

RADIOMETRIC GROUND TRUTHING FOR AIRBORNE AND SATELLITE SENSOR TESTS

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ABSTRACT:

This paper presents processes and performance for ground-based measurements used by The Boeing Company and RESOURCE21 for vicarious calibration tests of airborne and satellite multispectral and hyperspectral sensors. We highlight our methodology for measuring downwelling irradiance and scene radiance and reflectance from 400 to 2500 nm, and describe in-house enhancements made to commercial spectroradiometry hardware and software, developed over a period of four years, that facilitate data management and interpretation. Results from tests of the measurement protocols are presented. We present our web-based approach to file management and access, data processing, and quality assessment. Finally, "lessons learned" and issues associated with ground truthing for vicarious sensor tests are discussed.

1. INTRODUCTION

The Boeing Company has been conducting field tests of airborne and satellite multispectral and hyperspectral sensor systems in support of RESOURCE21, LLC (R21) of Denver, Colorado since 1996. Most tests supported development remote sensing products to support agriculture crop production, but many involved vicarious tests of the radiometric performance of the sensor systems. This paper highlights the instruments, measurement techniques, and data management systems used for ground truthing of the sensor systems tests with emphasis on the spectral measurements.

Organizations working with us included the United States Department of Agriculture/Agricultural Research Service (USDA/ARS), The University of Nebraska/Lincoln, and Agriculture and Agri-Food-Canada, a Canadian government organization similar to the USDA. Tests were conducted at multiple locations across North America, and included resident participants in addition to our own engineers and data analysts. Duplicate measurement equipment suites and protocols were used at the sites by different organizations, all operating in parallel. Data sets and measurement records were transferred to a central location, where they were accessible from each test location as well as by the R21 and Boeing research staff. A central processing center quality-checked and processed all ground-based hyperspectral measurements. Data sets were accessed and interpreted by multiple researchers who may not have been active participants in the data collection.

To accommodate this test approach, we developed a spectral measurement system with the following characteristics:

- Reflectance error of better than 1 percent, relative.
- Highly repeatable protocol, with measurement variability attributable to the protocol \ll 1 percent.
- Up to 6 hours continuous operation in the field

- Useable by students and technicians with little prior training
- An image record of the measured scene
- Protocol-cueing for the system operator
- Automated data quality assessment
- Automated data processing to radiance and reflectance
- Filenaming convention consistent with 35 other data types associated with associated ground and airborne measurements.

2. TEST SITE INSTRUMENTATION

At a typical test site (figure 1), crop stresses were established in 40 x 40-ft plots. This plot size was selected in order to provide a large number of pixels/plot in the image data collected by our airborne multispectral sensors. Numerous samples of crop tissues and soils were collected to quantify plant health and nutrient availability. Geometric and radiometric references were established on each site for testing the absolute geometric and radiometric calibration of the airborne system. A test site typically included reflectance reference tarps for which radiances and reflectances were measured during the sensor overflight. Our calibration tarps were of a canvas material, manufactured by Tracor Aerospace with nominal reflectances of 4, 8, 48, and 64%. They were deployed and retrieved for each overflight. MFR-7 multifilter rotating shadowband radiometers manufactured by Yankee Environmental Systems, Inc. were also established at each test site. These instruments provide the basis for specifying atmospheric column water vapour, ozone, and aerosol optical depth at the site, which can be used with a radiative transfer code to predict the radiance that should be measured by an airborne or space-based sensor for targets of known reflectance. Comparison of this "predicted" radiance with the radiance measured by the sensor provides a check on the sensor calibration and sensor control of stray light.



Figure 1. Example field test site.

All-sky cameras recorded cloud cover and distribution at each site during overflights. We used simple digital cameras suspended over “hubcap” mirrors to acquire a qualitative image record of the sky. The key instruments used for ground truthing the radiometric performance of the test sensors were FieldSpec FR hyperspectral radiometers, manufactured by Analytical Spectral Devices (ASD) in Boulder, Colorado. These instruments proved reliable and durable, operating in temperatures from freezing to over 100 degrees F. The application of these ASD radiometers to our measurement requirements is highlighted in this paper.

3. GROUND-BASED TARGET RADIANCE AND REFLECTANCE MEASUREMENTS

3.1 Boom-mounted system configuration

A boom-mounted system configuration proved advantageous for our ground-based spectral measurements (figure 2).



Figure 2. Boom-mounted spectral measurement system.

