Restoration Of An AFM Height Image Using A Deflection Image At Different Scanning Speeds

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Abstract**—The principle of the Atomic Force Microscope involves scanning an object using a probing tip that is mounted on the free end of a micro mechanical cantilever. While the sample is scanned horizontally the cantilever deflects. The deflection of the cantilever can be sensed among several methods. For instance, optical beam deflection where this method is often used because of it's simplicity. While the scanning process of the sample stage, the detected deflection is compared with the set point deflection. Then, the error signal which is the difference between the detected and set point deflection is minimized by moving the sample stage in the Z – direction. At a set point value this closed –loop feedback operation can maintain the cantilever deflection and hence the tip – sample interaction force. The sample surface is approximately traced by the resulting 3D movement of the sample stage. Therefore, usually the topographic image can be formed from the electrical signals which are used to drive the sample stage scanner in the Z- direction. In this paper, the AFM topographic image is constructed using values obtained by summing the height image that is used for driving the Z- scanner and the deflection image with a weight function that is close to 3. The value of has been determined experimentally using trail and error. This method gives more faithful topographic image.**

Keywords-AFM; height image; scanning speed; deflection image; image restoration.

I. INTRODUCTION

The Atomic Force Microscope (AFM) is a very useful tool that may be used to measure samples at a scale of only a few nanometres [1-3]. The Atomic Force Microscope is unique in its capability, completely different from that of STM or electron microscopy, to allow the high -resolution imaging of biological samples and observing insulting samples. In addition it has a unique ability to visualize nanometre-scale objects in liquids and it is also used in air for surface characterization, lithography, and data storage.

The principle of the Atomic Force Microscope involves scanning an object using a probing tip that is mounted on the free end of a micromechanical cantilever. During the scanning process the tip probes the object's surface, either in contact mode, when the tip is in permanent contact with the object, or in tapping mode, when the tip is being oscillated at the cantilever's resonance frequency [4]. In the case where contact mode is being used, the deflection of the cantilever can be measured with sub-nanometer accuracy. A cantilever deflection (in contact mode), or oscillation amplitude (in tapping mode or non -contact mode), is held constant by a feedback controller that tracks the probing force by varying the position of the sample (or the cantilever) in the vertical (Z) direction. Therefore, the topography information is represented by the output of the feedback controller [5]. For this purpose a high performance feedback loop is required and the positioning system must be precisely characterized and calibrated in the Z–direction. This requirement is necessary to minimize variations of the imaging force and to avoid damaging the tip and the sample. The tip–sample interaction force has to be kept constant and at a minimum to enable the imaging of soft biological samples. The dynamic behaviour of the individual microscope limits the scanning speed of current AFM systems. The main limitations are the bandwidth of the feedback loop that controls the interaction force between the tip and the sample, the dynamic behaviour of the scanning unit, the response time of the force sensor, and the speed of the data acquisition system.

II. PRINCIPLE

A typical contact mode AFM system that uses an optical cantilever system for height sensing is illustrated in Fig.1 The feedback system works properly as long as the scan speed is low enough to ensure adequate response time by the feedback unit. The piezo tube is controlled by the feedback signal in order to maintain the level of the cantilever signal at a set-point value (S_0); where the topography is represented by the signal F . The frequency component of the cantilever signal resulting from the surface topography depends on the scanning speed [6]. As a result of using higher scanning speeds, the feedback signal (F) and the cantilever signal (C) deviate from F_0 and S_0 when there is nolonger sufficient feedback bandwidth. These deviations which are between the feedback signal F and F_0, and between the cantilever signal (C) and S_0 , respectively are given by

$$\partial C = C - S_0 \quad (1)$$

$$\partial F = F - F_0 \quad (2)$$

The above two equations imply that there is a unique relationship between the differences ∂C and ∂F . When there is a condition where there is insufficient feedback bandwidth, the signal F_0 , which corresponds to the sample surface topography, can be obtained from the F and C signals. The parameter ∂C corresponds to the cantilever signal resulting from ∂F and the feedback bandwidth of F is the same as that of F_0 and therefore this results in the fact that the relationship between the differences ∂C and ∂F should be the same as that between the cantilever signal (C) and the feedback signal (F). The piezotube displacement responds linearly to the feedback signal when the feedback signal frequency is sufficiently lower than the resonance frequency of the piezotube. That is,

$$\partial C = \propto \partial F \quad (3)$$

Here , the coefficient $\propto$ is determined experimentally.

F_0 can be written from equations (1), (2), and (3) as follows:

$$F_0 = F - C/\propto + S_0/\propto \quad (4)$$

Where S_0 and $\propto$ are constants. Thus, the surface topography that corresponds to the variation of F_0 can be obtained from the cantilever signal and the feedback signal using the following equation.

$$T = F - C/\propto \quad (5)$$

Where T is the surface topography.

