Spatial Light Modulator-based Advanced Radiometric Sources

S. W. Brown, J. P. Rice, B. C. Johnson, D. W. Allen, G. T. Fraser, and Y. Ohno
National Institute of Standards and Technology, Gaithersburg, MD, USA

I. Fryc
Bialystok University of Technology, Bialystok, Poland

Abstract. We describe the development of spectrally programmable light sources that can generate complex spectral distributions for radiometric, photometric and colorimetric applications. One of the underlying goals of this work is to establish application-specific metrics to quantify the performance of radiometric systems. For example, systems may be quantified in terms of the accuracy of measurements of standardized, spectrally complex, sets of source distributions. In essence, the programmable spectral source will be a radiometric platform for advanced instrument characterization and calibration that can also serve as a platform for algorithm testing and instrument comparison.

Introduction

Current radiometric standards disseminated by National Metrology Institutes (NMIs) such as the National Institute of Standards and Technology (NIST) in the U. S. are spatially uniform and have spectral properties that vary smoothly with wavelength. The spectral and spatial characteristics of radiometric sources based around traditional technologies, *e.g.*, tungsten filament lamps and blackbodies; reflectance plaques and integrating spheres, are important for general calibration applications, but tend to have limited utility for advanced characterization and calibration measurements. The absence of relevant, application-specific, radiometric artifacts to evaluate the performance of instruments limits the ability of end users to verify the measurement results, sometimes with adverse consequences. Consequently, the need exists for advanced calibration artifacts to improve measurement accuracies in a wide variety of applications, ranging from basic colorimetric characterization to remote sensing radiometry.

Advanced calibration artifacts include spatially as well as spectrally complex sources. Spatial scene generators have been developed for infrared calibrators [Nelson], and spectrally programmable light engines are under development for use in medical endoscopes [MacKinnon], to generate standard source distributions [Fryc, Wall] and for general use in radiometric, colorimetric, and photometric research [Fryc]. In a fully integrated hyperspectral scene generator, spatially complex scenes with high spectral fidelity would be generated. There is a leadership role for NMIs, responsible for the development and dissemination of radiometric calibration standards, in the development of advanced radiometric artifacts, in particular in multidisciplinary fields where no other government agency or standards organization has a mandate. In this work, we describe the development of an Advanced Radiometric Source (ARS) and give several example radiometric characterization and calibration applications of the technology.

Advanced Radiometric Sources

A variety of different approaches to the development of spectrally tunable sources have recently been described, including the use of spatial light modulators [Serati] or light-emitting diodes (LEDs) [Fryc, Gamma Scientific, Ries]. In this work, we describe an ARS based around a dispersing element and a spatial light modulator (SLM). The system is basically a spectrograph, with a spatial light modulator replacing the multi-element detector at the focal plane of the spectrograph. In this case, the dispersed light falls on the SLM, creating a relationship between the spatial location on the modulator and the wavelength of the light. By varying the transmittance or reflectance of the elements comprising the SLM, spectrally diverse distributions can be created. High fidelity spectral matches to a specific target distribution can be readily achieved, with the resolution defined by the properties of the imaging system. The system can be operated in either dc or ac mode, creating either constant or pulsed spectral distributions.

While a variety of SLMs can be used, the ARS described in this work uses a Digital Micromirror Device (DMD) as a spatial light modulator. DMDs are selectively and dynamically controllable, micro-mirror arrays; they are commonly found in projector displays and wide format televisions. DMDs use aluminum mirrors, and spectrally tunable sources can be created from the ultraviolet to the short-wave infrared, limited only details of the imaging system. Replacing the window, spatial light modulators can be created in the infrared as well.

An arbitrarily shaped spectrum, representing a target spectral radiance, is generated by turning on different numbers of elements of a micro-mirror column corresponding to the required wavelengths. The fundamental radiometric distribution of the source depends on the spectral output of the primary source and details of the imaging properties of the spectrograph. Consequently, the source intensity can be modulated by changing the number of mirror elements 'on' while maintaining a constant spectral distribution.

Example Applications

Colorimeters are calibrated against Illuminant A and their uncertainties when measuring sources with spectral distributions similar to Illuminant A are commonly provided. However, those data provide little information about the performance of colorimeters when measuring sources with different spectral distributions. Using the ARS, a variety of spectral distributions can be readily generated to provide a more useful or accurate metric for the evaluation of the general performance of colorimeters. Example distributions, for example distributions similar to those used to generate a Color Rendering Index for sources, will be presented and discussed.

The ARS can produce spectral distributions tailored to a particular application. In a specific application to be presented, the ARS generates the spectral distributions of ocean color with varying chlorophyll concentrations. Instruments that measure ocean color can measure the same spectral distributions in the laboratory, thereby establishing or verifying their radiometric accuracy.

Summary

With the trend toward performance-based metrology requirements, NMIs well-defined role in measuring and verifying the performance of radiometric systems is becoming more critical. The development of spectrally tunable sources enables NMI measurement and calibration services to respond to new radiometric requirements by providing necessary, relevant technology that tests the end performance of radiometric systems used in critical applications.

Acknowledgments We would like to acknowledge and thank Jacqualine Jackson from the Brigham Young University for her assistance with this work.

References

Fryc, I., S. W. Brown, G. P. Eppeldauer, and Y. Ohno, LED-based spectrally tunable source for radiometric, photometric, and colorimetric applications, *Opt. Eng*., accepted for publication.

Gamma Scientific, Inc., San Diego, CA, USA; www.gamma-sci.com; RS-5M light source.

MacKinnon, N. et al., Spectrall programmable light engine for *in vitro* or *in vivo* molecular imaging and spectroscopy, *Appl. Opt.* 44, 2033-2040, 2005.

Nelson, N. R., P. Bryant, and R. Sundberg, Development of a hyperspectral scene generator, *Proc. SPIE* 5151, 480-484, 2003.

Ries, H., I. Leike, and J. Muschaweck, Optimized additive mixing of colored light-emitting diode sources, *Opt. Eng*. 43, 1531-1536, 2004.

Serati, S., T. Ewing, and J. Stockley, "New developments in high-resolution liquid-crystal spatial light modulators for wavefront control, *Proc. SPIE* 4825, 46-55, 2002.

Wall, C., et al., Construction of a programmable light source for use as a display calibration artifact, *Proc. SPIE* 4295, 259-266, 2001.