The improvement in the AFM image after applying a Lucy- Richardon deconvolution algorithm using a new technique for estimating the AFM tip shape from the square sample

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Abstract: - The images measured using AFM are distorted because of the influence of the tip geometry. This influence let the images do not accurately represent the real shape of the measured particles or cells. Therefore, it is necessary to reconstruct the AFM tip shape. This paper proposed a new approach (impulse response technique) to reconstruct the tip shape from a square sample. Once the tip shape is known, erosion or deconvolution process has been carried out between the estimated tip shape and the distorted image. The experimental results and the computer simulations validate the performance of the proposed approach in which it illustrates that the AFM image accuracy has been greatly improved. Also, we have compared the proposed algorithm with the blind tip estimation algorithm using computer simulations and real AFM images, and our algorithm has given better results. It is worth mentioning here that the blind tip estimation is the industrial and research standard algorithm for the restoration of AFM images.

Key-Words: - AFM, image restoration, tip estimation, Square sample, deconvolution.

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1 Introduction

The Atomic Force Microscope (AFM) is very important instrument for use in nanotechnology and biology since it can be used to measure a variety of objects such as nano-particles and cells**.** An AFM image is represented as the distorted sample due to the convolution effect, which produced by the finite size of the AFM tip. The image restoration problem has been studied by many researchers in terms of determining the cantilever tip shape for the AFM and then using it to restore the AFM images using a deconvolution algorithm. This formulation of the image restoration problem ignores the other parameters that affect the image acquisition process in the AFM such as the scanning speed, the response of the x, y and z piezo materials, and the bandwidth of the feedback loop system. As is well-known in digital image processing theory, the impulse response of a linear time invariant system “fully characterises” this system. This implies that our proposed algorithm aim of finding the impulse response of the AFM should take all these parameters inherently into consideration and should produce better and more faithful image restoration algorithm than those that already exist in the literature.

The first essential step in front-end digital image processing systems is that of capturing digital images. Many distortions occur during the image acquisition process and these distortions should be eliminated or alleviated using image restoration algorithms. Examples of systems where these distortions occur are in astronomical imaging using telescopes, confocal microscopy, computed tomography (CT) scanners and many other applications. These are similar research problems to the image restoration of AFM images [7-9].

In this paper we proposed a new method (impulse response technique), which is suitable for estimating the AFM tip from the AFM image of the square sample. Computer simulation and experimental results have been used for estimating the AFM tip shape. Then, in computer simulation an erosion operation has been used between the estimated AFM tip and the AFM image for obtaining more accurate an AFM image. In experimental results, a Lucy- Richardson deconvolution algorithm [1-2] has been used between the estimated AFM tip and the AFM image for improving the distorted AFM image.

2 AFM tip estimation

This paper presents a new technique for estimating the AFM tip shape from the square sample using an impulse response method. The proposed approach uses a tip characterizer (square sample) [3-5]. The AFM image of the square sample is considered as a convolution effect between the shape of the sample and the tip. Thus, the AFM tip can be reconstructed by eliminating the effects of the tip characterizer topography from the AFM image of the square sample. We have used a tip characterizer consists of a standard square sample and the impulse response approach for eliminating the effects of the tip characterizer geometry from the AFM image. In this paper we will show that the proposed approach of using an impulse response method is effective for estimating 3-D tip geometry, which then can be used in the restoration of more accurate AFM images.

2.1 Computer Simulation

In computer simulation, we constructed the computer models for AFM tip and the sample in which the tip has a pyramidal shape and the sample has square shape as depicted in Fig 1(a) and 1(b), respectively. The image of the square sample is represented by a dilation operation between the square sample and a pyramidal tip. It is clear from Fig. 1(c) that after applying a dilation operation between the sample and tip, the AFM image is distorted by AFM tip and does not accurately represent the sample. In order to improve AFM image, it is necessary to obtain information about the AFM tip shape. Once the tip shape is known, the opposite operation of the dilation which is the erosion can be applied between the distorted AFM image and the reconstructed tip to remove this distortion.

Then, we threshold the image of the square sample as shown in Fig. 1(c). The goal of thresholding is to segment the grey level image into two regions, background and objects. The optimal threshold value can be considered as a grey level that separates an object region and a background region without compromising the object integrity [6].