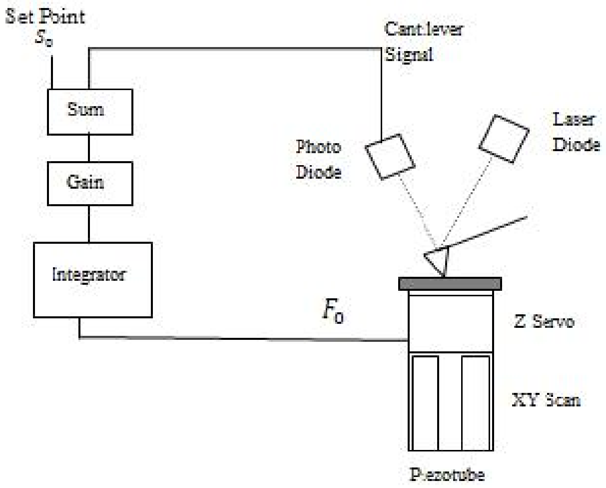


Figure 1. Illustrates a contact mode AFM system that uses an optical cantilever system for height sensing

III. FEEDBACK CONTROL

Fig. 2 shows a schematic block diagram of a typical feedback control unit that is used in AFM imaging. In an Atomic Force Microscope, the cantilever tip is scanned horizontally over the sample's surface. The cantilever deflection is kept constant by controlling the vertical position of the cantilever via the Z piezo actuator [7]. The feedback servo system that controls the cantilever deflection has a major influence on the quality of the image. The cantilever tip is held in a position relative to the sample surface by attractive Van der Waals and repulsive Pauli forces [3], [8]. The Z-piezo positions the sample surface that is being probed by the tip. The deflection of the cantilever is kept approximately constant by the controller. This results in a constant force interaction between the tip and the sample. It is desirable that a small force is exerted on the sample to avoid damaging soft samples, or the tip, where the set point of the controller is proportional to this force. As is shown in Fig. 2, the deflection image is formed from the cantilever deflection value and the topography image is formed from the controller output.

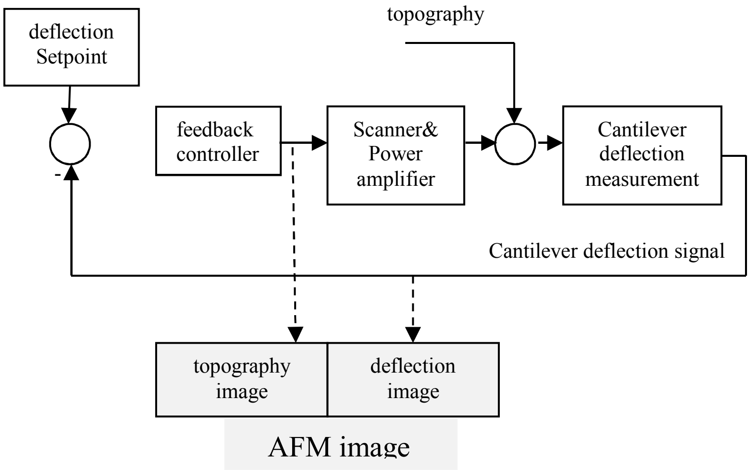


Figure 2. Shows a schematic block diagram of a typical feedback control system that is used in AFM imaging.

IV. RESULTS

The Atomic Force Microscope using contact mode forms the image by contacting the sample surface with a sharp tip that is attached to the free end of a cantilever. While the sample is scanned horizontally the cantilever deflects. The deflection of the cantilever can be sensed by using several different methods. For instance, optical beam deflection may be used to sense the cantilever deflection and this method is often used because of it's simplicity. During the scanning process of the sample, the detected deflection is compared with the set point deflection value. Then, the error signal which is the difference between the detected and set point deflection values is minimized by moving the sample stage in the Z–direction. At a set point value this closed–loop feedback operation can maintain a constant cantilever deflection and hence also a constant tip–sample interaction force. The sample surface is approximately traced by the resulting 3D movement of the sample stage. Therefore, usually the topographic image can be formed from the electrical signals which are used to drive the sample stage scanner in the Z-direction.In this chapter, the AFM topographic image is constructed using values obtained by summing the topographical height image that is used for driving the Z-scanner and the deflection image with a weight function that is denoted by the parameter , that for this instrument has a value that is close to 3. The value of has been determined experimentally here using a trial and error approach. This method gives a more faithful topographic image than the former method (the method described above which is illustrated in Fig. 1).

