EVALUATION OF THE RADIOMETRIC AND SPECTRAL CHARACTERISTICS OF THE CAISS

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ABSTRACT: The Compact Airborne Imaging Spectrometer System (CAISS) was jointly designed and developed as the hyperspectral imaging system by Korea Aerospace Research Institute (KARI) and ELOP inc., Israel. The primary mission of the CAISS is to acquire and provide full contiguous spectral information with high quality spectral and high spatial resolution for advanced applications in the field of remote sensing. The CAISS consists of six physical units; the camera system, the gyro-stabilized mount, the jig, the GPS/INS, the power inverter and distributor, and the operating system. These subsystems shall be tested and verified in the laboratory before the flight. Especially the camera system of the CAISS shall be calibrated and validated with the calibration equipments such as the integrated sphere and spectral lamps. To improve data quality and availability, it is the most important to understand the mechanism of hyperspectral imaging system and the radiometric and spectral characteristics. This paper presents the major characteristics of camera system on the CAISS and summarizes the results of radiometric and spectral experiment during preliminary system verification.

KEY WORDS: Hyperspectral Imaging System, CAISS, Calibration Instrument, System Verification

1. INTRODUCTION

Recently, with advancing technology, imaging spectrometer has begun to focus on the wide variety of earth science applications. Recent advances in remote sensing and geographic information has led the way for the development of hyperspectral sensors. Hyperspectral remote sensing is a relatively new technology that is currently being investigated by researchers and scientists with regard to the detection and identification of minerals (Clark et al., 1992, 1995), terrestrial vegetation (Clark et al., 1995, Aber and Martin, 1995, Merton, 1999), etc. also hyperspectral image data have been used to detect and map a wide variety of materials having characteristic reflectance spectra.

The multispectral imaging systems such as Landsat produce images with a few relatively broad wavelength bands. On the other hand, hyperspectral imaging systems collect the image data simultaneously in many narrow, adjacent spectral bands. These measurements make it possible to derive continuous spectrum information for each image cell. Hyperspectral data sets are generally composed of about 100 to 200 spectral bands of relatively narrow bandwidths (5-10 nm), whereas multispectral data sets are usually composed of about 5 to 10 bands of relatively large bandwidths (70-400 nm). However, in order to fully realize the potential of hyperspectral image data for various applications, it is necessary that imaging system with related subsystem shall be calibrated and validated in the laboratory before the flight (Lee, 2007).

The purpose of this study is to evaluate the radiometric and spectral characteristics of the camera system on the Compact Airborne Imaging Spectrometer System (CAISS). To fulfill this purpose, calibration instruments such as the integrated sphere and spectral lamps were used. This paper described the major characteristics of the camera system on the CAISS and summarized the results of radiometric and spectral experiment during preliminary system verification.

2. THE CAMERA SYSTEM OF THE CAISS

2.1 CAISS Overview

The CAISS was jointly designed and developed as the hyperspectral imaging system by Korea Aerospace Research Institute (KARI) and ELOP inc., Israel. The primary mission of the CAISS is to acquire and provide full contiguous spectral information with high quality spectral and spatial resolution for advanced applications in the field of remote sensing. The CAISS, as shown in Figure 1, consists of six physical units; the camera system, the gyro-stabilized mount, the Jig, the GPS/INS, the power inverter and distributor, and the operating system.

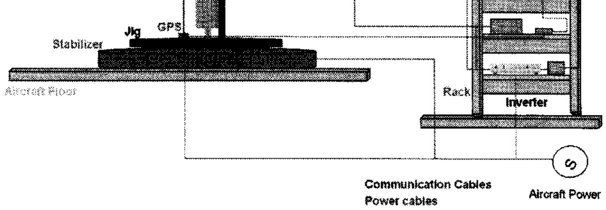

Figure 1. The CAISS configuration.

Also, some of operating software is certainly necessary during the mission. Figure 2 shows the necessary software and system operation workflow for imaging during the flight. However, different software have to be used for each of the camera system operation, GPS/INS operation, data pre- and post-processing.

