Real-Time Torque Sensing of Piezoelectric Ultrasonic Motors for Space Robotics Applications

James B. Dabney
School of Science and Computer Engineering

Thomas L. Harman
School of Science and Computer Engineering

Mary Randolph-Gips

Abstract—Piezoelectric ultrasonic motors (PUMs) offer dramatic improvements in a variety of space-based robotics applications, if the problem of real-time torque control can be solved. This research enhanced the UHCL PUM laboratory apparatus to include torque sensing, display, and recording. The apparatus was calibrated using torque computations Measured torque compared well with the computed torque.

SPACE-BASED ROBOTS TYPICALLY REQUIRE ACTUATORS exhibiting high precision, light weight, and simplicity. Piezoelectric ultrasonic motors (PUM) are well-suited to these requirements. PUMs can achieve high precision as a result of low speed, lack of gears and transmissions, and freedom from backlash. They are quite simple mechanically, consisting of a single moving part that provides the same functionality as motor, transmission, and brake in a conventional motor-driven system.[1]

A typical piezoelectric ultrasonic motor (Piezo Systems/Shinsei USR 30, Fig. 1)[2] consists of a toothed piezoelectric disk (stator) in contact with a metal disk (rotor). Time-varying electric fields applied to the piezoelectric stator

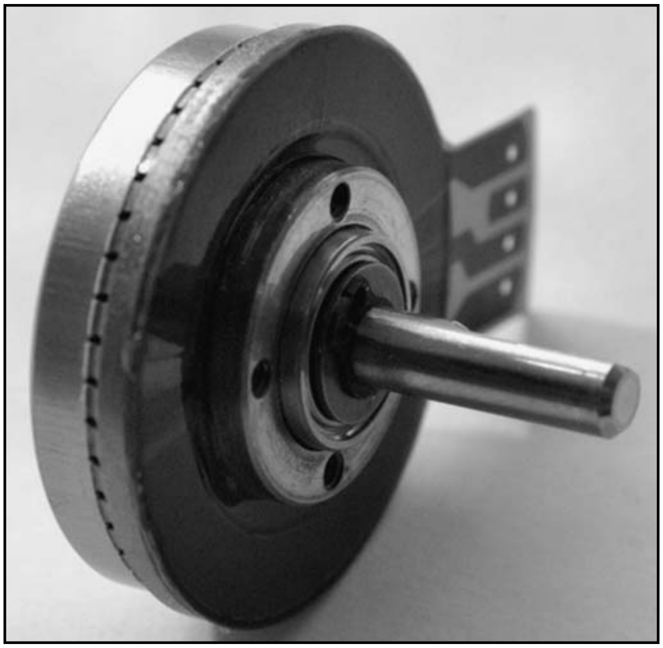

Figure 1. Piezo Systems ultrasonic motor (Shinsei USR30)

