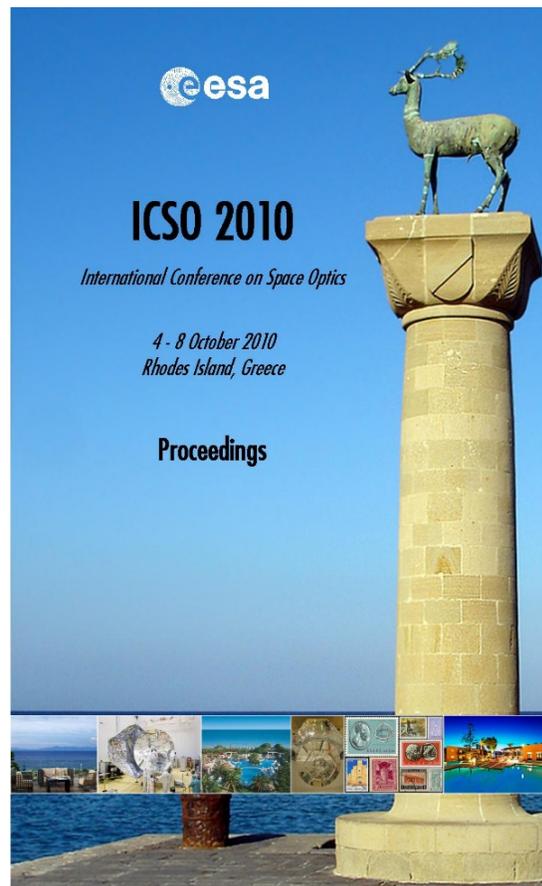


# International Conference on Space Optics—ICSO 2010

Rhodes Island, Greece

4–8 October 2010

*Edited by Errico Armandillo, Bruno Cugny,  
and Nikos Karafolas*



## *Imaging spectral signature instrument airborne campaign results*

*K. Viherkanto, U. Kantojärvi, B. Harnisch*



International Conference on Space Optics — ICSO 2010, edited by Errico Armandillo, Bruno Cugny,  
Nikos Karafolas, Proc. of SPIE Vol. 10565, 105655I · © 2010 ESA and CNES  
CCC code: 0277-786X/17/\$18 · doi: 10.1117/12.2552582

## IMAGING SPECTRAL SIGNATURE INSTRUMENT AIRBORNE CAMPAIGN RESULTS

K. Viherkanto<sup>1</sup>, U. Kantojärvi<sup>1</sup>, B. Harnisch<sup>2</sup>

<sup>1</sup> VTT, P.O. Box 1000, FI-02044, Finland, Kai.Viherkanto@vtt.fi

<sup>2</sup> European Space Agency, 2200 AG Noordwijk, The Netherlands

### I. INTRODUCTION

This paper describes aircraft flight campaign test results for the Imaging spectral signature instrument (ISSI) breadboard developed in the ESA contract 19754/06/NL/PA. The ISSI project was inspired by the Information-efficient hyperspectral imaging sensor (ISIS) [1]. The development and design of the ISSI breadboard is described in [2]. ISSI is a line imaging programmable correlation spectrometer. ISSI is implemented with a front objective, two spectrographs, a liquid crystal display (LCD) spatial light modulator (SLM) and a line sensor. A line imaged by the front objective is dispersed by the first spectrograph on the LCD. Any transmission pattern can be programmed on the LCD. The modulated image is then re-gathered by the second spectrograph to a line on the CCD line detector. Effectively the system performs a dot product between the transmission vector on the LCD and the spectral signature vector of the imaged pixel, where the spectral bins are the components of the vector. Different hyperspectral correlation algorithms, which contain this dot product, can be implemented. Maybe the most intuitive is the spectral angle mapper (SAM). This algorithm only requires advance knowledge of the searched signature itself. With ISSI the correlation result  $C$  of the SAM algorithm is approximated in the following way

$$C = \frac{\sum_{\lambda_n} s_{\lambda} R_{\lambda}}{\sum_{\lambda_n} R_{\lambda}}, \quad (1)$$

where  $s_{\lambda}$ =programmable transmission in the LCD,  $R_{\lambda}$ =target signature signal in the spectral channel, and  $\lambda_n$ =spectral bins. The signal value includes the ISSI total spectral efficiency response to the incoming radiance spectrum.

