Optimizing Product Quality and Cost for Small Satellite Earth-Imaging Constellations by Incorporating Automated Vicarious Calibration in the Processing Pipeline

STEPHEN J. SCHILLER PH.D. AND **JOHN SILNY**, SPACE AND AIRBORNE SYSTEMS | **MARCUS TETER PH.D.**, INTELLIGENCE, INFORMATION AND SERVICES

CONFERENCE REF. NO. SSC18-PI-29

SUMMARY

Small satellite constellations are increasingly being deployed for critical, high-value Earth-imaging missions in commercial space.

Best practice in maintaining profitable product development and quality is to efficiently evaluate and trend the in-flight performance of the constellation sensor systems.

An effective approach is to integrate into the mission architecture a global network of robotic calibration sites, essentially guaranteeing a daily flow of calibration, sensor performance and image quality data for in-flight verification throughout the year.

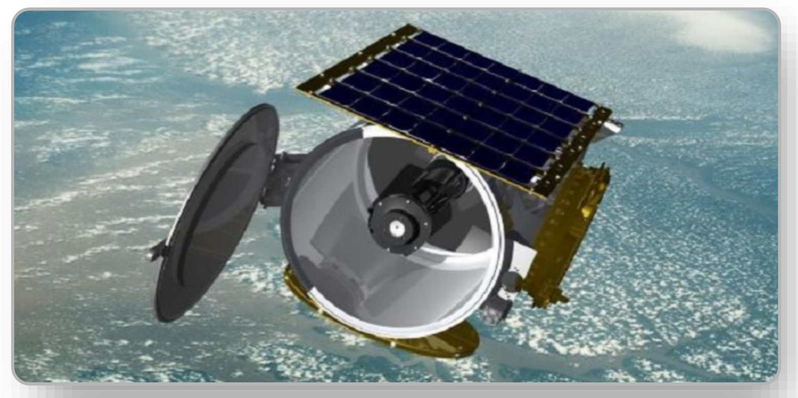
The Specular Array Calibration (SPARC) method is an adaptable small target solution that can be deployed and operated at any location. It uses ground-based convex mirrors to create small reference targets capturing radiometric, spatial, spectral, geometric and temporal characteristics of individual sensors for transforming the members of the constellation into a harmonious Earth-monitoring system. The SPARC target system can be fully robotic to provide automated, self-sustained and functionally constrained operation.

Such access allows the mission managers to autonomously bring new sensors online and products into the marketplace quickly, along with supporting a means for rapidly identifying, resolving and verifying sensor or processing anomalies should they manifest.

RADIOMETRIC CALIBRATION AND IMAGE QUALITY ASSESSMENT

Multiple government agencies (NASA, NGA, NOAA, DOD, etc.) are managing commercial data buys in which selection relies on the ability to demonstrate and maintain data quality through Calibration and Validation (CalVal). Vicarious methods provide a low-cost means to achieve this. The reasons for CalVal are many.

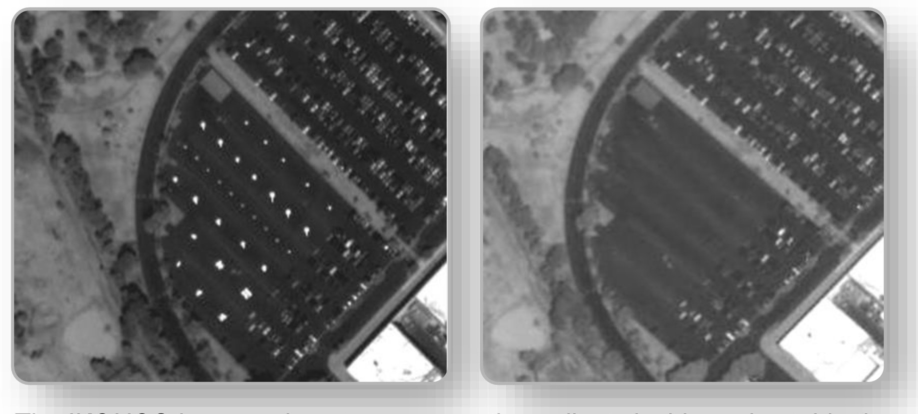
- Conversion from digital number (DN) to absolute units (i.e., radiance) allows physics-based exploitation for creating value-added products and enhanced data mining.
- Exploitation capabilities with calibrated spectral data include:
  - Searching pixel data for specific spectral signatures (target detection),
  - Finding changes at a geographic location between multiple scenes (change detection),
  - Assigning a label to each pixel surveying scene content (classification) and
  - Applying atmospheric corrections (extracting surface reflectance)
- Vicarious calibration monitors performance degradation over the lifetime of the mission. (Necessary even with prelaunch or onboard calibration.)
- For a constellation, calibration is necessary for the data products to become sensor independent. (Identify and correct relative biases.)