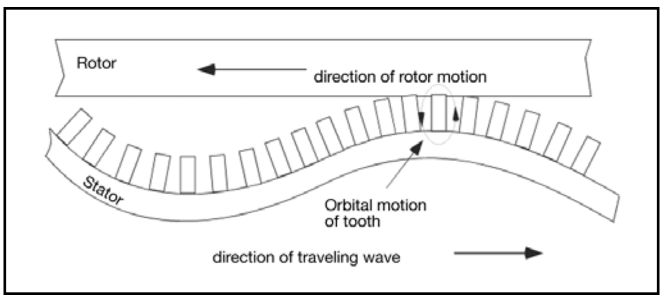

Figure 2. Traveling wave formation

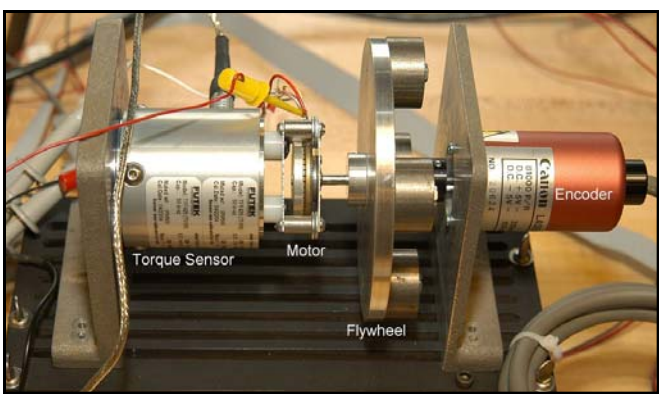

Figure 3. Motor and encoder assembly

induce a traveling wave which is mechanically rectified, causing the rotor to rotate (Fig. 2)[3]. This mechanism produces relatively high torque at low rotor angular velocities, eliminating the need for gearing. The friction between rotor and stator provides a passive holding torque typically larger than the rotating torque, eliminating the need for mechanical brakes or active holding torque. These motors can be built such 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.

The state of the art in control of the PUM is not fully developed. Good results have been achieved for applications requiring only speed regulation. Also, existing controller technology is adequate for positioning applications traditionally served by stepper motors. Current PUM control technology does not address the many important potential PUM applications requiring precise torque control.

Goals of the Project

The ultimate goal of PUM research being conducted in the UHCL Systems Engineering Laboratory is to develop a PUM driver/controller unit that implements model-based real-time torque control algorithms. Research supported by ISSO this year entailed modifying the PUM apparatus via the addition of a sensor to measure torque in real time. This enhancement is a necessary step in the implementation of an active load that will permit simulation of typical space-based PUM applications. This modification will also permit the research team to more fully characterize PUM torque behavior so as to improve the PUM models and simulations, an important step towards model-based torque control.

Results

A Futek torque sensor was integrated into the apparatus as shown in Fig. 3. The sensor was mounted to a bracket that was, in turn, mounted to the mechanical breadboard base. A motor mount adapter was fabricated to attach the motor to the torque sensor. The flywheel and encoder were also installed in a manner identical to the previous version of the apparatus.

The torque sensor was supplied with a calibrated digital readout (Fig. 4). This readout provides precise (+/-0.001 inch-ounce) indication of torque, but with a low bandwidth of less than 1 KHz. Using this calibrated readout, it is possible to measure static or steady-state torque; the bandwidth is not sufficient, however, to support real-time control. To permit real-time measurement, and, in the future, real-time control, a high-speed bridge circuit was designed and implemented on the electrical breadboard.

A system block diagram including the high-speed bridge circuit is shown in Fig. 5. The bridge circuit output was incorporated in the Simulink4 real-time control software using the dSpace interface (Fig. 6) to display and record measured torque. The torque measured, using the torque sensor and bridge circuit, was calibrated experimentally with torque computed from motor angular acceleration and flywheel inertia. A plot comparing filtered measured torque (using the bridge circuit) and computed torque is shown in Fig. 7. The

