Technical Session
Sensor Calibration and Testing for Hosted Small Satellite Payloads

Examining small satellite payload calibration, testing processes, and methods, including accuracy and precision, to discover ways to reduce cost and schedule while still meeting mission requirements

- Discussions about how new calibration and testing techniques and equipment can be applied to meet mission requirements while maintaining small satellite cost and schedule constraints
- Novel techniques and sources used to perform radiometric calibration of miniaturized payloads
- Trade-offs between performing testing at the sub-system, ground, and/or on-orbit levels
- Calibration planning for upcoming small sat missions
- Opportunities to cross calibrate multiple copies of the same sensor when they view the same scene

Session Chair: Sloane Wiktorowicz, The Aerospace Corporation

10:10
A Cubesat with On-Orbit Calibration System for Radiometric Infrared Imaging
Michael Adkins, Alfonso Amparan, Sandra Collins, John Ferguson, Thomas Kampe, David Osterman, Reuben Rohrschneider, Robert Warden – Ball Aerospace & Technologies Corp.

ABSTRACT: CIRiS (Compact Infrared Radiometer in Space) is a radiometric imaging instrument on a 6U CubeSat bus designed for earth imaging in the thermal infrared (7.5 to 13.5 um) spectral region. The instrument features a versatile calibration system for optimizing on-orbit radiometric calibration performance, and a modular design facilitating modifications for specialized missions. The objective of the upcoming CIRiS mission is to demonstrate technologies for high calibration performance within 6U CubeSat constraints. These include an uncooled microbolometer imaging focal plane array (FPA) that makes a cryocooler unnecessary, and high-emissivity (e > 0.996) carbon nanotube (CNT) blackbody sources on 1/8 inch-thick solid substrates, the latter replacing bulkier cavity blackbodies.

Instrument on-orbit operation utilizes up to three calibration views to deep space and to two CNT sources, one of which is heated and temperature controlled. A CIRiS radiometric uncertainty budget now under development employs ground measurement and space effect calculations. Thermal drift over the orbit potentially generates radiometric error via the FPA and other instrument components and is therefore the subject of ground measurement. Careful thermal control of the CNT sources and other critical hardware is an integral part of the calibration strategy.

The F/1.8 refractive optical system includes a butcher block filter over the 640 x 480 format FPA. This configuration enables simultaneous imaging in three infrared wavelength bands as the instrument scans the earth from low earth orbit (LEO). Assuming launch from the International Space Station into a 400 km altitude LEO the CIRiS ground sampling distance is 130 m with 83 km swath. On-orbit frame co-adding at the nominal 30 fps frame rate improves imaging and calibration SNR.

CIRiS’ calibration capabilities implemented from CubeSat constellations will enable accurate surface temperature and soil moisture data collection across much of the earth with short, potentially daily, revisit times. Variants on the CIRiS design could also provide an inexpensive and focused complement to more extensive earth radiation imbalance measurements.

10:35
Vicarious Radiometric Calibration for Hyperspectral Imaging Microsatellites–SPARK01/02
Hao Zhang, Zhengchao Chen – Key Laboratory of Digital Earth Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences
ABSTRACT: On December 22 in 2016, two wide-swath hyperspectral imaging microsatellites—SPARK 01/02 manufactured by the Shanghai Engineering Center for Microsatellites, were successfully launched at the Jiuquan satellite launch center by the CZ-2D rocket. Spark01 and 02 has the spectral range of 400-1000 nm, with the spectral resolution ranging from 1-10nm, and their swath is about 100KM with spatial resolution of 50 m. With the characteristics of lightweight, low cost and high performance, the two satellites can also be used in aspects such as environmental and disaster monitoring, target recognition, fine classification, providing basic information support for disaster monitoring, environmental protection, resource development and business application. Due to the lack of satellite calibration equipment, an in-situ vicarious calibration experiment were taken Dunhuang calibration site (500 * 500 m) during February 25 to March 7 in 2017 to derive absolute calibration coefficients for spark01/02. The atmospheric parameters (i.e. aerosol optical depth (AOD) and columnar water content) were measured by a sun photometer. The ratio of diffuse irradiance to total irradiance was also measured during a whole day when spark satellite passed. Also, the reflectance of Gobi in the calibration site was measured in two hours before and after the satellite overhead passed. In the meantime, the atmospheric profile was measured by radiosond near the time when satellite passing the calibration site. Modtran5 was used to derive the at-sensor radiance based the above in-situ measurements.

