Ultramicroscopy 118 (2012) 61–66

Contents lists available at SciVerse ScienceDirect

Ultramicroscopy

journal homepage: www.elsevier.com/locate/ultramic

Contact detection for nanomanipulation in a scanning electron microscope

Changhai Ru [a,b,*,1], Steve To [c,**,1]

[a] Automation College, Harbin Engineering University, Harbin 150001, China
[b] Robotics and Microsystems Center, Soochow University, Jiangsu 215021, China
[c] Department of Mechanical and Industry Engineering, University of Toronto, Ontario, Canada M5S3G8

ARTICLE INFO

Article history:
Received 7 November 2011
Received in revised form
29 April 2012
Accepted 29 April 2012
Available online 22 May 2012

Keywords:
Contact detection
Nanomanipulation
SEM
Computer vision microscopy
Automation

ABSTRACT

Nanomanipulation systems require accurate knowledge of the end-effector position in all three spatial coordinates, *XYZ*, for reliable manipulation of nanostructures. Although the images acquired by a scanning electron microscope (SEM) provide high resolution *XY* information, the lack of depth information in the *Z*-direction makes 3D nanomanipulation time-consuming. Existing approaches for contact detection of end-effectors inside SEM typically utilize fragile touch sensors that are difficult to integrate into a nanomanipulation system. This paper presents a method for determining the contact between an end-effector and a target surface during nanomanipulation inside SEM, purely based on the processing of SEM images. A depth-from-focus method is used in the fast approach of the end-effector to the substrate, followed by fine contact detection. Experimental results demonstrate that the contact detection approach is capable of achieving an accuracy of 21.5 nm at 50,000 × magnification while inducing little end-effector damage.

© 2012 Elsevier B.V. All rights reserved.

1. Introduction

Nanomaterials have been demonstrated in numerous device applications ranging from AFM imaging [1] and photodetection [2] to chemical [3,4] and biological sensing[5,6]. Existing nanofabrication methods, such as electron-beam nanolithography, HF etching processes, and anisotropic timed etching, are capable of reaching nanoscale features; however they come with high processing costs, complexity and low yields associated with e-beam lithography. Alternatively, accurate positioning of nanomanipulators and end-effectors has been shown to be effective in the guided synthesis of nanodevices [7–11] and the characterization of nanomaterials [12–16]. A nanomanipulation system consisting of a scanning electron microscope (SEM) and piezoelectric manipulators represents a powerful platform capable of performing simultaneous imaging and manipulation at the nanometer scale, including the capability for in-situ device testing and characterization. However, most of the nanomanipulations have focused on manual strategies for characterizing nanostructures. A skilled user operates the joysticks to control the nanomanipulators while monitoring the video-rate SEM images. One major challenge of performing visual servo tasks inside a SEM is balancing the needs of image quality. Moreover, the commercial standard SEMs deliver two-dimensional (2D) images without the depth information. The 2D SEM images provide the in-plane position of the end-effector and the operated objects. Since nanomanipulation is a three-dimensional (3D) task, accurate knowledge of the end-effector position in all three spatial coordinates is necessary. SEM images deliver high resolution 2D information enabling the automated planar positioning of nanorobotic manipulators [17,18]. Due to the lack of depth information along the *Z* direction, positioning an end-effector (e.g., nanoprobe) vertically is based on trial and error, and thus, time-consuming and skill dependent. Automated contact detection must be implemented in order to move automatically towards SEM nanomanipulation. So it is a challenge to obtain the missing depth information.

Earlier methods involved mounting optical microscopes to the side of the SEM sample chamber [19]. Recently, the use of an infrared camera in conjunction with a reflective micro-patterned scale installed perpendicular to the substrate [20] was reported. By monitoring the end-effectors reflection on the scale, the relative position between the end-effector and the target object was determined. However, the poor scale resolution and low magnification of the light microscopy provided a poor accuracy (worse than 5 μm). Three-dimensional visual feedback can also be achieved by analyzing stereoscopic SEM images obtained by applying rotational and translational changes to the specimen stage [21]. The major disadvantage of this approach is that the sample, nanomanipulator, and end-effector must all be rotated or

---

* Corresponding author at: Automation College, Harbin Engineering University, Harbin 150001, China.

** Corresponding author at: Department of Mechanical and Industry Engineering, University of Toronto, Ontario, M5S 3G8, Toronto.

E-mail addresses: rchhai@gmail.com (C. Ru), Steve.to@utoronto.ca (S. To).

[1] Shared the first co-authorship. Contributed equally.

0304-3991/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ultramic.2012.04.010

translated, which slows down and brings complexity to the automation process. An alternative method is to acquire the stereoscopic images through tilting the electron beam [22]. By magnetically deflecting the beam, two SEM images from different perspectives are obtained. However, this method needs to be equipped with a specialized hardware in a regular SEM.

A shadow-based depth detection method [14] was used to vertically align a microgripper with a protruding carbon nanotube. The performance of this shadow-based approach is highly affected by the SEM imaging conditions (e.g. accelerating voltage) and end-effector geometries. Touch sensors (piezoelectric [18], capacitive [23], and piezoresistive [24]) have also been used for contact detection. However, it is difficult to integrate these sensors into a nanomanipulation system. Furthermore, the touch sensors at micro–nano–Newton levels are fragile and highly prone to damage; extra care must be taken in the process of integrating these devices as well as in the process of nanomanipulation. Depth–from–focus methods were also implemented in SEM nanomanipulation systems for estimating the Z position of an end-effector relative to the object being manipulated [18]. Although depth from focus methods are often used in optical microscopy [25,26], the large depth of field of the SEM makes it difficult to precisely align the end-effector tip and target object to an exact co-plane.

