Miniaturized Hyperspectral Sensor for UAV Applications

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Introduction

Environmental monitoring (remote sensing) traditionally uses satellites and fixed-wing aircraft as platforms for precision instrumentation, such as hyperspectral. Hyperspectral technology is often preferred for this sort of work because it covers hundreds of spectral bands versus only several for multi-spectral instruments. Typical application areas include precision agriculture, environmental monitoring, geology, pipeline management, and others. Because UAVs have become more affordable to purchase and operate, easier to deploy in remote areas, and more stable, they have been supplanting these traditional craft (or at least supplementing them). However, challenges exist when pairing precision instruments aboard small, lightweight UAVs. This paper will address several of these challenges.

Grating-Based Spectrometer Design Overview

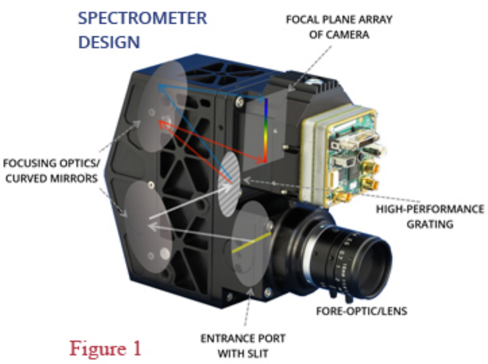

Figure 1

Hyperspectral sensors frequently utilize grating-based spectrometers (Figure 1) to separate small geographic sections of a scene, defined by a slit, to disperse the spectral contents of that scene onto discrete wavelength channels on the focal plane array (FPA). A sensor typically comprises a grating-based spectrometer, comprising a spectrograph and a sensor. Light is imaged through a lens onto a focal position that resides at the entrance slit of the spectrograph. The slit image that enters the spectrometer follows an optical path that includes dispersion from a grating. The grating will maintain spatial coherence in one dimension (length of the slit, measured in mm) and will cause the spatial information (across the width of the slit, measured in μm) to diffract, where the spectral content of the scene will transverse to known wavelength channels on the sensor.

In a grating-based spectrometer configuration for airborne applications, the core idea is to scan a scene in a pushbroom fashion. The slit of the spectrometer is scanned (via movement of the aircraft over the scene) such that at each image time point (frame rate of the sensor) a new slice as determined by the spectrometer's field of view (FOV) captures a new scan line of the scene. During flight, a three-dimensional hyperspectral data cube is generated comprising spatial information at one instance in time (spatial), spatial information based on the time of flight (temporal), and spectral information at each spatial-temporal location.

Grating-based optical designs are typically simpler, lighter, are more environmentally stable across wide ranges, and feature no moving parts. These are important considerations with respect to any airborne application.

Hyperspectral Data-Monitoring Loop (HDML)

Remote sensing basically involves gaining answers to known or unknown environmental analysis problems. Flying over a scene multiple times and using precise geographic correlation allows remote-sensing scientists to see whether any real change has occurred. The cycle of data collection, processing, and analysis is known as the hyperspectral data-monitoring loop (HDML). The use of small, affordable UAVs allows for more frequent cycles and better trend analysis. Primarily, outstanding spectral and spatial resolution plus a wide, aberration-corrected, field-of-view are important characteristics for airborne hyperspectral imaging. Aberration correction is a function of diffraction grating design; a wide and accurate field of view means the UAV needs to make fewer passes over the ground to collect the necessary image data.

Size, Weight, and Power (SWaP)

Because many of today's preferred UAVs are exceptionally small, they also are payload-restricted. Size, weight, and power-consumption considerations (collectively known as 'SWaP') are paramount whether the craft is a fixed-wing or a multi-rotor design. Instruments thus need to be compact and lightweight. Often, hyperspectral sensors are complemented by thermal and LiDAR technology to assure a more complete and calibrated data set. Accessories such as cabling and data processing hardware add to the payload. Also, overall power consumption must be managed because the batteries themselves add weight. Weight is the enemy of flight duration and battery life, so as much miniaturization and internal integration as possible helps to optimize these key variables. The benefit is a UAV that is more efficient in its remote-sensing mission.

A Miniaturized, Integrated Hyperspectral Sensor

Headwall Photonics, Inc. introduced its Nano-Hyperspec® hyperspectral sensor (Figure 2, shown mounted to a gimbal aboard a multi-rotor copter) in mid-2014. Covering the more popular Visible/Near-Infrared (VNIR) spectral range of 400-1000nm, it covers 640 spatial bands and 270 spectral bands, with a spectral sampling interval of approximately 2.2nm. Spectral resolution is about 5nm (FWHM, with a 20-micron slit). Full field-of-view is 15.9 degrees and the power consumption is about 10 watts.

