unknown alloys as shown in Figure 10. The difference between binary images and gray level images is determined so the number and type of phases were evaluated as shown in Figure 11.

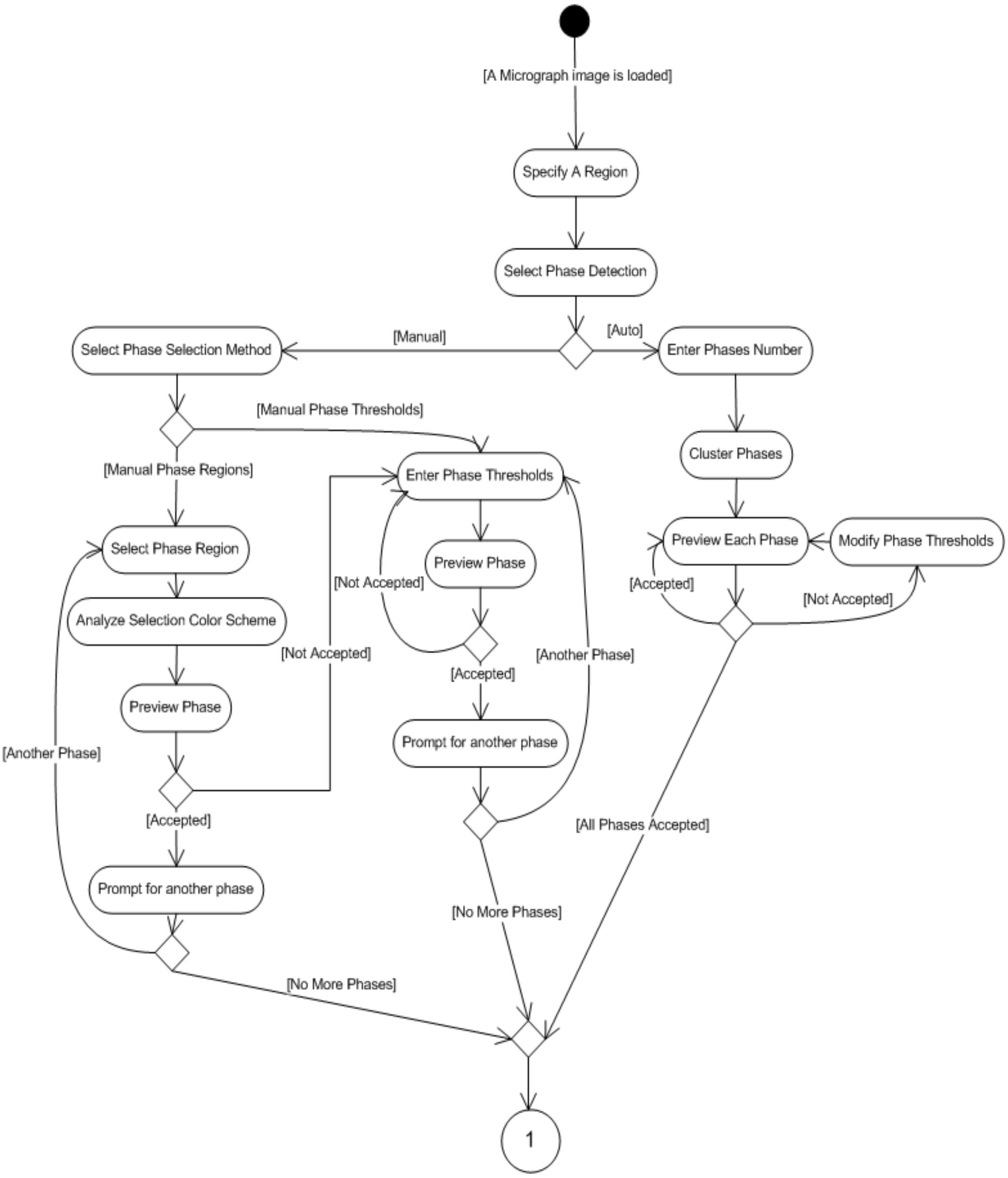


Figure 4. Proposed System Activity Diagram

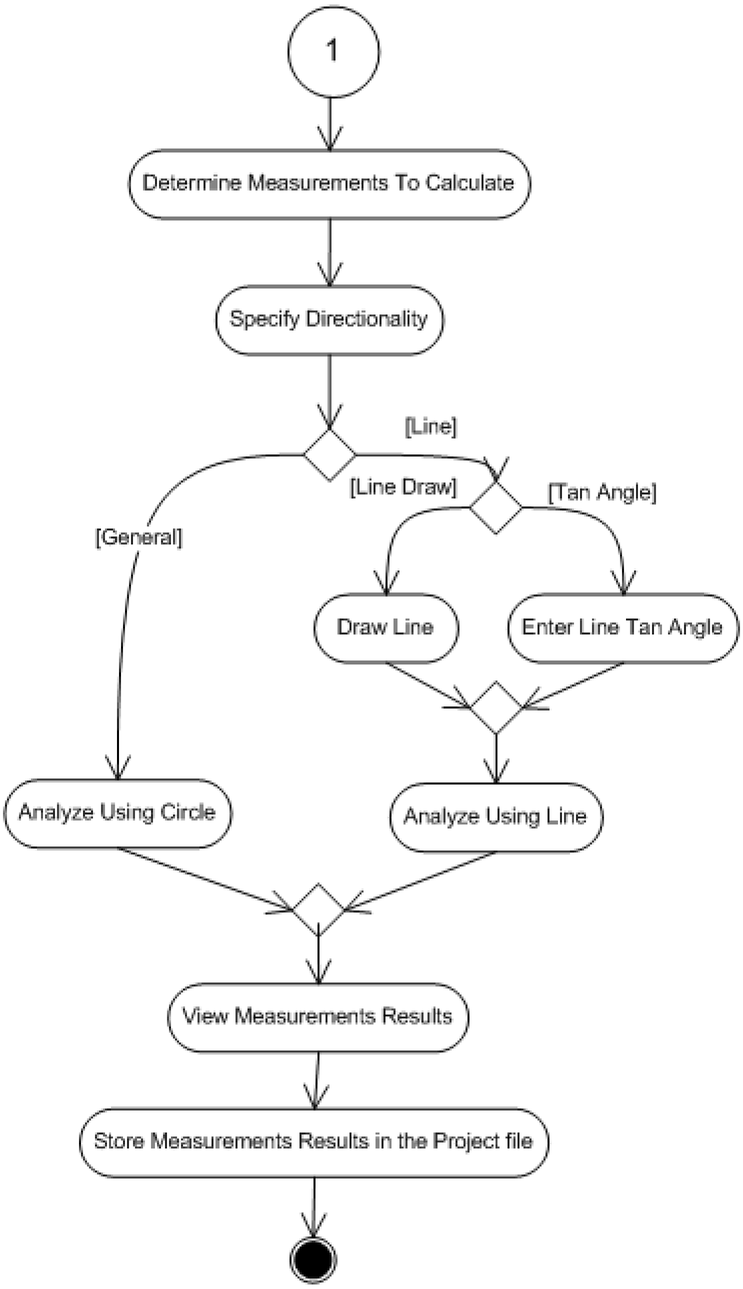


Figure 5. Proposed System Activity Diagram (continued)

