ROSI: the new NIST reference facility for UV-SWIR specular and diffuse reflectance calibrations

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We report on ROSI, the new NIST reference instrument for specular and bidirectional diffuse reflectance measurements at UV-SWIR (250 nm to 2400 nm) wavelengths. ROSI employs high-brightness tunable light sources and a robotic arm goniometer that have enabled the expansion of diffuse bidirectional reflectance calibrations in the SWIR and research measurements to out-of-plane geometries. We describe the determination of correction factors, uncertainty budget, and validation of ROSI. We will also describe the addition of an integrating sphere for directional/hemispherical reflectance calibrations.

INTRODUCTION

NIST maintains a robust program in reflectance calibrations and research in support of stakeholders from NASA and other government laboratories to manufacturers of optical instruments and components. For many years the NIST reference reflectometer for UV-SWIR wavelengths has been the Spectral Tri-function Automated Reference Reflectometer (STARR) [1]. The new facility, the Robotic Optical Scattering Instrument (ROSI),[2] addresses growing demand for reflectance measurements at expanded geometries, leverages technological advances in light sources, and features the unobstructed sample viewing, reliability and repeatability of a robotic arm goniometer. We describe the operation of ROSI for bidirectional and specular reflectance calibrations and report on progress towards the addition of directional/hemispherical calibrations to ROSI.

SYSTEM DESCRIPTION

As shown in Figure 1, light from either a broadband supercontinuum fiber laser or a Xenon laser-driven light source (LDLS) is coupled into a monochromator to allow tunable output from 250 nm to 2400 nm. After passing through a diffuser, chopper, and circular aperture (not shown), the output is polarized and imaged to a 1-cm diameter spot incident on the sample plane of the robot goniometer for bidirectional measurements. The 8/di measurement capability (dotted line illumination path) is under development.

In the robot goniometer, light is collected by the UV-SWIR receiver, which consists of a precision aperture followed by a lens that focuses light to one of two detectors that can be translated into position behind the aperture/lens assembly. A silicon photodiode is used for UV-NIR (250 nm to 1100 nm), and an extended InGaAs photodiode on a small integrating sphere is used for SWIR (1000 nm to 2400 nm) wavelengths. The reflectance measurements are absolute: the receiver can be positioned to measure both the incident and reflected flux. The combination of the robotic arm sample holder and the rotation of the receiver arm enables reflectance measurement at nearly any combination of incident and viewing angles.

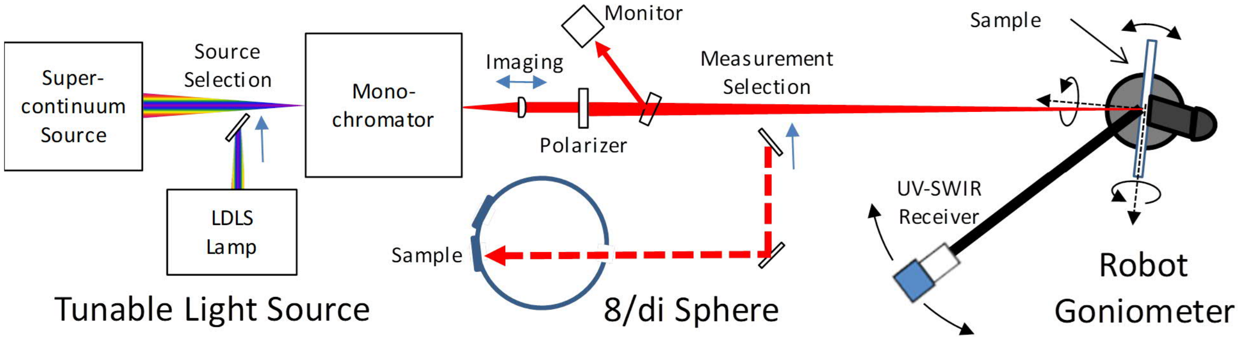

Figure 1: Schematic of the ROSI facility. Commissioning of the tunable light source for wavelengths from 250 nm to 2400 nm, and the Robot Goniometer for bidirectional reflectance calibrations, is complete. The 8/di sphere is operational, with directional/hemispherical calibration capability under development.

VALIDATION AND UNCERTAINTY

As part of the instrument validation for ROSI, we measured a sintered PTFE sample that had been previously measured by the NIST STARR facility and the Physikalisch-Technische Bundesanstalt (PTB) Gonioreflectometer for 0/45 diffuse reflectance factor [3]. The results and residuals are shown in Figure 2. The residuals generally fall within the combined expanded uncertainty for each pair of instruments, validating the quality of measurements obtained on ROSI.