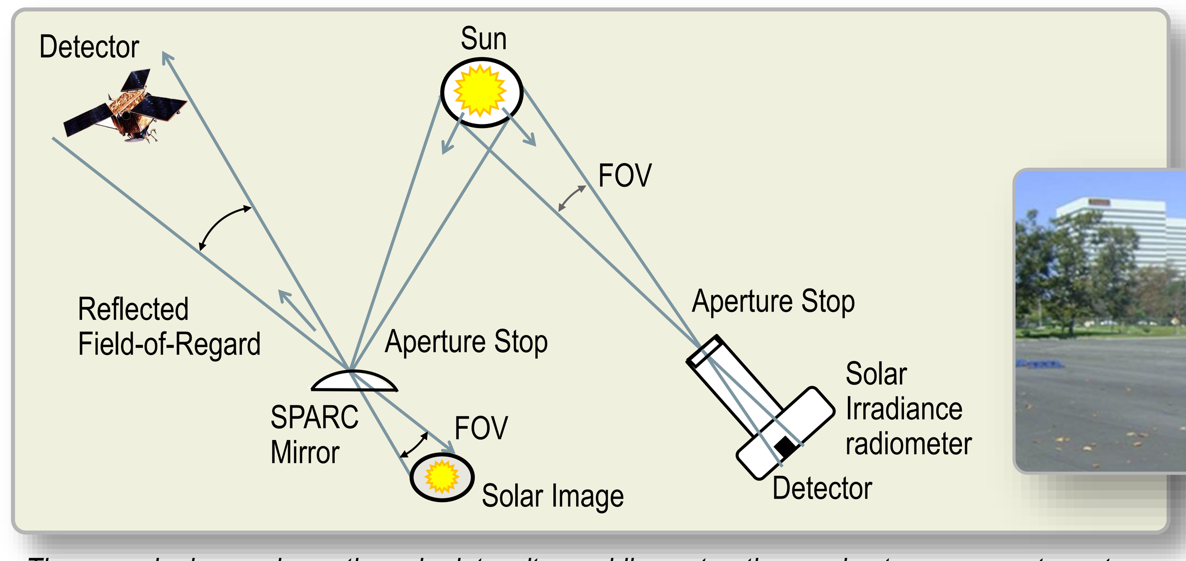
Raytheon recently delivered the first small imaging satellite to the Pentagon's Defense Advanced Research Projects Agency under the Space Enabled Effects for Military Engagements (SeeMe) program. The new mini-satellite will allow soldiers on the ground to see real- time pictures of the battlefield, which current military or commercial satellites cannot provide. Vicarious calibration is critical to the mission's success (https://www.raytheon.com/news/feature/small_satellites)

SPARC RADIOMETRIC CALIBRATION SYSTEM

The SPARC method uses spherical convex mirrors to create a collection of "solar stars" with identical spectra and well defined radiometric properties directly traceable to the exo-atmospheric solar spectral constant. The outcome is in-flight absolute calibration and sensor image quality achieved at a high level of repeatability and accuracy. It is stable over a wide range of illumination and view geometries with reduced atmospheric and adjacency effects compared to other vicarious methods. The small size and portability allow application in a wide variety of operational environments. SPARC targets allow the sensor to look directly at the sun without saturation for calibration and absolute traceability as shown in the following diagram.