At present the absolute radiometric calibration coefficients were derived by the reflectance based method. We analyze the calibration uncertainty through radiative transfer simulation caused by source of uncertainty in aerosol type, AOD, reflectance measurement, etc. The aerosol type assumption would cause much uncertainty in the shortwave bands, with maximum of 10%. The reflectance measurement error is estimated to be 2%, causing calibration uncertainty of 2%. The aerosol optical thickness measurement error of 0.05 wound introduces the calibration uncertainty of 1%. The water vapor measurement error is estimated to be 20%. It imposed much impact on the water vapor absorption bands (near 940 nm), causing a maximum calibration uncertainty of 7%. Besides, calibration uncertainty caused by other resources such as such as the spectral response function changes, observation geometry error, was estimated about 2%. In total, for the non-water absorption bands, the total uncertainty of spark 01 is less than 6%, and that of spark 02 is less than 7%; for the water vapor absorption bands, the uncertainty of spark 01 is less than 8%, and that of spark 02 is within 10%. In the future, we will derive radiometric calibration coefficients of spark 01/02 by irradiance calibration based methods and present more details.

11:00
Calibration of a Multi-Spectral CubeSat with LandSat Filters
Sloane Wiktorowicz, Ray Russell, Dee Pack, Eric Herman, George Rossano, David Ardila, Christopher Coffman, Brian Hardy, Bonnie Hattersley – The Aerospace Corporation

ABSTRACT: The AeroCube-11 spectral satellite (also known as AC-11 R3) is a visible and near infrared (VNIR) multispectral pushbroom imager integrated in a 3U CubeSat. AC-11 R3 utilizes six Landsat-8 Operational Land Imager (OLI) filters arranged in a butcher-block configuration overlaid onto the focal plane array (FPA). While CubeSats are designed to be small and relatively inexpensive, thorough ground calibrations were still performed with a short development time. We report on the calibration activities for AC-11 R3, which were performed in one of Aerospace’s TVac chambers fed by a large integrating sphere, a collimator, direct illumination by a lamp, and scattering of lamp light by a Lambertian screen. The calibration tests performed studied dark current (as a function of FPA temperature and gain), reciprocity (by varying illumination and integration time), electron conversion gain (by varying illumination), small source linearity (by toggling a weak source on and off in the presence of a brighter, varying illumination source), flat field, end-to-end spectral response, modulation transfer function (MTF, via a knife edge test), point response function (PRF, via a point source), and distortion (via imaging of a grid of dark points). Some of the lessons learned from the characterization process are recounted to improve speed and efficiency of characterization of similar systems.

A high level GUI was developed to operate the FPA in different modes and to test the effect of low-level FPA settings on data quality. This mitigates human error when manipulating FPA settings at a low programming level. For instance, determination of optimal bias for the FPA for different FPA temperatures and gains is crucial prior to calibration tests. It was necessary to increase bias such that the full +/- 3 sigma distribution of pixel values lay above zero to make accurate statistical assessment of images. Additionally, ensuring optimal clocking of data channels (skew correction) minimizes frame-to-frame variation in signal per pixel. However, as this was performed after the FPA was integrated into the payload, some basic functionality tests were performed on the critical path. Ideally, such testing would be performed prior to FPA integration so experienced users could minimize the time spent on calibration. Finally, rather than performing each calibration test
sequentially, we exposed the FPA to a matrix of temperatures, illumination levels, integration times, and gains in order to perform many tests in parallel. For example, the same images may be used for both reciprocity and electron conversion gain.

