

Spatial Domain based Image Enhancement Techniques for Scanned Electron Microscope (SEM) images

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Abstract

The growing need for efficiently processing and analyzing the information contained in digital images is a continuous challenge in order to apply image processing. Digital images are captured from different imaging media elements like cameras, scanned electron microscopes etc. While going through the imaging process, Images get distorted in various forms resulting in extreme dark or light areas. All these things lead to the loss of information. The goal in each case is to extract useful information. In that case, Image processing extracts useful information by applying various image enhancement and algorithms. In this paper, we have discussed a practical implementation of various enhancement methods for Scanned Electron Microscope (SEM) images and their experimental results. SEM images lead to very dark and light areas in an image. While imaging the information in the front scene is not only the source of information but some scenes on the dark side can also have the useful information. Before processing any further we require to enhance such images and one of the enhancement techniques i.e. Histogram Statistics comes out to be an ideal approach.

KEYWORDS: *Scanned Electron Microscope, Global Image Enhancement, Histogram Equalization, Local Image Enhancement, and Histogram Statistics.*

1. Introduction

Image processing can be defined as a process that transforms a degraded image to another image of better quality in order to facilitate its posterior interpretation. Image processing techniques can be then applied in order to facilitate the interpretation of images by further using computer vision algorithms. Therefore, in this context, image processing can be considered to be a preprocessing stage for computer vision [1]. The process involved in making an image more interpretable for particular application is image enhancement.

Image enhancement refers to the process of performing a set of operations on an image so that to improve its visual appeal. This involves an increase of the contrast range or an improvement of the perceptibility of the various details present in an image. There exist a variety of spatial and frequency domain methods that achieve the same. One of them is the modification of the image histogram to improve the dynamic pixel range - called as "Histogram Equalization". It is believed that the information that a certain image tends to convey, is dependent upon the probability of occurrence of pixels of the different gray levels. By re-distributing this probability in a uniform manner, the perceptibility of the image details improves [2]. The global histogram

equalization (GHE) method consists of a transformation of the histogram of the entire image. The method is simple and efficient in terms of implementation. Though the global method is suitable for overall enhancement, it is often necessary to enhance details constrained to a certain region of the image. To achieve better attention to local detail, the histogram can be calculated over a window centered at each pixel of the image. The window can then be moved from pixel to pixel. At each pixel, the histogram of all pixels in the window is computed, and the transformation function is applied to the pixel centered in that window or neighborhood [3]. This technique is known as local histogram equalization (LHE). However it is observed that both these methods often produce results that leave a lot to be desired. Instead of using the image histogram directly for enhancement, we can use some statistical parameters obtainable directly from the histogram. The method named is Histogram Statistics. We have given experimental results of histogram statistics method that takes into account the regional statistical information, rather than global image enhancement. This way we can maintain the brightness relationship between regions. This method succeeds in bringing out much detail in the regions of low and high brightness in the same image. In our research we have discussed SEM images issue as sample. The scanning electron microscope (SEM) is a type of electron microscope capable of producing high resolution images of a sample surface. Due to the manner in which the image is created, SEM images have a characteristic three-dimensional appearance and are useful for judging the surface structure of the sample [4].

In the next section, the spatial domain methods for image enhancement have been defined. In Section III various comparative image enhancement methods are being discussed for SEM images and respective histograms have been shown. In section IV experimental results have been discussed and finally conclusion has been given.

2. Spatial Domain Methods

The principal objective of image enhancement is to modify attributes of an image to make it more suitable for a given

task and a specific observer [5]. During this process, one or more attributes of the image are modified. The choice of attributes and the way they are modified are specific to a given task. Spatial domain methods directly manipulate the image data array, either by point processing or area processing. Basically it deals with spatial frequency, i.e. difference between the highest and the lowest values of a contiguous set of pixels. The approaches regarding image enhancement using spatial domain methods can be divided into two categories – global image enhancement and local image enhancement. Global methods are mainly histogram modifications that aim to exploit the full dynamic range of a rendering device by modifying the histogram of an image. The attractiveness is their simplicity and minor computational effort. However it is often necessary to enhance detail over a smaller area. So, the local image enhancement method plays a major role in those applications.

3. Enhancement Techniques

The four main techniques have been discussed here under global and local image enhancement techniques. The effectiveness of various methods has emerged out from the respective output image. The results obtained are sufficient enough to prove the effectiveness and usefulness of all these techniques in image enhancement field. We have already discussed that global enhancement method apply transformation function on all the pixels while local enhancement methods perform transformation on a small area of the image. So the application of every method comes as per the requirement of the image. It is very clear that sometime global method leaves the enhancement of small areas while local enhancement method takes care about it.

