Advanced Radiometric Characterization and Performance Validation Metrology for Hyperspectral Imaging Systems

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Abstract

Current radiometric calibration standards, specifically blackbody and lamp-based optical radiation sources, produce spatially, spectrally, and temporally simple scenes. Hyperspectral imaging instruments, which in-practice view spatially, spectrally, and temporally complex scenes, would benefit from advanced radiometric artifacts that more closely resemble scenes the sensor will ultimately view. Techniques and artifacts that advance sensor characterization and algorithms that reduce the impact of scattered light on sensor performance are presented in this work. Example applications of the new technologies and algorithms on remote sensing hyperspectral imaging instruments are presented.

Introduction

Currently, the lack of appropriate artifacts limits the ability of researchers to fully characterize and understand the radiometric performance of hyperspectral imaging sensors in the laboratory with the result that problems in a sensor's performance can remain undiagnosed or be first observed when the instrument is in-use. Lacking adequate characterization, it is not possible to develop algorithms that correct a sensor's output for limitations in performance. Advanced radiometric artifacts that enable more complete instrument characterization in the laboratory facilitate development of correction algorithms with the resulting potential benefit of improved radiometric performance. In this work, advanced characterization and performance validation tools are discussed along with spectral and spatial scattered light correction algorithms.

Radiometric Characterization Tools

The wavelength accuracy, bandwidth, and available power combine to make tuneable lasers powerful tools for characterizing and calibrating larger aperture hyperspectral imaging systems. The National Institute of Standards and Technology, NIST, (USA) has recently expanded on laser-based facilities previously developed at NIST and the National Physical Laboratory, NPL, (UK) and developed a broadly tunable laser-based radiometric calibration facility.[1] The facility has been used to characterize and calibrate spectrographs as well as hyperspectral imaging systems.

Scattered Light Correction Algorithms[2, 3]

Spectral[4] and spatial [4, 5] stray light correction algorithms have been developed for spectrographs and imaging systems based on the characterization of the radiometric system using tunable laser sources. These algorithms correct measurements for errors introduced by scattered light by one to two orders of magnitude. The spectral stray light correction algorithm has been successfully used to correct hyperspectral instruments used in the vicarious calibration of ocean color satellite sensors[6] and instruments used to measure Light Emitting Diodes (LEDs).

Absolute Detector-based Spectrally Tunable Source[7, 8]

Spectrally tunable sources (STSs) with user-definable output are based on placing a Digital Micromirror Device (DMD) at the focal plane of a spectrograph, thereby replacing a multi-element detector, such as a CCD, with a 2-d array of aluminum mirrors that can be individually addressed, i.e. turned on or off. In an STS, incident radiation is dispersed across the array of mirrors. By turning on different columns of mirrors, different spectral components of the incident radiation are reflected; by turning on individual mirrors within a column, the intensity of the reflected radiation at that particular wavelength can be controlled.

By running the tunable source in ‘monochromator-mode’, so turning on only one (or a few) column(s) at a time, and measuring the resultant output radiant flux with a calibrated photodiode, it is possible to place an absolute spectral radiant power scale on the integrated output of the source, resulting in an absolute detector-based source. The source can be used to directly calibrate an instrument, and it can be used to validate the performance of an instrument by generating a variety of known source spectral distributions.

Hyperspectral Image Projector[9]

A Hyperspectral Image Projector (HIP) is a system designed to project a potentially different, user-definable spectral distribution into each pixel in a projected scene. HIP consists of an STS coupled with a spatially programmable projection system. HIP serves as a radiometric platform for the development of application-specific metrics to quantify the performance of sensors and systems in terms of the accuracy of measurements of standardized sets of spatially, spectrally and temporally complex source distributions. In essence, HIP will be a radiometric platform for laboratory validation of a hyperspectral imager calibration. The same platform can also serve as a basis for algorithm testing and instrument comparison.

Conclusions

The technologies and algorithms I will be discussing should serve to improve the characterization, calibration and ultimately the performance of radiometric hyperspectral imaging systems, instruments that play a key role in areas ranging from Earth remote sensing, medical imaging and law enforcement. Work continues at NIST on exploration of new technologies and algorithms to aid in the characterization and calibration of radiometric instrumentation.

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