Table 1 shows the components of a typical uncertainty budget for reflectance factor of sintered PTFE. Dominant uncertainty components come from the receiver efficiency uniformity, sample uniformity, illumination centering, and viewing angle. The latter two components are geometrical and arise from our ability to set and maintain alignment of the incident and viewing. Sample uniformity is sample dependent and is evaluated by measurements at different locations on the sample. The receiver efficiency uniformity component is the uncertainty in a correction factor that accounts for differences in efficiency of collecting diffusely scattered reflected flux compared to collimated incident flux. Details of the instrument characterization, uncertainty budget, and research applications of ROSI will be presented at the conference.

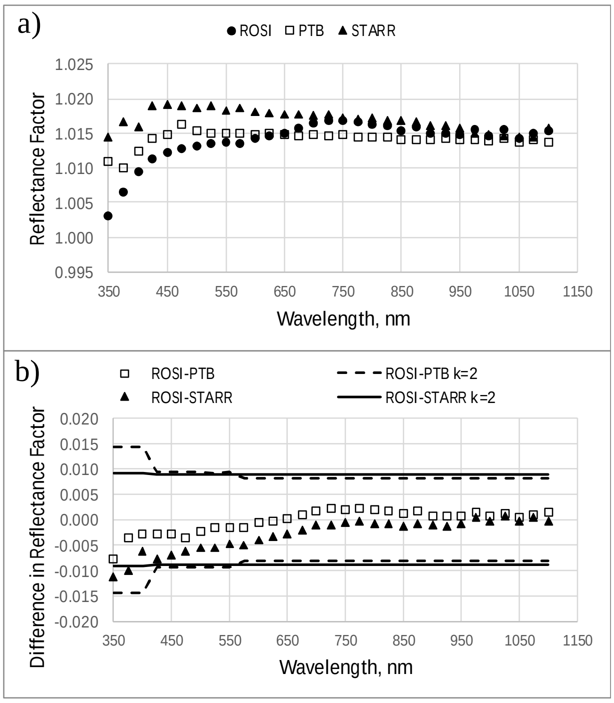

Figure 2a). Reflectance Factor vs. Wavelength for a sintered PTFE sample, denoted PTFE#1 in Ref. 3, as measured by ROSI (solid circles), the NIST STARR facility (solid triangles) and PTB (open squares). STARR and PTB data from Ref. 3. **b)** Residual difference in Reflectance Factor between ROSI and STARR (solid triangles) and ROSI and PTB (open squares) along with the combined *k* = 2 for each instrument pair.

Table 1. Nominal Relative Uncertainty Contributions (*k* = 1) and Expanded Relative Uncertainty (*k* = 2) for 0/45 reflectance factor of a typical sintered PTFE diffuse reflectance standard measured at 550 nm.

Source of Uncertainty	Relative Uncertainty Contribution
Aperture Distance	0.03 %
Aperture Area	<0.01 %
Finite Solid Angle Calculation	0.05 %
Illumination Centering	0.16 %
Detector Gain Ratio	0.06 %
Lock-in Amplifier Sensitivity Ratio	0.02 %
Receiver/Monitor Gain Ratio Stability	0.04 %
Receiver Efficiency Uniformity	0.32 %
Detector Noise	0.01 %
Wavelength	<0.01 %
Sample Uniformity	0.20 %
Incident Angle	<0.01 %
Viewing Angle	0.09 %
	Expanded Relative Uncertainty
	0.86 %

FUTURE WORK

The characterization and validation of an integrating sphere for 8/di reflectance measurements is underway, and when commissioned, will complete the transition of all UV-SWIR reflectance calibration services to ROSI.

REFERENCES

1. J.E. Proctor and P.Y. Barnes, “NIST high accuracy reference reflectometer-spectrophotometer”, J.Res. NIST 101, 619-627, 1996.
2. H.J. Patrick, C.J. Zarobila, and T.A. Germer, “The NIST Robotic Optical Scatter Instrument (ROSI) and its Application to BRDF Measurements of Diffuse Reflectance Standards for Remote Sensing”, in Proc. SPIE 8866, edited by J.J. Butler, 886615-1–12, SPIE, Bellingham, 2013.
3. C.C. Cooksey, M.E. Nadal, D.W. Allen, K.-O. Hauer, and A. Hoepe, “Bidirectional reflectance scale comparison between NIST and PTB”, Applied Optics 54 (13), 4006-4014, 2015.