Supermedia User Interface for Scanning Probe Microscopy

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Abstract: When using SPM as a nanomanipulation tool, its lack of real-time sensory feedback has hindered its wide application. In this paper, a supermedia user interface is developed aimed to overcome this problem. The supermedia interface can not only provide the operator with real-time visual feedback of the scanned image, but also let the operator feel the 3-D real-time operation force. Furthermore, the operator can directly control the tip motion of SPM through a joystick. The experimental testing results demonstrate the efficiency and effectiveness of the supermedia user interface.

Index terms: Supermedia, Nanomanipulation, SPM, Haptic Feedback.

1 INTRODUCTION

Scanning Probe Microscopy (SPM)[1] has been proven to be a useful tool to study sample surfaces down to the nanometer scale. More importantly, not only can it characterize sample surfaces, it can also effect the sample surface by means of some manipulation[2], [3], [4], [5]. The SPM, as an actuator, can be used to fabricate and assemble some kind structures or devices in nano scale for special purposes. However, in the SPM based nano manipulation, the main problem is the lack of real-time sensory feedback, which would seriously influenced a user to operate SPM correctly. The operator has to conduct the manipulation in the dark. The results can only be verified by followed scan image after the manipulation. To obtain the new scan image, it will usually take several minutes. Obviously, this scan-design-manipulation-scan cycle is very time-consuming and inefficient [6].

In this paper, a supermedia user interface (SUI) is developed aimed to overcome this problem. The sketch of the SUI was given first. Then the operation methods of SUI were introduced. At last, the experimental testing results were presented to demonstrate the efficiency and effectiveness of the SUI

2 Supermedia User Interface

A supermedia user interface (SUI), as shown in Figure 1, has been developed, the supermedia includes the traditional multimedia such as visual/audio, and text, and the haptic information.

Supermedia gives more information to operator than traditional media, especially the real-time force telepresence which is fed to operator through a haptic device (Phantom from Sensable Co.), utilizing the knowledge of force telepresence, operator can obtain a lot of real-time information transformed from the true

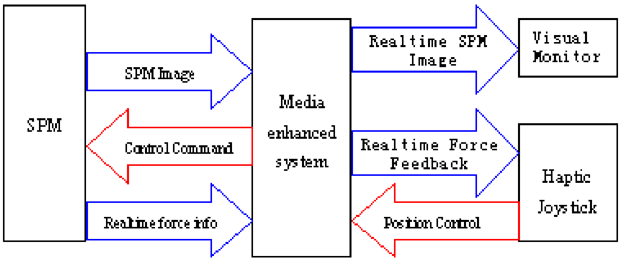

Figure 1.Super media user interface for AFM, the blue arrow delegates real-time SPM image and real-time force feedback info, the red arrow delegates control command. Though supermedia user interface, the operator can not only control the tip motion through a haptic joystick, but also, in the same time view the real-time SPM image and feel the real-time force feedback during nanomanipulation.

operation environment. In addition, a real-time visualized image is also displayed by locally updating the SPM image based on real-time force information. The models of nano operation are hard to obtain, by means of the assistance of real-time visual images and haptic force feedback, human's intelligence is imported to such a super system, the operator can control the tip motion of SPM in a virtual environment, he can make on-line planning and change the strategy of nanomanipulation to compensate the error between the force model and the true environment. In this way, the efficiency and effectiveness of nanomanipulation is significantly increased.

3 Application of Supermedia Interface

Supermedia should provide real-time 3-D force feedback. How to measure 3-D interaction forces on the cantilever-tip from PSD signal? Some researchers have done a lot of work to study this problem [7], [8], but there is still not an accepted method. The interaction force under nano scale is very complex, there are some unpredictable and unmeasurable forces such as surface tension and van der Waals force. Here we won't take much attention to the disturbance, but focus on the problem how to obtain feedback force from the real-time PSD feedback signal.

Since the size of the objects under manipulation is usually small compared to the size of the cantilever-tip body, therefore, the force applied to the tip by the object can be considered as a point force on the tip apex. The normal force applied to the AFM tip can be calculated from cantilever deflection according to the spring model of the cantilever.