ISSI has operated satisfactorily under static laboratory conditions. The next step was to determine how well the concept performs in airborne remote sensing with all environmental variables present.

### II. SIGNATURE DETERMINATION

The spectral signature to be programmed on ISSI needs to be known a priori. Ideally the signature would be measured with ISSI itself operating in a spectrometer mode. However, this is possible only in static laboratory conditions. Therefore in real remote sensing applications, the spectral signature must be obtained either with another spectrometer instrument from the ground or with another hyperspectral imager from the air. In the first case the reflectance spectrum of the target is obtained with field spectroscopy. Using an atmospheric radiative transfer model such as MODTRAN, the radiance spectrum of the target at the flying height and conditions is predicted. In the second case the radiance spectrum is obtained directly from a calibrated hyperspectral instrument. In order to determine the shape of the transmission signature to be programmed on the SLM, the radiance spectrum must be multiplied by the ISSI total spectral efficiency.

In addition to the signature image (the numerator in Eq. 1), the reference image (the denominator in Eq. 1) needs to be obtained simultaneously. The ISSI breadboard has only one channel and therefore the reference image in the test campaign was obtained with a conventional hyperspectral imager synchronously with ISSI. This instrument was also used to gather the a priori target signatures.

### III. FLIGHT CAMPAIGN

The test setup described in [3] consisted of the ISSI breadboard mounted side by side with an AisaEAGLE hyperspectral system. In order to provide context data a digital frame camera was included in the payload. For georectification a global positioning system and inertial measurement unit (GPS/IMU) was included. The

aircraft was a twin-engine Cessna 401. The baseline imaging phase ground speed was 65 m/s and the aircraft can operate for ca 4 hours with this payload. In addition to the pilot three operators were required.

The ideal flight campaign consists of two separate missions over the same area under similar illumination conditions. On the first day the area is mapped with the AisaEAGLE system and a priori signatures obtained from spectral libraries and field spectroscopy are tried with ISSI. After the first day the hyperspectral data is processed to absolute radiance values and signatures for selected targets are extracted and imported to ISSI. On the second flight day these signatures are used in ISSI. The AisaEAGLE also collects data in order to check how much the target signatures have changed since the previous acquisition. The digital camera provides context data of the targets with higher spatial resolution and assists in the georectification processing.

As there were many constraints and secondary objectives, the following two areas west of Helsinki, Finland, were selected for the campaign: a geodetic test field (Sjökulla) containing geometric and spectral calibration targets, and a waste dump site (Ämmässuo) containing heaps of different sorted materials. Also a simultaneous ground campaign was planned at the geodetic test field in order to obtain the local ground illumination and target reflectance conditions. This data was planned to be used to correlate the target reflectance to the radiance spectrum at the flying height. The ground campaign required a cloud coverage of less than 2/8 in order to be useful and this posed the tightest weather requirements for the whole campaign.

However, reality did not go as planned. The imaging season of 2008 in southern Finland was the worst in decades and this caused problems, both for the campaign itself and the aircraft availability as the same aircraft was reserved by operational users. Additionally an incident forced a flight ban over the originally planned target areas. Therefore the flight campaign plans had to be quickly remade for different areas and the flights were performed in suboptimal weather and illumination during September 10-12<sup>th</sup>, 2008. A mixture of urban and rural landscapes in the cities of Lahti and Pori were selected and covered twice during three days from 650 m and 1000 m heights. Due to the suboptimal weather conditions (cloud coverage more than 4/8), the ground campaign could unfortunately not be performed.

#### IV. DATA PROCESSING

The data processing steps consisted of radiometric conversion of the AisaEAGLE images to radiance values. Next ISSI image landmarks were registered to the corresponding AisaEAGLE image landmarks using manual point measurement. The ISSI images were then warped to the Aisa image geometry using a triangulation method. Georectification of the images was not performed owing to lack of resources and the emphasis on spectral performance instead of spatial quality.

The ISSI correlation image is obtained by dividing the ISSI pixel value with the total signal value obtained from the hyperspectral data first multiplied with the ISSI total spectral efficiency. Pixel mismatching between ISSI and AisaEAGLE images introduces clutter in the correlation image for nonhomogeneous targets.

