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Image 3D Reconstruction Based on Binocular Vision

Fang Duan[1,a,*], Wei Sun[1,b], Jianpeng Zhu[1,c]
[1]College of Rail Transit, Shanghai Institute of Technology, Shanghai, 200235, China
[a]doujiang202102015@163.com, [b]740710829@qq.com, [c]2731611252@qq.com
[*]Corresponding author

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Abstract: SEM can be used for studying the microstructure observation and crystal structure analysis of materials. FIB-SEM dual beam system can be simply understood as the coupling of single focused ion beam system and SEM. In order to fully utilize the grayscale information contained in microscopic morphology images, this paper proposes a three-dimensional reconstruction study based on the principle of binocular stereo vision and image processing technology. The study uses binocular vision to measure the depth information of the sample space, and combines image processing technology and visual programming technology to restore the three-dimensional morphology of the sample surface, providing data basis for a real-time feedback system for nano material processing based on FIB-SEM dual beam system images is of great significance for micro morphology observation and nano material processing.

1. Introduction

Microscopic instrument is a powerful tool for observing and studying the microstructure of materials, which opens a door for human to explore the micro world. The emergence of electronic microscopic system improves the resolution to the nano field. The final gray image can provide various information of the sample, which can be used to study the microstructure observation and crystal structure analysis of materials[1]. The FIB-SEM dual beams system is a very important instrument for ultra-fine processing and characterization[2].

With the continuous development of computer vision technology, the use of digital image processing technology to achieve three-dimensional reconstruction of sample micro morphology is of great significance to all aspects of science. For example, biological researchers can use the obtained 3D surface model of specimens to study their surface features, and medical researchers can observe the anatomical structure of cells through 3D modeling. The research direction of this paper is to use FIB-SEM dual beam system to obtain micro and nano sample images from different angles, accurately measure the depth information of sample surface features, and realize 3D reconstruction of micro and nano samples.

1.1 Research status and analysis

3D surface modeling and visualization based on 2D images has always been a practical research field in the field of computer vision (CⅤ) and artificial intelligence[3]. There has been a lot of research on obtaining 3D information in the macro world from images [4][5]. The three-dimensional reconstruction methods of sample micro morphology combined with digital graphics processing technology can be roughly divided into the following three categories according to the number of image viewing angles: (1) single view measurement method; (2) Multi angle measurement; (3) Fusion measurement method. Another kind of method uses FIB-SEM or electron tomography (ET) to reconstruct the crystal structure of the sample by means of continuous slices. This kind of method requires high skills and may cause damage to the sample, while the binocular vision used in this paper only needs to reconstruct the three-dimensional surface of the sample.

The combination of stereo vision and SEM for 3D measurement is the first proposed 3D measurement method under SEM: Boyde used the principle of stereo vision to reconstruct and measure sparse 3D point data[6]. In 1998, Lacey et al. Used B-spline interpolation algorithm to interpolate sparse data to further obtain dense data. However, due to the low density of sparse data, it is difficult to make the difference, resulting in low data accuracy [7]. Through theoretical derivation and a large number of experiments, Marinello et al. believed that the main factors affecting the accuracy and stability of stereo vision method were image quality (distortion) [8],and the largest uncertainty comes from the rotation angle[9]. On the other hand, FIB-SEM dual beam system affects the etching efficiency of ion beam on micro and nano samples due to factors such as sample surface defects during the etching process. Accurate sample surface depth information is required to provide feedback for ion beam processing and further control the ion beam etching efficiency.

1.2 FIB-SEM dual beam system imaging

The FIB-SEM dual beam system scans the sample with a finely focused electron beam or ion beam in the form of grating scanning through the scanning system, and interacts with the sample to produce secondary particles.

The generation of secondary electrons is the result of ionization of electrons outside the nucleus due to the interaction between high-energy incident electrons and electrons outside the nucleus of the sample. If this process occurs in the surface layer of the sample, as long as the free electrons overcome the escape work of the material, they will leave the sample and become secondary electrons. The principle of secondary electron image imaging is based on the difference in the yield of secondary electrons emitted from the sample[1]. The sample shows that the details with large inclination angle produce more secondary electron signals than those with small inclination angle. Even if the fluctuation is as small as nano scale, the morphology in nano scale can be observed[1].

1.3 Research motivation and work objectives

Binocular vision technology often faces the problem of low measurement accuracy in the measurement of micro sample spatial depth information. In addition, the etching efficiency of ion beam on micro and nano samples is affected by factors such as sample surface defects in the etching process of FIB-SEM dual beam system. Accurate quantitative data is needed to provide real-time feedback for ion beam processing and further control the ion beam processing efficiency. Therefore, this paper uses digital image processing technology to make the sample image clear, and uses binocular vision technology to measure the spatial depth information of the sample in the target area, which provides data basis for optimizing the real-time feedback system of micro nano material processing based on FIB-SEM dual beam system image.

