

STOP! What's that light at the end of the tunnel?

By Murray Johns

The safety of after dark driving depends partly on the retro-reflective property of road signs, pavement markings, and other traffic control devices. However, measurements of this property, which is the material's ability to bounce light back from a vehicle's headlights, have varied by as much as 20 to 40 percent between available instruments and from laboratory to laboratory. These variations and the lack of national calibration standards for retro-reflectivity can lead to difficulties between signage manufacturers and buyers representing state departments of transportation.

To resolve these variations and to establish industry standards, the National Institute of Standards and Technology (NIST) has established the Center for High-Accuracy Retro-reflection Measurements. The heart of the new center is a dedicated reference instrument: a high-precision, six-axis goniometer designed by Dynamic Structures and Materials LLC (DSM) and installed at NIST's Gaithersburg, MD facility. The goniometer provides closed loop control of six independent degrees of freedom and travels 30 meters on a precision rail assembly. The system's robust design is large enough to accommodate road signs such as the octagonal STOP sign used in the U.S. (about 1 meter in diameter).

The 50-meter black tunnel houses the goniometer to eliminate stray illumination that could interfere with researchers' measurements. During experimentation, light is projected from a source (representing a headlight) onto a test object such as a road sign or pavement marking. The light is retro-reflected to a photometer, which measures the amount of returning light (simulating what a vehicle's driver might see). Measurements in the facility are traceable to the candela, a SI unit maintained by NIST.



System specifications for high angular resolution

The specifications for high angular resolution and accuracy in the goniometer's operation resulted from the desire to use the equipment as a research instrument as well as a calibration device. Vertical deviation of the goniometer system's center over the 30-meter rail length is within ± 0.75 mm, and horizontal deviation of the center is within ± 1.0 mm. Table 1 shows the final system specifications.

As part of the system's post-installation characterization, NIST determined that for any one axis move, the system's sphere of confusion is an ellipsoid of dimension 0.35 millimeters in the vertical direction and 0.12 millimeters in the horizontal direction.

Researchers at a remote PC control the motion of the system's axes through

custom software written under National Instruments' (NI) LabWindows software. MXI-3 technology, a PCI master/slave system, couples the remote PC via a fiber-optic data link running the length of the hallway to a National Instruments PXI-1002 chassis incorporated into the goniometer's structure. The PXI chassis also houses two NI PXI-7334 stepper motor motion cards and an NI PXI-8421/2 card to provide an interface for RS-485 communication with the system's 30-meter linear encoder.

DSM also incorporated an enclosure in the system's structure to protect the stepper motor drives and two NI UMI-7764 Universal Motion Interfaces. The UMI boxes provide connections for step and direction signals from the motion controllers to the stepper motor drives as well as connections for the majority of the position encoders. E-stop switches installed on the goniometer

Axis of Motion	Range of Motion	Minimum Step Size	Positioning Accuracy
X (parallel to rail)	± 46 cm	< 100 µm	< ± 0.25 mm
Y (perpendicular to rail)	± 30.5 cm	± 10 µm	< ± 0.050 mm
Z (vertical)	± 30.5 cm	± 10 µm	< ± 0.050 mm
Pitch	± 95 deg	0.0002 deg	< 0.001 deg
Yaw	± 95 deg	0.0002 deg	< 0.001 deg
Epsilon	± 185 deg	0.0002 deg	< 0.001 deg

Table 1

frame in easy reach of any bystander are routed to relays that disable power to the system's motors.

Precision motion control system

The accuracy of the goniometer's motion control system over such large motion ranges is made possible through the use of high-end motion components and sensors. Five-phase Vexta Nanostep CFKII 569 stepping motors were chosen to produce precision motion for the three rotational axes of the goniometer. Two-phase Vexta CSK 268MAT stepping motors drive the linear axes of motion. When set at the smallest step angle, the five-phase Vexta stepper motors have 125,000 steps per revolution. DSM successfully coupled the stepper motors to high accuracy harmonic drives with a 160:1 gear reduction that yielded a potential resolution of greater than 20 million steps per revolution. Using

rotary encoders to provide position feedback, actual *closed-loop* minimum step size for the three rotational axes was less than 0.0002 degrees or 1.8 million steps per revolution.

DSM selected HD Systems harmonic drive gear reducers to couple with the stepping motors. The harmonic drives achieved a 160:1 single stage gear reduction in a very small package. The HD systems CSF-2UH gearheads have virtually zero backlash and come with built in roller bearings to support the output shaft. The HD harmonic drives provided dramatic increases in stepper motor holding torque to control the rotation of the large goniometer support frame with authority.

Each axis of the goniometer is monitored by an encoder and limit switches. The limit switches were incorporated

into the frame to protect each axis against overtravel by disabling signals to the respective axis motor. The encoders selected for the three rotary axes are from the Mercury 2000 family of high precision encoders from MicroE Systems, Inc. The optical encoders use glass-scales with interpolator electronics that enable up to 4.19 million counts per revolution. MicroE Systems precisely mounted the glass scales to DSM's custom-designed encoder hubs. The encoders' small read heads were easily incorporated into the goniometer's structural design, and their robust tolerance to misalignment made adjustments during installation fast and simple.

With the aid of the new goniometer system's capabilities, NIST researchers hope to achieve agreement among retro-reflectivity instruments and to make federally mandated standards more precise. **PXI**



Murray Johns enjoys time with his family and working with the great team at DSM. He received his BSME degree

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