The IKONOS images show two consecutive collects inside and outside the mirror's field-of-regard, illustrating the effectiveness of isolating the direct solar signal. The sensor's response to each "solar star" provides a known effective at-sensor radiance for deriving radiometric gain coefficients.

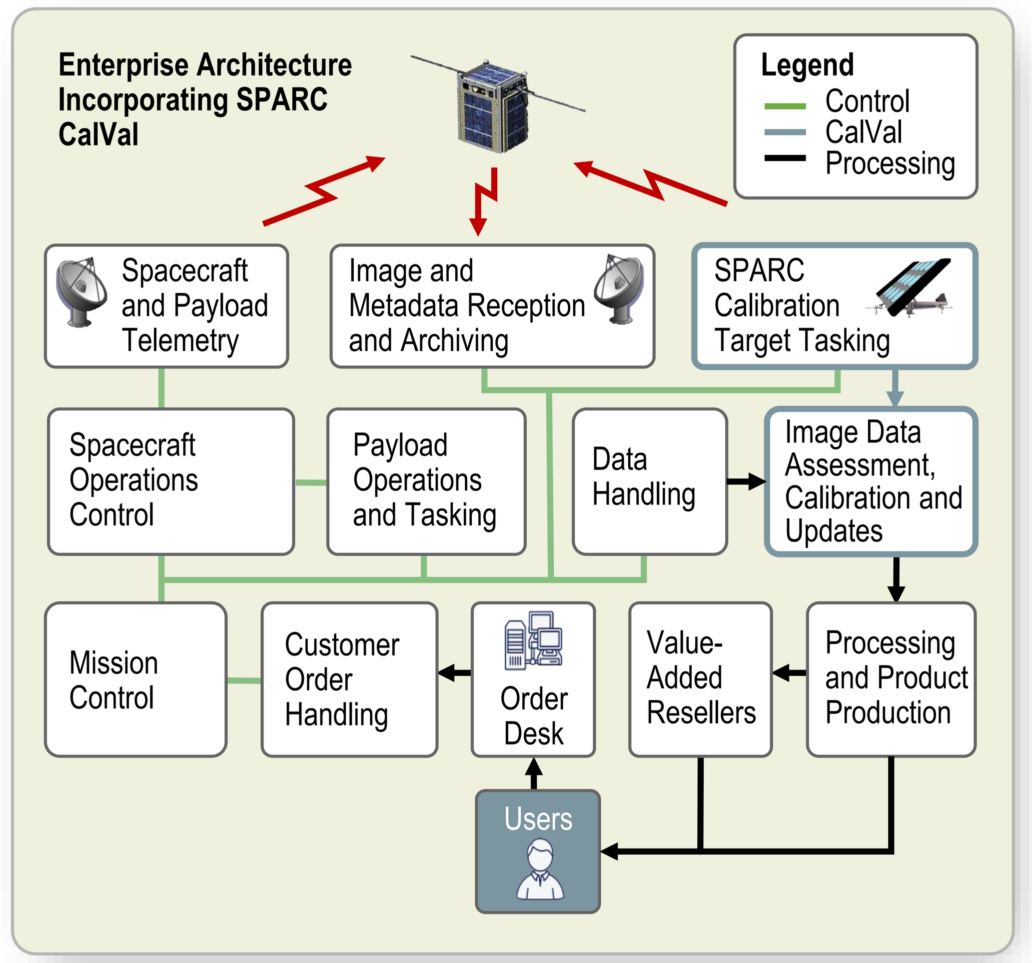


The curved mirror reduces the solar intensity, avoiding saturation, and acts as an aperture stop, isolating the solar signal from background sources. Calibration proceeds much like with a solar radiometer, requiring only characterization of transmittance for atmospheric corrections.

SPARC mirror targets deployed at the Raytheon parking lot in El Segundo, California.

