CALIBRATION OF THE MEIS MULTISPECTRAL IMAGER

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ABSTRACT

The MEIS airborne multispectral imager was the first solid state linear array imager to provide data to the remote sensing community. The development started in the 1970's with the MEIS I which was developed by the Canada Centre for Remote Sensing as part of a multi-year Canadian program to evaluate pushbroom imager technology and to develop remote sensing applications. This was followed in 1982 by the MEIS II which became the primary sensor in the CCRS airborne electro-optical facility, acquiring data for more than 200 remote sensing missions. The MEIS program has included not just the sensor development and airborne operation, but an extensive program of system evaluation, data handling development, and implementation of data processing methodologies.

Since the MEIS is a linear array imager characterised by high quality radiometric, spectral and spatial performance, a major component of the development has been the design and operation of a laboratory calibration facility appropriate for such a system. The automated facility, developed specifically for calibration of multi-detector array systems such as MEIS, is a computer-controlled facility which is used to provide the mapping function of pixel to view angle, to provide the geometric precision of the imagery. It is also used for rapid acquisition of radiometric calibration data, and will play a valuable role in the validation of future systems, for example in the measurement of the modulation transfer function. The laboratory calibration has been accompanied by the investigation and development of correction algorithms for scene-related radiometric effects and aircraft-motion-induced geometric distortions.

The paper will describe the calibration aspects of the MEIS program.

INTRODUCTION

The MEIS (Multi-detector Electro-optical Imaging Sensor) was developed by the Canada Centre for Remote Sensing (CCRS) as part of a multi-year Canadian program to evaluate pushbroom imager technology and to develop remote sensing applications of linear array imagery. The MEIS I was a two-channel prototype developed for CCRS under contract by MacDonald Dettwiler and Associates (Vancouver, British Columbia). It was flown by CCRS in 1978 and successfully demonstrated the concept of the solid state pushbroom imager (Zwick, 1979). MEIS I was followed in 1982 by the MEIS II, an eight-channel multi-spectral linear array imager with real-time processing (Neville et al., 1983). This became the primary sensor in the CCRS airborne electro-optical facility, and between 1983 and 1986 it acquired imagery on over two hundred missions throughout Canada, in Australia and in the USA (Till, 1986). After completing its fourth year of operation as part of the research and development program of CCRS, the MEIS II and the airborne facility in 1987 began a new phase of operation by industry for commercial applications of remote sensing (Till, 1987).

Data acquisition with the MEIS has been accompanied by an extensive program of research and development, including system development, development of data handling, data processing and interpretive methodologies, and the introduction and evaluation of new applications. A major component of the development program has been the design and implementation of a laboratory calibration facility appropriate for such a system. The high radiometric, spectral, and spatial performance potential of the MEIS sensor can be realized only if the calibration system satisfies very stringent requirements.

MEIS II

The MEIS II has been described in detail elsewhere (Neville et al, 1983, Till et al, 1983, Gibson et al, 1983). It comprises three main components. The head has eight individual channels, each consisting of a 1728 element linear array detector, located in the focal plane of an imaging lens, a spectral filter which is interchangeable, and a digitiser (8 bit). The data processor provides radiometric correction in real-time, compensating for vignetting and for non-uniformities amongst the detector elements or in the optics. In order to do this, radiometric coefficients are acquired in the laboratory using a source that is uniform across the field-of-view (of 50^{o}) of the imager; the coefficients are stored in MEIS II memory and recalled during the real-time data processing. The third component is the image data resampler which in real-time provides inter-channel pixel registration, and geometric correction for optical distortions and platform roll. The coefficients that are required for this process are acquired in the laboratory, by mapping the MEIS output pixel as a function of view angle for each of the eight channels. These coefficients are then stored in MEIS memory (E-PROM) for up to ten sets of eight spectral filters.

The output data from the MEIS are recorded on high density digital tape, with 1024 resampled pixels recorded per channel for line sampling rates of up to 200 Hz. Ancillary data from the inertial navigation system on board are also recorded.

CALIBRATION REQUIREMENTS

The principle of the linear array imager offers a greatly improved radiometric responsivity, compared to other systems such as the mechanical scanner type of imager (e.g. the multispectral scanner MSS). This has been realized in the case of MEIS II and has allowed the acquisition of image data (and reflectance values) in narrow spectral bands and with high spatial resolution. The noise equivalent radiance is as low as 1.5×10^{-8} W cm^{-2} sr^{-1} nm^{-1} (rms) at 100 Hz line rate and 1 nm bandwidth; pixel sizes are down to 0.4 m, in both dimensions along- and across-track, even in high speed aircraft. This type of airborne data and information has not previously been available and has fostered the development of new remote sensing applications (Gauthier et al, 1985, Ahern et al, 1986, Gibson et al, 1987). To make full use of the information contained in the imagery data, and to be able to validate small changes in reflectance of the scene that are observed by the imager, the performance of the system has to be calibrated and measured with a precision of $\pm\frac{1}{2}$ least significant bit ($\pm$0.2%), which means the use of stable, uniform calibration sources.

For cartographic applications, the geometric precision of the imagery is of major importance, and the geometric properties of the system have to be measured, again with adequate precision. In the case of MEIS II, each channel has a detector array comprising 1728 detector elements, each of 13 micron linear dimension, with an output pixel size corresponding to 0.7 mrad. The real-time processing provides inter-channel pixel registration to within $\pm$0.15 pixel, for the range of aircraft altitudes from 700 m to 11,000 m, and for the pixel sizes from 0.5 m to 8 m. In order to attain commensurate geometric accuracies, a laboratory calibration facility with a precision optical table assembly has been developed to map the MEIS output pixels as a function of view angle across the image swath.

