Applications of Image Processing Technology in Electron Probe Microanalyzer

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The X-ray image in EPMA does not always show an ideal appearance. In this report, three kinds of image processing to improve the image quality are introduced together with some examples.

1. Introduction

Previously, X-ray images in electron probe microanalysis were recorded on a photographic film as a group of white dots, each of which has the X-ray intensity over a certain X-ray count. Along with the progress of computer technology, the X-ray count has now been accumulated and displayed on a CRT as an image. Accordingly, the researcher can use various types of image processing for the image display.

The most popular processing of an X-ray image is to modify the signal level and to display the data in pseudo-colors. When the signal level is modified, the image is significantly improved as a result of a visibility increase in the contrast intensification. In addition, by the color-coding of the image with pseudo-colors, the regions with the same level of X-ray counts are found at a glance. Moreover, an electron probe microanalyzer (EPMA) is furnished with a variety of image-processing functions such as the particle measurement function for measuring the shape of a binary image, composite mapping function for combining two or more maps color-coded in red, blue and green gradations, smoothing, bird’s-eye view display function, and contour map display function, for user’s convenience.

Raw data is most important because it carries original information. However, when the researcher tries to explain a data to another person, the use of image-processed data emphasizing significant information or weakening insignificant information is quite helpful.

This paper introduces the following image-processing methods, which are effective for displaying X-ray images, secondary-electron images (SEI) and backscattered-electron images (BEI), together with actual examples of processed images.

- Emphasizing significant information by superimposing a BEI on an X-ray image (Section 2: Synthesis of images)
- Splining thinly dotted data due to insufficient number of analysis points (Section 3: Data interpolation)
- Sharpening a blurred image (Section 4: Sharpening SEI and BEI, and Section 5: Reduction of X-ray image blur due to electron scattering in the sample)

By the use of these types of image processing, measured data becomes to show more natural appearance and the image quality becomes higher. As a result, we obtained various merits, such as the acquisition of data in a shorter time and the enhancement the quality of an image obtained using a tungsten filament to a level comparable to that obtained using a LaB₆ tip. We will report these effects in this paper.

2. Synthesis of Images

A BEI provides a contrast corresponding to the average atomic number, and therefore it is similar to the X-ray image reflecting the composition distribution (Fig. 1).

The BEI has advantages over an X-ray image as it has a higher spatial resolution and shows clearer outlines. However it is not easy to identify elements distributed in an observed area only from the contrast of the composition image. On the other hand, the X-ray image provides information on the distribution of specific elements in spite of its low spatial resolution.

The X-ray image and the BEI are different in their advantages. Therefore, if we superimpose these two kinds of images arithmetically, the synthesized image may show their respective advantages.

3. Data Interpolation

Another example of image processing in EPMA is data interpolation. As a typical example of it, bi-cubic interpolation is introduced. The outlines of X-ray image can be made conspicuous by binarizing or multilevel-coding of the BEI. A mask is made to display only a part possessing desired information, and then this mask is applied to the X-ray image (Fig. 2).

An image intermediate between the X-ray image and the BEI is synthesized by multiplying the X-ray image and the BEI or dividing the former by the latter (arithmetic of images).

The bright parts of the BEI are in a high signal level and the dark parts are in a low signal level. Numerically, the brighter part is larger in the count number than the darker part. Using this property, if the X-ray image is multiplied by the BEI, the brighter part of BEI becomes higher in the signal level and darker part becomes lower in the signal level. This emphasizes the bright parts. On the other hand, when the X-ray image is divided by the BEI, the dark part in the composition image is emphasized as shown in Fig. 3.

Effects

By applying a mask based on the BEI to an X-ray image blur by scattered electrons, it is possible to make the outlines of X-ray image conspicuous. This contributes to the clarification of the correspondence between the X-ray image and the BEI. On the other hand, since this method uses a simple mask, the X-ray count at the masked part becomes zero, and so the outline does not change smoothly, showing sometimes an unnatural appearance.

By comparing the X-ray image with the BEI arithmetically, we have succeeded in changing the outlines to show their natural appearance. Though this arithmetic has a disadvantage that only the brightest or the darkest part of the BEI is emphasized, this technique is effective to make the image outlines conspicuous.

3. Data Interpolation

(bi-cubic method)

Often, because of the limitation of measurement time, the researcher cannot obtain a suffi-
cient number of analysis points for the map analysis. This lowers the resolution and degrades the appearance of the map. However, as long as the total measurement time is limited, even if the number of analysis points is increased, the analysis time per point is reduced and so the S/N ratio decreases, producing difficulty in seeing the data.

One of the causes of the difficulties in seeing the data is that each data point on the map is displayed as a square pixel, this is because, when the number of analysis points is small, the shape of the squares becomes conspicuous. As the distribution of constituent elements cannot be a group of squares, we have developed a method of displaying a clear map by the interpolation of analysis points (Fig. 4).

**Purpose**
To convert an image data composed of square pixels, which produces an unsightly distribution due to a small number of analysis points, into a clear image by applying the bi-cubic method.