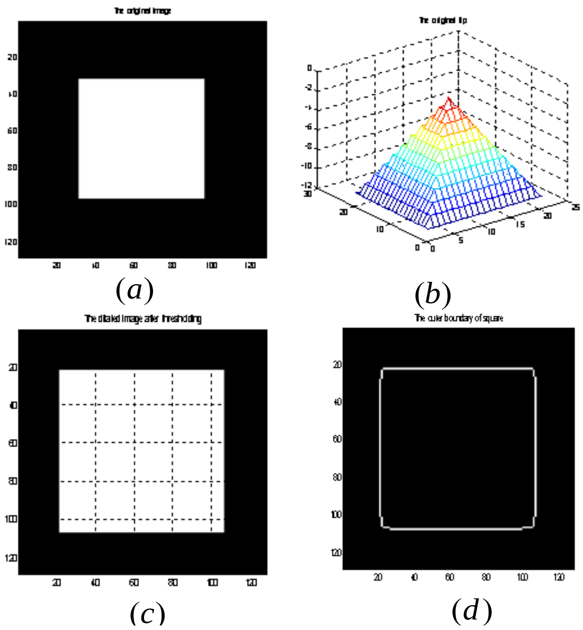


Fig.1. Shows the Simulation results of impulse response technique using square sample.

Next, we determined the outer boundary of the square using the edge canny detection which is known to many as the optimal edge detector. Once the outer boundary is known as illustrated in Fig 1(d). The pixels that belong to the image of the square are eliminated and the tip data that are available around the eliminated square have been moved to the centre of square. The resultant image which illustrated in Fig. 2. is the impulse response of the AFM.

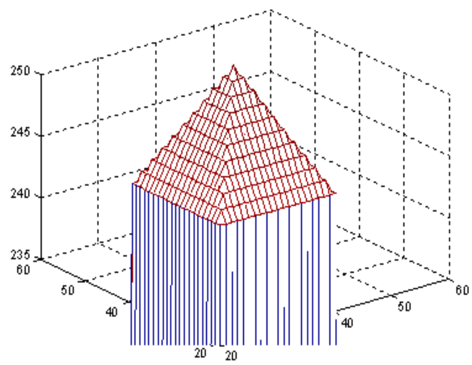


Fig. 2. Illustrates the Simulation results of the 3D image of reconstructed tip.

Fig. 3(a) and 3(b) illustrates the three dimensional image of the square sample and the reconstructed image after applying an erosion operation, respectively. An erosion operation has been carried out between the reconstructed AFM tip and the dilated image of the square. The result of an erosion operation, which represents the reconstructed image is improved.

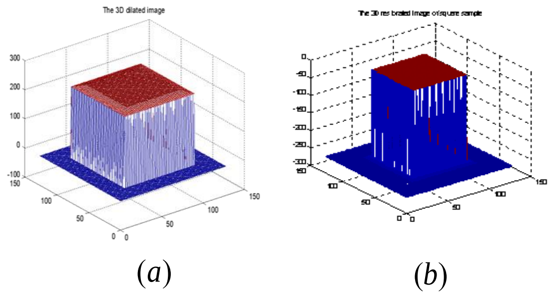


Fig. 3. Depicts the simulation results of impulse

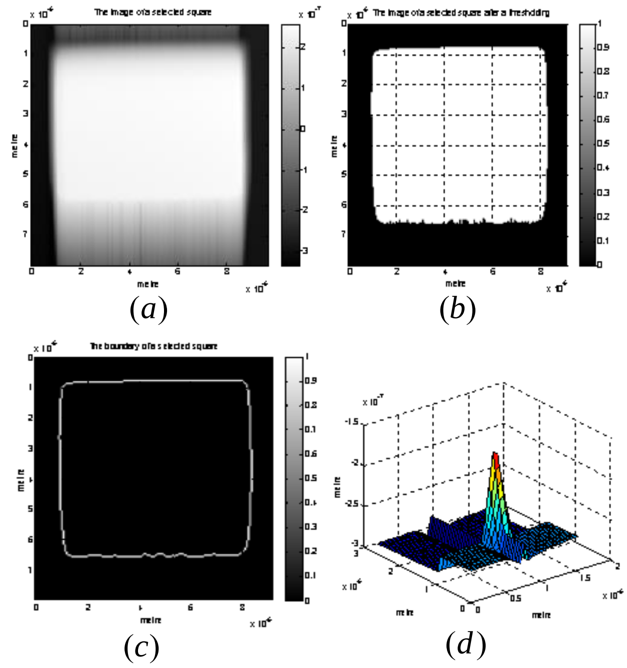


Fig.4. Shows the experimental results of impulse response technique using a real sample that contains squares.

