AN ADVANCED TOOL OF THE CNR IMAA EO FACILITIES: OVERVIEW OF THE TASI-600 HYPERSPECTRAL THERMAL SPECTROMETER

S. Pignatti, V. Lapenna, A. Palombo, S. Pascucci, N. Pergola and V. Cuomo*

National Research Council, Institute of Methodologies for Environmental Analysis (CNR IMAA), 85050 Tito Scalo (PZ), Italy (**pascucci@imaa.cnr.it)*

ABSTRACT

The paper shows the TASI-600 thermal hyperspectral sensor acquired by the Italian National Research Council - Institute of Methodologies for Environmental Analysis (CNR-IMAA) and describes some of the checks carried out during the commissioning phase. Furthermore, the first data acquired during the test-flight on hot spots of the volcanic island of Ischia (Central Italy) are shown.

TASI-600 sensor has 32 spectral bands in the 8.0-11.5 μm spectral range, with a swath of 300 pixels and an IFOV of 1.2 mRad.

The paper gives an overview of the principal TASI-600 characteristics, the CNR IMAA performance requirements and an overview of the technical innovation.

Some of the outcomes of the tests performed in our laboratory in the Final Acceptance Test were focused to verify the linearity of the sensor up to higher temperatures (i.e. up to 500 K). Preliminary analysis of the in-flight and lab functional tests demonstrated that TASI-600 meets CNR IMAA requirements and as regard the radiometric accuracy it results higher than the requested.

Index Terms — TASI, hyperspectral thermal imager, pushbroom sensor, radiometric accuracy

1. INTRODUCTION

Visible ShortWave InfraRed (0.4–2.5 μm; VSWIR) hyperspectral imagery has been applied in the last decades to address some of the problems inherent to Earth science observation studies. Applications of such data have included numerous research themes, among them noteworthy are: accurate land cover mapping; remote measurement of plant physiology; target detection - identification and modeling of surface optical properties to retrieve physical-chemical parameters related to surface materials [1-2]

However, this spectral range can be not sufficient to provide clearly distinctive signatures unique of surface materials or individual plant species [3-5].

Thermal infrared spectral features in the LWIR range (8.0–14.0 μm) alone or combined with the VSWIR spectral behaviors, has been revealed as powerful for detecting and identifying surface materials and gases [4, 6].

In particular the 8-12-mm TIR atmospheric window has been used in numerous remote sensing studies to map variations in surface and mineral composition [7]. Up to nowadays imaging multi-channel airborne and satellite radiometers such as Thermal Infrared Multispectral Scanner (TIMS), Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) have been used in numerous studies to characterize the Earth surface.

In the last years the advance in the Focal Plane Array industries has allowed the application of IR cooled detectors for the deployment of IR spectrometer.

Within the deployments of the cooled prism spectrometer SEBASS [8] that measures the MWIR/LWIR (2.42–5.33 μm and 7.57 – 13.52 μm) with a spectral resolution of 0.088 μm @ 11.25 μm, a number of IR spectrometers faced the research market. Among them the "Commercial Of The Shelf" pushbroom sensors are: the ITRES TASI-600 and the SPECIM AisaOWL. Moreover, in the same TIR intervals also interferometer technologies (e.g. TELOPS FIRST) are at present operating, while the ONERA SYSIPHE sensor will be available in 2012.

In this context, to track the most challenging future research themes in EO systems, in 2009 the CNR IMAA has decided to upgrade its observing facilities composed by ground hyperspectral and IR broadband sensors, airborne VSWIR hyperspectral sensors and a multi-mission satellite receiving station, with the TASI-600 hyperspectral spectrometer.

The paper describes the TASI-600 sensor requirements, the sensor characteristics' requested in the tender, the commissioning test performed on the acquired sensor at the time of the instrument final acceptance tests and the first data collected on a test site are also presented.

