

THE HYMAP™ AIRBORNE HYPERSPECTRAL SENSOR: THE SYSTEM, CALIBRATION AND PERFORMANCE

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ABSTRACT

An airborne hyperspectral sensor, HyMap, has been developed in Australia and now deployed for commercial operations around the world. With almost contiguous spectral coverage across the wavelength interval 0.45 – 2.5 μm , the HyMap sensors have achieved high performance levels in terms of signal to noise ratio, band to band registration and image quality. This paper describes some aspects of the sensors including system architecture, calibration and operational performance.

KEY WORDS: remote sensing, spectroscopy, hyperspectral, HyMap, airborne

INTRODUCTION

For almost two decades now, there has been a high level of worldwide research and development into the application of high spectral resolution remote sensing or imaging spectroscopy to various earth resource and environmental mapping and monitoring tasks. The success in applying such techniques often relies on the detection of subtle variations in the spectral properties of one or more of the components being imaged and on the integrity of the sensor's calibration. Such requirements have driven sensor technology to achieve higher signal to noise ratios, improved operational stability and improved levels of traceable spectral and radiometric calibration. The word "hyperspectral" recently entered the remote sensing literature and is used to distinguish sensors with many tens or hundreds of bands from the more traditional multispectral sensors of which LANDSAT MSS and TM are probably the best known examples.

One of the earliest applications of hyperspectral remote sensing identified was geological mapping and its commercial role in mineral exploration. Thus it was of no great surprise that Integrated Spectronics' first contract to produce an airborne hyperspectral sensor came from an international mining and exploration company. Integrated Spectronics and the Optical Systems Engineering group of the CSIRO Manufacturing Science and Technology combined to develop the core technologies that now are featured in the HyMap series of airborne hyperspectral sensors.

The first sensor of the HyMap series was delivered as a 96 channel instrument operating over the wavelength range 0.55 – 2.5 μm . This sensor was highly optimised for mineral exploration tasks which demanded very high signal to noise ratios (SNR) in the 2 – 2.5 μm spectral region.

Subsequent HyMap sensors have been delivered with up to 128 bands covering the 0.44 – 2.5 μm spectral region and with two thermal bands (one band in the 3 – 5 μm atmospheric window and another in the 8 – 10 μm spectral region). This type of configuration is now finding an expanding role in tasks such as environmental pollution monitoring, agriculture and forestry, soil mapping and the assessment of natural and introduced vegetation.

SYSTEM OVERVIEW

The term "HyMap" (Hyperspectral Mapper), is more than the trade name applied to a specific instrument. It actually designates the design and configuration concepts of the sensor. The design is fundamentally modular and this leads to an ability to configure the spectral and spatial characteristics to suit the customer's specific requirements. However, the high performance achieved by the current generation of HyMap sensors is partly derived from optimising the system for a certain operational envelope. Table 1 provides some guidelines as to the configuration and operational bounds of the current HyMap sensors.

Spectral regions	VIS, NIR, SWIR, MWIR, TIR
Number of channels	100 - 200
Spectral bandwidths	10 – 20 nm
Spatial resolution	2 – 10 m
Swath width	60 – 70 degrees
Signal to noise ratio (30 degrees SZA, 50% reflectance)	>500:1
Operational altitude	2000 – 5000 m AGL

Table 1. Typical design envelope for a HyMap type sensor

The HyMap sensor is an optomechanically scanned system incorporating spectrographic/detector array modules, on-board reference lamp and a shutter synchronised to scan line readouts for dark current monitoring. The fully enclosed optomechanical system (views the ground through a window) is mounted in a 3 axis, gyro-stabilised platform.

Associated with the optomechanical subsystem are the power subsystem, control and data acquisition subsystem and the navigation subsystem. The configuration of the entire airborne equipment is shown in the schematic of Figure 1.