Fig. 3 illustrates a schematic of AFM measurement using the method for combining the cantilever signal and the feedback signal. In this chapter the scan direction is defined as the x axis and the direction perpendicular to this as the y axis. The piezotube responds linearly to the feedback signal, without delay, as long as the cantilever signal is fed though a low pass filter to the feedback loop in order to restrict the feedback bandwidth. In this case, three different scanning speeds are used 2 Hz, 6 Hz, and 9 Hz, where the image data are acquired in the given scan line direction. For instance when the scan speed is 6 Hz and the image data are acquired in the given scan line direction, a single 512*512 pixel image can be acquired in a time of 1.5 minutes, where the frequency of the measuring point is approximately 6 KHz. In this combination method the piezotube length has to be changed to satisfy the condition in Equation (3). However, the piezotube exhibits approximately linear hysteresis. The effect of piezotube hysteresis on the image appears through F in Equation (5) since the hysteresis exists between the F signal and the changed shape of the piezotube and the C signal responds linearly to the surface height. Local distortion of an image becomes high when the F signal has a higher frequency component, where the piezotube shows a lot of minor hysteresis loops.

If the combining process, which is given by Equation (5), is to be carried out, the coefficient has to be determined experimentally. For the AFM located in GERI labs [a reference to the AFM type], the coefficient $\propto$ is equal to 3.

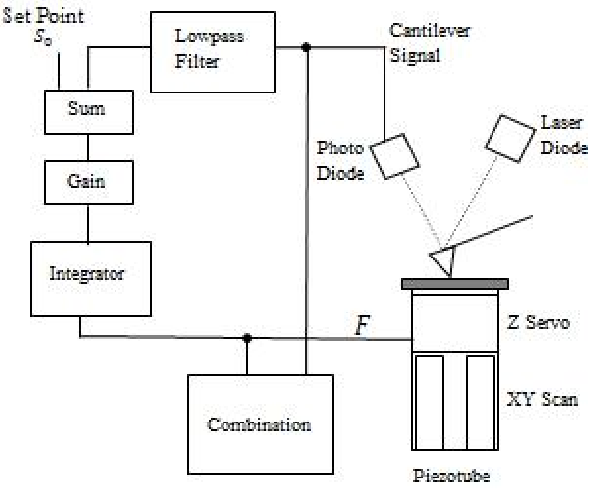


Figure 3. illustrates the schematic of AFM measurement using the method combining the cantilever signal and the feedback signal

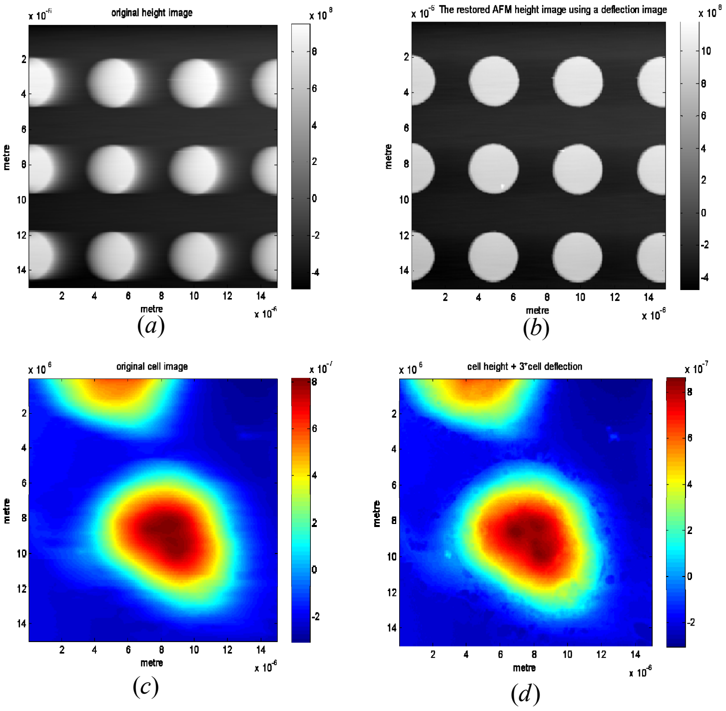


Figure 4. Shows the experimental results for the proposed combining process technique at a scanning speed of 2 Hz. (a) The original height image of the standard sample that is constructed from silicon and consists of a 2D array of small columns; (b) The image of the standard sample that is constructed from silicon and consists of a 2D array of small columns after applying the combining process; (c) The original image of the cell sample; (d) The image of the cell sample after applying the combining process.