CALIBRATION FACILITY

The laboratory calibration facility that has been developed is a computer-controlled facility for the geometric and radiometric calibration of multi-detector array systems such as MEIS. It is used before the start of each new flying season to acquire the radiometric and geometric coefficients required by the real-time processor of MEIS II. It has also been used in the validation and evaluation of the MEIS, for example to acquire extensive sets of modulation transfer functions, and to investigate the signal and noise characteristics of the imager system.

Geometric Calibration

The geometric component of the calibration facility comprises an optical table assembly, with a collimated light source and a precision angular indexing table on which is mounted the MEIS head. The collimator is a 406 mm diameter, 2.54 m focal length off-axis paraboloid. The angular indexing system consists of a Contraves Goerz rate table (Model 813) with a Modular Precision Angular Control System (Model 30H), providing a resolution of 1×10^{-4} degrees. This system and the MEIS sensor are interfaced to an LSI-11 based microprocessor, which provides control and data acquisition functions. This is used to map the MEIS output pixel as a function of view angle for each of the eight MEIS channels, and to produce the coefficients which are to be accessed in flight in real-time. This procedure is repeated for each filter set to compensate for the scale variations resulting from the wavelength dependence of the lens focal lengths, and to correct for any additional distortions introduced by the filters.

Prior to the geometric calibration the sensor is mounted on and aligned relative to the calibration facility, the sensor's spectral filters are installed, apertures are set, and the lenses are individually focussed on the collimated pinhole calibration target. Following these manual operations the angular mapping process is almost completely automated, requiring operator interaction only initially to identify the calibration target in the sensor field-of-view. The computer program (MAGIC) developed for this purpose controls the interrogation and analysis of the MEIS data, and based on the results of this analysis, controls the precision indexing table, scanning MEIS across its complete field-of-view. Because subpixel accuracies are required, detector element boundaries are used for calibration. The table is rotated until the calibration target, a subpixel (~1/6 pixel) sized collimated pinhole is registered on a prescribed pixel boundary. When this condition is achieved, the table position is read and stored in computer memory.

This is repeated for 19 locations across the field-of-view of each of the 8 sensor channels. These pixel location-view angle data pairs are then fitted to a 5th order polynomial in the tangent of the angle, and the coefficients are determined and stored. This is repeated for up to 10 filter sets. An E-PROM, with the calculated coefficients for all 10 sets, is installed in the MEIS image data resampler. The program then checks the accuracy of the end-to-end procedure by measuring the locations of a different set of pixel boundaries in the resampled image data.

Radiometric Calibration

The radiometric calibration, required for the uniformity correction, is carried out using a standard integrating sphere, which has been measured to give uniform radiance to within 1% over the $\pm 25^0$ field-of-view of the sensor. Each channel of the MEIS is illuminated in turn by this uniform radiance source. The sensor processor then uses these measurements, which are stored in PROM and accessed in real-time, to provide a multiplicative uniformity correction. Another integrating sphere traceable to the National Bureau of Standards is used to provide the absolute radiometric calibration. Responsivities are calculated and are recorded for reference in header files of the imagery CCT's delivered to the client.

This technique, involving the use of the integrating sphere for the relative radiometric calibration probably does not provide the required uniformity correction. This is due in part to the optical feedback from the sensor into the sphere which potentially introduces indeterminate non-uniformities in the sphere radiance. In an attempt to achieve the goal of $\pm\frac{1}{2}$ LSB (least significant bit) uniformity a new technique has been developed in which the sensor views a moderately uniform ($\pm 5\%$) radiance target while being translated parallel to the detector array direction. In this technique, it is important that the target radiance provided by tungsten-quartz-halogen lamps be temporally invariant and that the sensor be sufficiently isolated from the target to avoid reflections from the sensor. If these precautions are taken, then the technique is capable of providing the required $\pm\frac{1}{2}$ LSB for the MEIS II sensor, which has 8-bit digitization, and for other sensors with even higher digital resolution.

As for the geometric calibration, the sensor data acquisition and translation control are accomplished under computer control. Once the sensor is mounted in the radiometric calibration facility the operation is completely automatic. The controlling software package (MARIC) has been developed and is currently undergoing initial testing. The resulting uniformity coefficients are stored in PROMs, one for each channel-filter pair, which are then installed in the sensor processor unit which applies them to the image data in real-time.

CONCLUSIONS

A sensor's full capability can be realized only with adequate calibration. The improvements in geometric resolutions to 0.25-0.5 mrad for airborne imagers and to 10 μrad for satellite imagers impose increasingly demanding requirements on the geometric measurement facility used to calibrate these sensors. Similarly the higher digitization resolutions, to 8, 12, and 16 bits, require exceedingly precise calibration techniques to achieve commensurate uniformities.

We have developed a computer assisted, electro-optical calibration system at CCRS which can provide geometric accuracies to $1x10^{-4}$ degrees (1.7 μrad). Also to be installed on the same system is software which implements a technique which can provide uniformities corrections to $\pm\frac{1}{2}$ LSB, independent of the digitization resolution of the sensor being calibrated.

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