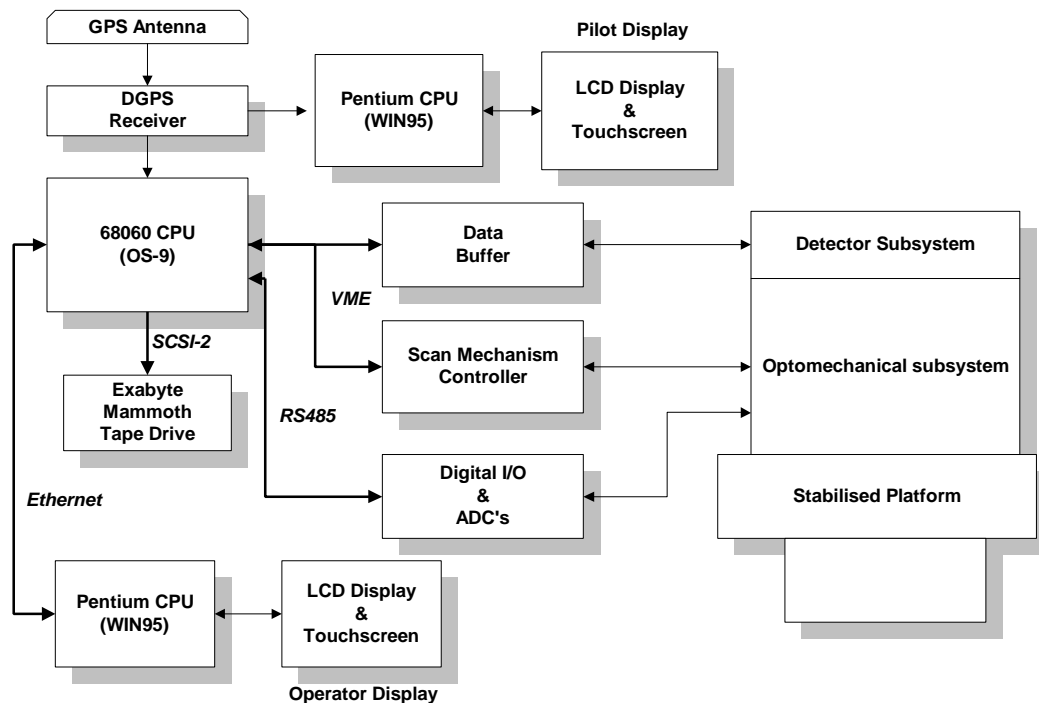


Figure 1: The schematic illustrates the major subsystems that make up the airborne component of the HyMap sensor.

The Zeiss-Jena SM2000 stabilised platform is hydraulically actuated and provides +/- 5 degrees of pitch and roll correction. The yaw can be offset by +/- 20 degrees with +/- 8 degrees of stabilisation. The yaw offset or drift is currently set manually by the operator. The platform provides a residual error in nadir pointing of less than 1 degree and reduces aircraft motion effects by a factor ranging from 10:1 to 30:1.

Data is recorded on Exabyte Mammoth tape drives, two of which are installed to provide an on-line storage capacity of up to 80 GB. The HyMap sensors currently generate data at approximately 2.5 MB per second, well within the capability of a single Exabyte Mammoth drive.

Temperature monitors and heater strips provide temperature control to the main mechanical buss structure of the sensor. The HyMap sensors are designed to operate in unpressurised aircraft where the expected cabin temperature range is 0C to 30C and the outside air temperature range is -40C to +40C. The lower mechanical

structure can experience low air temperatures and so the mechanical structures are designed to be stable while immersed in temperature gradients of up to 50C from the top of the structure to the bottom.

To further discuss the spectral, spatial and radiometric characteristics of the HyMap series sensors, we will concentrate on the 126 band system currently operated by HyVista Corporation (a subsidiary company of Integrated Spectronics Pty Ltd). The performance of this particular sensor is typical of others in the current HyMap production series.

Various operating and configuration specifications are given below.