2. LWIR SENSOR REQUIREMENTS

The system selection process has been driven by the CNR IMAA requirements defined at the time of the tender. The main sensor requirements are briefly reported in the following table (Table 1).

	Sensor's minimal requirements	
Spectral channels	> 30	
Across track pixels	>300	
FPA pitch	30x30 micron	
FOV	≥40°	
IFOV	≤2 mrad	
Foreoptics	≤ f/2.5	
Total distortion	0.35 pixel	
Sensor linear response within the sensor nominal spectral range	0-800°C	
Digitalization	14 bit	
NEdR @ 300K with a FOV of 40°, for an across-track dimension of at least 300 pixels.	max NEdR requested (mW m^{-2} sr^{-1} μm^{-1})	
	@ 8µm	40
	@ 10µm	50
	@ 11µm	70

Table 1. List of the main sensor's characteristics requested by the CNR IMAA for the LWIR sensor.

In Table 1 the total distortion parameter, was defined as:

$$D = \sqrt{ss^2 + sk^2} \quad \text{Eq. 1}$$

where, *ss* is the spectral smile and *sk* is the spectral keystone. The total distortion parameter was evaluated to take into consideration the optical distortions occurring inside the scan head both spectral and spatial, i.e. the so called spectral "smile" and "keystone" errors.

The sensor NEdR requirements shown in Table 1 are referred to: (a) a square pixel, (b) an emissivity of 1, (c) a FWHM of 0.1µm ±5% and (d) an integration time compatible with a flight altitude of 1000m for a flight velocity of 120Knots.

The NEdR values reported in Table 1 correspond to the maximal values requested, nevertheless, in the evaluation of the sensor performances, CNR has scored sensors presenting more strict NEdR requirements (i.e. lower than 20, 25, and 35 mW m^{-2} sr^{-1} μm^{-1} respectively @ 8, 10 and 11 µm).

3. TASI SENSOR BRIEF DESCRIPTION

TASI sensor is a composed by: *i*) the Scan Head Unit (SHU); *ii*) the Instrument Control Unit (ICU) and *iii*) the pre-processing software.

The SHU is provided with a custom Stirling Cycle cooled MCT detector (HgCdTe) specifically designed for the TASI-600 Sensor. TASI-600 is designed with custom athermal optics which removes the need for internal environmental control systems that can fail and produce electronic noise. The optical design assures a diffraction-limited sensor.

The ICU storage device is provided with a Compact FLASH Card media that allows for a quick recovery or update in the field and removes the need for conventional hard drives that are susceptible to vibrations and shocks. The ICU also contains a secondary real time Slave processor, which minimizes the likelihood of dropped frames to better than 1 frame (scanline) every 10,000 and improves time synchronization to less than 1ms of error between the navigation system and the image system.

The TASI-600 is controlled by ITRES' control software, which incorporates a real time diagnostic system, i.e. the Health Aperture Logic (HAL). HAL allows users to monitor the system during data acquisition and also critical system temperatures, voltages and parameters and other noteworthy housekeeping data.

The system includes licensed pre-processing software to radiometrically correct (RADCORR) and geometrically correct (GEOCOR) TASI data. RADCORR removes system offsets (i.e. dark current); data can be output as spectral mSRU radiance units (1 mSRU is equal to 1 nW cm-2 sr-2 nm-1) or apparent temperatures. The GEOCOR is software specific for use with ITRES airborne sensor systems. It incorporates photogrammetric bundle adjustment solutions to produce orthocorrected imagery utilizing precision IMU/GPS and terrain height data from the most common systems and sources.

4. SENSOR COMMISSIONING PHASE

The sensor acceptance was performed according to a shared protocol (between CNR and ITRES) that has leaded to the definition of a Final Acceptance Test Procedure (FATP). FATP includes a set of trials based on functional test and procedures finalized to verify the correct sensor functionality and technical performances. The FATP included: a) hardware check for the ICU, HSU and peripherals; b) lab tests for verifying the technical and hardware performances and c) airborne tests.

