Vibration and Position Control of Piezoelectric Tube Scanners for Fast Atomic Force Microscopy

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To my parents,

for your love, support and prayers.

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying subject to the provisions of the Copyright Act 1968.

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Iskandar Al-Thani Mahmood

October, 2009

List of Publications

During the course of this research, a number of papers have been submitted to international journal and conferences. The following is a list of those articles which have already been appeared in international journals or accepted for publication, as well as a list of conference papers which have been presented or accepted for presentation.

Journal Articles

1. I. A. Mahmood, S. O. R. Moheimani and B. Bhikkaji. A new scanning method for fast atomic force microscopy. Conditionally accepted in *Nanotechnology, IEEE Transactions on*, 2009.

2. I. A. Mahmood and S. O. R. Moheimani. Fast spiral-scan atomic force microscopy. *Nanotechnology*, Volume 20, Number 36, Pages 365503 (4pp), September 2009.

3. I. A. Mahmood and S. O. R. Moheimani. Making a commercial atomic force microscope more accurate and faster using positive position feedback control. *Review of Scientific Instruments*, Volume 80, Number 6, Pages 063705 (8pp), June 2009.

4. I. A. Mahmood, S. O. R. Moheimani and K. Liu. Tracking control of a nanopositioner using complementary sensors. *Nanotechnology, IEEE Transactions on*, Volume 8, Number 1, Pages 55 – 65, January 2009.

5. I. A. Mahmood, S. O. R. Moheimani and B. Bhikkaji. Precise tip positioning of a flexible manipulator using resonant control. *Mechatronics, IEEE/ASME Transactions on*, Volume 13, Number 2, Pages 180 – 186, April 2008.

Conference Papers

1. I. A. Mahmood and S. O. R. Moheimani. Improvement of accuracy and speed of a commercial AFM using positive position feedback control. *American Control Conference*, St. Louis, Missouri, June 2009.

2. I. A. Mahmood, K. Liu and S. O. R. Moheimani. Two sensor based H_∞ control of a piezoelectric tube scanner. *IFAC World Congress*, Seoul, Korea, July 2008.

3. I. A. Mahmood, S. O. R. Moheimani and B. Bhikkaji. Precise tip positioning of a flexible manipulator using resonant control. *Advanced Intelligent Mechatronics*, Zurich, Switzerland, September 2007.

4. I. A. Mahmood, B. Bhikkaji and S. O. R. Moheimani. Vibration and position control of a flexible manipulator. *Information, Decision and Control*, Adelaide, Australia, February 2007.

ABSTRACT

The performance of piezoelectric tube scanner in Atomic Force Microscope (AFM) is limited by vibrations and nonlinearities exhibited by the piezoelectric material such as hysteresis and creep. The aforementioned limitations restrict the use of the piezoelectric tube scanner for fast and high resolution operations. As such, this thesis presents several ways of improving the speed and accuracy of piezoelectric tube scanner for the use in Atomic Force Microscopy. In this thesis, two types of feedback control approaches are designed and implemented experimentally in order to improve the performance of piezoelectric tube scanners. The first approach uses strain voltage signal induced in the piezoelectric tube to measure of high frequency displacements of the scanner. Together with capacitive sensor, the use of strain voltage signal allows the closed-loop bandwidth to be increased for fast scans without the additional sensor noise otherwise contributed by the capacitive sensor during fast operation of the scanner. In the second approach, a Positive Position Feedback (PPF) control scheme is implemented on a commercially available AFM to compensate for scan-induced vibration and cross-coupling of its piezoelectric tube scanner. As a result of the implementation of the PPF control scheme, the scanning speed is doubled in comparison to the scanning speed obtained from the standard controller supplied with the commercial AFM. Finally, a spiral scanning method is comprehensively described and evaluated for the use in AFM. Two modes of spiral scanning method, Constant Angular Velocity (CAV) and Constant Linear Velocity (CLV) modes, are presented and compared with the widely used raster scanning method. The use of the spiral scan in CAV mode is shown to allow the scanning speed to be increased very high, approaching the mechanical bandwidth of the scanner. The use of the spiral scan in CLV mode allows scanning of samples to be done at linear velocity, a property shared with the raster scan.

Contents

List of Figures

List of Tables