We leased these platforms from local equipment suppliers, and hard-mounted the measurement equipment to them. The platforms supported deep-cycle batteries connected to DC-to-AC inverters for hours of continuous measurements. The platforms also provided line-of-site control, ensuring nadir-viewing over variable terrain conditions, and allowed operators to position themselves over the center of the reference tarps or crop plots at heights appropriate for the desired sampling size. We typically operated at 35-ft above the target, which resulted in a 90-inch diameter measurement area for our radiometer. A slider mechanism was mounted to the bottom of the personnel cage and supported a 1x1-ft Spectralon panel that could quickly be positioned beneath the foreoptic for a reference measurement, and then withdrawn into a protective enclosure for target measurements. Typically, readings of the spectralon panel and target were separated by 10-15 seconds. The entire system could be operated by one person if necessary, although it was preferable to have two people in the basket (one driver and one instrument operator) to acquire measurements at a faster rate. Our protocol was a measurement of the spectralon panel followed by a target reading, for every reflectance measurement. We recorded raw digital numbers, which were later processed to radiances for the spectralon reference and target scenes.

3.2 Radiometer modifications

The FieldSpec FR hyperspectral radiometers use a fiberoptic cable bundle to bring light into the instrument, where it is split and delivered to three spectrometer systems, providing spectral coverage from 350–2500 nm. We developed a customized foreoptic, as well as additional control software to expand the utility of the data from the instrument.

3.2.1 Foreoptic

To limit the radiometer field of view to about 12-degree (FWHM), we used a simple well-baffled foreoptic (fig 3) which was attached to the radiometer fiberoptic cable. A Tiffen 2A haze filter on the foreoptic facilitated monitoring system dark current for the visible spectrometer from 350 to 370 nm, a wavelength regime that was not critical to our applications. This foreoptic also served as a sturdy mount for a Sony XC-999 color video camera and still camera that allowed us to capture low and high resolution images of the targets.



Figure 3. Baffled tube foreoptic with film and video cameras.

3.2.2 Custom software interface

In 1997 we initiated a contract with Analytical Spectral Devices to modify their system control software to allow interaction with a Windows-based software application that we developed. Figure 4 shows the control menu and screen that the operator sees when operating the radiometer.

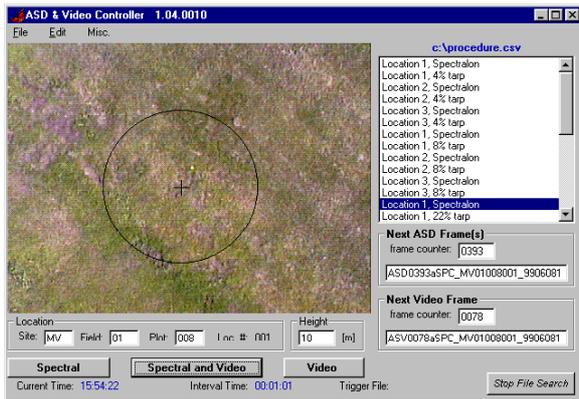


Figure 4. Video and ASD radiometer control interface.

This interface features:

3.2.3 Video window. A real-time video display from the video camera on the foreoptic is displayed on the system operator's control computer screen. The black circle indicates the field of view of the FieldSpec FR.

3.2.4 Protocol script window. The protocol script window displays pre-programmed measurement steps to be executed by the system operator. In the script shown in figure 4, the operator was to take a reading of the spectral reference panel, followed by a reading of the reference tarp, and repeat that process three times before proceeding to the next tarp.

3.2.5 File name for the spectral data. Our filenames protocol identifies every spectral file with abbreviations for data type, a sequence number, system setup identifier, target type (e.g., spectralon, tarp, canopy, soil), site name, field number, plot number, measurement number, and date and time of measurement. In the example shown the next file to be recorded would be identified as data recorded by an ASD instrument, sequence counter number 0393, system setup "a", of a spectralon panel measured in Mount Vernon (MV) Washington, field number 01, tarp identifier 008, measurement number 01, recorded June 8, 1999. The file name would also include time of day to the nearest minute.

3.2.6 File name for the video frame. The video frame filename is identical format to the spectral data filename, except with a different data type preface.

After positioning the system for a measurement, the operator need only press the control computer RETURN key, initiating the following sequence:

1. FieldSpec radiometer readings were recorded, and the files named according to the naming convention.
2. A single video frame was captured, and the file named according to the desired naming convention.
3. The control script incremented and highlighted the next step to be performed.

This protocol scripting helped standardize the measurement procedure, sped up data collection, ensured consistent file

naming for automated post-processing, and minimized operator-required interactions with the equipment.

