Prototype Micromanipulator of Space Robotics Applications

by James B. Dabney and Thomas L. Harman

James B. Dabney

Thomas L. Harman

ABSTRACT—Piezoelectric actuators offer dramatic improvements in a variety of space-based robotics applications. Bending piezoelectric actuators offer a simple, lightweight, and reliable means for actuating end effectors. This research produced a single degree-of-freedom micromanipulator prototype which can be used to solve open issues in bending actuator control, especially in hysteresis modeling and control.

PIEZOELECTRIC ACTUATORS HAVE CONSIDERable potential for space-based robots. This research produced a prototype single-degree-of-freedom (DOF) micromanipulator consisting of a piezoelectric bending actuator and a capacitive position measuring system. The actuator will facilitate research to solve open issues in piezoelectric actuator control, particularly in hysteresis modeling and control.

Premises of the Project

Piezoelectric actuation is ideal for space-based robotics applications requiring inherent lightweight features, simplicity, and immunity from magnetic fields. End effectors for miniature space-based robots must also be simple and lightweight and can also benefit from immunity from magnetic fields. Therefore, a piezoelectric actuator is an ideal candidate for an end effector.

A piezoelectric bending actuator (Fig. 1) consists of two layers of piezoelectric material bonded together with opposite polarity in the form of a cantilever beam. The application of an electric field to the actuator causes one layer to extend slightly and the other layer to contract slightly.[1] The differential length causes the beam to bend toward the contracting layer. By controlling the applied electric field precisely, it is possible to control the movement of the beam tip. The tip of this particular actuator has a range of motion of ±0.5 millimeters. *Labview* version 6.0 is used to generate voltages in the range +5V to –5V which are, in turn, supplied to a piezo-linear amplifier. The piezo-linear amplifier is used as a high voltage drive source for the piezoelectric actuating device. The capacitive sensor[2] senses the motion and produces an analog voltage proportional to the distance between the capacitive probe and the piezoelectric actuator. *Labview* 6.0 is used to record the capacitive sensor output.

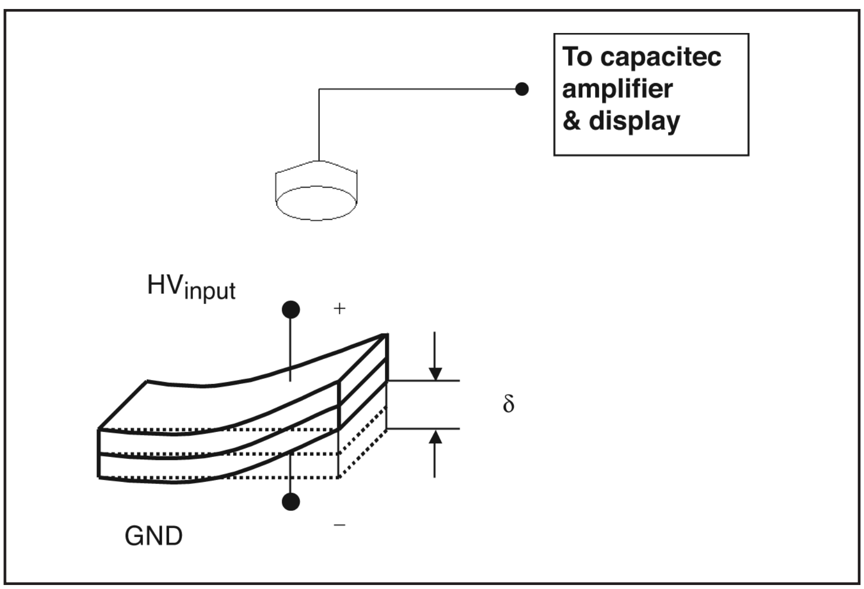

Figure 1. Schematic of the Principle of Operation

Laboratory Apparatus

The UHCL micromanipulator system will facilitate research in dynamics and control of micromanipulators. The device uses a piezoelectric bending actuator that has a range of