For the hyperspectral data itself the standard SAM calculation was performed for the same signature as used in ISSI. The quality of target detection was then assessed from this data set.

In order to have a measure for the statistical separation between target and background correlation results the separation metric (SM) as described in [4] is used.

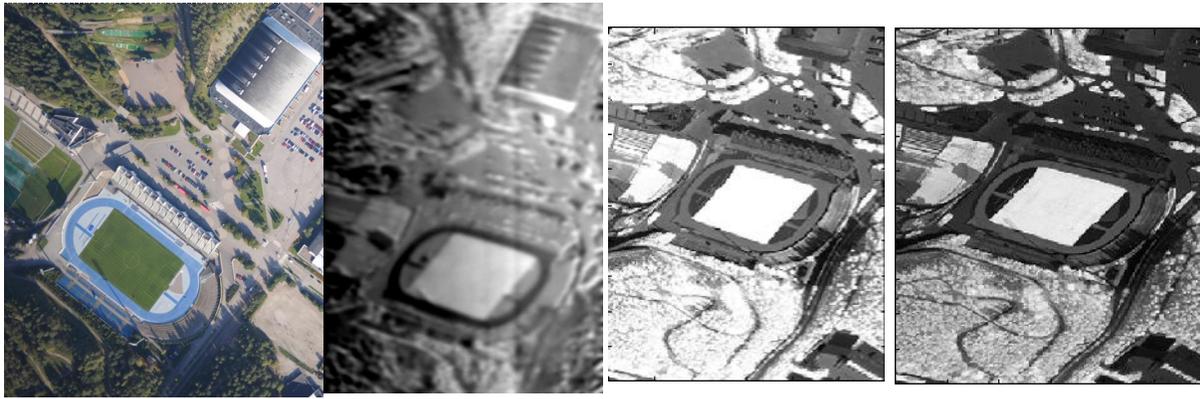
$$SM = \frac{|\mu_1 - \mu_2|}{\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{2}}}, \quad (2)$$

where  $\sigma$  = standard deviation of the signal and  $\mu$  = mean value of the signal. Subscripts 1 and 2 stand for the target and background respectively. The SM is the number of “average standard deviations” that fit between the means of two signals. The bigger the SM value, the better the two targets can be discerned.

#### V. SAMPLE RESULTS

Limited paper space prevents discussing more than just two “school examples” from the data set.

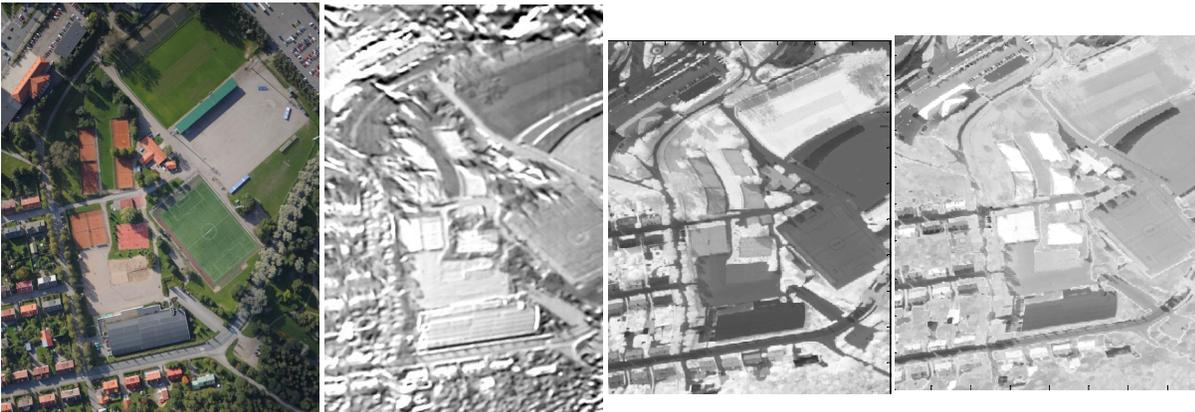
The first sample is obtained using the signature of green grass.



**Fig. 1.** Frame camera context image (left) next to an unrectified raw ISSI correlation image using the signature of grass. Correlation images for grass calculated from the AisaEAGLE data using the ISSI approximation and the SAM method (right).