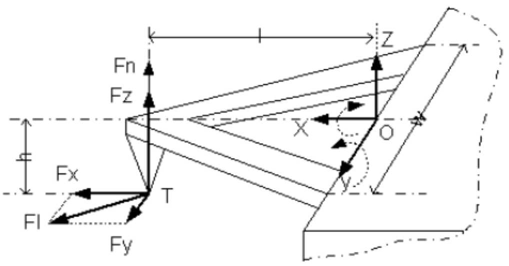

Figure 2. The force analysis model of the cantilever: *O* is the origin of Cantilever frame; ω and l are the cantilever width and length respectively; h is tip height which includes the thickness of the cantilever; T is the tip apex.

We can get the following three equations (for more detail see [9]):

$$F_y = \frac{k_l K_l}{h} S_l \qquad (1)$$

$$F_x = -F_y \operatorname{ctan} \phi \qquad (2)$$

$$F_z = k K_n S_n - \frac{h}{l} F_x \qquad (3)$$

where K_l and K_n are system constants that need to be calibrated, k_l is the torsional constant of the cantilever. ϕ delegate the angle of the tip lateral motion with respect to X-axis of the cantilever frame, S_n and S_l are the normal signal and lateral signal outputs which are obtained as follows:

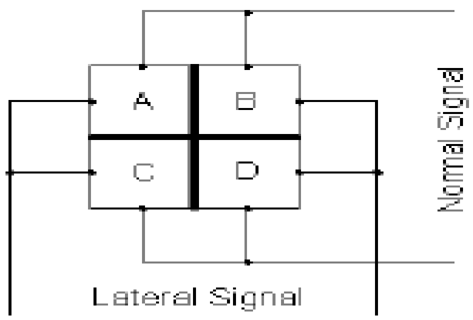

Figure 3. The quad photodiode detector: A, B, C, and D are the signal output of the quad photodiodes.

$$S_n = \frac{A+B-C-D}{A+B+C+D} \quad \text{and} \quad S_l = \frac{A+C-B-D}{A+B+C+D}$$

From (1) and (3), we can calculate the interaction force on cantilever-tip and display it through haptic device after magnifying an appropriate multiple.

Supermedia should also provide visual feedback, it should display the environment changes and a dynamic tip position during manipulation. Instead of using 3-D graphics as used in virtual reality environment, a 2-D image with height information encoded in color directly from AFM is used as the background for graphic display in operating environment (Figure 4). The height information of cantilever tip is also represented by color contrast, so the operator still can obtain visual 3-D information of the operating environment.

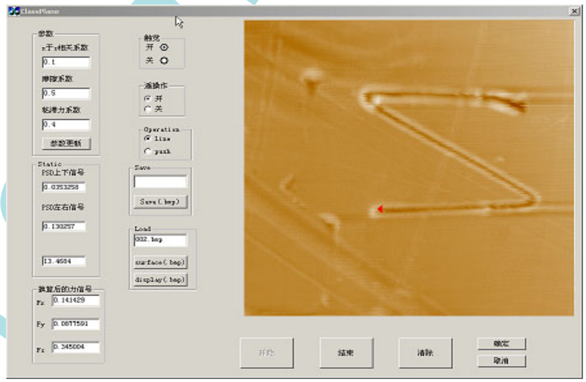

Figure 4.Operating environment in supermedia interface, a 2-D image with height information encoded in color.

4 Experiments and System

In order to demonstrate the efficiency and effectiveness of the supermedia user interface. Nano-imprint is performed and the nano forces are recorded real-time during nano-imprinting.

4.1 System Configuration

A sample-scanning AFM (model CSPM-2000wet, Ben Yuan Ltd., China) was used for imaging and nanomanipulation. A scanner is equipped in the AFM head with a maximum XY scan range of 50um X 50um and a Z range of 5um.The AFM based nano manipulation system is shown in Fig. 5.

In the system, the cantilever deflection signals obtained by PSD, mounted in AFM head, go into the A/D convertor card inside the AFM control computer and are real-time sent through Ethernet to the Phantom TM interface computer where the forces are calculated. A Phantom TM (Sensable Co., USA) is used for 3D nano forces feeling and motion commands input, that is, the forces are felt by operator from the Phantom TM joystick and the scanner motion command produced by joystick is sent through

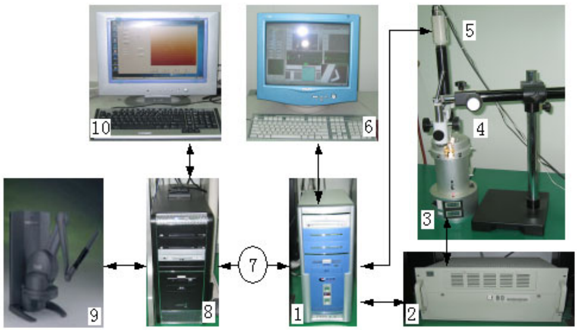

Figure 5. The configuration of AFM based nanomanipulation system: 1, AFM control computer; 2, CSPM 2000wet controller; 3, AFM head; 4, optical microscope; 5, CCD camera; 6, monitor for imaging and optical vision; 7, Ethernet device; 8, Phantom TM interface computer; 9, Phantom TM; 10, monitor for Phantom TM manipulation interface.

