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ASI – A NEW AIRBORNE HYPERSPECTRAL IMAGER

Ivar Baarstad, Trond Løke and Peter Kaspersen

Norsk Elektro Optikk AS
Solheimvegen 62A, N-1471 Lørenskog, Norway

Norsk Elektro Optikk AS (NEO) has over the last years developed a series of compact, high performance imaging spectrometer systems (hyperspectral cameras) under the working title ASI (Airborne Hyperspectral Imager).

The instrument concept is based on the results of the HISS definition study (Hyperspectral Imager for Small Satellites), performed by NEO for ESA in 1996-97.

The development is currently (2003-2006) partly funded by the French and Norwegian Ministries of Defence, within the context of the EUCLID-project HYPOLAC (Hyperspectral Polarimetric Active and Passive Imaging). This project is undertaken by a French-Norwegian consortium consisting of NEO, Thales Research and Technology, Thales Optronique SA and the Fresnel Institute - University of Marseille. Within the HYPOLAC project, high resolution hyperspectral data from the developed imaging spectrometer has been used in order to select the appropriate wavelengths for a laser based active polarimetric multispectral camera. Additionally, the receiver unit of the active instrument has been built around the imaging spectrometer developed by NEO.

The unique hyperspectral camera concept developed within theses studies has also demonstrated significant potential for use in civilian airborne, laboratory and industrial applications of imaging spectrometry. Four different versions of the instrument have been realized so far, with the following main specifications:

Module	VNIR-640	VNIR-1600	SWIR-320i	SWIR-320m
Detector	Si CCD 640*480	Si CCD 1600*1200	InGaAs 320*256	HgCdTe 320*256
Spectral range	0.4-1µm	0.4-1µm	0.9-1.7µm	1.3-2.5µm
Spatial pixels	640	1600	320	320
FOV across track	18.4°	17°	14°	14°
Pixel FOV across track/ along track	~0.5mrad/ 0.5mrad	~0.187mrad/ 0.375mrad	0.75mrad/ 0.75mrad	~0.75mrad/ 0.75mrad
Spectral sampling	5nm/10nm*	3.7nm	5nm	5nm
# spectral bands	128/64	160	160	256
Digitization	12bit	12bit	12bit	14bit
Frame rate to HD	500/850fps*	120fps	350fps	100fps

*Binning 2x vertically

The instrument design is flexible, and the specifications can be tailored to individual users and applications. All instruments employ the pushbroom scanning principle, acquiring one spatial line of the scene at a time. Some images of the instruments are shown in Figure 1 below.