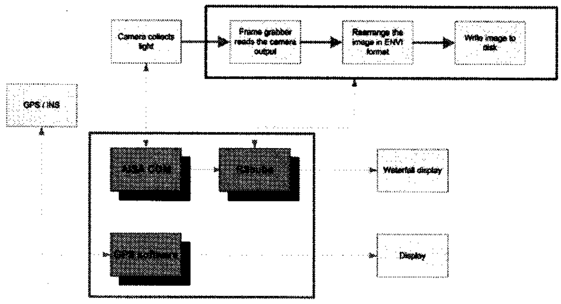

Figure 2. The CAISS operation workflow during the mission.

2.2 The Camera System of the CAISS

The camera system of the CAISS in Figure 3 consists of the DALSTAR 1M30 digital camera, the ImSpector V10E imaging spectrograph, the PCI frame grabber, the power supply, and cables.

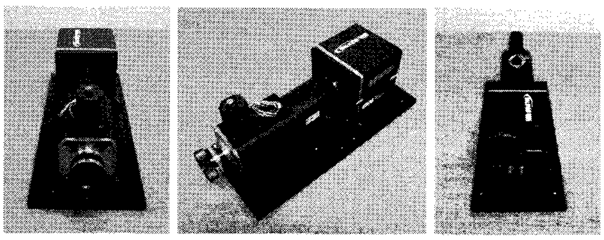

Figure 3. The camera system of the CAISS.

The DALSTAR 1M30 digital camera provides high-sensitivity images with 1k x 1k spatial resolution. The 1M30 is a frame transfer CCD camera using a progressive scan CCD to simultaneously achieve outstanding resolution and gray scale characteristics (DALSA, 2001). The numbers of spatial pixels are 512 pixels and pixel size is 12 ㎛. The ImSpector V10E image spectrograph was assembled with the DALSTAR 1M30 digital camera for acquiring the full contiguous spectral information with high quality spectral and spatial resolution.

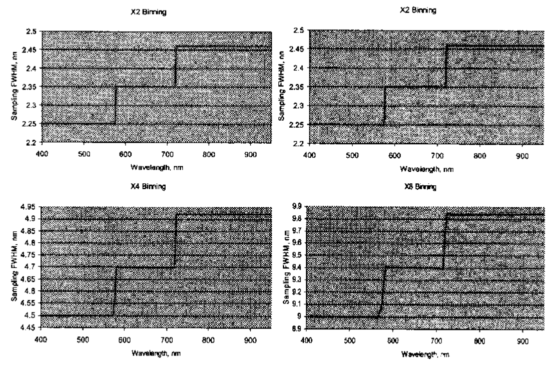

Figure 4. The spectral binning.

In the camera system, it is possible to control a spatial binning which is essentially aggregating pixels at the detector level. Data can be spatially binned by 2 to provide 512 pixels. Also spectral binning is aggregating several spectral bands together. This is usually done at the detector level to reduce noise. Figure 4 shows the spectral binning mechanism of the camera system on the CAISS.

The major specifications of camera system are as follows; the system Field of View (FOV) is 39.6 degree. The spectral range is 400nm to 950nm. Minimum spectral resolution is 1.25nm for 480 bands and the maximum spectral resolution is 10nm for 60 bands. Swath and Ground Sample Distance (GSD) is almost 2,070m and 4m at 3,000m altitude. Radiometric resolution is 12 bits. The frame system is capable to work with frame rates of up to 43Hz. It is controlled by command. Frame rate is defined as the time period between the first frame to the next. Since altitude is directly connected to the spatial resolution, we could calculate and plot a graph relating altitude and frame rate for several ground speeds. Figure 5 shows the results of relationship between altitude and frame rate in the spatial binning of 1 and 2. Since the focal length of the camera is fixed, any change in altitude would immediately affect the spatial resolution.

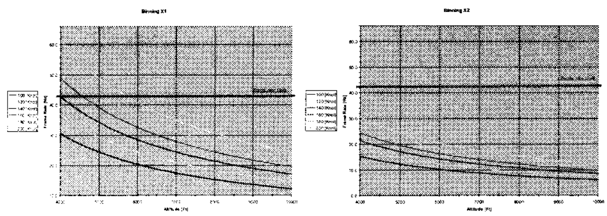

Figure 5. Relationship between altitude and frame rate.

Integration time is the time in which the camera collects light. It starts with the frame rate and ends according to the user definition. The integration time is usually shorter from the frame rate time. The camera system of the CAISS has an ability to change the integration time without changing the frame rate, within the limits of the frame rate time.