2. Image 3D reconstruction theory based on binocular vision

First, the electron beam and the ion beam of the FIB-SEM double beam system are taken at a certain angle to take a sample image.

After the image is segmented, the centroid of the sample contour can be extracted as the feature point. After the feature points are extracted from the image, the feature points of the two images need to be matched. The abscissa of a point in the sample photographed from two different angles and mapped to two feature points in the image according to parallel projection is the same. Feature points can be matched in two images according to the matching of the spacing between two feature points, and the spacing between a pair of feature points in the image can be described by the absolute value of the difference between the abscissa of the feature points. The specific matching steps are as follows:

1) Find benchmark set

First, find a benchmark in the image, and match the feature points according to the distance between the reference point and other feature points. Compare the feature points of the side view with the feature points of the top view, and find a pair of points with the same abscissa into the set of possible matching points. Find a pair of points that meet the following conditions in the above point set:

For a pair of possible matching points, find a pair of reference points in their respective images as follows:

(1) The abscissa distance between the pair of reference points in their respective images and the pair of possible matching points is the same;

(2) The pair of reference points are both greater than or less than the ordinates or abscissa of the pair of possible matching points in their respective images;

(3) The difference between the vertical coordinate distance between the reference points and the points to be matched in their respective images is the smallest;

A pair of reference points that meet the above conditions are included in the datum point set.

2) Feature matching based on benchmark

Do the following for any point in the benchmark set: calculate the distance between the reference point and other points in the two images respectively, compare their distances, and the same distance is a pair of matching points. If there are more than one point with the same distance, compare the absolute value of the difference between them and the longitudinal coordinates of the reference point, and select the pair of points with the smallest value as the matching points.A pair of matching points are marked with the same sequence number in the two images.

After matching the feature points, in order to obtain the position information of the matched feature points in 3D space, it is necessary to establish the mapping model and spatial coordinate system from 2D image to 3D space. One edge of the collected two sample images is overlapped to align the abscissa of the matched points. Schematic diagram of spherical sample feature point mapping model shows the mapping model drawing of mapping intersection points obtained from the ray derived from the matching feature points in two spherical sample drawings to 3D space.

The image coordinate system of the library is in pixels, the origin is in the upper left corner of the image, the X axis is horizontal to the right, and the Y axis is vertical to the down.

In order to establish a three-dimensional space coordinate system, in the image coordinate system of the top view, at the origin of the coordinate system, the ray with the direction perpendicular to the top view and the upward direction is the Z axis, and the space coordinate system is established. The results are shown in Figure 1.

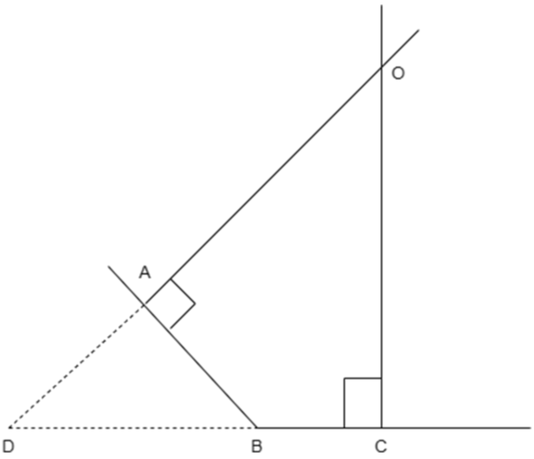

Figure 1: Mapping model vertical sections

In the vertical section of the mapping model, AB and BC are the side view and top view of the sample respectively, B is the position where the edges of the two images coincide, and O is the intersection of the matched feature points a and C mapped to the three-dimensional space along the direction perpendicular to the projection line of the image. In order to calculate the height OC from the intersection O to the top view, extend the intersection of OA and BC at point D, and the included angle of AB and BC is θ. Using OpenCV library to read two images can obtain the coordinates of a and C and the length of the side view in the y-axis direction, which is recorded as l. The Y-axis of A and C are y_A , y_C respectively,The lengths of AB and BC are $l - y_A$, y_C respectively,The length of OC can be calculated from right triangle OCD and right triangle ABD. That is, the Z coordinate of point O corresponding to A and C in three-dimensional space, and the formula is as follows:

$$y_Z = \left({(l - y_A)}/{\cos\theta} + y_C \right) / {\tan\theta}$$

According to the ruler of the image, the coordinate units of O points are converted from pixels to the actual length, and the difference of Z coordinates between feature points is the depth information of three-dimensional space. Finally, an imaging model is constructed to project the matched feature points from two images into three-dimensional space to obtain the three-dimensional morphology of the sample.

3. Experimentation

The specific experimental steps and key technologies are as follows:

Figure 2 (a) shows a diamond sample image. Each diamond sample has an obvious bright edge. According to the principle of secondary electronic imaging, the bright edge should be the side wall of the diamond sample. The bright edge is extracted by image segmentation. According to the bright edge, the inner and outer contours of the diamond sample can be obtained by further processing, and the relative depth of the inner and outer contours can be calculated to draw the three-dimensional model of the diamond sample.