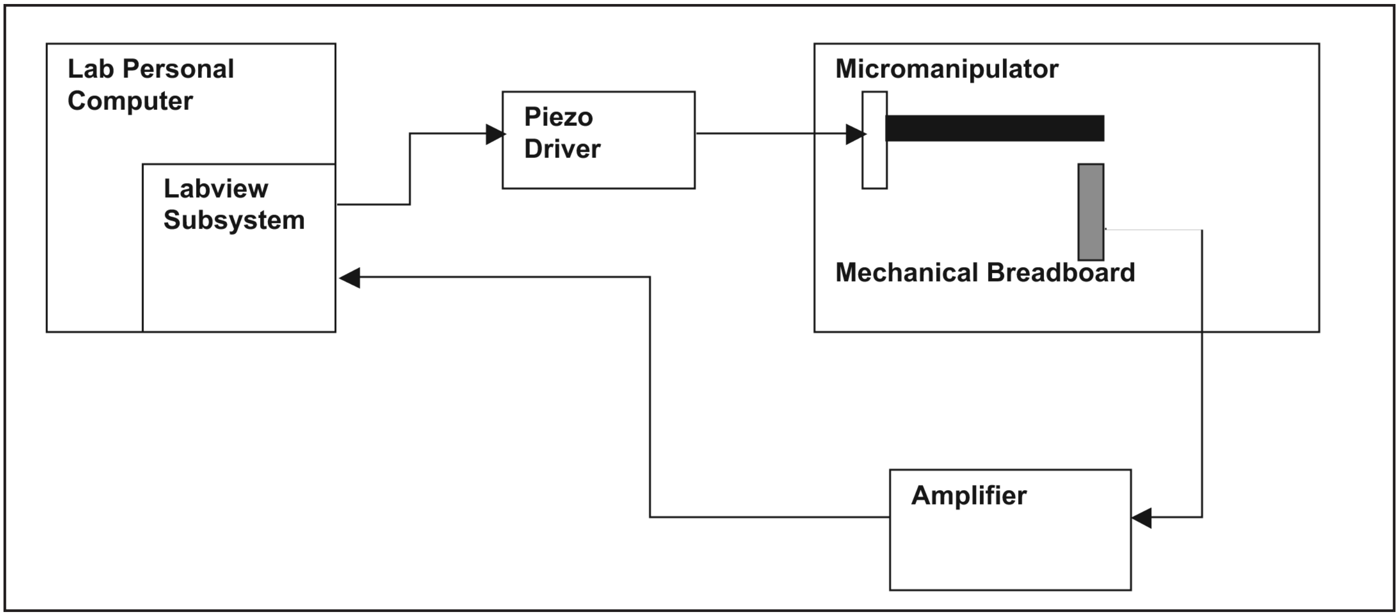

Figure 2. Block Diagram of the Experimental Setup

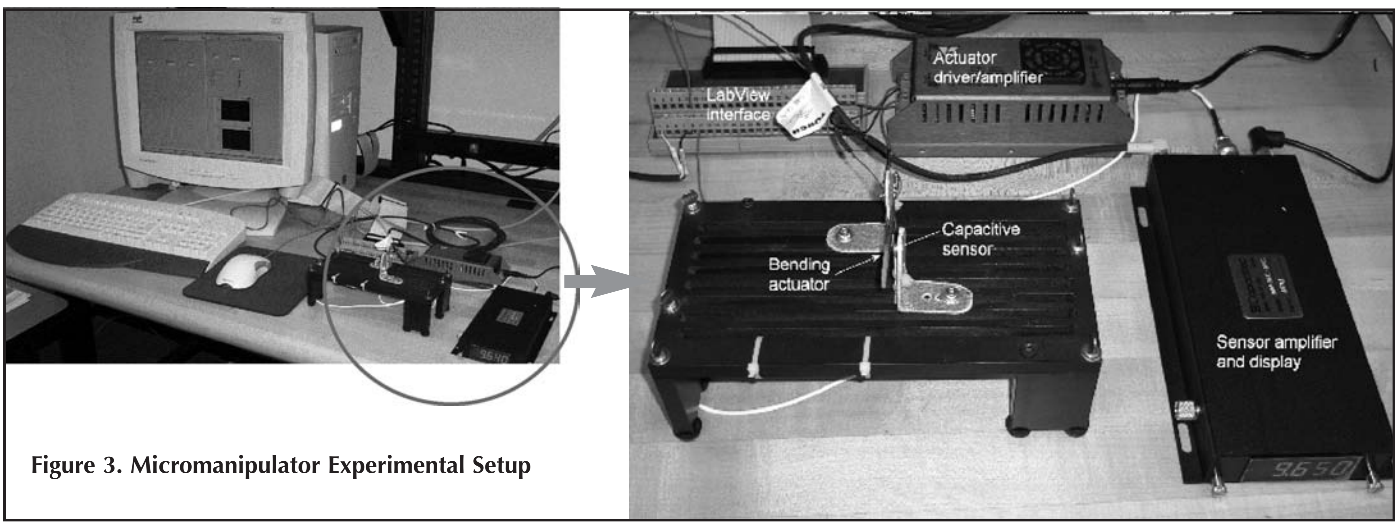

Figure 3. Micromanipulator Experimental Setup

motion of approximately ±0.5mm. A block diagram of the apparatus is shown in Fig. 2.

The apparatus consists of the piezoelectric bending actuator mounted to a mechanical breadboard and driven by a piezo-linear amplifier (Model EPA 007). The EPA-007 is a very compact high voltage linear non-inverting amplifier, which is used as a high voltage drive source for the piezoelectric actuating device. The manipulator position is measured using a commercial high-resolution capacitive position sensor (Series 4000 Capacitec amplifier) mounted to the mechanical breadboard. *Labview* version 6.0 is used to generate drive voltages to the piezo driver and measure capacitive sensor output.

