

Student Researchers at the University of Houston-Clear Lake



TESTING—Sunitha Yadagirdi (*r.*), Hyderabad, India, reviews details of a PIC-DEM Board for testing control systems, under the supervision of Dr. Thomas Harman (*l.*). She is pursuing an M.S. degree in computer engineering.



DIGITAL—Patrick Lorenzo checks a digital signal processing board. He is pursuing an M.S. degree in computer engineering. He earned his B.S. at the New Era University in Diliman Quzon City, Mexico.



TORSION—Tatyana Ivanova monitors the performance of a torsion control system. A native of Kazakhstan, she earned a baccalaureate in mathematics and computer science at the Ouachita Baptist University in Arkadelphia, Arkansas. She is presently engaged in research at UHCL in pursuit of her master's degree in computer engineering.

Dynamic Properties of Piezoelectric Ultrasonic Motors for Space Robotics Applications

James B. Dabney [UHCL] / Thomas L. Harman [UHCL]

Abstract

Piezoelectric ultrasonic motors have great potential for space-based robot applications. The motors are light in weight and mechanically simple. The motors possess high friction when static, and, therefore, can also function as mechanical brakes. Development of advanced torque control techniques is necessary to exploit the motor's advantages in critical applications. This research enhanced the UHCL piezoelectric ultrasonic motor apparatus by the addition of an inertial load and measured motor dynamic response using a commercial motor driver.

Premises of the Project

Space-based robots typically require actuators exhibiting high precision, light weight, and simplicity. Piezoelectric ultrasonic motors (PUM) are well-suited to these requirements. PUM 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 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, obviating 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 PUM is not fully developed. Good results have been achieved for applications requiring only speed regulation. 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 the PUM research being conducted in the UHCL Systems Engineering Laboratory is the development of model-based real-time torque control algorithms for PUM. Research supported by ISSO this year entailed modifying the PUM apparatus with the addition of an inertial load and characterizing the motor dynamic response using this load.



Figure 1. Piezo Systems Ultrasonic Motor (Shinsei USR30)

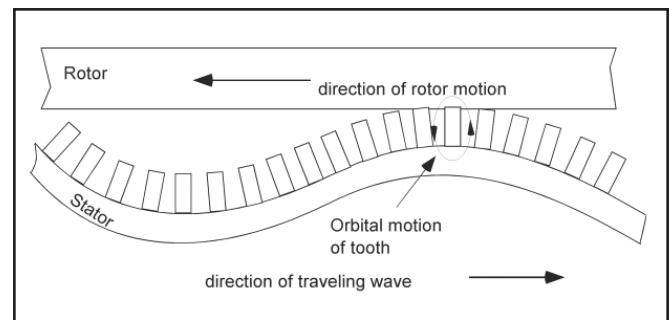


Figure 2. Traveling Wave Formation

Results

An aluminum flywheel was designed, fabricated, and installed on the PUM apparatus. Figure 3 shows the modified apparatus. Figure 4 shows a schematic of the apparatus and control system used for these experiments. The flywheel is mounted directly to the motor drive shaft and, in turn, drives the laser encoder via a flexible coupling. In addition, the PUM control software (Simulink/dSpace⁴) was modified to automatically perform the experiments and record time histories of key parameters. Finally, several experiments were performed to measure dynamic response using the commercial motor driver.

The motor speed response using the commercial driver is shown in Fig. 5. The motor torque is proportional to the slope of the curves in Fig. 5. In each case, the motor torque