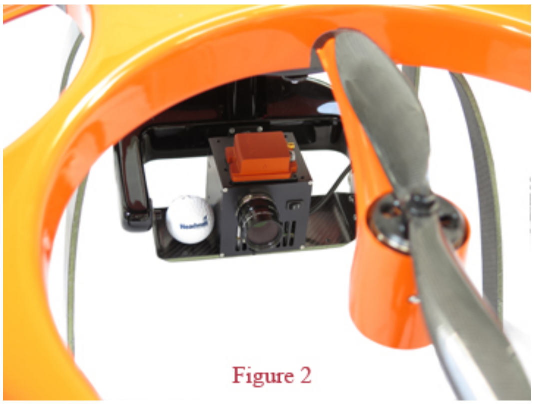

Figure 2

The Nano-Hyperspec weighs less than 0.68 kg in a package measuring only 76.2mm x 76.2mm x 119.2mm in size. Internal integration is demonstrated by onboard data storage comprising 480GB (which yields two hours of flight time at a nominal frame rate of 100fps). With no data processing unit (DPU) and cabling to carry, space is thus available for LiDAR and thermal. Keeping track of the UAVs whereabouts with pinpoint accuracy is the GPS/INU, which Headwall has also integrated onto the sensor housing at any of three attachment points depending on how the Nano-Hyperspec is oriented on the craft. This correlates the geographic position of the UAV to the sensor data while also accounting for airborne characteristics such as roll, pitch, and yaw. A motorized two-position gimbal sharing INU data can also correct for flight variances, but this too represents a payload penalty.

Software is Key

While reducing size and weight of the hyperspectral sensor is a crucial goal, so too is the development of hyperspectral software to help manage everything while aloft and during post-processing. Headwall's Nano-Hyperspec can be paired with an airborne version of its Hyperspec III software to manage control of the sensor while aloft. The software (Figure 3) has a polygon tool to determine precise 'start-stop' coordinates for the sensor, and it also can pull in the GPS data necessary for orthorectification during post processing. This represents a truthful representation of the hyperspectral data, aided by the addition of LiDAR instruments that can determine the height of objects and artifacts below the UAVs flight path.

With everything a user needs to manage UAV flight, sensor operation, and so on, it is helpful to have a software platform that has a simple interface but powerful enough to collect and manage gigabytes of hyperspectral data. The basic Headwall hyperspectral software accomplishes these important tasks, but Headwall has added a layer of specialized functionality for airborne applications so that GPS data and orthorectification during post-processing can be handled using the same software.

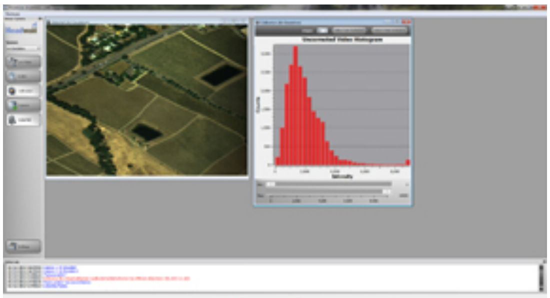

Figure 3

Conclusion

UAVs are quickly becoming the 'go-to' platform for airborne remote sensing research. But integrating the entire package with desired hyperspectral and LiDAR instrumentation is a challenge that Headwall Photonics is able to help manage. While choosing a 'SWaP-optimized' aberration-corrected sensor is crucial, airborne software including orthorectification capabilities will allow users to collect and analyze the best image data possible.

Users often compare multi-spectral sensors to their hyperspectral counterparts. If the objective is to capture complete spectral data across a wide field of view with high spatial and spectral resolution and aberration-correction, hyperspectral will often be the better choice.

BIBLIOGRAPHY

[1] Ryan, H., Mitcheslll, J., Anderson, M. and Glen, N.F. "Radiometric and geometric analysis of hyperspectral imagery acquired from an Unmanned Aerial Vehicle," Remote Sens. 4, 2736-2752 (2012).

[2] Eismann, M.T. [Hyperspectral Remote Sensing], SPIE Press, Bellingham, WA (2012).

[3] Watts, A.C.; Ambrosia, V.G.; Hinkley, E.A. Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use. Remote Sens. 2012, 4, 1671–1692.

[4] Zarco-Tejada, P.J.; Gonzalez-Dugo, V.; Berni, J.A.J. Fluorescence, temperature and narrow-band indices acquired from a UAV platform for water stress using a micro-hyperspectral images and a thermal camera. Remote Sens. Environ., 117, 322–337 (2012).

[5] Laliberte, A.S.; Rango, A. Texture and scale in object-based analysis of subdecimeter resolution unmanned aerial vehicle (UAV) imagery. IEEE Trans. Geosci. Remote Sens. 2009, 47, 761–770.

[6] Berni, J.A.J.; Zarco-Tejada, P.J.; Suarez, L.; Fereres, E. Thermal and narrowband multispectral remote sensing for vegetation monitoring from an unmanned aerial vehicle. IEEE Trans. Geosci. Remote Sens. 2009, 47, 722–738.