The four methods and their respective enhanced images have been given below. Here we have taken special case of SEM images of tungsten filament wrapped around a support. Figure1 shows the filament in the center of the image and its support is quite clear and easy to study. There is another filament structure on the right side of the image, but it is much darker and its size and other features are not as easily discernable. SEM images

often have both very bright areas and very dark areas, and both may contain important details. The darkness or brightness ratio is given by the histogram of concerned image. Figure2 shows the histogram of original SEM image of tungsten filament. The problem is to enhance dark areas while leaving the light area as unchanged as possible since it does not require enhancement [6].

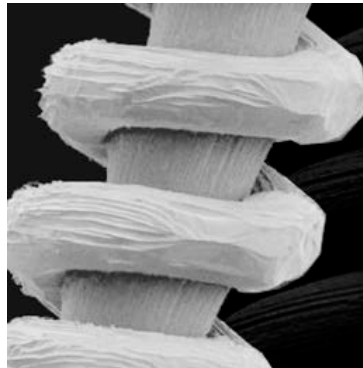


Fig. 1 SEM image of Tungsten Filament

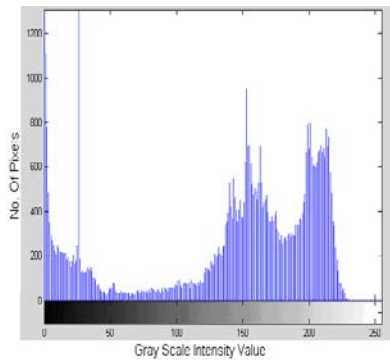


Fig. 2 Histogram for original image

3.1 Contrast Stretching

This type of transformation is used to enhance low contrast images. In a low contrast image specific details are difficult to determine due to the fact that most pixels are at the same intensity value. Contrast stretching resolves this problem by boosting the lighter pixels to a higher intensity level, and doing exactly the opposite to the lower intensity pixels. Contrast stretching is applied to an image to stretch a histogram to fill the full dynamic range of the image. This is a useful technique to enhance images that have low contrast [7].

In general the contrast stretching equation is:

$$new\ pixel = \frac{old\ pixel - low}{high - low} * 255 \quad (3.1)$$

Here lowest and highest value pixels have been used. The value on the left hand side gives the gray scale value of the output image. Figure3 shows the enhanced SEM image of tungsten filament and Figure4 gives the concerned histogram after applying contrast stretching on the given image.

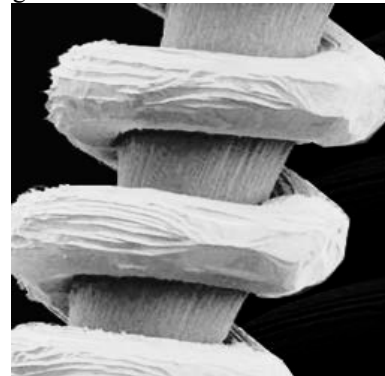


Fig. 3 Contrast Stretched SEM image of Tungsten Filament

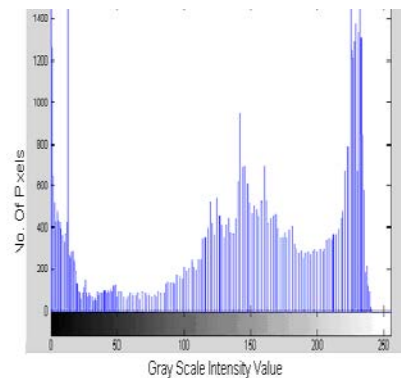


Fig. 4 Histogram for Contrast stretched SEM image

3.2 Histogram Equalization

Histogram equalization is the technique by which the dynamic range of the histogram of an image is increased. It assigns the intensity values of pixels in the input image such that the output image contains a uniform distribution of intensities. It improves contrast and the goal of histogram equalization is to obtain a uniform histogram [8]. This technique can be used on a whole image or just on a part of an image.

$$O_i \equiv \left[\sum_{j=0}^i N_j \right] \times \frac{Max.IntensityLevel}{No.ofPixels} \quad (3.2)$$

Figure5 gives the results of enhanced image using histogram equalization method. Similarly Figure6 shows the respective histogram of the enhanced image.

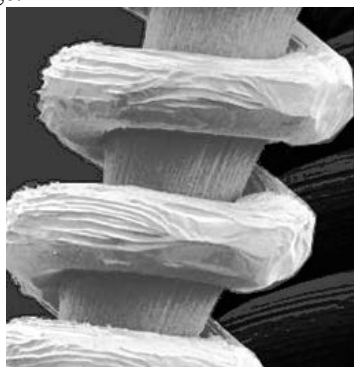


Fig. 5 Histogram Equalized SEM image of Tungsten Filament

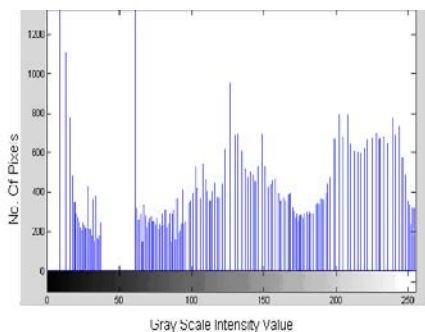


Fig. 6 Histogram for Histogram Equalized Image

It is well known that the appearances of the resulting image from the equalization process are not visually pleasing for most of the cases [9]. Various algorithms have been proposed to improve results of histogram equalization. One factor has been discussed using decimation method to control the sudden change in image brightness by taking decimated image with less resolution than the original resolution for reduced computation cost [10].