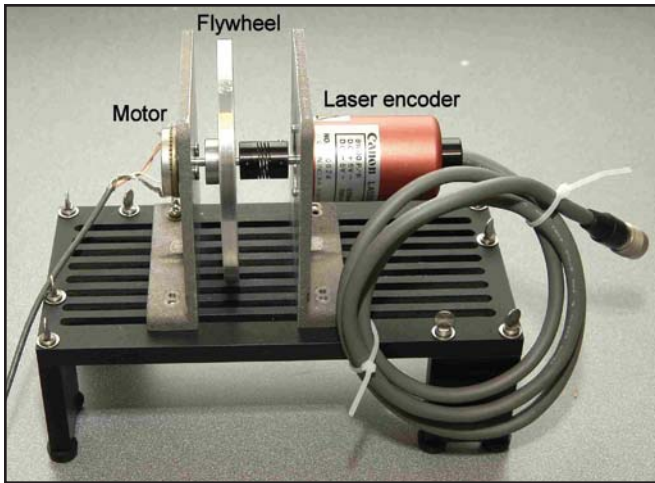


Figure 3. Motor and Encoder Assembly

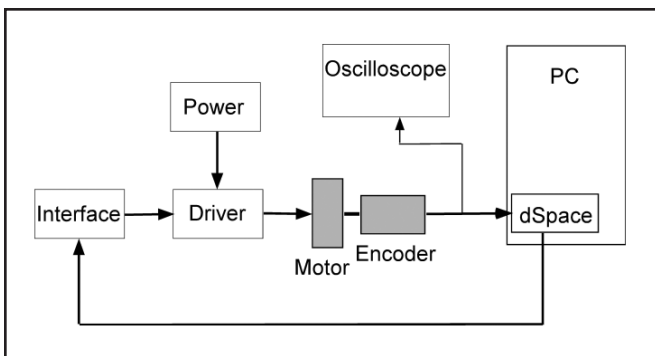


Figure 4. Apparatus Schematic

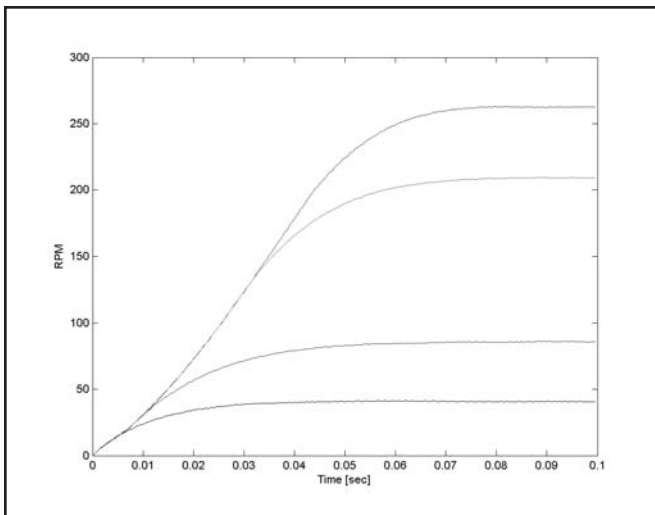
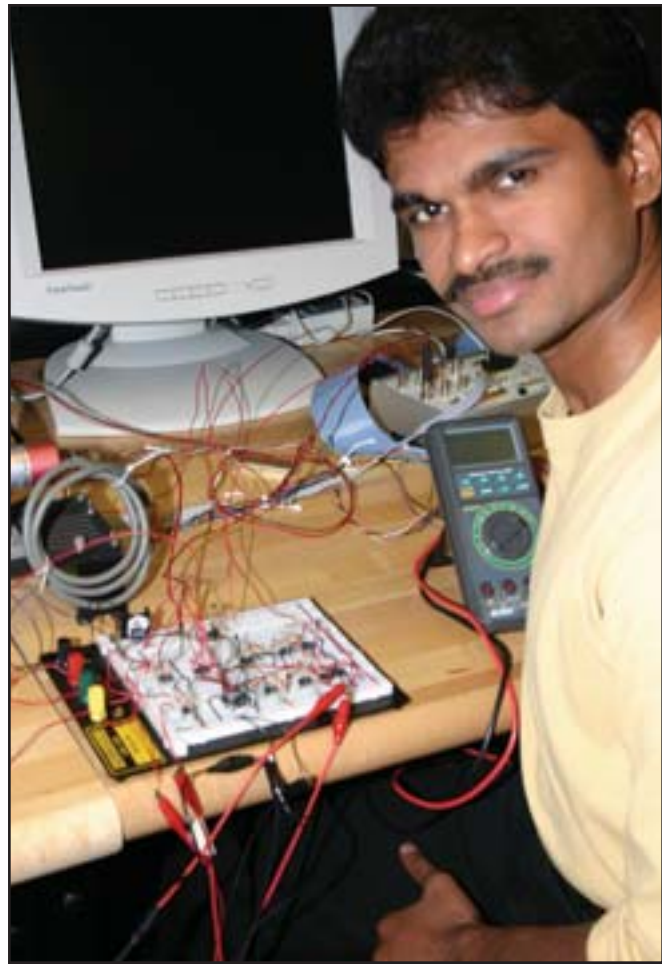


Figure 5. Speed Response with Commercial Driver

decreases as motor speed increases, reducing to zero as the speed reaches the commanded speed. This result is consistent with previous investigations of PUM dynamics.³

Results shown in Fig. 5 are not sufficient for devising model-based control due to the behavior of the commercial controller. This controller is intended to regulate motor speed and, therefore, varies drive signal frequency as a function of



PUM—A specialist in custom-driven motors, Chakkungal Joseph Joseph arrived at UHCL with a B.S. in electrical engineering from the Cochin University for Science and Technology, India. He earned an M.S. in systems engineering at UHCL, studying space-based robots that typically require actuators exhibiting high precision, light weight, and simplicity. Piezoelectric ultrasonic motors (PUM) are well-suited to meet these requirements.

motor feedback signal amplitude. Furthermore, the controller does not permit operation at the low speeds that may be necessary in space robotics applications. In order to facilitate more precise measurements and control, a new driver was designed that permits precise control of drive signal frequency and amplitude throughout the range of drive signal frequencies and amplitudes and motor speeds. The new driver schematic is shown in Fig. 6. This driver was subsequently fabricated and will be used to perform more exhaustive experimental characterization of motor dynamic response.