Ethernet into the AFM control computer to control the scanner's motion. The optical microscope and CCD camera help the operator to adjust the laser to focus on cantilever end and search for interesting area on substrate.

4.2 Using supermedia interface in nano-imprint

In this experiment, we using supermedia interface to imprint three characters 'SIA' as shown in Fig.6 in the surface of a soft material called polycarbonate. We know only the vertical force is heavier than an appropriate value, is there a snick in the surface of polycarbonate, the stronger the vertical force is, the deeper the snick is, this is the base that we display real-time results in the SUI. The forces during imprinting are real-time recorded, and real-time displayed through Phantom^{TM}. AFM nano-probe (model NSC15-F5, MickoMasch Inc., USA) with triangle cantilevers whose force constant has been calibrated is used, and the probe is made of silicon (100) with radius of tip apex about 10nm and full tip cone angle less than 20^0.

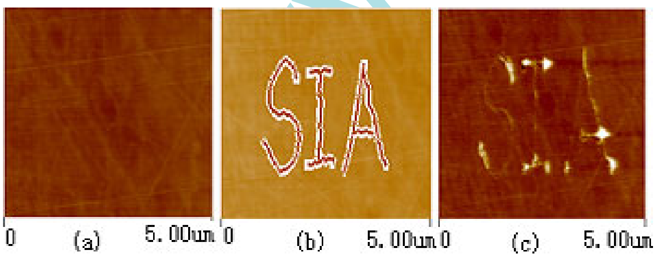

Figure 6. Nano-imprint on polycarbonate: (a) scanning image before nano-imprint;(b) the real time result displayed on the supermedia interface during nano-imprint (c) scanning image after nano-imprint.

The vertical force and horizontal force along x-axis during imprinting character 'S' are demonstrated in Fig. 7. To our experimental polycarbonate, a lot of the experimental testing results showed that only the vertical force is heavier than about 100nN, is the imprinting successful performed. During nano-imprint, if the magnitude of the vertical interaction force on the cantilever-tip is heavier than 100nN, the image in operating environment (Figure 6b) is real time updated with a snick. Figure 6 and 7 approved the rule works well: the results displayed in operating enviroment matched with the results in the new scanning image well.

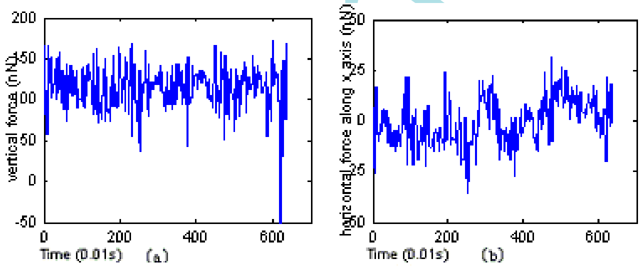

Figure 7. Forces in nano-imprinting character 'S': (a) vertical force; (b) horizontal force along x-axis.

The whole process is performed continuously without a new scanning image, it takes about six seconds to imprint character 'S', figure 6 shows that nano-imprint has been successfully performed, from this we can see under assistance of the supermedia interface, the nano-imprint is performed effectively and efficiently.

Conclusion

Applying supermedia interface to the SPM based nano manipulation system, the operator not only can feel the real-time 3-D interaction force but also can observe the changes of the operating environment, more importantly, human's intelligence is imported to the system, operator acts as a central controller, on-line planning based on feedback information is realized, in this way, several operations can be performed successfully without a new image scan, as the experimental testing results shown, the efficiency and effectiveness of nanomanipulation are significantly improved. The final goal of nanomanipulation using SPM is to make nanodevices and nanosensors by assembly of nanorods, nano-wires and nanotubes. We believe under assistance of the supermedia interface, nano-assembly such as constructing nano patterns, making nano devices, building nano sensors will become feasible and applicable.

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