3. EXPERIMENT FOR RADIOMETRIC AND SPECTRAL VERIFICATION

3.1 Calibration Equipments

The calibration equipments are not part of the CAISS. However, these equipments are an essential component of any imaging instruments. Figure 6 shows the prepared calibration equipment for the camera system of the CAISS.

The radiometric and spectral calibration and validation of the camera system are performed with the integrated sphere and spectral lamps in the laboratory. In order to conduct the radiometric calibration of the camera system, integrated sphere is necessary. The wavelength spectrum of integrated sphere in this study is 300-2400 nm, luminance uniformity is larger than 98% (percents), peak radiance is 95mW/㎠-sr-㎛@0.9 ㎛, diameter of sphere, and exit port are 12 inches and 4 inches (Labspere Inc., 2006). The integrated sphere provides the capability of the National Institute of Standards and Technology (NIST) traceable luminance calibration. The purpose of spectral calibration is to evaluate the camera system spectral response to be similar as of the spectral lamps. Four different spectral lamps (HgNe, Krypton, Xenon and Neon) are used for the spectral verification of the camera system.

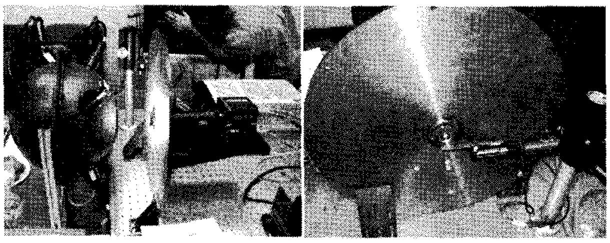

Figure 6. The calibration equipments for the CAISS.

3.2 Radiometric Calibration

The preliminary radiometric calibration was conducted during the CAISS Acceptance Test (AT) in the laboratory, Israel. The data consists of dark and light image in a length of 300 lines over the whole field of view of the CAISS. These images were taken for spatial binning of 1 and 2 and spectral binning of 1, 2, 4 and 8, thus giving 8 different binning combinations. For each binning combination 10 pairs of dark and light images were acquired. For each pair of images, the calibration coefficient was calculated by the calibration program. The calibration would be done according to the following equation:

$$CalibrationCoefficient_{(x,\lambda)} = \frac{\mathrm{Rad}_{\lambda} \times \mathrm{I.T}}{\left(\mathrm{Img}_{(x,\lambda)} - \mathrm{dark}_{(x,\lambda)}\right)} \quad (1)$$

where,

Calibration Coefficient$_{(x,\lambda)}$: the calibration coefficient for each spatial pixel$_{(x)}$ and each wavelength$_{(\lambda)}$

Rad$_{\lambda}$: the radiometric value of the integrating sphere flat field

Img$_{(x,\lambda)}$: the integrating sphere flat field image from the CAISS

Dark$_{(x,\lambda)}$: the dark image from the CAISS

I.T. : the integration time for acquiring the dark image and flat filed image

The ten calibration coefficients was calculated for each of the binning combination as described above. Figure 7 and Figure 8 show the results of radiometric calibration coefficients. The error between the various calibration coefficients was calculated by dividing the STD by the average of the ten calibration coefficients calculated. Error between the ten calibration coefficients was smaller than 0.3% for all calibration coefficients for the various spatial and spectral binning.

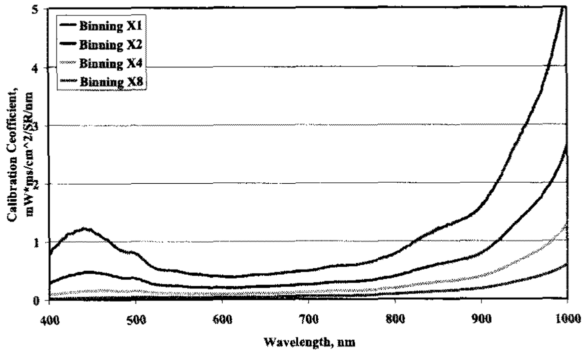

Figure 7. Calibration coefficients for spatial binning 1 and spectral binning 1, 2, 4, and 8.