Typical Operational Parameters	
Platform	Light, twin engined aircraft e.g. Cessna 404, unpressurised
Altitudes	2000 – 5000 m AGL
Ground Speeds	110 – 180 kts

Spatial Configuration	
IFOV	2.5 mr along track 2.0 mr across track
FOV	60 degrees (512 pixels)
Swath	2.3 km at 5m IFOV (along track) 4.6 km at 10m IFOV (along track)

Spectral Configuration			
Module	Spectral range	Bandwidth across module	Average spectral sampling interval
VIS	0.45 – 0.89 μm	15 – 16 nm	15 nm
NIR	0.89 – 1.35 μm	15 – 16 nm	15 nm
SWIR1	1.40 – 1.80 μm	15 – 16 nm	13 nm
SWIR2	1.95 – 2.48 μm	18 – 20 nm	17 nm

Figure 2 shows the spectral band positions relative to both the atmospheric transmission spectrum and the reflectance spectrum (typical) of green vegetation. This spectral configuration provides contiguous sampling across the spectral range of 0.45- 2.48 μm except for gaps in the strong atmospheric water absorption bands near 1.4 and 1.9 μm .

The VIS module includes a Si detector array operated at ambient temperature and the NIR, SWIR1 and SWIR2 modules incorporate InSb arrays cooled by liquid nitrogen to 77K. Each spectrographic module provides 32 spectral channels.

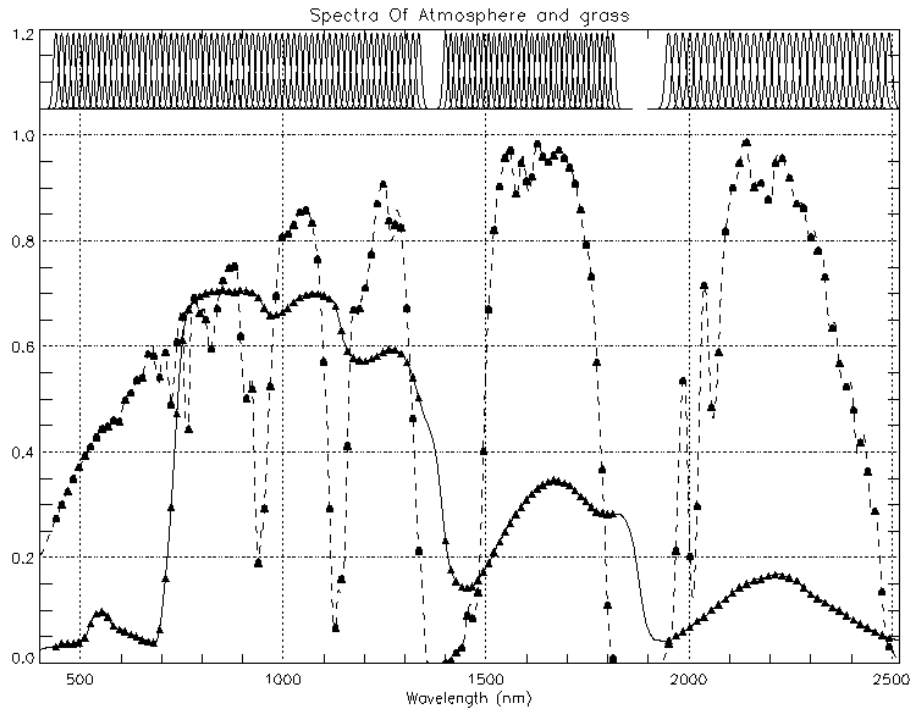


Figure 2: The bands of the HyMap sensor shown relative to the atmospheric transmission and green vegetation spectra.

CALIBRATION

The spectral calibration procedures are used to determine the band centre wavelengths and bandwidths. Additionally, the procedures can be used to verify that the sensor has met specification with regard to out of band leakage that could have been caused by problems such as scattered light or multi-order diffraction.

The HyMap sensor is spectrally calibrated in the laboratory by programming it to view in the nadir. A 150 mm diameter beam from a collimator is directed into the sensor (which has a working aperture of 100 mm). Co-alignment of the optical axes of the collimator and the sensor is achieved with an adjustable fold mirror placed between the sensor and the collimator. The angular extent of the collimator beam is approximately equivalent to 2 times the IFOV of the sensor.