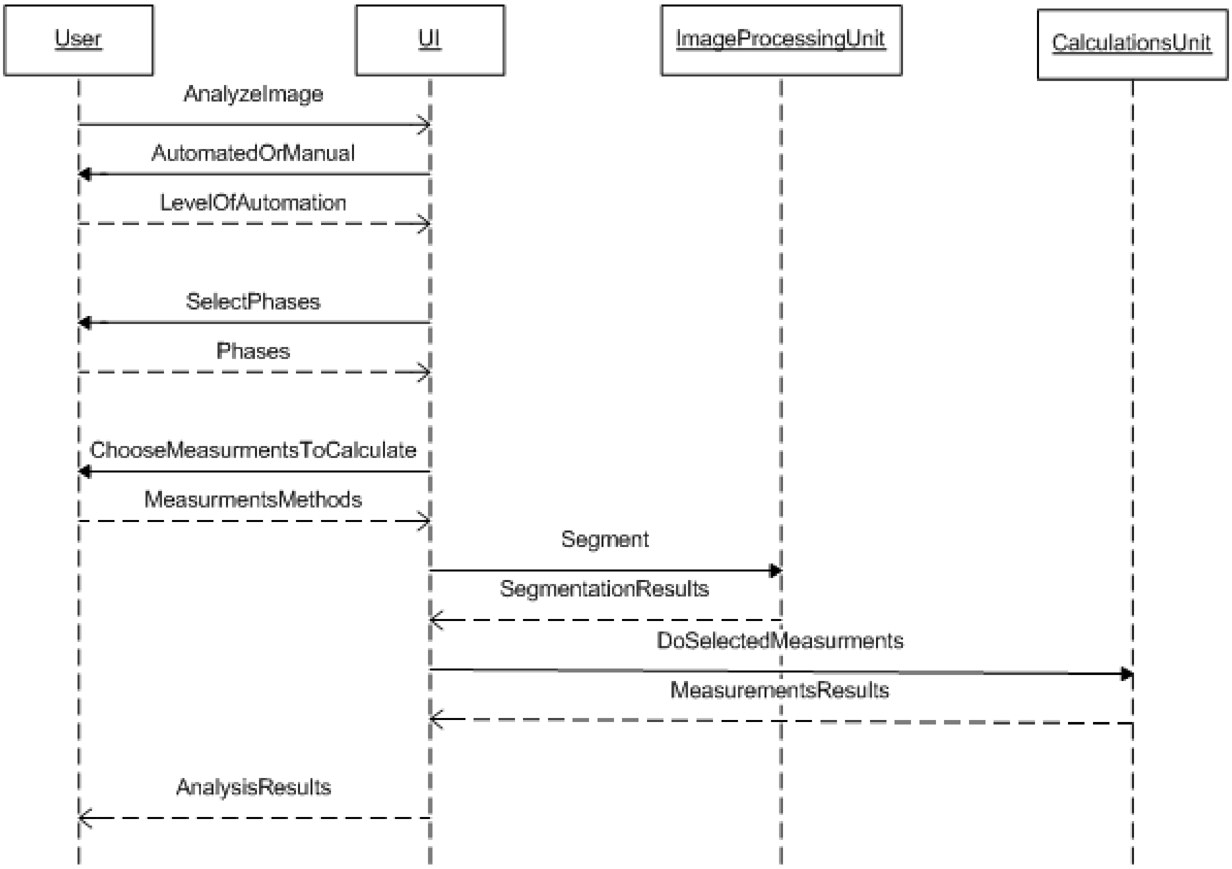
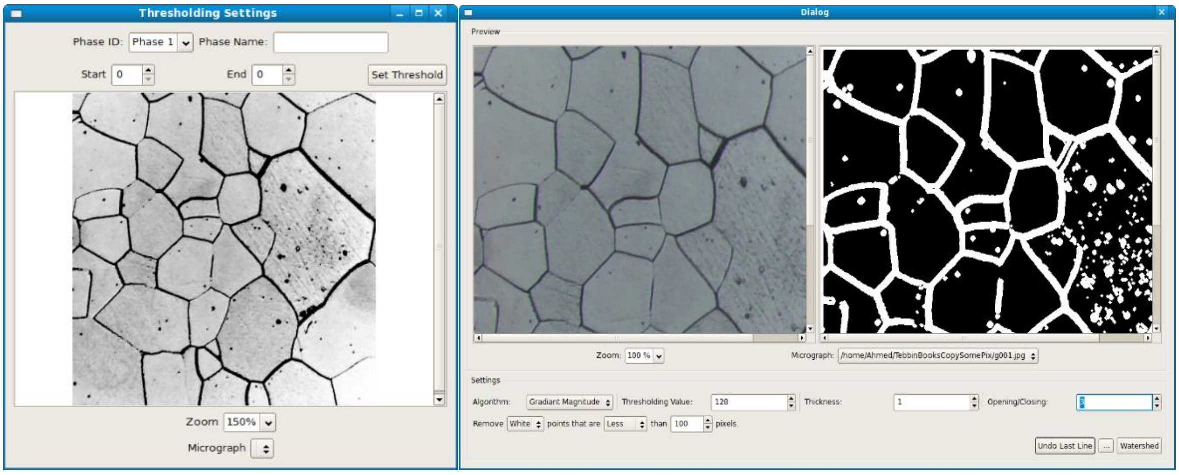


