The TEM Image Segmentation Based on ICM-MRF Algorithm

Hui Min GUO, Ling Chao ZHAN
Department of Information Engineering, Jincheng College, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu 211156, China
hmguo@nuaa.edu.com

Abstract. This paper develops an application of the ICM segmentation algorithm based on MRF to realize the rapid and accurate segmentation of TEM images of supper nanoparticles. Through the experiment, we found that it can remove the background in the images of the bridge effectively, segment and identify the particles accurately. It was concluded that the algorithm can be used to laid a solid foundation for further material analysis.

1. Introduction

Transmission electron microscope (TEM) is a kind of microscope with high resolution and high magnification, which is an important tool for materials science. TEM is an analytical platform, which can realize the morphology observation, microstructure analysis, micro-area component analysis and in-situ experiment. It has great influence on the production of materials science, physics, nano-science, chemistry and life sciences. Therefore, the processing and analyzing TEM image is very important.

Therefore, it is necessary to adopt the proper segmentation algorithm and obtain the accurate segmentation results to carry out further particle calibration, particle size statistics, and determination of multiple morphological parameters. Through this, quantitative characterization of the homogeneity of the material can be possible [1].

At present, researchers mainly use the software such as Digital Micrograph, Image processing and analysis to process and analyze images of micrometers, particle size of nanometer material. However, it is important to note that the analysis and treatment of particles using the above software also has many problems. 1). Due to the small size and irregular distribution of nanometer materials and electron microscope images’ contrast is not obvious, the simple segmentation algorithm, such as the edge detection algorithms, threshold method and the operator will inevitably cause the particle identification errors; 2). Researchers tend to focus on a certain direction (such as the width of a nano-rod), and the above software were difficult to meet the analytical requirements. 3) In the light of the actual application, the image is not uniform, and the phenomenon of particle overlap is often present in the image. This will make it difficult for particle segmentation and quantitative analysis of the statistical and relevant characteristic parameters of the particle, and affect the subsequent processing. Some of the existing software does not add these subtle steps [2].

2. Solutions:

The TEM image processing procedure adopted in this paper is summarized in the following steps, which is given in Figure 1:

Step 1, copper nanoparticles produced by electron beam irradiation of TEM images for image
preprocessing, use the filter (smooth filtration) method to remove the image noise;

Step 2, the ICM algorithm based on MRF is used to realize the fast classification of images. If there is a background bridge, the segmentation method can be effectively removed;

Step 3, remove the small negligible particles in the image and remove the incomplete particles;

Step 4, the adhesive particles are separated if the image has adhesive particles;

Step 5: morphological treatment of binary images generated by the final transformation is made. By identifying the connected domain of the target particles, the target particles are identified and the relevant parameters are calculated.

![Figure 1 The TEM image processing procedure using ICM-MRF](image)

2.1. The ICM algorithm based on MRF.

In the process of ICM iterative solution, the final category label of the image can be obtained by simply giving the number of categories of images. While using ICM iterative algorithm for solving, eventually get the local optimal value, but corresponding to the TEM images, the final segmentation category number is less, and contextual relevance based on MRF model, can help to quickly remove has nothing to do with the grain of the background image, fast convergence and will not affect the particle identification. The MRF theory has the following key questions: (1) how to use MRF to describe the context information; (2) how to design the target function, especially the posterior distribution to obtain the optimal solution; (3) which algorithm will be chosen to find the optimal solution. The problem of context constraint is the objective function optimization problem for the designed objective function [3]. The maximal posterior probability (MAP) is the most commonly used optimization criterion in MRF modeling. The MRF model is combined with MAP guidelines is called the MAP-MRF system. This architecture was first proposed by German and German in literature [1]. The F and the D are the two-dimensional Random Field, D is the observed image, F is the original image. Only an estimate of F is given according to D, and the MAP is the method of solving the Maximum, which we can see in the formula (1):

$$f = \arg \max \ P\{F = f \ | D = d\}$$  \hspace{1cm} (1)$$

And because of equivalence:  $$P(F = f) = \frac{1}{Z} e^{-U(f)}$$ \hspace{1cm} (2)$$

$U(f)$ is the prior energy function, so it can be concluded that the posterior energy function
is:
\[ U(f \mid d) = U(d \mid f) + U(f) \]  
(3)
In this way, the maximum problem of the MAP is converted to the minimization of the posterior energy function. 
\[ \hat{f} = \arg \min_f U(f \mid d) \]  
(4)

The expression of energy functions in MRF model can be defined as follows:
\[ U(f) = h\sum \beta_{i,j} \delta(f_i \neq f_j) \]  
(5)

Among them, the value \( \beta_{i,j} \) is selected according to the nature of the image, after the confirmation of the value of \( \beta_{i,j} \), coefficient of parameter \( h \). The ICM algorithm was proposed by Besag and Panjwani [3,4], which adopted the "greedy" strategy in iteration maximization. It is difficult to maximize the joint probability of an MRF in practice [2, 3]. Therefore, the ICM algorithm maximizes the probabilistic probability \( P(f_i \mid d, f_{S\setminus\{i\}}) \) after the given data \( d \) and other pixel values \( f_{S\setminus\{i\}} \), which in turn will be updated. The following corresponds to the minimum of the posterior potential function:
\[ f_{i}^{k+1} \leftarrow \arg \min_{f_i} V(f_i \mid d_i, f_{i'}^{k}) \]  
(6)