Acknowledgments

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References

¹T. Sashida and T. Kenjo. *An Introduction to Ultrasonic*

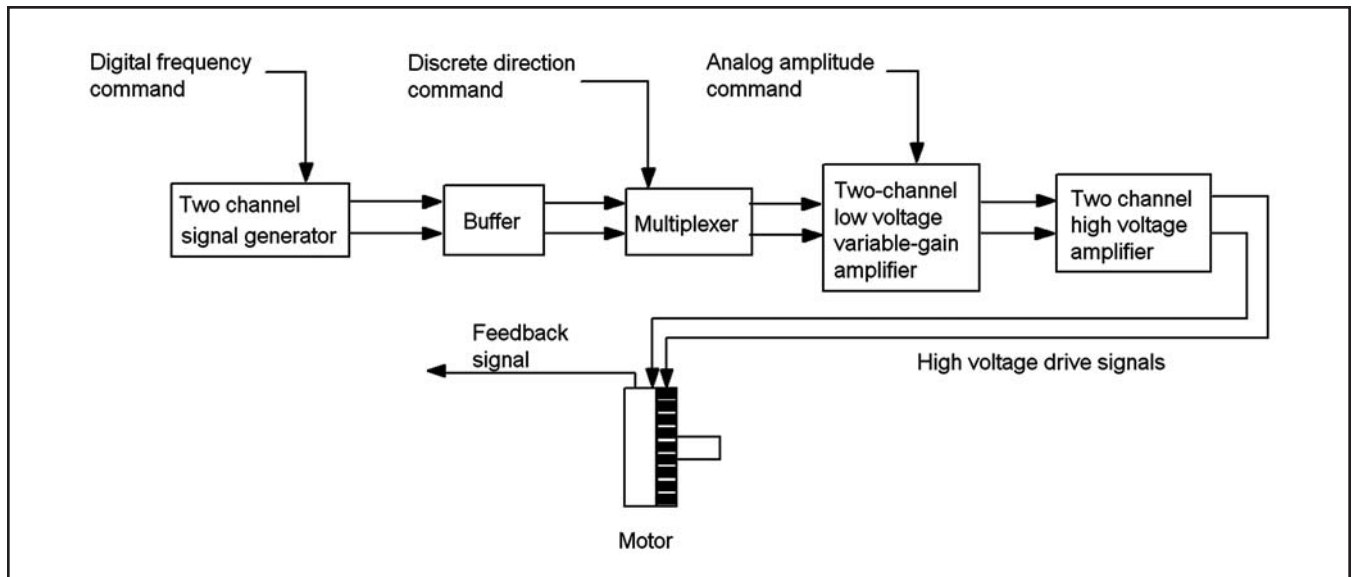


Figure 6. Custom Motor Driver Schematic Diagram

Motors. Oxford, UK: Clarendon Press, 1993.

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

³N. 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.

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

Publications

Dabney, J. B., T. L. Harman, and J. J. Chakungal. "Kinematic Control of a Piezoelectric Ultrasonic Motor." UHCL Systems Engineering Laboratory Report, SEL-005. Houston: UHCL, 2003.

Dabney, J. B., T. L. Harman, and F. H. Ghorbel. "Piezoelectric Ultrasonic Motor Modeling and Kinematic Control." UHCL Systems Engineering Laboratory Report, SEL-006. Houston: UHCL, 2003.

Presentations

Dabney, J. B., T. L. Harman, and F. H. Ghorbel. "Piezoelectric Ultrasonic Motor Modeling: State of the Art and Future Directions," International Conference on Signals, Systems, and Information Technology, Sousse, Tunisia, March, 2003.

Dabney, J. B., T. L. Harman, and F. H. Ghorbel, "Issues in Piezoelectric Ultrasonic Motor Modeling," Innovations Conference, Houston, TX, May, 2003.

Funding and proposals

Dabney, J. B. "Advanced Piezoelectric Ultrasonic Motor Driver Development and Testing," UHCL Faculty Research Support Fund, Jan.-June, 2003, \$10,180.

—. "Piezoelectric Ultrasonic Motor Modeling and Control," Texas ARP, June, 2003 (*program cancelled*).

—. "Advanced Control of Piezoelectric Ultrasonic Motors," National Aeronautics and Space Administration, Aug., 2003. \$100,000.