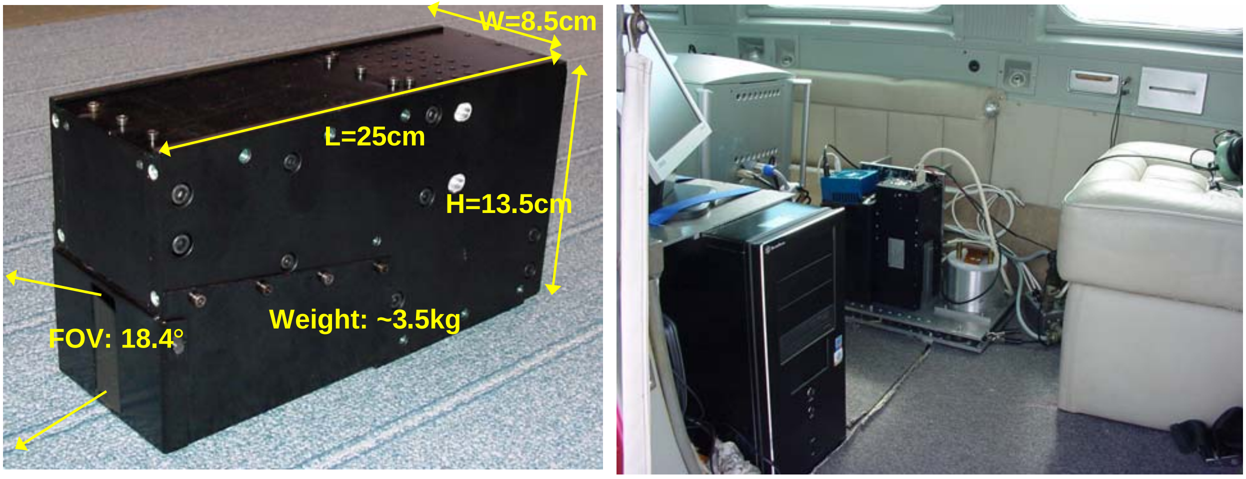

Figure 1 The VNIR-640 instrument (left) and the VNIR-1600 and SWIR 320i mounted in a plane with IMU (right)

All instruments are being calibrated spectrally and radiometrically, using several narrow band sources and a calibrated integrating sphere in order to produce absolute radiance spectra (in W/m^2 nm sr) for each pixel in the image.

The VNIR-1600 and SWIR-320i modules have been integrated into an aircraft, where GPS and INS data are logged continuously to enable geometric correction and georeferencing of the images. Airborne images have been acquired for several military and civilian research institutions in 2003, 2004 and 2005.

The VNIR-640 module, being capable of continuous acquisition of more than 850fps with a window of 640 spatial pixels by 64 spectral bands, can be adapted to various industrial and airborne applications. As an example, when mounted 1m above a conveyer belt, a belt speed of 1m/s is feasible with 1mm spatial resolution and 64 bands.

A tripod mountable scanning stage has been designed, providing synchronous operation of the spectrometer with the scanning platform. This setup can be used to acquire lab or field measurements of stationary scenes, and has been employed for data acquisition for several different users and applications.

The unique and compact mirror based fore optics minimizes spherical and chromatic aberrations. A slit defines the instantaneous field of view, and a transmission grating disperses the light spectrally before it is focused by a lens system onto the focal plane array detector. The lens system has been carefully optimized for minimization and equalization of the point spread function across the FOV and spectral range, as well as for minimization of distortions such as spectral keystone and smile effect.

The high optical quality is documented in Figure 2 where "spot" diagrams and "ensquared energy" diagrams are shown for three different wavelengths (430nm, 700nm and 1000nm) and five different fields of view (0º, +/- 5º, +/- 8º) for the VNIR-640 module. From these plots, one can see that when a point source is imaged through the optical system, most of the energy is contained within one pixel (7.4µm) which is a good measure of the optical performance. Similar results are achieved for the VNIR-1600 module and the SWIR modules.

