RADIOMETRIC CONSIDERATIONS IN REMOTE SENSING SYSTEMS

Alexander F. H. Goetz

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Introduction

All sensor systems designed to acquire quantitative data undergo radiometric calibration. The following discussion describes the types and potential accuracies of calibration as well as the needs for calibration in the practical application of sensors. The recent and ongoing experience with the Shuttle Multispectral Infrared Radiometer (SMIRR) will be used as a reference.

Definition of Terms

Calibration is defined as the process by which the output of a sensor is related to the input stimulus. In radiometers and radiometric imaging systems using detectors that translate incoming photons into electrical signals, an amplified output voltage is calibrated in terms of measured spectral radiance in watts m^{-1} sr^{-1} μm^{-1}. The uncertainty of this measurement is dependent on the calibration source and the stability of the detector-electronic sensor system. The sources of spectral irradiance are lamps calibrated by the National Bureau of Standards (NBS) to a standard of spectral radiance such as a high temperature graphite blackbody. The lamps provide a specified spectral irradiance at a given distance from the filament. The absolute accuracies in irradiance under NBS conditions range from 1.4% at 350 nm, 1.1 % at 800 nm and 1.2% at 1600 nm (Slater, 1980). However, international comparison of spectral-irradiance measurements in the 300 - 800 nm range reveal inconsistencies as great as 6.5% (Gillham, 1977).

Although absolute calibration is necessary for establishing standards of comparisons among systems, the present-day requirements for remote sensing of the earth are best served by understanding a spectral sensing system in terms of relative calibration.

Relative calibration means that the output of a sensor under a varying input stimulus maintains the ratio between input and output in all spectral bands. In other words, the spectral character of the reflectance or emittance curves is maintained to the accuracy required for proper interpretation, but the absolute values are not necessarily known. Relative calibration is more readily achieved than absolute calibration and more important for the interpretation of remote sensing data.

Detector response can be either linear or more often non-linear with respect to variation in irradiance. Within a sufficiently small range of irradiance values, depending on the detector type, the output (O) can be described in terms of the input (I) and two constants (a,b) by $O = aI + b$. Over a larger range of values, a series of linear approximations must be used or a power curve of the form $O = aI^c + b$ where c is usually greater than 0.5 and less than 2. Silicon detectors and photomultiplier tubes have inherent linear responses over a large dynamic range while detectors such as HgCdTe used in sensors for wavelengths beyond 1 μm are notoriously non-linear.

Radiometric sensitivity defines the minimum amount of scene contrast that can be detected by a sensor. Signal-to-noise ratio is another term used to describe the same sensor quality. Present-day practice is to define system sensitivity in terms of the minimum detectable change in reflectance, nE$\Delta\rho$ or noise-equivalent change in reflectance for the reflective portion of the spectrum, and nEΔT or noise-equivalent change in temperature in the mid-IR.

Sensors

The analysis and interpretation of earth-looking data today largely ignores the question of calibration. Data are received from the appropriate agency on computer tape in the form of digital numbers (DN) and they are assumed to be relatively calibrated and linear with respect to irradiance. Papers published on interpreted results do not reveal whether the authors were aware of the nature of the calibration or the consequences of any possible miscalibration. The reasons for this are two-fold.

1. Interpreters have a blind faith in the sensor builders.
2. The variability in the irradiances measured due to atmospheric scattering and absorption, surface slope uncertainty, the inhomogeneities in the surface reflectance or emittance, and the uncertainties in interpretation are much greater than the inaccuracies introduced by faulty calibration.

The blind faith in sensor builders is not misplaced. However, to an interpreter who would like to assure himself that his faith is well placed, precious little data are available on calibration procedures and the results of calibration for the spectral imaging systems in use today. An exception is the Landsat MSS (NASA, 1976).

Aircraft scanners in general have reference blackbodies or calibration lamps that provide data at the end of each mirror rotation or scan. These are useful to set amplifier gains and for comparison among data taken at different times. In most cases engineering measurements are ignored by the interpreter. An exception is the use of thermal scanners to determine radiometric temperatures of surfaces. Here high and low temperature blackbodies scanned during each mirror revolution are set to bracket the temperature range to be measured. A single ground temperature measurement is then sufficient as a reference for low-flying missions over a restricted area.

In all cases the relative response of the detector to an input stimulus must be calibrated and the output linearized either internally to the instrument or the departures from linearity available in an accessible calibration report.

SMIRR

As an example of one calibration procedure, the Shuttle Multispectral Infrared Radiometer (SMIRR) will be discussed (Goetz and Rowan, 1982). It was calibrated with an irradiance standard traceable to an NBS standard (Goetz and Brownell, 1982). The standard consists of a hemisphere containing two, 1000 W quartz-iodide lamps. The hemisphere is coupled with a cone capped with an etched fused-silica face plate. At the base of the cone, in front of the hemisphere exit port is an iris to control the face plate illumination and therefore the irradiance. During calibration runs the output of the hemisphere calibrator is measured with a spot photometer containing a standard traceable to NBS. The relative spectral output was measured with a calibrated spectrometer over the range 0.4 - 2.5 μm. The estimated error in absolute irradiance is 10% while the relative error is probably less than 5%. In comparison the relative calibration using internal reference lamps showed a 10% variation in system response during the flight of SMIRR aboard Shuttle in November 1981. During the three years of intermittent laboratory calibration measurement, the system response decreased by 25% presumably due to detector degradation. The above demonstrates that a one-time, absolute calibration of a sensor is not sufficient and that a continuous relative calibration is necessary if high precision measurements are desired.

Data Interpretation

The necessity for calibration or lack thereof in the interpretation of natural surfaces can be drawn from the experience and the present-day understanding of the process of extracting information from airborne and spaceborne spectral scanners.

The image interpreter is primarily interested in the quality of the image and whether a combination of spectral images will yield the desired identification or at least discrimination of the units of interest. Scanner images should be free of "striping" which means that there should be no variations in response from one image line to the next. With multiple detectors, such as the 6 per band in the Landsat MSS, striping can be a problem if the response curves of the detectors are not matched. The matching can be obtained by accurate relative calibration.

Accurate spectral reflectance curves from a radiometer or an imager are only possible if relative calibration has been carried out. The effect of the atmosphere can be modeled, but normally more parameters need to be known than can be acquired. Therefore the interpreter, for instance in the case of reflectance measurements, is forced to pick a calibration point on the ground and normalize the surrounding data to this point. This procedure has been used with success in the preliminary reduction of data from SMIRR in Egypt (Goetz et al, 1982). Ground samples were collected and measured in the laboratory. The laboratory spectra were used to normalize the data and remove the atmospheric effects. By this means several hundred km of ground coverage could be investigated and spectra obtained. The resulting spectra were interpreted on the basis of the relative inter-band spectral values giving characteristic shape to the curves. The absolute reflectances were of little interest since the surface topography, the major source of overall brightness variations, was unknown.

The use of ratio images (Rowan et al, 1974) immediately obviates the need for absolute calibration but relies on a linear or known detector response. Other techniques such as principal component analysis, in which the maximum contrast is sought for display of an individual scene, does not require knowledge of sensor characteristics but makes the assumption that the detector responses are linear (J. Conel, personal communication).

Conclusion

The interpretation of spectroradiometric information from multispectral sensors to present-day levels of accuracy requires thorough instrument calibration, primarily to determine the response (non-linearity) of the detector, spectral bandwidth and relative response among the spectral bands. Absolute calibration is of value for intercomparison of instruments but does not contribute significantly to data interpretation.

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