Just for the concision of this article, the paper presents the primary tests performed at the CNR IMAA lab in Potenza (Italy) to verify the achievements of the main requirements of Table 1. In particular, the tests aim at verifying: a) the system linearity response within 0-800°c and b) the NEdR performed on the data acquired by ITRES and by using the CNR IMAA facilities.

4.1. System linearity response

As in Italy active volcanoes are present and, therefore, real sensor operational scenarios can be characterized by high temperatures (e.g. lava flows), we put our attention on testing the TASI-600 system linearity over the full dynamic range (from 100 to 280 °C). To demonstrate the linearity over the TASI dynamic range, we use a calibrated cavity black body source (MIKRON-M310 certified for a temperature range of +5 to 350°C and an emissivity = 0.99 at 8-14 µm; aperture diameter of 76 mm, temperature accuracy 1°C). This cavity black body positioned in front of the slit, even though not optimal for image uniformly the entire FOV, allowed us to record TASI-600 imagery by increasing the black body temperature (with a step procedure) and varying the integration time. The linear behavior of the sensor was recovered by plotting the variance of a region of interest selected on the imagery of the black body vs. the average values pertaining to the same region of interest.

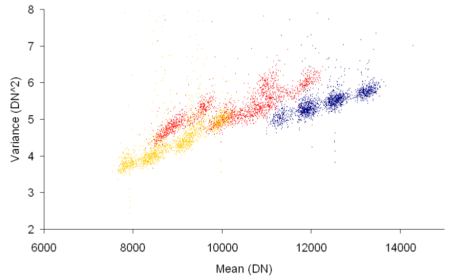

Figure 1. Example of variance vs. average plot for three different temperatures (blue-36°C, yellow-130°C, red-280°C) recorded with different integration times.

The mean of the raw values (DN) and its variance were calculated for a restricted, homogeneous area within the black body area covered by the TASI-600 imagery.
For this task, we've selected the integration times varying from 190 to 370 msec and the black body temperatures ranging from 36 to 280 °C. As example, Figure 1 shows the mean (DN) values vs. variance plot as obtained by varying the integration times that allows to cover the TASI-600 dynamic range at different temperatures (i.e. 36°C, 130°C, 280°C). The performed tests and the relative plots assure that the TASI-600 signal does not saturate and that its response is linear in the analyzed dynamic range.

4.2. Radiometric Accuracy

The radiometric performance requirements in terms of NEdR were verified on the radiance images acquired at ITRES lab on its standard black body. The ITRES black body size is greater than the TASI-600 scan line thus allowing to calculate the NEdR by using the standard deviation of the total radiance image. The NEdR was calculated using three different configurations of binning (i.e. no binning, 4 and 16 pixels summed; see Figure 2).

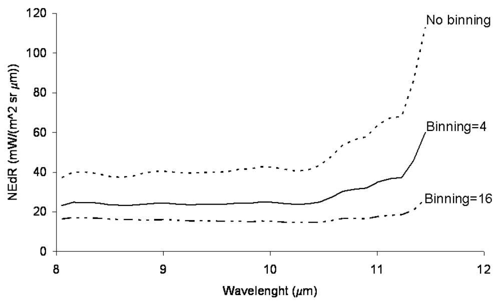

Figure 2. NEdR calculated from imagery on a reference certified black body @300°K

The obtained values show that the instrument fully meets the more strict CNR IMAA requirements (i.e. @300°K with $\varepsilon = 1$ and square pixel; 20, 25 and 35 mW m^{-2} sr^{-1} μm^{-1}, respectively @ 8, 10 and 11 µm; see Table 1).

Nevertheless, a cross check to validate the correctness of the recorded radiance values with respect to the theoretical radiance values as given by Planck's equation has been performed on the data collected at the CNR using the temperatures and emissivity of the CNR BB (see Figure 3).