This paper reports on a computer-vision-based contact detection approach that determines the contact point between an end-effector and the target surface without the need for additional equipment, devices or sensors. Using SEM visual feedback, the end-effector is visually tracked in real time as it descends towards the target surface using a depth from focus method. Once the probe is within the depth of focus with the target surface, the system transitions to fine contact detection where the probe descends at a relatively higher accuracy and lower speed. When the contact between the end-effector and the target surface is established, further motion of the end-effector in the vertical Z direction causes the end-effector to slide on the target surface, a phenomenon detectable from image processing.

2. Contact detection

2.1. Nanomanipulation system

The system consists of a nanomanipulation setup (Zyvex S100) mounted onto the specimen stage of a SEM (Hitachi S-4000). There are four quadrants of 3-DOF nanomanipulators, each of which is composed of a macro-positioner and a nano-positioner. The macro-positioner contains three identical piezoelectric slip–stick motors, having a travel range of 12 mm with 100 nm resolution. The nano-positioner is equipped with a piezoelectric tube having a travel range of 10 μm along the axis of the tube and 100 μm along each of the two orthogonal directions with 5 nm resolution. A tungsten nanoprobe is mounted onto the nanomanipulators as end-effectors (Fig. 1). Before loading the probes onto the nanomanipulators, the probes are chemically cleaned to remove the native tungsten oxide using KOH solutions and HF. After the cleaning procedure, the probe tips have a radius of 100 nm and are installed at a tilting angle of 45° from the substrate. Electrical connections are established for the nanoprobes and the substrate via the feedthrough ports on the SEM.

The x–y motorized stage of SEM controlled by a joystick can move and adjust the nanomanipulators and sample platform within the vacuum chamber. The sample can be observed using the image processing software running on the SEM PC and its joystick positioning controller. With large scale motion, the macro-positioner will move faster, but will have a coarser, rougher motion. The fine-positioner can achieve ultra-precise motion in the nanoscale. After adjusting the SEM image, control signals produced by the computer are used to drive the three-axis macro-positioner for the coarse positioning of the probe tip close to the substrate surface. Then the probe is driven by the nanomanipulator to approach the substrate surface with a speed of 1 μm/step. Once the distance between the substrate and the probe tip is in the stroke of the nano-positioner, the control is switched to nano-postioner to realize the fine approach with 10 nm steps.

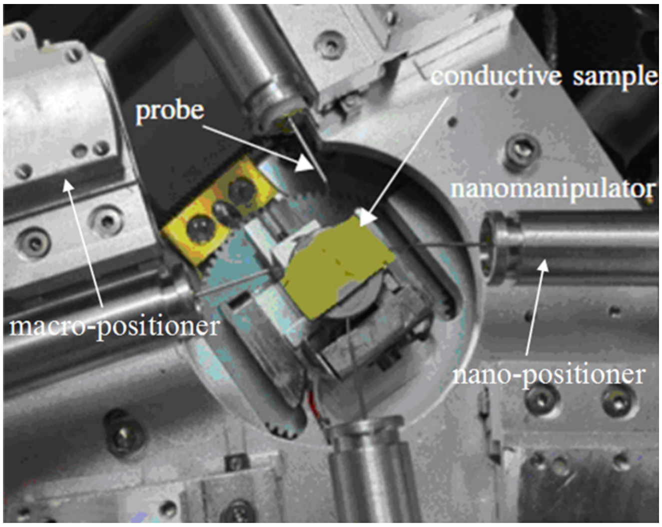

Fig. 1. Nanomanipulators equipped with nanoprobes inside SEM.

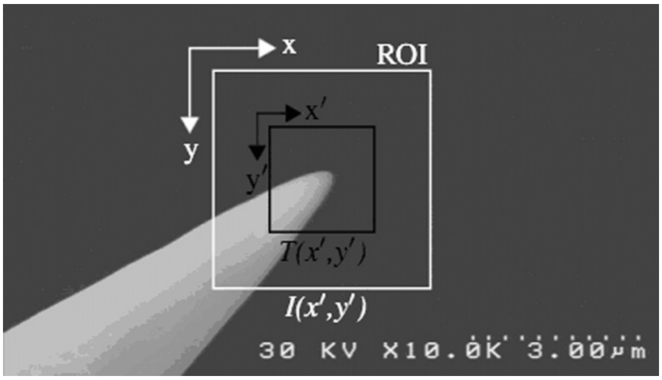

Fig. 2. Nanoprobe tip is visually tracked using normalized cross correlation template matching. $T(x',y')$ is the template image. A search window within the proximity of the probe tip is chosen as the ROI, $I(x,y)$.

2.2. Visual tracking

For contact detection, the nanoprobe tip is visually tracked with a normalized cross-correlation template matching method that is robust to additive noise and to the brightness or contrast changes inherent in video-rate SEM images [32,33]. The pixel intensity of an image and the template image can be represented by $I(x,y)$ and $T(x',y')$, where (x,y) is the pixel position in the image coordinate frame and (x',y') is the pixel position in the template image coordinate frame, as shown in Fig. 2.

A region of interest (ROI) surrounding the probe tip for tracking is identified in order to track the probe and obtain the real position of the probe tip. Two simple methods are used to obtain the ROI. The first method involves the operator clicking on the probe tip to obtain a 150 × 150 ROI probe tip template for

Download English Version:

https://daneshyari.com/en/article/1677558

Download Persian Version:

https://daneshyari.com/article/1677558

Daneshyari.com