A monochromator and QI light source are used to illuminate (via an optical fibre coupling) the field stop of the collimator. During a spectral calibration sequence, the monochromator is scanned in wavelength and the sensor records the signal levels at each wavelength. This process is controlled by a PC that communicates with the sensor over an ethernet link and with the monochromator over an RS232 link.

Figure 3 shows the results of the spectral calibration procedures for the SWIR1 module. The broad amplitude modulation that appears on this figure is due to factors such as the spectral variation of detector responsivity, monochromator diffraction efficiencies and the variations of the throughput of the sensor itself. Such data is sufficient to determine band wavelengths and bandwidths. However to generate spectral libraries to be used in various spectral identification and unmixing procedures, the data such as shown in Figure 3 has to be normalised to unit area before convolving the bandpass shapes with the higher resolution spectral libraries such as available from the USGS.

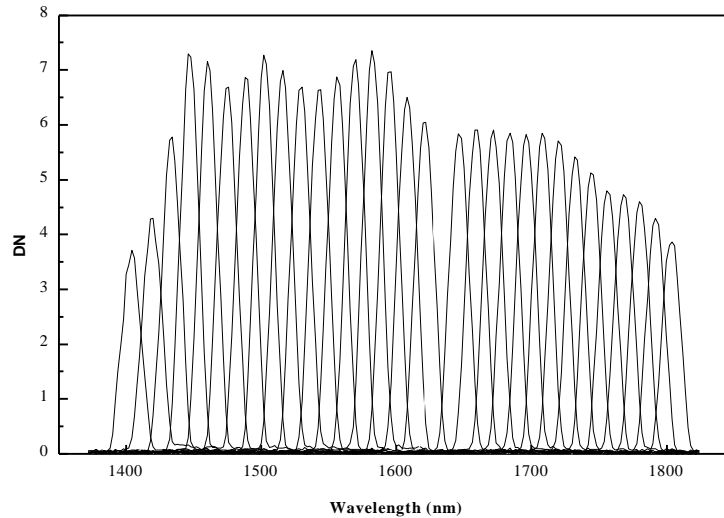


Figure 3. *SWIR1 module band profiles.*

The monochromator (Oriel MS257) is specified as having a wavelength accuracy of 0.2 nm. Before the spectral calibration begins the monochromator is programmed for any wavelength offsets. These offsets are determined by measuring wavelength positions of emission lines from a Ne lamp or the absorption band positions present in some plastic (these band positions are verified with a Nicolet FTIR). Typically such offsets are less than 0.5 nm. The monochromator is operated with slit widths that provide a bandwidth of 2.5 – 3 nm. This typically adds about 0.3 nm to the measured sensor bandwidths that are typically 15 – 20 nm. The scan to scan repeatability of the monochromator is typically about 0.2 nm.

However the greatest single factor in determining the accuracy of spectral calibration is the variation in the angular uniformity of the collimator beam. As in most imaging spectrometers, the field stop also acts as the input slit of the spectrograph and the detector element acts as the exit slit. If the angular intensity of the collimator beam is not sufficiently uniform, then there will appear an intensity weighting across the input slit of the sensor's spectrograph. Such weighting will result in "apparent" wavelength shift in the measured band profiles. To achieve the required angular beam uniformity, various numbers and types of transmissive diffusers are inserted between the output of the monochromator coupling fibre bundle and the field stop of the collimator. Incorrect selection of diffusers can cause spectral calibration errors as large as 3 nm in the HyMap calibration procedures. However, at this time we believe that the overall spectral calibration accuracy is not worse than 0.5 nm.

The HyMap sensor is radiometrically calibrated by having the sensor directly view a 250 mm square pad of Spectralon (SRT-99-100 from Labsphere) which is illuminated by a 1000 W QI lamp (Optronics Laboratories FEL-C). The lamp is about 650 mm from the pad and illuminates it at normal incidence. The sensor views the pad at an angle of 45 degrees. The calibration data for the Spectralon pad and FEL lamp are supplied by the manufactures and are traceable to NIST standards.