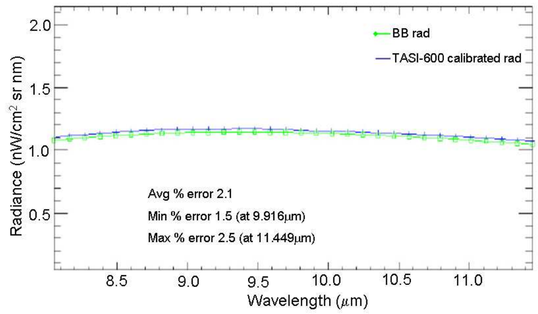

Figure 3. Comparison between the CNR BB radiance and the calibrated to radiance values measured by TASI-600.

Figure 3 shows that the average error across the entire spectral range, in retrieving the CNR BB radiance, is 2.1%.

4.3. Airborne tests

On January the 12th, 2011 we have performed the TASI-600 acceptance test flight. The instrument was mounted in Naples on a Partenavia P68 Observer airborne (Figure 4) and the flight test was on the Ischia island where volcanic activities take place an therefore different temperature targets occur and, in particular, natural thermal hot waters gush into the sea.
The test flight has demonstrated operatively that the instrument works well and properly and with an optimal synchronization with the INS/GPS system.

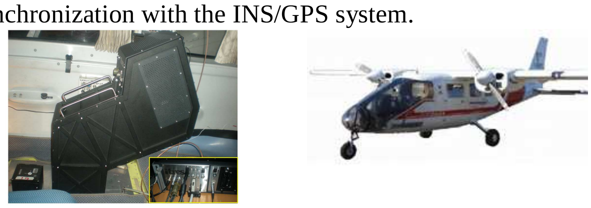

Figure 4. TASI-600 sensor mounted on the Partenavia P68 Observer airborne.

In Figure 5 is presented an RGB example imagery acquired during the test-flights over the Ischia island; Figures 5 (b) and (d) show two details that highlight natural streams of spouting hot water gushing into the sea.

5. DISCUSSION

With respect to the differences between the results from the data recorded at ITRES and at CNR with the CNR BB, it should be stressed that the CNR BB is not an optimal device for the TASI-600 because of the BB cavity and because of the dimension doesn't assure the fully illumination of the

TASI field of view. Thus, in addition to the regular sources of error that influence the accuracy of such measurements (such as the uncertainties of the uniformity, stability, emissivity and temperature) there are to consider other sources of error due to the setup. However, by focusing on the small illuminated section of the TASI-600 image will hopefully help reduce some of the errors due to the setup or other environmental factors (reflection, scattered light, background emission, etc.).

The "rad. file", provided by ITRES, was used to process the CNR BB data to produce radiometrically corrected radiance files. These files were then compared to the theoretical radiance values as given by Planck's equation (using the BB temperatures and emissivity of the CNR BB) in order to verify these values with an independent source. In Figure 3 is shown the percentage error calculated on CNR BB images, which is higher of one order of magnitude of the error obtained by using the ITRES certified extended area BB and a more accurate experimental set up (avg % error 0.1% by using ITRES extended area BB).

The validation check performed on the CNR black body, even though with the above mentioned limitation, has showed that the same level of accuracy is achieved below 100 °C as above it (up to 280 °C) indicating that the sensor is linear and that the calibration file (rad file) is adequate for producing valid radiance results when viewing targets are greater than 100 °C

6. CONCLUSIONS

The CNR IMAA TASI-600 resulted to be an advanced and suitable EO tool, meeting all the goals required by the commitment: radiometric performance and high spectral resolution. These optimal combine represent a very powerful instrument providing excellent quality airborne thermal hyperspectral imagery to the science community involved in the Earth's environment.

ACKNOWLEDGMENTS

We would to thanks Nuova Avioriprese s.r.l. (Napoli, Italy) for providing the P68 airborne and helping us in the TASI-600 installation and test flights.