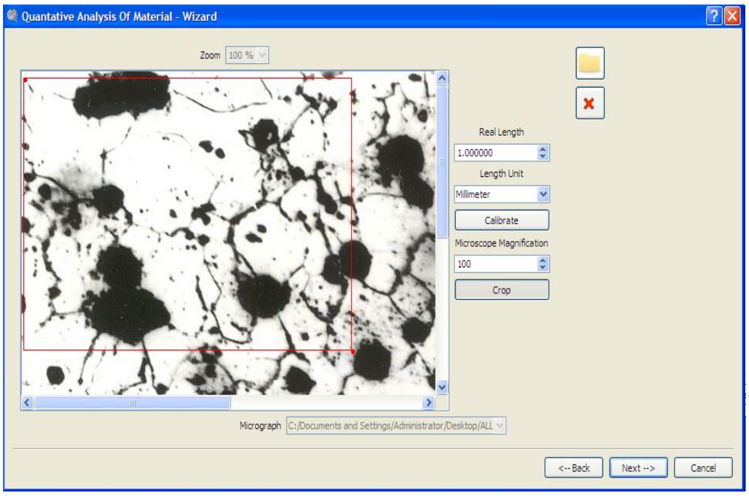
Figure 6. Proposed System Sequence Diagram



Phase ID: Phase 1
Phase Name:
Start 0
End 0
Zoom 150%
Micrograph

Zoom: 100 %
Micrograph: /home/Ahmed/TebbinBooksCopySomePix/g001.jpg
Algorithm: Gradiant Magnitude
Thresholding Value: 128
Thickness: 1
Opening/Closing: 3
Remove White points that are Less than 100 pixels.