3.3 Local Enhancement Method

The neighborhood operation method works on the brightness and contrast parameters of an image i.e. mean and variance. The local transformation based

on these concepts maps the intensity of an input image $f(x, y)$ into a new image $g(x, y)$ by performing the following transformation at each pixel location (x, y) :

$$[g(x, y) = A(x, y) \cdot [f(x, y) - m(x, y)] + m(x, y)]$$

Where

$$A(x, y) = k \frac{M}{\sigma(x, y) + b} \quad 0 < k < 1 \quad (3.3)$$

In this case, we have come out with the best combination of parametric values in the range:

$$0.1 < k < 0.5 \text{ and } 1.5 < b < 7.5$$

And this results in the reduced noise level and enhanced image quality shown in Figure7 for the SEM image. The concerned histogram in Figure8 provides the clear picture of changes in the original image after applying this technique.

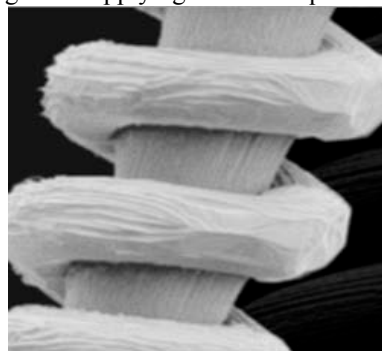


Fig. 7 Local Enhancement method result for SEM image

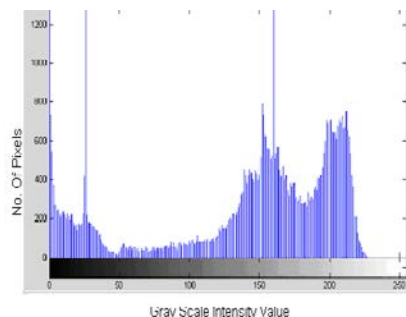


Fig. 8 Histogram for Local Enhancement method result for SEM image

An enhancement kernel generated based on this approach using genetic algorithm take into account some other factors like: locality and adaptability of the method to the given image, as opposed to global enhancement methods, automation of the image enhancement process and robustness that produces good

enhancement results on a large category of images [11].

3.4 Histogram Statistics

Although the global approach is suitable for overall enhancement, there are cases where it is necessary to enhance details over small areas in an image. The number of pixels in these areas may have negligible influence on the computation of a global transformation, whose shape does not necessarily guarantee the desired local enhancement. In this particular case, the problem is to enhance dark areas while leaving the light area as unchanged as possible since it does not require enhancement. We can use the concepts presented in this section to formulate an enhancement method that can tell the difference between dark and light and, at the same time, is capable of enhancing only the dark areas. The formula for histogram statistics is:

$$g(x, y) = \begin{cases} E \cdot f(x, y) & \text{if } m_{s, xy} \leq k_0 M_G \text{ and } K_1 D_{g, xy} \leq \sigma_{s, xy} \leq K_2 D_g \\ f(x, y) & \text{otherwise} \end{cases} \quad (3.4)$$

Where E , k_0 , k_1 , and k_2 are specified parameters; M_G is the global mean of the input image; and D_G is its global standard deviation [6].

We will consider the pixel at a point (x, y) as a candidate for processing to compare local average gray level if $m_{s, xy} \leq k_0 M_G$, where k_0 is a

positive constant with value less than 1.0. Similarly, we will consider the pixel at a point (x, y) as a candidate for enhancement, as far as contrast is concerned, if $\sigma_{s, xy} \leq K_2 D_g$, where D_G is

the global standard deviation and k_2 is a positive constant. The value of this constant will be greater than 1.0 if we are interested in enhancing light areas and less than 1.0 for dark areas. Finally, to avoid enhancement of constant gray level area, we also set a lower limit on the local standard deviation by requiring that

$$K_1 D_{g, xy} \leq \sigma_{s, xy} \text{ with } k < k_2. \text{ Here again the}$$

major factor is the combination of parameters. Normally, making a successful selection of parameters requires a bit of experimentation to gain familiarity with a given image or class of images. During our experimentation we have come out with suitable parametric values ($E=5.5$, $k_0=0.95$, $k_1=0.040$, $k_2=0.95$) that have resulted in better quality image. Finally, the choice of size for the local area should be as small as possible in order to preserve detail and keep the computational burden as low as possible. We chose a small (3*3) local region and the results of this application are shown in Figure 9. The enhanced contrast measure is shown in the form of histogram in Figure 10.