In this paper, autocanny is used to extract the edge features of diamond samples. From the edge extraction results Figure 2 (b), there are white bright spots outside the edge of the diamond sample. This is because the gray value of the white bright spot is close to the gray value of the diamond edge, which is recognized by autocarny as part of the edge, which brings difficulties to its edge extraction. Other edge extraction algorithms can be used to improve the edge extraction effect, such as watershed algorithm. The height of the side wall of the sample is the relative height of the inner and outer contours. Use the ruler of the standard sample after angle correction to measure the height of the side wall. The diamond sample image is drawn using Python's Matplotlib library, and the effect is shown in Figure 3.

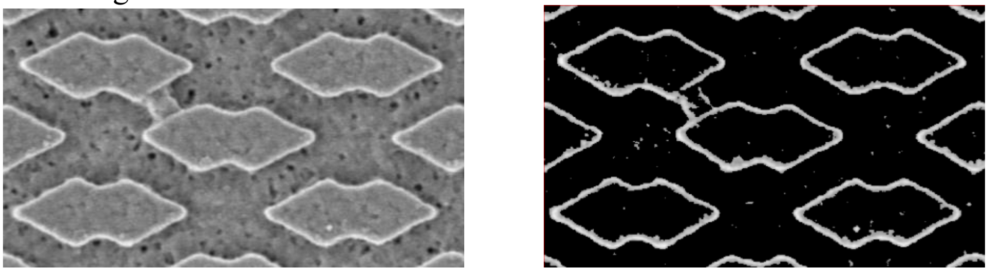

Figure 2: a. Diamond sample image b. diamond sample edge detection diagram

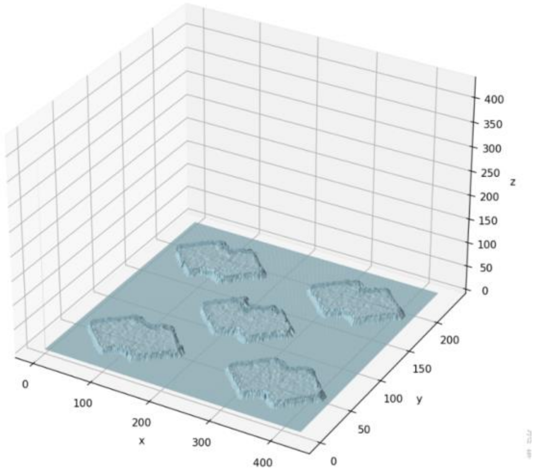

Figure 3: 3D model of diamond sample

4. Conclusions

In this chapter, we successfully implemented the FIB-SEM double beam system rhombic table sample image three-dimensional reconstruction experiment based on the principles described in this chapter, which further confirmed the effectiveness of the proposed method. In order to make the acquired image features clear, we combined Gaussian filter, median filter and bilateral filter to optimize the image denoising effect. For the sample with regular shape, we extract the vector information of the centroid or edge of the sample contour after segmentation of the target area of the two images, which reduces the number of image feature points and the difficulty of fe time feedback for ion beam processing and further accurately control the ion beam processing efficiency. This work only realizes the measurement of the depth information of a point at the center of mass or edge of the target area, and fails to specify the measurement of the depth information of a feature point for the staff in the target area.

Lack of a large number of experimental data sets. In order to further improve the quality of the three-dimensional reconstruction algorithm of the micro morphology of the sample, artificial intelligence can be used to operate a large number of data sets to achieve a more intelligent three-dimensional reconstruction algorithm. There is no public database on the micro morphology image of the sample on the Internet to provide sufficient data sets for experiments.

3-D reconstruction of samples with complex surface morphology has not yet been realized. The number of feature points extracted in the target area of the sample is small, which is suitable for 3D reconstruction of the sample with relatively simple shape. For the samples with complex surface morphology, it is necessary to appropriately increase the number of feature points extracted, optimize the accuracy of the feature matching algorithm, and further improve the reliability and adaptability of the algorithm.

Secondly, in the double beam system with parallel projection imaging model, we propose a feature point mapping model to calculate the depth information of the feature points. It is hoped that this work can provide an effective reference for the development of real-time feedback system based on FIB-SEM dual beam system images.

There are still many problems and challenges in this work that need further research and resolution:

The measurement accuracy of sample spatial depth information needs to be improved. When the FIB-SEM dual beam system takes samples, due to the influence of factors such as the change of sample surface heat, most of the images obtained are distorted. Due to the short working time, it fails to model and correct the distortion, which will have a certain impact on the measurement results. At the same time, due to the limitations of experimental conditions, the height of the checkerboard was measured directly on the side view of the checkerboard, and the reference value of the height of the checkerboard could not be obtained by a more superior method.

The measurement of the depth information of the specified feature points in the target area of the sample image is not realized. In the process of sample etching by FIB-SEM dual beam system, it is necessary to measure the depth information of a concerned feature point in the target area.

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