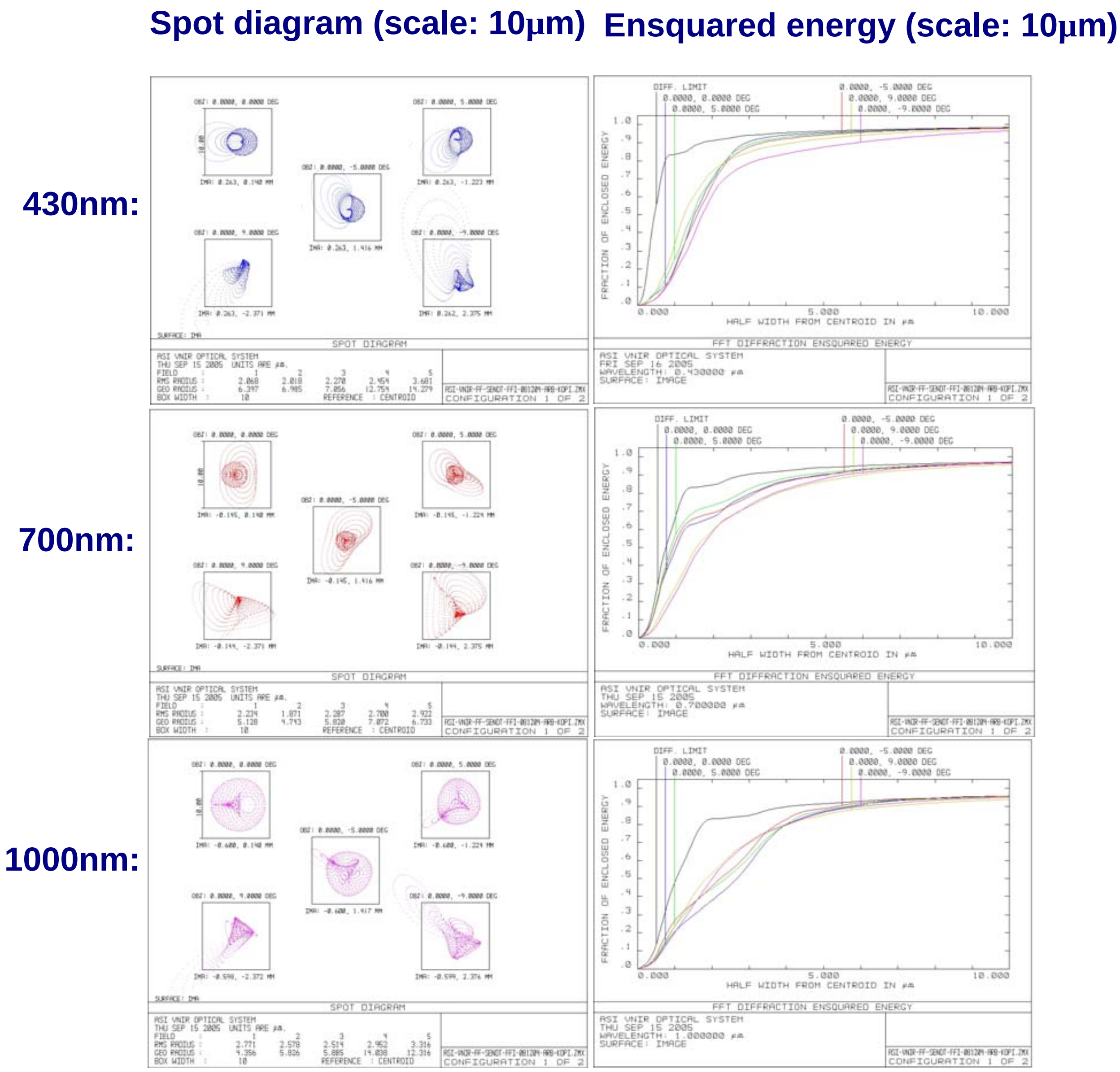

Figure 2 Spot diagram (left) and ensquared energy diagrams (right) for different wavelength and fields of view for the VNIR-640 module.

A detailed tolerance analysis has been performed in the optical design software Zemax in order to determine how tight the optical and mechanical components should be specified in order to transfer the good theoretical performance to the practical system.

All the spectrometers have been tested extensively in order to document the performance as detailed as possible. For each spectrometer module, the following parameters have been tested and characterized:

- Spatial resolution
- Spatial sampling
- Spectral keystone/alignment of grating and sensor/slit
- Spectral resolution
- Smile effect/alignment of slit and sensor
- Spectral sampling

- Responsivity matrix
- Stray light
- Second order suppression
- Sensor characteristics
- Radiometric accuracy
- Performance in real images

Since most of the results are a function of either spatial position or wavelength or both, the complete documentation of the results is quite extensive and does not belong in this paper.

But generally the results of all tests have been encouraging and have confirmed the good performance expected from theoretical simulations.

In conclusion, a new series of high performance imaging spectrometers have been developed my NEO. Results of theoretical simulations and experimental test/characterization demonstrate the good performance. Furthermore, analysis of real data from a variety of civilian and military airborne and ground based applications have demonstrated the usefulness of these camera systems.