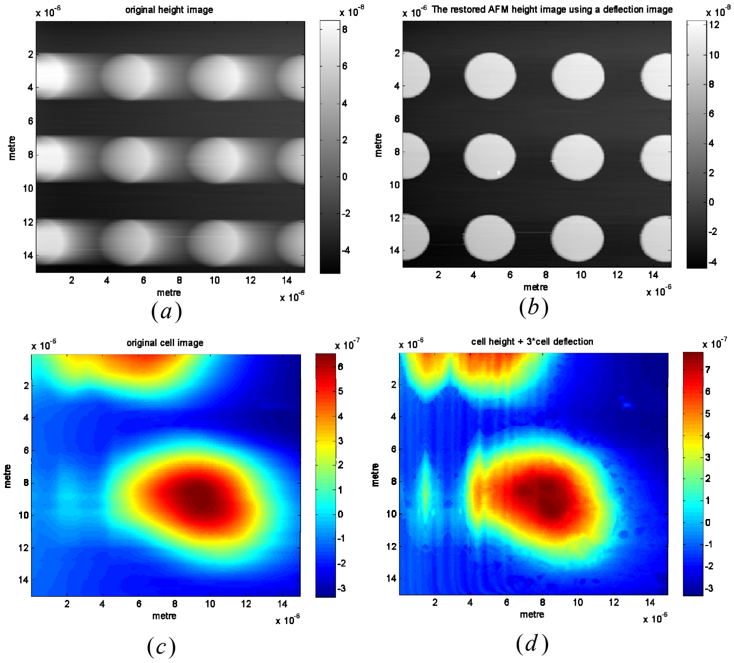
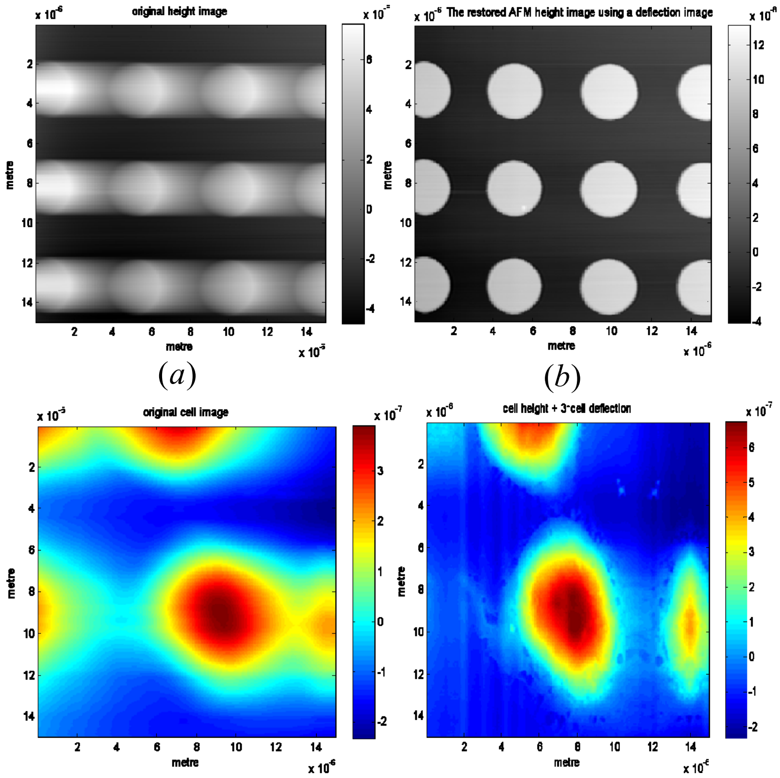


Figure 5. Shows the experimental results for the proposed combining process technique at a scanning speed of 6 Hz. (a) The original height image of the standard sample that is constructed from silicon and consists of a 2D array of small columns; (b) The image of the standard sample that is constructed from silicon and consists of a 2D array of small columns after applying the combining process; (c) The original image of the cell sample; (d) The image of the cell sample after applying the combining process.



(a) (b)

(c) (d)

Figure 6. Shows the experimental results for the proposed combining process technique at a scanning speed of 9 Hz. (a) The original height image of the standard sample that is constructed from silicon and consists of a 2D array of small columns; (b) The image of the standard sample that is constructed from silicon and consists of a 2D array of small columns after applying the combining process; (c) The original image of the cell sample; (d) The image of the cell sample after applying the combining process.

V. CONCLUSION

In this paper the principle of a restoration AFM height image using a deflection image has been described. It has also been shown how this approach was applied to higher scan speed imaging at different dynamic scanning speeds. This was performed by observing the surface measurement results for contact mode AFM for two different samples, namely a standard SPM calibration sample that consists of a 2D array of small raised columns and the surface of a living cell. This approach depends on weighting the AFM deflection image by a constant number and then adding the weighted image to the AFM height image. The resultant image is much more clear and accurate than the original height image that has been distorted as a result of the dynamic frequency response of the instrument when scanning at higher speeds.

VI. REFERNCES

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