3.3 Automated Data Quality Assessment

When taking a spectral measurement, we record five separate, sequential spectral data files in rapid succession, typically taking about five seconds duration. Post processing comparison of those five files allows a first-order check on data consistency. We compare averages of the VNIR, SWIR1 and SWIR2 spectral regions between the files. If they vary by a predetermined tolerance (typically 1% for the VNIR), then the data is disregarded as having excessive variability. Typically, this occurs for two reasons: the illumination was changing on a time scale of seconds or (2) a malfunction in the control software handshaking between the DOS-based ASD control and Windows-based video control programs that are running simultaneously on the system.

4. PROTOCOL QUALIFICATION TESTS

Qualification tests for reflectance accuracy and measurement repeatability confirmed the performance of our measurement protocols.

4.1 Reflectance Accuracy

In 1998 we made a side-by-side measurement test with the USDA/ARS Southwest Watershed Research Center group in Tucson, AZ. In this test, a USDA Exotech 4-band radiometer was used to independently measure the reflectances of our tarps. We used our boom-mounted system to simultaneously measure the tarps, and wavelength-averaged the hyperspectral data across the Exotech spectral bands. The two methodologies agreed to within 0.3% with an R-square correlation coefficient of 0.9997 (fig 5).

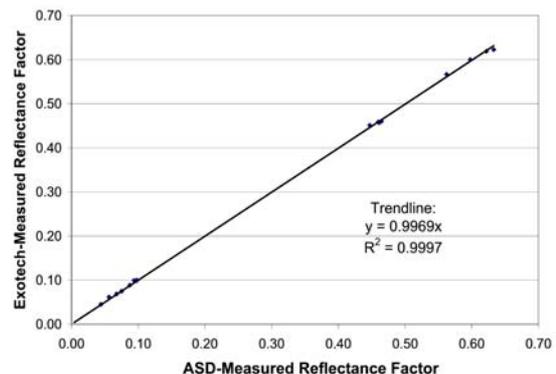


Figure 5. Agreement between tarp reflectance measurements made using an Exotech vs. FieldSpec radiometer.

4.2 Measurement Repeatability

To test the measurement protocol repeatability, we collected sets of 30 successive measurements of tarp reflectances on a clear, stable day using the boom-mounted system from our standard height of 35-ft above the target.

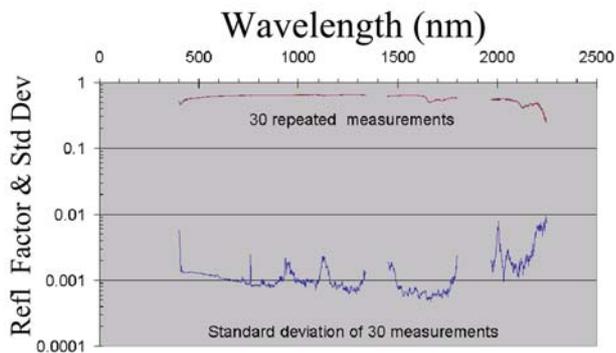


Figure 6. Example results from protocol repeatability test, showing reflectance measurements and the standard deviation as a function of wavelength for a set of 30 measurements of the 64% tarp.

Our results (fig 6) show worst-case standard deviations of < 0.0013 for target reflectances up to about 0.57 (0.23%, relative error) and 0.0002 for dark targets of about 0.04 reflectance (0.56%, relative error). These are worst-case deviations, occurring at blue wavelengths. Better performance was achieved at green and longer wavelengths, within atmosphere-transmitting spectral windows.

5. DATA MANAGEMENT

Our field research database includes 35 different data types from measurements made at 11 test sites (to date) and are stored on a Boeing server in Seattle, WA. A web-based browser permits local or remote users with approved access to browse the data sets, examine individual data files, and compile similar-type files into tables for analysis. Figure 7 illustrates the user interface, where searches may be initiated by data type, site, and date.

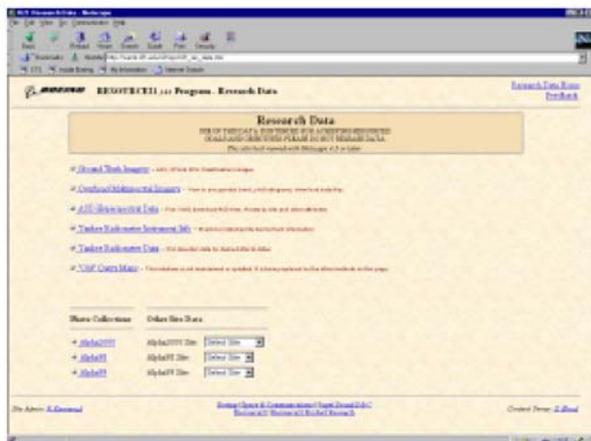


Figure 7. User interface to the research database.

