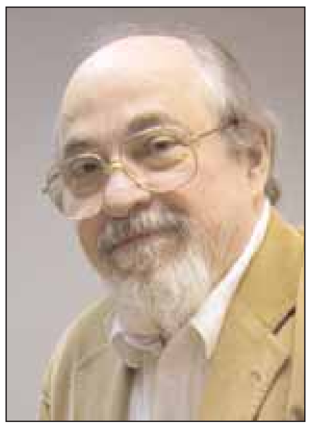
Real-time active loading of piezoelectric ultrasonic motors for simulating space robotics applications

James B. Dabney and Thomas L. Harman

ABSTRACT—Piezoelectric ultrasonic motors (PUMs) offer dramatic improvements to a variety of space-based robotics applications, if the problem of real-time torque control can be solved. This research used the UH-Clear Lake PUM laboratory to develop, implement, and experimentally validate a real-time model-based PUM torque control law that in recent experiments has demonstrated favorable stability properties.

PREMISE OF THE PROJECT



Thomas L. Harman

Space-based robots typically require actuators incorporating a high degree of precision, light weight, and simplicity. Piezoelectric ultrasonic motors (PUMs) are well-suited to these requirements. PUMs can achieve high precision because of their low speeds, because they lack gears and transmissions, and because they are free from backlash. In addition, these motors can be built so that they neither produce nor are affected by magnetic fields, making them useful in highly magnetic environments and applications in which magnetic fields are harmful. (Figure 1 shows a typical piezoelectric motor, the Piezo Systems/Shinsei USR 30.)

The state of the art in control of PUMs was not fully developed before this work was undertaken. Good results had been achieved for applications requiring only speed regulation. Also, existing controller technology was adequate for positioning applications traditionally served by stepper motors. The new UHCL model-based torque control algorithm addresses the many important potential PUM applications requiring precise torque control.

GOALS OF THE PROJECT

The ultimate goal of the PUM research conducted in the UHCL Systems Engineering Laboratory was to develop a PUM driver/controller unit that implements model-based real-time torque control algorithms. The goal was achieved in the form of a prototype driver/controller that implemented a model-based control law developed in the UHCL Systems Engineering Lab.

RESULTS

The PUM hardware is shown in Figure 2. It is mounted to a torque sensor and drives a flywheel that, in turn, drives a magnetic particle brake. The brake is connected via a flexible coupling to a laser encoder that measures the motor angular position. The magnetic particle brake and driver are shown in Figure 3.

Previously, the experimental apparatus was used to characterize the relationship among drive signal frequency, motor speed, and motor torque. A control law was implemented that inverts the torque surface shown in Figure 4 to compute drive signal frequency as a function of instantaneous motor speed and commanded torque. The control law was implemented, and regulation and tracking experiments were performed to demonstrate that the control law is effective throughout the PUM operation range.

A factor that degraded tracking performance somewhat was drift in drive signal amplitude each time the drive signal phase (sense) switched. More recently, however,

Figure 1. Piezo Systems ultrasonic motor (Shinsei USR30)

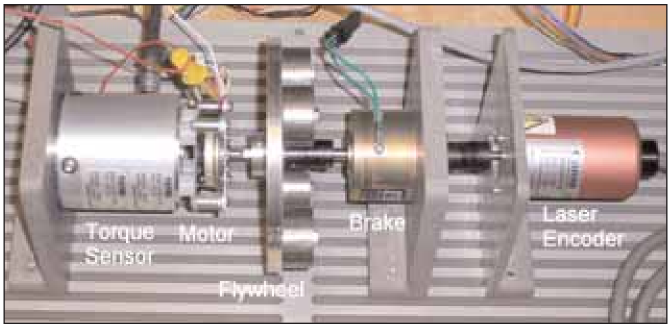


Figure 2. Motor and encoder assembly

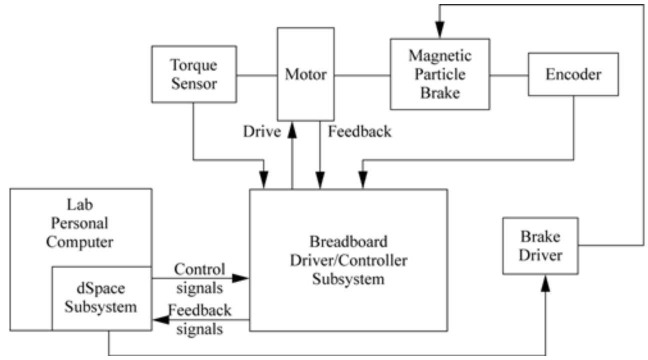


Figure 3. Apparatus schematic

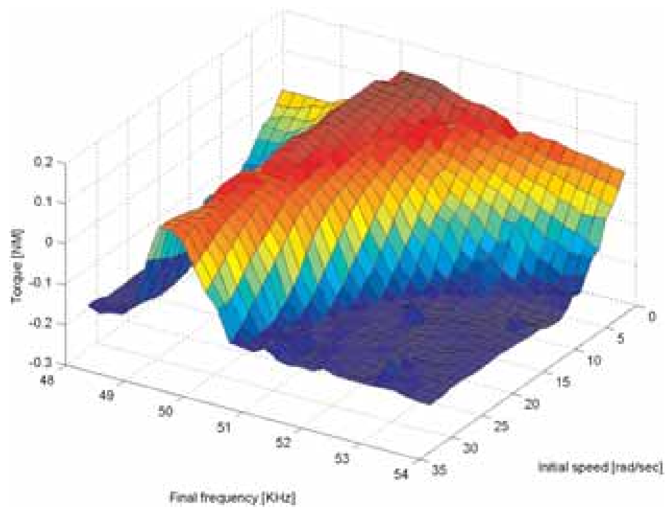


Figure 4. Example PUM torque surface

we have demonstrated that the torque control algorithm dynamics have favorable stability. (See the 2006 *Annual Report* for a full description of this project.)

CONCLUSIONS AND FUTURE WORK

This work has demonstrated the feasibility of model-based torque control for an important class of traveling wave piezoelectric ultrasonic motors. Future work will entail development of a single degree of freedom haptic display using the present apparatus.

ACKNOWLEDGMENTS

This work was partially supported by ISSO mini-grants for the summers of 2002, 2003, 2004, and 2005. Additional support was provided by NASA/JSC and by the UHCL Faculty Research Support Fund. A UHCL Systems Engineering Capstone team implemented the controller software.

PUBLICATIONS

Dabney, J.B., Harman, T.L., and Ghorbel, F.H. Stable torque regulation of piezoelectric ultrasonic motors. Earth and Space 2008 Conference. Long Beach, CA (March 3–5, 2008) (*submitted*).

PRESENTATIONS

Dabney, J.B. Recent advances in the modeling and control of piezoelectric ultrasonic motors. Innovations 2007, Houston, TX (2007).