ENTERPRISE OPERATIONAL INTEGRATION OF A SPARC AUTOMATED CALIBRATION AND VALIDATION SYSTEM

Incorporating deployment and control of SPARC target sites provides an efficient means of monitoring and maintaining product quality while minimizing operational costs in the process. The objective is to include CalVal as a fully automated component of mission control and product production for an Earth-imaging constellation.



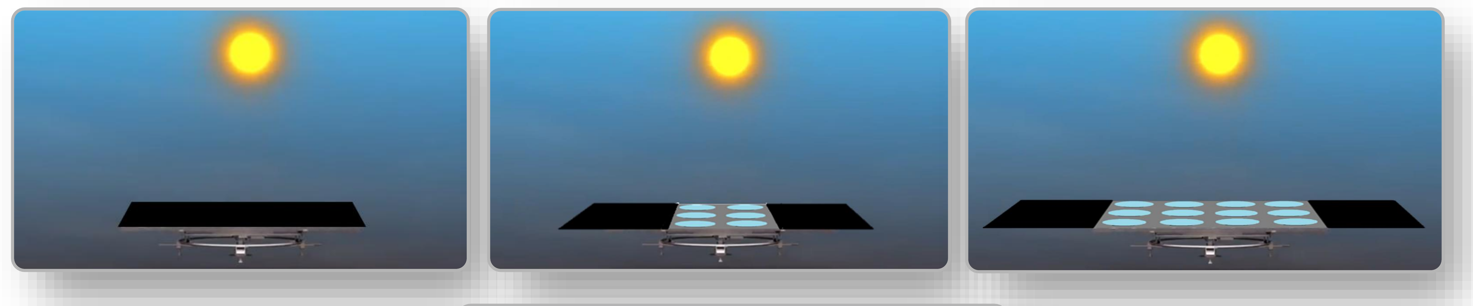
CalVal adds to the mission architecture:

- Image data assessment and calibration
  - Radiometric calibration and validation
  - Uncertainty assessment
  - Image quality performance and analysis
  - Image registration and geometric calibration
  - Temporal performance monitoring
- Intersensor absolute bias analysis
- Calibration coefficient updates
- Product quality assessment

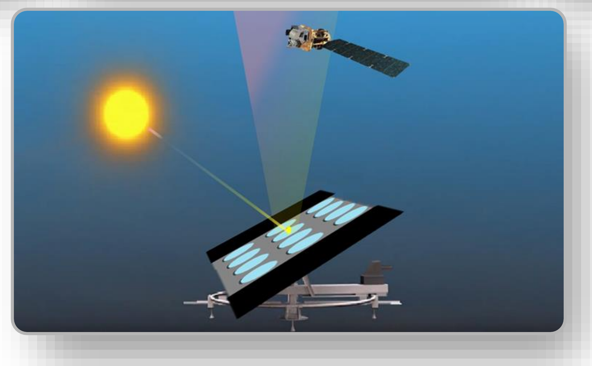
AUTOMATED SPARC

The SPARC method enables an automated approach to ground-based vicarious calibration that does not require on-site personnel during the overpass of an Earth-imaging sensor. Operation provides continuous access to ground-based data collected throughout the year. Operational capabilities include the following.

- Mirror array panels are fixed to a two-axis steerable mount, aligning the panel normal to the midpoint between the sun and satellite at overpass.
- Computer-controlled pointing by inputting altitude and azimuth coordinates via Wi-Fi link.
- Orbital tracking provides intensity illumination of the sensor from horizon to horizon.
- Continuous availability for supporting a large constellation.
- Mirrors are exposed to the weather for only a few minutes at overpass to keep mirrors clean.
- Pointable to an accuracy better than +/- 0.5 degrees.
- Panels are low profile, remaining in a horizontal stow position until the overpass time.