11:25
Slanted Edge MTF Focus Test Verification with PRF Testing to Establish Best Focus Position of Infinite Conjugate Space Optical Systems
Lennon Reinhart, Trent Newswander, Duane Miles, Deron Scott – USU/Space Dynamics Laboratory; David Riesland – Self

ABSTRACT: For earth-viewing, fixed-focus space optical systems, carefully finding the best focus position of the instrument is critical to achieving the best possible image performance and mission success. For such space optical systems, modulation transfer function (MTF) test data is directly applicable to system optical resolution. Furthermore, MTF test products can be combined to predict overall imaging performance. The infinite conjugate slanted edge MTF test can be used in ground testing to identify best focus of the optical system while taking into account the entire imaging system, operational parameters, and simulated operational environment. The point-response function (PRF) test can be used to verify the results of the slanted edge MTF test to ensure that the optimum best focus position is determined. This paper discusses the slanted edge MTF test for establishing best focus and the PRF test for verifying the best focus. Actual MTF and PRF test results are presented.

11:50
Absolute Radiometric Calibration of the Planet Dove Constellation
Nicholas Wilson, Arin Jumpasut, Joshua Greenburg, Alan Collison, Horst Weichelt – Planet Labs

ABSTRACT: Maintaining the radiometric accuracy of the 140-satellite Planet Dove constellation has required the development of a more automated approach to on-orbit radiometric calibration given the number of satellites and the operational behavior. In nominal operations, Dove Satellites are non-tasking and are nadir pointing. A methodology has been developed that utilizes a hybrid approach to combine lunar calibration and cross calibration to enable on-orbit absolute radiometric calibration of each individual Dove satellite. The cross-calibration approach utilizes instantaneous crossovers in spectrally characterized pseudo-invariant calibration sites with RapidEye, Landsat8, and other Dove satellites. Lunar Calibration utilizes an implementation of the ROLO model [1] and daily moonshots taken by each satellite during both the waxing and waning moon phases. This approach is automated, with new crossovers for each satellite processed and stored daily, and moonshots on a monthly cadence. This has allowed for regular monitoring of the radiometric calibration for each satellite and regular updates to ensure calibration accuracies. Initial validation of this approach using 40 Dove satellites shows an uncertainty of 5% at 1-sigma is achieved across all satellites using instantaneous crossovers with Landsat8 as a validation dataset. This paper describes the absolute radiometric calibration approach, how this method will scale to the larger 140 satellite constellation, and a discussion on the initial results.


12:15
Self-Assessed Data Quality Standards (SAQS)
B. Guenther, Cole Rossiter – Stellar Solutions, Inc.

ABSTRACT: At the Goddard Memorial Symposium, 2017, Greenbelt, MD, Dr. St. Germain, NOAA NESDIS Lead Engineer, agreed that the evolving systems of Small Satellites may offer significant benefits in terms of cost, schedule, incorporation of technical improvements and risk management for NOAA meteorological applications. But Small Satellite systems do not offer similar benefits for simple incorporation of these data sets for operational forecast models. Many developers of small satellite systems have broad and innovative engineering experience but do not have a broad understanding of what data users expect as background to the data set. [We could consider this information as metadata to the observations data set.] The users consider specific information on how the data is acquired to be essential to understand the details and nuances of the actual data sets. We usually look for detailed information on sensor design, how the sensor was tested, how the test equipment was verified, how the long-term stability of the sensor is established, and how will the data product be
validated. Our initial thinking on this matter will be presented, and will be verified with Goddard Ocean Color Biology experience with ingest of the Ocean Color Monitor data from the OCEANSAT-1 Mission.

Additional conversation and discussion on the topic is being carried over to a poster in this Conference. The intent is to provide one potential framework for what users of meteorological data or other data regimes may expect when agencies look to use (purchase?) data from small satellite systems. This information always is easier to organize and provide when developers understand these expectations during the development stage and “bake” their approaches to meeting these expectations into early mission planning. Some institutions that are planning the development of space hardware intended to deliver “data buy” hardware are mature and experienced in these matters and will not need this guidance. Other institutions are not mature and likely do not realize the full expectations of the user community for these metadata.