Novel Actuation Techniques for Piezoelectric Tube Actuators

Dissertation

Precision Mechatronics Lab

Digvijay Singh Raghuvanshi

October 26, 2018

Supervisors
A/Prof Yuen K Yong
Prof Andrew J Fleming
Dr Steven I Moore

A thesis submitted in fulfilment of the requirements for the degree of Master of Philosophy in Electrical Engineering at The University of Newcastle, Australia.

Statement of originality

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision.

The thesis contains no material which has been accepted, or is being examined, 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 the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved .

Digvijay Singh Raghuvanshi, October 26, 2018

Statement of collaboration

I hereby certify that the work embodied in this thesis has been done in collaboration with other researchers and staff at the University of Newcastle. I have included as part of the thesis a statement clearly outlining the extent of collaboration, with whom and under what auspices.

- In Section 3.4 and Section 4.4, the experiment jigs were prepared in collaboration with Mr. Phillip Dombkins and Mr. Peter Turner from the machining shop.
- In Section 3.4 and Section 4.4, the preparation of electrodes on the tubes was conducted in collaboration with Mr. Ben Routley from Precision Mechatronics Lab.
- In Section 4.2, the analytical modelling for an eight-electrode tube was conducted in collaboration with Dr. Steven I. Moore from Precision Mechatronics Lab.

Digvijay Singh Raghuvanshi, October 26, 2018

Acknowledgment

I expresses my most sincere gratitude and personal homage to my supervisors Dr. Yuen K. Yong and Dr. Andrew J. Fleming for giving me the opportunity to undertake this project at a state-of-the-art facility, the Precision Mechatronics Lab. I am grateful for their invaluable guidance and support throughout the research and to my fellow lab members Mr. Meysam Omidbeike and Mr. Ben Routley for their time and support during experiments. A very special thanks to Dr. Steven I. Moore for providing valuable insights during the analytical modelling and being a mentor while compiling thesis results with constant words of motivation. I thank Mr. Phillip Dombkins and Mr. Peter Turner from the machining shop for their assistance in experimental setup. A sincere thanks to the PVC Office, the School Office and the Graduate Studies Office for the administrative support during my RHD tenure. A very warm thanks to all the office colleagues of EF-108 room in Engineering F building for uplifting my spirits through tough days. Most above, I am forever grateful to my parents and mentors Dr. Shashee K. Raghuvanshi and Mrs. Rita Raghuvanshi for being the pillars of personal support, and to the love of my life and my best friend, Mahima, for believing in me and waiting for me. I am grateful to the entire University of Newcastle for giving an international student the opportunity, the environment and the support to carry out an engineering research, allowing a small town boy across the seas to take the first step towards his goals.

OM NAMAH SHIVAYA

(glory to Shiva, the transformer, the destroyer, the supreme reality, the inner self, the consciousness that dwells in all)

Abstract

Piezoelectric tube actuators are widely used in applications such as fibre optics alignment, endoscopy imaging and scanning probe microscopy. Piezoelectric tubes are thin-walled cylinders of radially poled piezoelectric ceramics. In almost all applications, the tube is fixed at one end and free at the other. A conventional tube in atomic force microscopy consists of quartered outer electrodes, which cover two-thirds of the length for lateral actuation. The remaining one-third of the length is covered by a circumferential electrode for vertical actuation. The inner surface is covered by a continuous electrode grounded at all times. For lateral actuation (bending) along the X or Y-direction, two outer quartered electrodes on opposite sides are driven by voltages of equal magnitude but opposite polarity. Voltage applied to the top circumferential electrode produces vertical actuation.

The simplest way to increase the scan range of a piezoelectric tube actuator is to increase its length. However, this increases the physical size and reduces the resonance frequency. This thesis describes a new method for increasing the vertical scan range by driving the internal electrode rather than grounding it. This approach eliminates the need for a circumferential Z-electrode, which is typically one-third of the tube length, thereby allowing longer quadrant electrodes for larger lateral scan range. Since the proposed technique does not change the physical size of the tube, it is ideal for compact applications. Experimental results show a 62% increase in lateral scan range and an 86% increase in vertical scan range with negligible increase in cross-coupling. Analytical modelling shows that driving the internal electrode does not interfere with the lateral scan range.

This thesis also proposes to implement similar technique for an eight-electrode tube actuator to compensate for angular (tilting) and vertical cross-coupling. The conventional quartered electrodes are split into two vertical segments of equal length to create a total of eight electrodes. The tilting and vertical cross-coupling due to the lower segments is compensated by the upper segments giving a sigmoid shape to the tube during lateral motion. Finite element simulations and experimental results confirm a 96% decrease in tilt angle and 43% reduction in vertical cross-coupling. However, the trade-off encountered with this method is a 44% decrease in lateral scan range.

Publications

- Digvijay S. Raghuvanshi, Steven I. Moore, Andrew J. Fleming and Yuen K. Yong, ”Electrode Configurations for Piezoelectric Tube Actuators with Improved Scan Range and Reduced Cross-Coupling”, IEEE/ASME Trans. Mechatronics (under review).

Contents

List of Figures

List of Tables