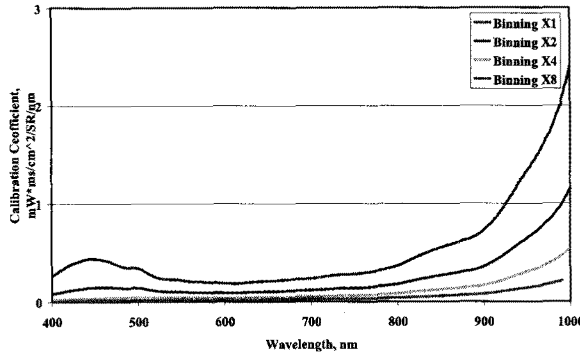

Figure 8. Calibration coefficients for spatial binning 2 and spectral binning 1, 2, 4, and 8.

3.3 Spectral Verification

Four spectral lamps (HgNe, Krypton, Xenon and Neon) are used for verification of spectral characteristic of the camera system. The 300 frames of the lamps illumination and a dark image were acquired from the camera system. For each of the spectral lamp, all four binning (x1, x2, x4 and x8) were measured using the lamps. To subtract the dark signal from the image, according to the following equation:

$$\text{Dark Corrected Signal} = \overline{\text{Image}} - \overline{\text{Dark Image}} \quad (2)$$

where,

Dark Corrected Image: the image

Image : the average in signal of the spectral lamps image acquired by the CAISS for each spatial pixel

Dark Image: the average dark signal of the CAISS in each spatial pixel

The peaks of each lamp in the spectral profile of three spatial pixels were found. Then, the position of the peaks was compared to the spectral lamps data sheet. For all measurements, consequently, it was found that the spectral deviation is lower than the Full Width Half Maximum (FWHM) of the system for each of the binning.

Figure 9 shows the results from comparison of the measured wavelength from spectral lamps and the literature wavelength on the data sheet for each of the binning.

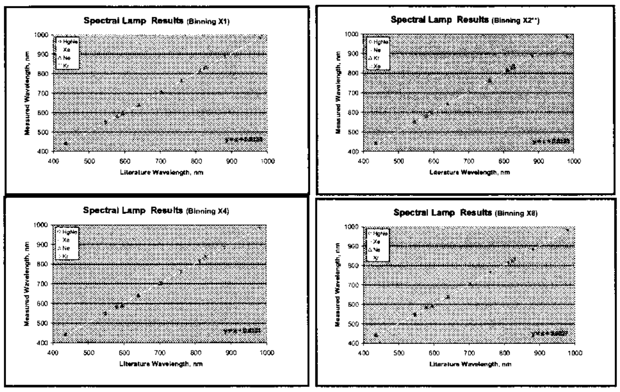

Figure 9. Comparison of the measured wavelength from spectral lamps and the literature wavelength on the data sheet for each of the binning (**Dark image of XE lamp in the binning of 2 was simulated using the acquired dark image from the binning of 4 because of the system error.).

4. SUMMARY

The hyperspectral imaging systems with high spatial and spectral resolution have become an important component of wide variety of earth science applications. However, in order to fully realize the potential of hyperspectral image data and improve data quality, it is the most important to understand the mechanism of imaging spectrometer and its characteristics.

This paper describes the major characteristics of the camera system on the CAISS and summarizes the preliminary results of radiometric and spectral experiment during acceptance test. The CAISS is the high performance imaging spectrometer system which will meet full contiguous spectral requirement with high spatial resolution for advanced applications in the field of remote sensing. Also, the CAISS has the ability to use as the vicarious calibration equipment for the cross-calibration of satellite image data. However, it is necessary that the camera system of the CAISS shall be calibrated and validated periodically with the calibration equipments such as the integrated sphere and spectral lamps for maintenance of radiometric and spectral properties. The preliminary test and analysis for verification of radiometric and spectral characteristics were conducted during acceptance test in Israel. For the radiometric calibration and validation, ten pairs of dark and light images were acquired for spatial binning of 1 and 2 and spectral binning of 1, 2, 4, and 8. The ten calibration coefficients were calculated for each of the binning combinations. The error between the ten calibration coefficients was smaller than 0.3% for all calibration coefficients for the various spatial and spectral binning. In order to verify the spectral characteristics, four spectral binning (x1, x2, x4 and x8) were measured using each of the spectral lamps and the position of the peaks was compared to the spectral lamps data sheet. For all measurements, it was found that the spectral deviation is lower than the FWHM of the system for each of the binning.

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