**Principles**
In the image processing, there is a technique called the bi-cubic method, and it is used to improve the resolution of image (number of analysis points in analysis).

The bi-cubic method is a method of interpolating between data points with curved surfaces expressed piecewise by cubic polynomials. If this method is linked to a graph, the display of one analysis point with a square makes a bar graph. The bi-cubic method converts it into a graph consisting of a curve passing through each data point (Fig. 5).

The bi-cubic method can be expressed as follows: Let \( f(x,y) \) be the source image data at the coordinates \( (x, y) \), \( F(x,y) \) the image data after the bi-cubic interpolation, and \( H_j(x) \) the one-dimensional cubic interpolation along the X-axis.

\[
F(x, y) = H_{j-1}(x) C_3(y-j) + H_j(x) C_2(y-j) + H_{j+1}(x) C_1(y-j) + H_{j+2}(x) C_0(y-j),
\]

for \( j \leq y < j+1 \)

\[
H_j(x) = f(i-1, j) C_3(x-i) + f(i, j) C_2(x-i) + f(i+1, j) C_1(x-i) + f(i+2, j) C_0(x-i),
\]

for \( i \leq x < i+1 \)

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Fig. 1. X-ray image (left) and BEI (right) of Si on an electrode-plate surface. The dark part of the X-ray image corresponds well to the bright part of the composition image.

Fig. 2. Image with clear outlines (right) is synthesized by applying a mask (center) made from the BEI to the X-ray image (left).

Fig. 3. Image with clear outlines (right) is synthesized by dividing the X-ray image (left) by the BEI (center).

Fig. 4. Interpolation of analysis points.

Fig. 5. Bi-cubic interpolation graph.
\[ C_0(t) = -at^3 + at^2 \]
\[ C_1(t) = -(a+2)t^3 + (2a+3)t^2 - at \]
\[ C_2(t) = (a+2)t^3 - (a+3)t^2 + 1 \]
\[ C_3(t) = at^3 - 2at^2 + at \]

\( a: \) Spline constant within the range of \(-1 < a < 0\)

**Effects**

The bi-cubic method allows the data with a small number of analysis points to be displayed clearly. As a result, its application is expected to bring the following two effects to the analysis:

**Reduction of analysis time**

The bi-cubic method makes it possible to display the data with a small number of analysis points fairly clearly, thus enabling the researcher to shorten the analysis time. For example, if an analysis of 500×500 points can be replaced by an analysis of 125×125 points, the total measuring time is reduced to 1/16.

**Display of enlarged image**

If a part of the map is enlarged, an unsightly mosaic-like image appears, reflecting the shape of square pixels. The bi-cubic method provides a smooth enlarged image (Fig. 6).

4. Sharpness of SEI and BEI (unsharp mask)

The image processing technology includes some methods for processing a defocused image to an apparently focused image. The unsharp mask, the 2D-FFT, and the Wiener method are its examples. Among these techniques, the unsharp mask is incorporated in PhotoShop℠, which is widely used image-processing software, and is useful for processing the SEI and BEI (Fig. 7 and Fig. 8).

**Purpose**

To sharply display the blurred SEI or BEI as an apparently focused image by the use of the unsharp mask.

**Principles**

The unsharp mask aims to sharpen the image. This may sound contradictory, but the name of the unsharp mask comes from its processing method.

When an original image is intentionally blurred and reversed, and then added to the original image, the image of edge is obtained (Fig. 9). Adding this image again to the original image results in an image with further emphasized edges (Fig. 10). In such a way, an image blurred is used for this masking technique. Therefore, it is named “unsharp mask”.

**Effects**

Unsharp masking displays the blurred image more clearly.

Although there are several other techniques for sharpening images, unsharp masking produces fewer artifacts (virtual images resulting from image processing), and so can be used with fairly high reliability. Also, the operation is easy. However, unsharp masking amplifies noise in the image, and significantly reduces the S/N ratio. Because of this, this techniques...
is desirable to be applied to the case where raw data has a high S/N ratio.

5. Reduction of X-ray Image Blur due to Electron Scattering in the Sample (Filter to reduce the X-ray image blur)

The electron beam is scattered in a sample and spread in a region of approximately several micrometers in diameter and generates the characteristic X-rays (Fig. 11). For this reason, the X-ray is inevitably blurred, and the blur becomes remarkable in a highly magnified image.

If sharpening described in Section 4 is applied to image data such as a blurred X-ray image, various merits may be expected. Unlike the usual photographs, however, the X-ray image contains a lot of noises. Thus, if sharpening is made by the use of the ordinary image-processing software, the noise may be amplified to cause an image deterioration rather than improvement.

In consequence, when sharpening is applied to the X-ray image, its application must be carried in such a way that the process does not suppress the image deterioration. Accordingly, we have designed an image-processing filter capable of sharpening the X-ray image taking the magnitude of electron beam scattering into consideration. We have named this filter “Filter to reduce X-ray image blur (FRX)”, since it is has been designed to the obtain an image close to the image that might be obtained if the electron beam were not scattered in the sample.