The experimental laboratory setup is shown in Fig. 3.

Research Plan

The main components of the prototype micromanipulator were available commercially. They were integrated mechanically, and a hardware-software interface was developed to permit experimentation. Three main research issues were addressed:

- To design and implement the actuator and capacitive sensor mounting system.
- To design and implement circuitry to power and control the actuator and to record sensor output via *Labview* 6.0 software.
- To develop a *Labview* 6.0 user interface to generate control signals for the actuator and record key parameters and tip position from the capacitive sensor.

Results

The actuator, capacitive position sensor, actuator driver, and sensor amplifier were assembled as shown in Fig. 3. *Labview* 6.0 software was developed to control the actuator driver and capture the sensor amplifier output. Using *Labview* software, preliminary experiments were performed to verify the operation of the system throughout the actuator range of motion.

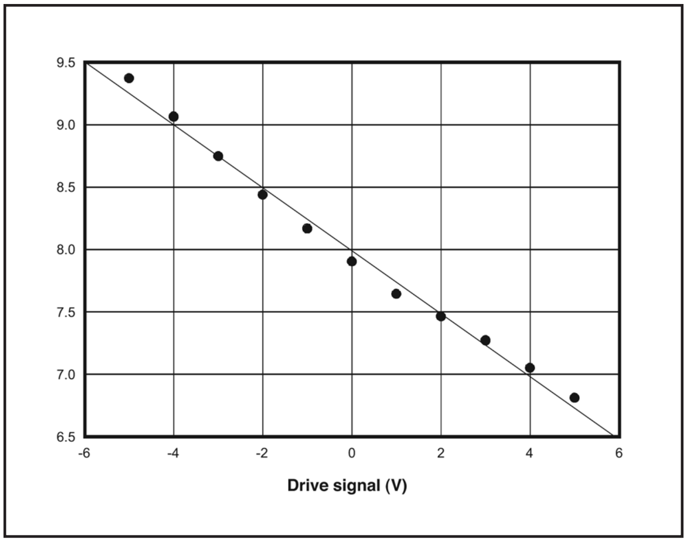

Figure 4. Response of Piezoactuator as a Function of Drive Voltage

For example, the approximate linear input-output relationship between the commanded position (actuator driver command voltage) and position (amplified capacitive sensor output voltage) was measured, as diagrammed in Fig. 4.

Future Work

An extensive literature is available on the control of piezoelectric micromanipulators. Among the control techniques studied are standard linear, non-model-based techniques such as proportional-integral-derivative control, linear control techniques including robust control, and adaptive control. The inherent precision feasible with piezoelectric micromanipulators is not attainable using these techniques because the piezoelectric actuators exhibit significant hysteresis. Preliminary results on dealing with the hysteresis have recently been reported[3] but the techniques discussed in the literature deal only with repetitive motion. Therefore significant work remains in order to achieve the potential of these actuators for space-based robotics and other applications.

Piezoelectric bending actuators are also ideal for flapping-wing micro air vehicles. Among the issues to resolve are precise control of flapping amplitude and tailoring of flapping motion.

Acknowledgments

This study was supported by an ISSO mini-grant for the summer of 2006.

References

[1]M. Novotny and P. Ronkanen, "Piezoelectric Actuators," <http://www.ad.tut.fi/aci/courses/ACI-51106/pdf/Piezo/PiezoelectricActuators.pdf>

[2]M. A. Ayer, *Operation/Maintenance Manual: Series 4000 Capacitec Amplifiers and Rack Accessories*, Ayer, MA: Capacitec, Inc., 1998.

[3]J. Zhong and B. Yao, "Adaptive Robust Repetitive Control of Piezoelectric Actuators," 2005 International Mechanical Engineering Conference and Exposition, Orlando, FL, 2005.

[4]J. Yan, R. J. Wood, S. Avadhanula, M. Sitti, and R. S. Fearing, "Towards Flapping Wing Control for a Micromechanical Flying Insect," 2001 Intl. Conf. on Robotics and Automation, Seoul, Korea, 2001.

Publications

Garud A., J. B. Dabney, and T. L. Harman, "Micromanipulator Modeling and Control: Initial Experiments," UHCL Systems Engineering Laboratory Report, 2007.

Funding

Dabney, J. B., "Gulf Coast Consortium of Control and Dynamics Interactive Remote Laboratory," NSF Collaborative Proposal, $54,000 (Joint proposal with UH, Rice, UH-Downtown). (*Not funded*.)

Dabney, J. B., A. J. Meade (co-PI), "Micro Air Vehicle Modeling and Control," Air Force Office of Scientific Research, $81,694. (*Pending*.)