Figure 7. Detection of grain size features by the system



Zoom 100 %

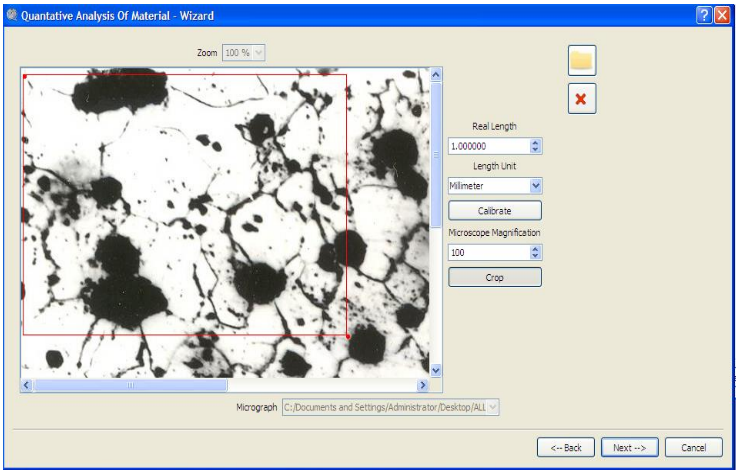
Real Length 1.000000

Length Unit Millimeter

Microscope Magnification 100

Micrograph C:/Documents and Settings/Administrator/Desktop/ALL

Figure 8. Detection of volume fraction by the system



Zoom 100 %

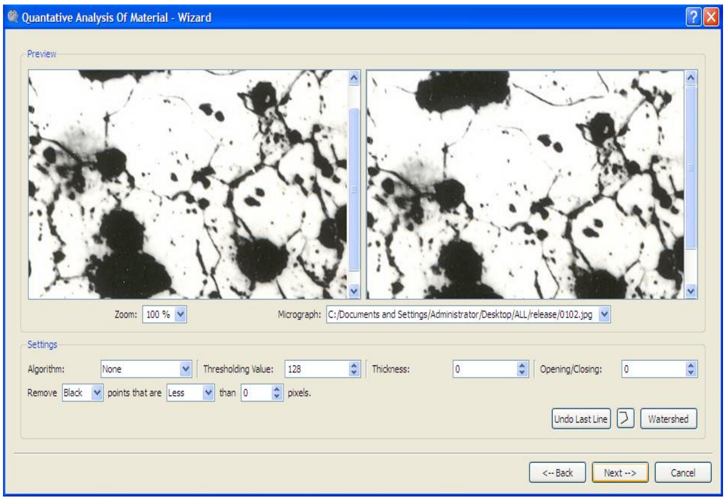
Real Length 1.000000

Length Unit Millimeter

Microscope Magnification 100

Micrograph C:/Documents and Settings/Administrator/Desktop/ALL

Figure 9. Selection of magnification and units



Zoom: 100 %

Micrograph: C:/Documents and Settings/Administrator/Desktop/ALL/release/0102.jpg

Algorithm: None

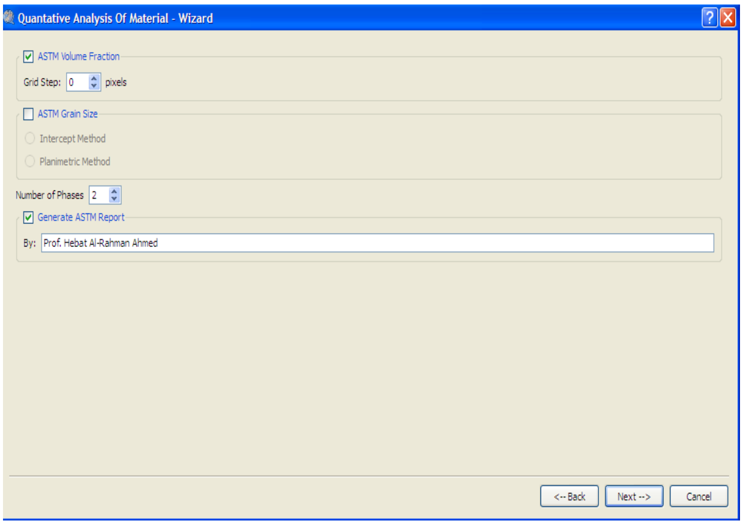
Thresholding Value: 128

Thickness: 0

Opening/Closing: 0

Remove Black points that are Less than 0 pixels.

Figure 10. Comparing two photos by software



Quantative Analysis Of Material - Wizard

☑ ASTM Volume Fraction

Grid Step: 0 pixels

☐ ASTM Grain Size

○ Intercept Method

○ Planimetric Method

Number of Phases 2

☑ Generate ASTM Report

By: Prof. Hebat Al-Rahman Ahmed

Figure 11. Determination of the number of phases

2.5 Limitations and Assumptions

We are not responsible for detecting grains or phases of close color components. Grains or phases to detect should be easily separable by color. In the situation of close color components, two or more grains may be detected as a single grain, or two or more phases may be detected as a single phase.

2.6 Extra options in the proposed system

The following options were inserted into the proposed system:

1- deal with both samples and photos
2- deal with any magnification
3- complete automatic analysis
4- Independent of the type of camera and can deal with the digital camera, CCD camera, and any type of camera.
5- Compare results with standard ASTM samples and data.

So Quantilizer is considered the cheapest and most abundant system in quantitative analysis of materials

3. Conclusion

1.Computer image processing and analysis techniques were used as a tool in the quantitative analysis of some typical microstructures to specify the grain and phases features such as amount, distribution, and defects

2.An affordable system reduces the time-consuming of manual stereological methods and conventional image analyzer methods

3.Using the computational power of computers, the Point Counting Technique with a test grid that maps the dimensions of the image can be applied.

4.A digital image consists of discrete pixels; each has its color component, the system depends on the contrast analysis of every component, and the system is capable of extracting many features from materials, especially metals and alloys.

5.The system has different industrial and medical applications such as material selection, crack detection, blood component analysis, reverse engineering, and material detection

6.The image detection can be carried out with high efficiency, the measurement error mainly depends on whether the analyzed objects are well-defined contrast.

7.The system tests each point of intersection (represents a pixel now), and it covers all the pixels of the image. This gives the most accurate result for a measurement value per digital image (micrograph), evaluating the value using the population under examination. re-sampling and filtering using different algorithms are the main tools in the system.

8.The system is less expensive relative to the common software used besides high efficiency.

9.The system depends on the intercept method which is one of the grain size detection methods.

4. References

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