By the use of FRX the X-ray image blur was noticeably reduced.

**Purpose**

To reduce the X-ray image blur caused by the scattering of electrons, using FRX.

**Principles**

**Region of X-ray generation**

The amount of X-ray image blur is determined by the size of the region of X-ray generation. So far, this size has been simply described as the region of scattering of the electron beam. However, to be precise, the sum of the diameter of the electron beam and the size of the electron beam scattering in the sample is the region of X-ray generation.

As a simple method of determining the expansion of electron beam in the sample, the use of a nomogram is recommended (Fig. 12).

Since the diameter of an electron beam varies depending on the electron gun used, the use of actually measured data is necessary. For the JEOL EPMA, the data shown in Fig. 13 is available.

The expansion of the electron beam obtained from the analysis conditions (accelerating voltage, probe current, and sample) can be used as the parameters of the FRX.

**FRX**

Generally, the value of measured counts in the X-ray image ranges from several to several hundreds of counts. It inevitably includes noise based on the statistical errors. The sharpening of an X-ray image applies the sharpening...
process to the noisy data with a low S/N ratio. For this reason, a simple application of the ordinary image processing to the X-ray image deteriorates the image quality significantly.

FRX is designed to minimize the deterioration of an image by taking into consideration the expansion of electron beam calculated from the analysis conditions as a parameter. In its application, a recursive calculation is carried out, and sharpening is made to remove only the blurring component predictable from the expansion of electron beams.

**Effects**

Supposing that the X-rays image blur follows a Gaussian distribution, we tried to apply FRX to image sharpening. We found that such a simple model as a Gaussian distribution brought a great effect (Fig. 14).

When the line profiles before and after the processing are compared, the peaks after the processing are higher than those before the processing, while the valleys are deeper (Fig. 15).

We performed a simulation (Fig. 16) of line profiles of an image blurred with a Gaussian distribution, and reconstructed an image with FRX. Then, we could succeed in reducing the width of blur in the X-ray image about half.

Thus, if an appropriate model is made for the X-ray image blur caused by the scattering of electron beam, we can say that FRX may reduce the amount of X-ray blur apparently to about half.

**Verification of effects of FRX**

The use of FRX can visually suppress the X-ray image blur. To verify the reduction of X-ray image blur in actual measuring conditions, we took the X-ray images under three different conditions of the accelerating voltage, probe current and electron gun, and applied the image processing to them in order to investigate the effect of FRX.

**Experimental results**

- **Change in the accelerating voltage**

  When the accelerating voltage is changed, the electron scattering area in the sample also changes. Taking this into consideration, we investigated the removal of blur due to the scattering of electrons in the sample (Fig. 17).

  The measured data shows that the image blurs are more remarkable with an increase in the accelerating voltage. Processing the image using FRX eliminates the blur and displays all the data more clearly and easily to look. The processed data proves that the image quality is equivalent to the data taken at an accelerating voltage lowered by about 3 to 5kV.

- **Change in the probe current**

  When the probe current is changed, the diameter of electron beam also changes. Taking this into consideration, we investigated the reduction of the influence of a large-diameter beam on the blur of an image outline (Fig. 18).

  It was found that as the probe current increases, particles appeared thicker. The possible cause is that the distribution of the probe current takes a shape closer to the cylindrical form rather than a Gaussian distribution with a broad skirt.

  The data subjected to FRX had a clear

![](Image)
Image synthesis

An X-ray image is masked using a BEI. An X-ray image is synthesized with a BEI through multiplication or division. It is easy to establish and understand the correspondence between the X-ray image and BEI.

Bi-cubic interpolation

Data points are interpolated between gaps to make the image conspicuous. Dots of the X-ray image with fewer data points or enlarged image can be made less conspicuous. Since a conspicuous image can be obtained for data with fewer analysis points, the analysis time can be shortened.

Unsharp mask

A blurred image is sharpened. An SEI or BEI can appear more focused when displayed.

FRX

Image blur due to the scattering of electrons or the expansion of the electron beam is removed. The blur of an X-ray image is removed, ensuring ease of operation. Applying image processing to data obtained with a W filament makes the data close to one obtained with a LaB₆ chip.

Table 1.

<table>
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<th>Process</th>
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Comparison between the use of LaB₆ tip and the use of tungsten filament

The use of a LaB₆ tip in place of a tungsten (W) filament narrows the beam. We took the data with a W filament (W data) and with a LaB₆ tip (LaB₆ data), and these data were processed with FRX (Fig.18.). In the filtered W data, the blur decreased, and the image becomes clear and easy to see, approaching the LaB₆ data. Of course, the best data is the filtered LaB₆ data (Fig. 19).

Prospects for FRX

At the present time, FRX calculates the amount of image blur and determines the parameters by inputting physical conditions such as the accelerating voltage, current and information on the sample. When the FRX is built into an actual EPMA, the instrument can read the accelerating voltage and current from the measuring conditions. Accordingly, the only thing that the user should do is to input the information on the sample.

6. Summary

We conducted experiments on four kinds of image processing. The respective results are summarized in Table.1.