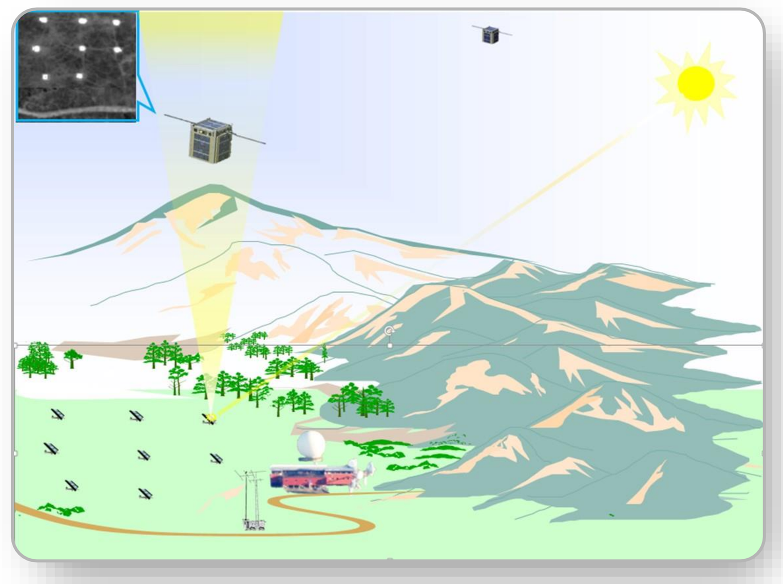


At the time of sensor overpass, the automated SPARC target wakes up and from stow position, panel doors open to expose a specified number of mirrors. This allows the targets to provide a verity of selectable illumination intensities.



Altitude and azimuth coordinates for the midpoint between the satellite and sun are sent to the panel mount by Wi-Fi and it slews to illuminate sensor under calibration for a few minutes. It then returns to stow position for the next overpass.

SPARC HARDWARE INTEGRATION AT GROUND STATION



SPARC calibration sites can be incorporated into existing ground station facilities, making use of already established infrastructure, network communication, access and personnel. Such a link can improve timely feedback to satellite operators on the status of their satellite imaging system.

Illustration of a fully automated SPARC system co-located with ground station operations.

SPARC AT ANOTHER LOCATION

Onboard processing and power limitations may not allow simultaneous downlink and image acquisition, making it impractical to locate a SPARC calibration site at the operational ground stations. An advantage can still be created by utilizing a SPARC calibration site at a high-altitude, predominantly clear sky location where useable CalVal and image quality data can be collected with a higher success rate. These, however, will generally be located at lower latitudes than the ground stations, reducing the number of potential overpasses.

Fortunately, SPARC targets are highly portable systems allowing a large trade space in finding optimum locations for good weather and overpass accessibility. For example, the STK figure shown presents potential SPARC calibration locations modeled for overpass access. The number of overpasses are shown for locations at 45 and 50 degree northern latitude for an International Space Station (ISS) orbit. The portions of orbits within a 10 degree off-nadir of target locations are shown (thick lines of various colors) over the arbitrary seven-day period of May 23–29.

CONCLUSION

Calibration and validation are essential parts of establishing and demonstrating product quality for users of remote sensing imagery. Especially for a constellation of sensors producing "Big Data," maintaining product uniformity is critical and incorporating a vicarious calibration methodology within the enterprise processing pipeline can significantly enhance the total cost and profit envelope of a satellite program. The automated SPARC method offers a comprehensive, efficient and flexible CalVal solution for enabling profitable Earth-imaging space and airborne ventures.

REFERENCES

Stephen Schiller, John Silny and Marcus Teter "Comprehensive Vicarious Calibration and Characterization of a Small Satellite Constellation Using the Specular Array Radiometric Calibration (SPARC) Method", Proceedings of the 31st Annual AIAA/USU Conference on Small Satellites, 2017, Logan Utah.

Stephen Schiller and John Silny, Conference on Characterization and Radiometric Calibration for Remote Sensing Utah State University, Logan, Utah, August 24, 2016, CALCON Technical Conference, "Using Vicarious Calibration to Evaluate Small Target Radiometry," https://digitalcommons.usu.edu/calcon/CALCON2016/all2016content/2/

Stephen Schiller and John Silny, "The Specular Array Radiometric Calibration (SPARC) method: a new approach for absolute vicarious calibration in the solar reflective spectrum", Proceedings of SPIE Vol. 7813, 78130E (2010).