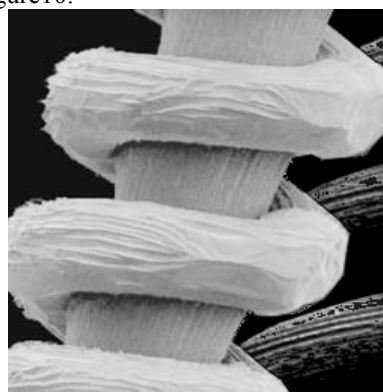


Fig. 9 Histogram Statistics SEM image of Tungsten Filament

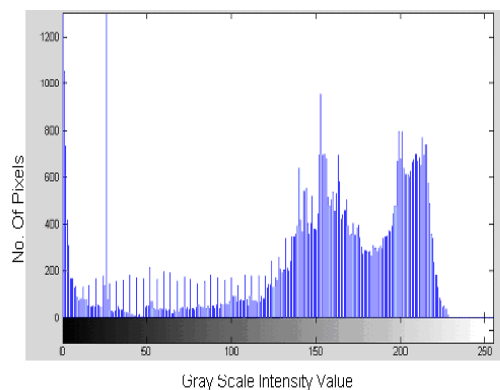


Fig. 10 Histogram of Histogram Statistics transformed image

4. Performance Evaluation - Fidelity Criteria

As a part of performance evaluation we apply the fidelity criterion. The fidelity criterion is of two types – Objective and Subjective. The Objective fidelity criterion is better given by root mean

square (RMS) error between an input and output image.

The total squared error averaged over the $M*N$ area is given by:

$$e_{rms} = \left[\frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} [\hat{f}(x, y) - f(x, y)]^2 \right]^{\frac{1}{2}} \quad (4.1)$$

While the Signal to noise ratio (SNR) is represented by:

$$SNR_{ms} = \frac{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} \hat{f}(x, y)^2}{\sum_{x=0}^{M-1} \sum_{y=0}^{N-1} [\hat{f}(x, y) - f(x, y)]^2} \quad (4.2)$$

By applying this formula, we obtained the root mean square error in the image after enhancement [12].

The main point discussed during this research work was to check whether the obtained image is having information or noise. So, we have found out root mean square error for output images obtained through various methods. The respective values are shown in Table1.

In all the above discussed techniques contrast stretching, histogram equalization, Traditional local enhancement method

Table 1: Comparison of root mean square (rms) error in various enhancement techniques

Sr. No	Enhancement Method	Root Mean Square (rms) error (db)
1.	Contrast Stretching	1
2.	Histogram Equalization	1.732
3.	Local Enhancement Method	1
4.	Histogram Statistics	2.236

and histogram statistics method, root mean square error comes out to be a small definite amount. The enhanced image obtained with the Histogram Statistics method is shown in Figure9. In comparing this image with the original in Figure1, we note the detail that has been brought out on the right side of the enhanced image. It is worthwhile to point out that the un-enhanced portions of the image (the light areas) were left intact for most of the parts as compared to the enhanced ones. We do note the appearance of some small bright dots in the shadow areas. These are undesirable artifacts created by the enhancement technique. The key point here, however, is that the image has been

enhanced in a most satisfactory way as far as bringing out the desired detail is concerned.

As we know that image enhancement deals in improving the visual quality. In digital imaging, we apply image enhancement to bring the maximum information out of an image. In this process, the presence of minor artifacts is avoidable in front of the amount of information retrieved.

5. Conclusion

In digital imaging, the large volume of data is a major issue. Statistical parameters provide information about an image in just a few numbers. Statistics are useful in characterizing image qualities such as rightness and contrast and can be used as the basic of digital image processing algorithms to visually improve the displayed image. The local enhancement methods discussed in this paper using statistical parameters enhance image details over smaller areas. Here local mean and variance are used as the basis for making changes that depend on image characteristics in a predefined region about each pixel in the image. It helps in enhancing details over small areas in an image. The image has been enhanced through this method in a most satisfactory way as far as bringing out the desired detail is concerned.

The major point here is the combination of statistical parametric values that have been adjusted to get fine details. Finally, root mean square error has been calculated to prove the efficiency of the methods being discussed.

6. Future Research

There is ample scope for future work in this research work to further improve the performance of the Local Image Enhancement Method.

- Automation of this method will help getting the combination of satisfactory parameters faster.
- Adaptive approach to neighborhood calculation will increase the efficiency of image enhancement process.

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