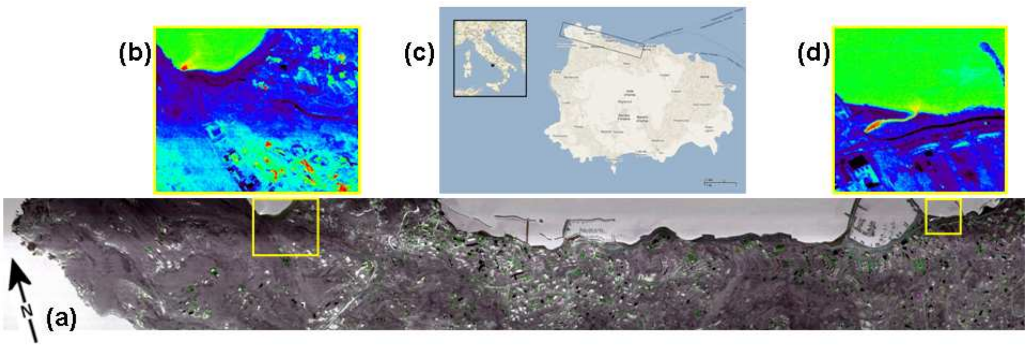

Figure 5. (a) Example of TASI-600 imagery (R-10244 nm; G-8492 nm; B-9587 nm) acquired over the Ischia island, Italy (c) on January the 12th, 2011. (b) and (d) two zoom images of TASI-600 band 21 (10244 nm) color stretched highlighting natural streams of spouting hot water (thermal waters) gushing into the sea.

REFERENCES

[1] Viscarra-Rossel, R. A., Walvoort, D. J. J., Mcbratney, A. B., Janik, L. J., & Skjemstad, J. O. (2006). Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties. Geoderma, 131, 59−75.

[2] Pignatti, S., Cavalli, R.M., Cuomo, V., Fusilli, L., Pascucci, S., Poscolieri, M., Santini, F. Evaluating Hyperion capability for land cover mapping in a fragmented ecosystem: Pollino National Park, Italy (2009) *Remote Sensing of Environment*, 113 (3), pp. 622-634.

[3] Bassani, C., Cavalli, R.M., Cavalcante, F., Cuomo, V., Palombo, A., Pascucci, S., Pignatti, S. Deterioration status of asbestos-cement roofing sheets assessed by analyzing hyperspectral data (2007) *Remote Sensing of Environment*, 109 (3), pp. 361-378.

[4] Pascucci, S., Bassani, C., Palombo, A., Poscolieri, M., Cavalli, R. Road asphalt pavements analyzed by airborne thermal remote sensing: Preliminary results of the Venice highway (2008) *Sensors*, 8 (2), pp. 1278-1296.

[5] Ribeiro da Luz, B., J.K. Crowley. Identification of plant species by using high spatial and spectral resolution thermal infrared (8.0–13.5 μm) imagery (2010) *Remote Sensing of Environment*, Volume 114, Issue 2, pp 404-413

[6] P. Lucey , T. Williams , M. Winter and E. Winter. Two years of operations of AHI: An LWIR hyperspectral imagery, Proc. SPIE, vol. 4030, pp. 31 2003.

[7] Kahle, A. B., Palluconi, F. D., & Christensen, P. R. (1993). Thermal emission spectroscopy: application to the Earth and Mars, Chap. 5. In: C. Pieters, & P. Englert (Eds.), Remote geochemical analysis: elemental and mineralogical composition (pp. 99 – 120). Cambridge University Press.

[8] Hackwell, J. A., et al. (1996). LWIR/MWIR imaging hyperspectral sensor for airborne and ground-based remote sensing. In: Imaging spectrometry II, Proc. of the International Society for Optical Engineering, vol. 2819, pp. 102–107.

[9] M. Razeghi. Long wavelength infrared detectors. Gordon and Breach science publishers,1996.