At this time, the largest source of radiometric calibration error (particularly in the SWIR region) is the uncertainty in the lamp calibration information supplied by the manufacturer.

PERFORMANCE ACHIEVEMENTS

The HyMap series of sensors has attained a significant level of performance in areas such as signal to noise ratio, band to band registration, image quality, calibration accuracy and operational stability.

Band to band registration is within 1/10th of a pixel and the images show no obvious artefacts such as striping. However, it is in the realm of signal to noise ratio that the HyMap sensors have delivered very good performance.

Figure 4 shows the signal to noise ratios achieved by the sensor while imaging a 50% reflectance target at a solar zenith angle of 30 degrees. The pixel integration time used in this measurement was equivalent to operation at 14 lines per second (or a 5 m IFOV). These results indicate that in spectral regions of the atmospheric windows, the sensor achieves signal to noise ratios approaching 1000:1 or better.

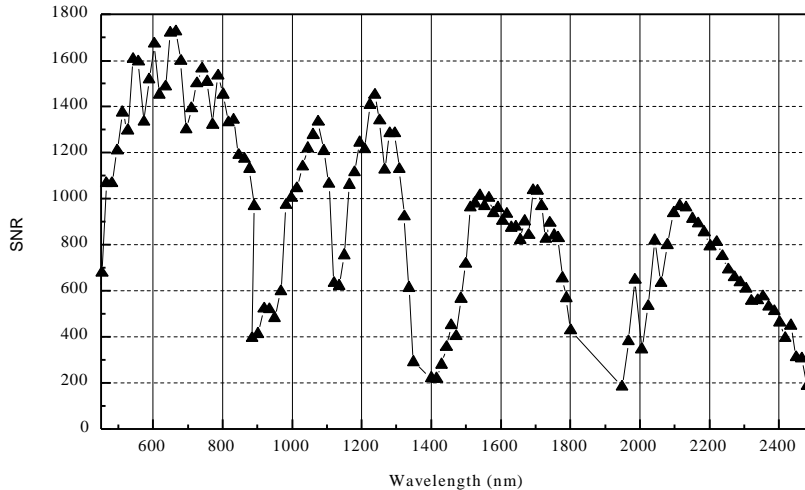


Figure 4 Signal to noise ratio measured while viewing a 50% reflectance target, SZA = 30 degrees.

However, the measurements that generated Figure 4 were not made in flight and so there could be some question as to whether such results could be achieved in flight. To address this concern, we compared various aspects of dark images (with the sensor’s shutter closed) recorded on the ground using laboratory power and during flight. The aim was to detect the presence of any extraneous noise sources that were introduced by the aircraft’s operation.

To date, no significant levels of noise have been attributed to either the vibrational or electrical environment of the aircraft. Typically, the dark current noise will vary by only about 0.1 DN between laboratory and airborne measurements. Thus we believe that the ground based measurements of signal to noise ratio are a very good indicator of the sensor’s in-flight performance.

CONCLUSION

At this time, four sensors of the HyMap type have been manufactured and have been operated in many countries around the world and in a variety of aircraft. Work continues to improve the calibration procedures and to develop ancillary equipment for in-field “QA”. The installation of equipment to accurately measure the sensor pointing variations will lead to improved pixel geolocation and modifications to the servo control systems of the gyro-stabilised platform will lead to improved image quality and minimise the requirements for strip to strip image overlap.

However, the lessons learnt and confidence gained in developing the HyMap series of sensors have now led us to initiate work on the next generation. Starting with the design concepts and technology developed for the current HyMap sensors, work has begun on designing and prototyping subsystems that will deliver improved spectral and spatial resolutions while still maintaining the signal to noise ratios of the current generation and lead to an improved ability to incorporate spectrographs operating at infrared wavelengths beyond 2.5 um.

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