Among them,
\[ V(f_i \mid d_i, f_{i'}^{(k)}) = \sum_{(i',j)} V(f_i \mid f_{i'}^{(k)}) + V(d_i \mid f_i) \]  
(7)

At present, people often use the maximum likelihood estimate as its initial value:
\[ f_i^{(0)} = \arg \max_f p(d \mid f) \]  
(8)

Corresponding to (6), The iterative formula for each pixel value is as follows:
\[ f_i = \arg \min_{k \in \{0, 1, \ldots, M-1\}} \left\{ V(d \mid k) + \beta \sum_{j \in S} \delta(k \neq f_j) \right\} \]  
(9)

2.2. TEM image segmentation result using ICM algorithm
Figure 2.a) shows an experimental original TEM image. The scale bar is 20 nm. Segmentation results are shown as in Figure 1 by Double threshold algorithm and the ICM algorithm. The image of Diagram of region boundary data points is shown in Figure 2.b), Then, ICM algorithm The calculation result of ICM algorithm depends on the initial value selection, which is fast, but it is likely to fall to local convergence. But we can find that the accuracy by ICM algorithm (with the parameters C=3 and h= 10,) Figure 2.e) and f) shows the result image of adding the boundary, and the image of the particle edges. This experiment was convenient and also essential. The ICM method reduces the influence that the TEM image of polymer nano-composites is not big enough in a statistical sense. The method reduces the influence of the human intervention in selecting non-scaling region.

It has the certain disparity with theory, makes the ICM algorithm obviously did not converge to the smaller energy function values. However, ICM algorithm can results demonstrate the effectiveness of the proposed algorithm. The recognition of particles after the processing of grid method have markedly improved, and keep the original features, as shown in Figure 2 d). The image segmentation effect is better. The impact of human intervention on the evaluation parameters in the selection process of the scale-free zone is reduced due to the TEM image size and the influence of the evaluation parameters in the statistical sense.

2.3. Comparisons between the Results of different algorithms
Moreover, in order to compare the experimental results, we also used the watershed segmentation algorithm. As shown in Figure 2.c), the accuracy of watershed segmentation is not very good. We can find that the phenomenon of excessive segmentation is serious.
Figure 2 a) TEM image of copper nanoparticles. b) The image of Diagram of region boundary data points c) Segmentation results by Double threshold algorithm. d) Segmentation results by ICM algorithm (C=3). e) The result image of adding the boundary. f) The image of the particle edges.

Figure 3 a) Open operation, b) Closed operation, c) The results of watershed segmentation.

The current DM software can find out the boundary of the particle through the analysis of the intensity distribution of images. The contrast of the particle and the background is not very good, sometimes the edge of the support pore membrane is very dark, forming a grey color ribbon, which makes it impossible to distinguish between particles or bridge, it can also be difficult to be correctly segmented. The comparison between the two algorithms is analyzed as shown in the Figure 3 Figure 4. We can clearly see that the removal of the background bridge is more effective in the ICM algorithm.
3. Subsequent Processing

After the following subsequent processing steps: Removing inappropriate size particle, Removing the boundary particles, filling the granule cavity, scavenging (Particles less than 300 pixels are not displayed), Separation of adhesion particles. We can get the number of particles identified after segmentation is 24, and the duty ratio is 25% using contour tracking. Figure 5 shows the subsequent processing results of Figure 2 a) in the first experiment:

Figure 5 a) The binary image (C=2) after removing the boundary particles b) The particles boundary image

Other effective follow-up processes include removing the boundary particles and separating the sticky particles and filling the hole area. Quantitative analysis of TEM particle segmentation can be made through mathematical morphology or the Snake Model. Which you can refer to the references [5],[6] The quantitative calculation of parameters such as circumference, number of particles and area can be calculated.
4. Conclusions
This paper presents and discusses the TEM image segmentation based on MRF-MAP. The ICM algorithm can realize faster segmentation and get better effect (less number of iterations), but its convergence calculation time is shorter, is suitable for TEM image segmentation; After the background bridge the overlapped particles were removed, and the treatment of the boundary particles. It can demonstrate the effectiveness of the proposed algorithm. With the requirement of analysis of nano-materials, the image can be quantitatively segmented quickly and accurately.

References
[1] Geman S, Geman D. Stochastic relaxation, Gibbs distributions, and the Bayesian restoration of images. IEEE Trans.Pattern Anal Machine Intell,1984 , l( (PAMI - 6) :721-741.
[2] Li S Z. Markov Random Field Modeling in Image Analysis. 2nd Ed. Berlin: Springer-verlag,2000: 32-41.
[3] Elliott H, Derin H, Cristi R, et al. Application of the Gibbs distribution to image segmentation. Proc IEEE Int Conf Acoust Speech Signal Process, 1984 , 2 : 321511-321514.
[4] Panjwani, Healley. Markov random field models for unsupervised segmentation of textured colors images. IEEE Trans Pattern Anal Machine Intell,1995 ,17(10) :939-954.
[5] LI J M, LU Li. Quantitative analysis of irregularity of graphite nodules in cast iron [J]. Materials Characterization, 2000: 83-88.
[6] Marturelli, Leandro. Costa, Lilian; Cidade, Automated object length measurement applied to AFM, STM and TEM images based on the snake model. Advances in Intelligent and Soft Computing, v 122, p 569-574, 2011, Foundations of Intelligent Systems: Proceedings of the Sixth International Conference on Intelligent Systems and Knowledge Engineering,Shanghai, China, Dec 2011 (ISKE2011).