The SM in the ISSI image between homogeneous samples of ca 100 pixels of grass and asphalt is ca 3. For the correlation images calculated from the hyperspectral data the SM is 16 and 60 for the ISSI approximation and SAM method, respectively.

A second sample is obtained using the signature of red clay. The SM between red clay and grass is 11 and the SM between clay and grey gravel is 5.



**Fig. 2.** Frame camera context image (left) next to an unrectified raw ISSI correlation image using the signature of red clay. Correlation images for red clay calculated from the AisaEAGLE data using the ISSI approximation and the SAM method (right).

Correlation images calculated from the hyperspectral data show that the ISSI approximation does not produce the highest correlation from the clay but from the grass. A more accurate simulation of ISSI performance is obtained when the hyperspectral data is first weighed with the ISSI spectral efficiency. Then Fig. 3 is obtained.



**Fig. 3.** ISSI correlation image simulation using AisaEAGLE data. The SM between clay and grass is 63 and between clay and grey gravel is 32. The intensities of different targets are qualitatively in the same order as in the real correlation image.

## VI. CONCLUSIONS

Based on the correlation images inspected the performance of ISSI in terms of contrast between the target signature and backgrounds is poorer than expected from laboratory or simulation results.

Any errors in the ISSI and AisaEAGLE spectral radiometric calibration inevitably degrade performance. Errors affect both the signature imported to ISSI and the total signal in the ratio calculation. An additional degradation comes from the variability between the source signature and the target signature. However, in the best ISSI images there was not a major difference between the a priori and the actual signatures although targets, time and weather were different.

The above reasons were due to the campaign arrangements. A complete ISSI instrument would need to be implemented with two channels and radiometrically accurately calibrated.

A fundamental problem with the ISSI approximation to the SAM method is that the contrast between spectrally “flat” signatures and backgrounds tend to be smaller than with the true SAM method. The ISSI approximation is unfavourable compared to SAM for most of the campaign signatures used and backgrounds encountered.

Optimising the ISSI signatures by cutting out certain bands with poor SM would have led to better results. Simulations for the first green grass example indicate that the SM could have been increased from 3 to 7 at least. However, due to the last minute force majeure change of plans, unavailability of real time ISSI correlation images and quick turnaround time from signature to flight, it was not possible to simulate and verify the performance of signatures in advance. This underlines the importance of posing the actual question of what target needs to be detected with respect to what backgrounds in advance with sufficient detail.

The correlation images contain many artefacts and outlier data resulting from that the lines are unrectified and pixels are mismatched. However, the conclusions are not expected to be different if the images were rectified.

Nevertheless, ISSI has operated under flight conditions. ISSI can only asymptotically approach a hyperspectral processing result and all non-idealities (calibration, pixel misalignment, signature variation) reduce the contrast between the target and backgrounds. The advantages of the ISSI concept in terms of the real time result, potentially improved signal to noise ratio versus a hyperspectral imager and reduced data processing requirements remain to be demonstrated for an Earth observation application.

## ACKNOWLEDGEMENTS

Specim is acknowledged for operating the AisaEAGLE hyperspectral system.

## REFERENCES

- [1] W. Sweatt, C. Boye, S. Gentry, M. Descour, B. Stallard, and C. Grotbeck, “ISIS: an information-efficient hyperspectral imaging sensor”, SPIE Conference on Imaging Spectrometry IV, San Diego, California, July, 1998, SPIE Vol. 3438.
- [2] U. Kantojärvi, K. Viherkanto, V. Aallos, H. Saari, E. Herrala, and B. Harnisch, “Performance of the imaging spectral signature instrument (ISSI) breadboard”, Sensors, Systems, and Next-Generation Satellites XI, Proc. of SPIE Vol. 6744.
- [3] U. Kantojärvi, E. Parmes, H. Saari, K. Viherkanto, and B. Harnisch, “Imaging spectral signature instrument airborne campaign”, ICSO - 7<sup>th</sup> International Conference on Space Optics, Toulouse, France, 14-17 October 2008.
- [4] B. Stallard and S. Gentry, “Construction of filter vectors for the information-efficient spectral imaging sensor”, SPIE Conference on Imaging Spectrometry IV, San Diego, California, July, 1998, SPIE Vol. 3438.