Figure 4. Torque sensor digital display

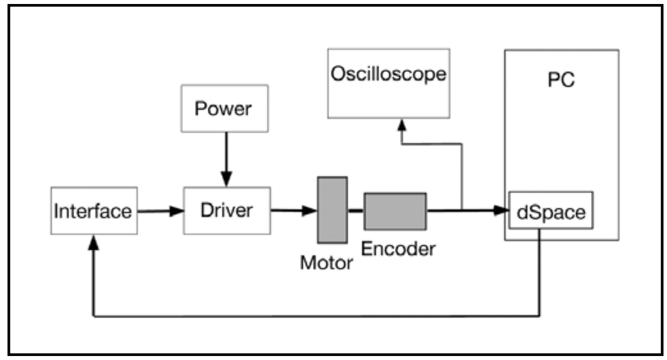

Figure 5. Apparatus schematic

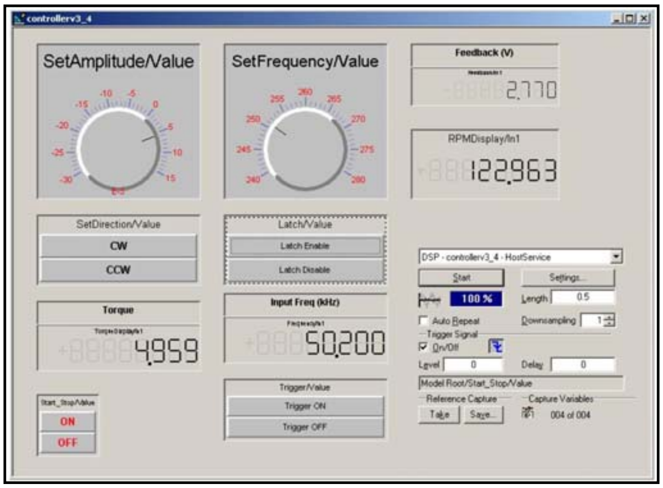

Figure 6. dSpace interface with real-time torque display

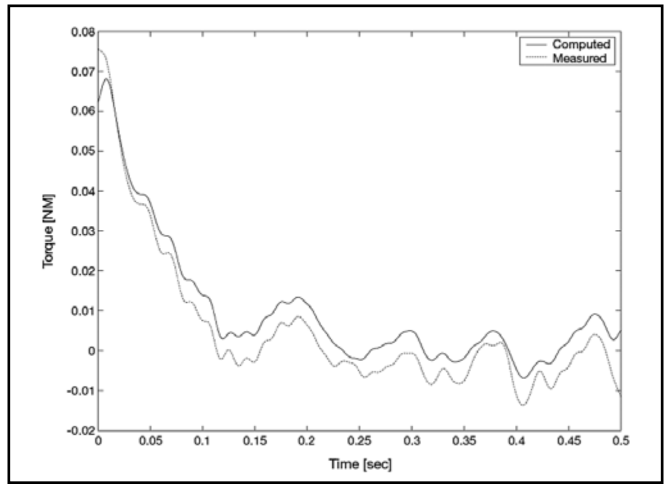

Figure 7. Measured torque compared to computed torque

steady-state offset between the measured and computed torque is expected and is caused by friction in the system. Thus, once calibrated, the torque sensor provides improved accuracy using only the inertial (flywheel) load, as well as making feasible the addition of an active load.

The results shown in Fig. 7 indicate that the torque sensor dynamics, using the custom bridge circuit, are adequate for the real-time monitoring and control applications. The next phase of the project will be to implement an active load to permit modeling a variety of potential applications and to permit more extensive characterization of motor dynamic and steady-state response.

Acknowledgments

This work was partially supported by a ISSO mini-grants for the summers of 2002, 2003, and 2004. Additional support was provided by the NASA Lyndon B. Johnson Space Center and by the UHCL Faculty Research Support Fund.

References

[1]T. Sashida and T. Kenjo, *An Introduction to Ultrasonic Motors* Oxford: Clarendon Press, UK, 1993.

[2]*Operating Manual*: *Ultrasonic Rotary Motor and Driver*, Cambridge, MA: Piezo Systems, Inc., 2001.

[3]N. W. Hagood and A. J. McFarland, "Modeling of a Piezoelectric Ultrasonic Motor," IEEE *Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, 42.2 (March 1995): 210-31.

[4]J. B. Dabney and T. L. Harman, *Mastering Simulink*. Upper Saddle River, NJ: Prentice Hall, 2004.

Funding

Dabney, J. B. "Advanced Control of Piezoelectric Ultrasonic Motors," National Aeronautics and Space Administration, Aug., 2003, $100,000 (*funded*).

—. "Model-Based Torque Control of Piezoelectric Ultrasonic Motors," Jan., 2005, $600,000 (*pending*).