Once data sets have been identified, samples of like data type may be selected for visual examination such as for image data (Fig 8), or tables may be constructed to combine numerical measurements for analysis.

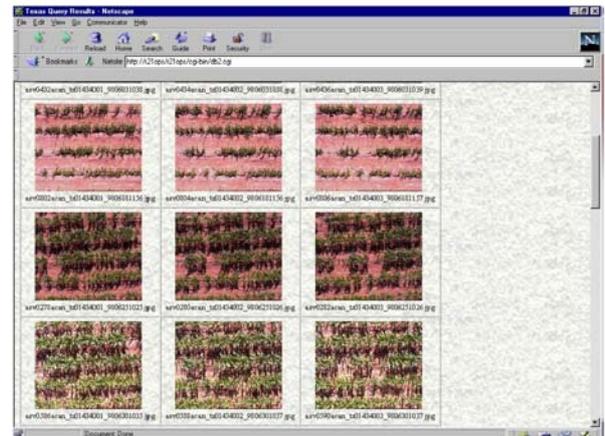


Figure 8. Example of database browse results, showing nadir-viewing image data captured of research plots. Image data such as these accompany most spectral measurements to provide scene context.

6. LESSONS LEARNED AND RECOMMENDATIONS

At the end of each field research year from 1996 to 1998, our group compiled “lessons learned” by polling system users, analysts, field workers, and program management. Our lessons-learned list actually doubled in size each year, rather than decrease as one might expect. But each year, although the number of lessons increased, the impact of each lesson was smaller, which we took as an encouraging confirmation of progress.

At the risk of stating the obvious, here are some of our most significant lessons and recommendations:

1. Allow at least a year to learn the idiosyncrasies of a new instrument. Complex systems such as the MFR-7 shadowband radiometer and ASD spectroradiometer can generate a prodigious quantity of data, good and bad. It may take several months to learn the system characteristics such dark current drift rates, spectral filter shifts, long-term system response drifts, and other sources of measurement variability.
2. Understand how the data is to be used before collecting it. Ideally, one should have a data analysis plan with prioritized collection objectives prior to starting the collection effort. When defining the collection plan, there will be conflicts of collection breadth vs depth, and quantity vs quality. Different users will have different demands, and by having prioritized collection objectives, one may de-conflict data requests. Budgets are never large enough to measure every parameter with the accuracy, frequency and duration that might cover every source of variability with the desired statistical significance. It takes milliseconds to collect an airborne image and hours to collect the ground truth for it, during which time illumination and target conditions are changing and resources are limited.

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3. Take time to understand sources of data variability, and estimate their significance on the end analysis product before starting collections. That way, dollars may be targeted at the biggest offenders.
4. Calibration tarps and panels are often used for testing calibration of airborne and satellite sensors, yet their reflectance properties are rarely understood. Tarps that are folded for storage become creased and are not lambertian, they do not stay clean, and they cannot be cleaned to like-new condition. They should be measured at the time of use, for the illumination and viewing conditions that correspond to the sensor system under test.
5. Unless the tarps or panels become so dirty that their reflectances are no longer in the desired regime, it is preferable to not clean them between uses. If cleaning is attempted, tarps will likely not recover their original reflectances, and it becomes difficult to interpret trends of their reflectance properties over time.
6. When introducing a new measurement protocol to field technicians, test it by having them use it at least 4-6 times on their own on known targets. This will allow both operator and analyst to have confidence in future measurements.
7. An analyst may spend most of his time, perhaps 90% or more, in grouping and compiling data before analysis and interpretation can be made. Although our archive structure is convenient for checking, and archiving multiple data types, improvement is needed to facilitate compiling different data types for correlation analysis.
8. Establish a long-term data archive and data management infrastructure only where it makes sense. It may be more cost effective to maintain a data archive for only a couple of years, and only keep the analysis results conveniently available long-term. Rarely does one revisit "cold" data with success. The conditions under which it was collected are usually not totally recorded, and those involved have either forgotten the details or have gone on to something else.
9. Data analysts should visit the measurement site, and participate in or at least observe ground truth measurements being made. They then have a better awareness of sources of variability in the data that may not be captured in field notes.

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