3 Experimental Results

3.1 Experimental results for estimating 3-D AFM tip

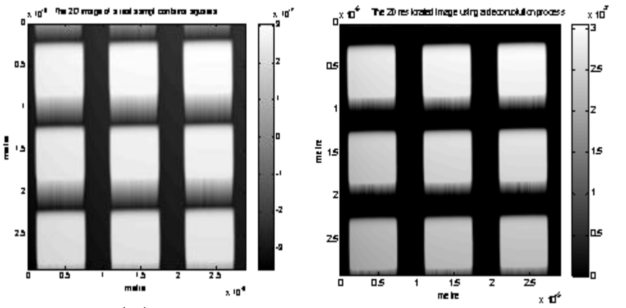
The three- dimensional impulse response of the AFM could be determined by performing the following steps. Measuring a standard AFM calibration sample using the AFM, shown in Fig 4(a), that contains a square with a priori faithfully known dimension. The 2-D topographical image produced by AFM for the sample contains the square profile, but this is broadened due to the convolution between the tip and the square. Digital image processing such as the thresholding and canny edge detection have been used to determine the exact location of the square in the image as illustrated in Fig 4(b) and 4(c), respectively. As the height of the square is a priori known and those pixels that represent the square has been eliminated by moving the inherent image distortions that have been introduced due to convolution effect to the centre of the image of the square. The resultant image which is considered as the three-dimensional AFM tip using the impulse response method is illustrated in Fig 4(d).

4 Restoration of experimental AFM images

The first essential step in front-end digital image processing systems is that of capturing digital images. Many distortions occur during the image acquisition process and these distortions should be eliminated or alleviated using image restoration algorithms. Examples of systems where these distortions occur are in astronomical imaging using telescopes, confocal microscopy, computed tomography (CT) scanners and many other applications. These are similar research problems to the image restoration of AFM images [7-9]. Restoration of subsequent images produced by the AFM can be carried out by performing a deconvolution process between the raw AFM image that is acquired and the impulse response that was found as detailed in the previous section. Many algorithms can be used such as the Wiener, Regularized filter, Lucy- Richardon, and Blind deconvolution algorithms[10-11].

Fig. 5(a) and 5(b) illustrate the blurred AFM image and the AFM image after applying the deconvolution process, respectively. As a result the

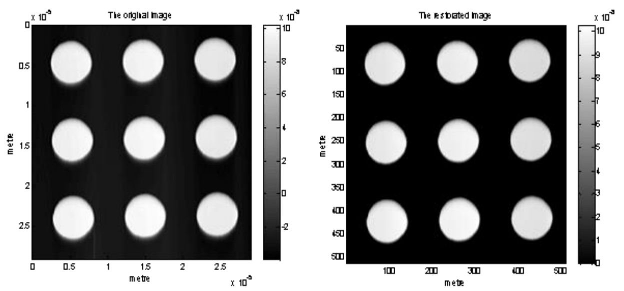
AFM image after applying the deconvolution algorithm is improved by removing the effects of the AFM tip from the blurred image.



(a) (b)

Fig. 5. Illustrates the experimental results of impulse response technique using a Lucy- Richardson deconvolution for reconstructing a real sample that contains squares.

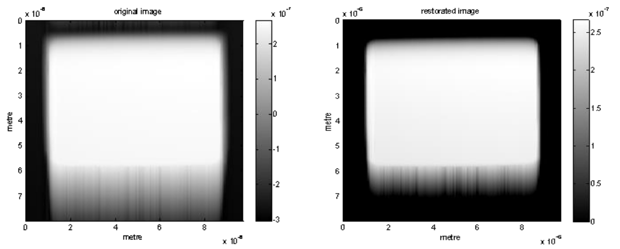
Fig. 6(a) depicts the AFM image of a real sample that contains pillars measured using the Atomic Force Microscope in our lab. Where Fig. 6(b) illustrates the AFM image after applying a Lucy-Richardson deconvolution (the restorated image). It is clear that from the restorated AFM image the distortion is eliminated and the image is sharper than the blurred AFM image.



(a) (b)

Fig. 6. depicts Comparison between the Experimental AFM image and the restorated AFM image.

Fig. 7. the AFM image of a selected square from a real sample that contains squares is shown on the left. The restorated AFM image after applying a Lucy- Richardon deconvolution algorithm is depicted on the right. As a result the distortion in the resorted image is reduced compared with the original image.



(a) (b)

Fig. 7. Illustrates the experimental results of impulse response technique using a Lucy-Richardson deconvolution to restore the image of a real square sample.

4 Conclusion

In this paper, A real sample that contains pillars has been measured using an AFM. The original image was captured in contact mode AFM when the tip scans the sample.

The tip estimation technique using square sample has been demonstrated to be a useful tool in restorating the AFM images. Both the computer simulation and experimental results have shown the improvement in the AFM image after applying an erosion operation and a Lucy- Richardon deconvolution algorithm.

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Conflict of Interest

The author has no conflict of interest to declare that is relevant to the content of this article.