Compact Full-Spectrum Hyperspectral Imaging

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ABSTRACT

Current development status of a compact full-spectrum hyperspectral image (HSI) collection and airborne analysis suite will be presented. The developed HSI system is a wing-mounted, podded instrument with weight and size goals significantly lower than current state of the art for full-spectrum HSI instruments. Status of the current program developments will be presented; this will include description of the HSI camera assemblies, avionics and pod integration, and airborne embedded HSI processing suite.

1.0 INTRODUCTION

The US Naval Research Laboratory (NRL) and Corning Net Optics are jointly developing a compact full-spectrum hyperspectral imaging (HSI) sensor and analysis system. This project is supported by the Defense Threat Reduction Agency (DTRA) and is part of an effort to enable high-quality HSI collections from smaller platforms. The Compact HSI system (CHSI) is composed of two independent camera modules having spectral coverage for full day-night operations. These cameras are co-aligned so that they can observe the same ground locations during data collection operations. Collected HSI data are then pre-processed to correct for atmospheric effects and are then passed through a full HSI detection engine. This produces HSI detections that are passed to the ground sensor operators for further analysis and follow-up investigation. The CHSI prototype system, in an underwing podded configuration, is to be assembled in 2023 with ground and flight testing to be performed in 2024.

Presented below is a summary of the current status and plans for the CHSI system. The paper presents an overview of the CHSI program, followed by descriptions of the relevant sub-systems and components. This is then concluded with a discussion of CHSI integration and test plans.

2.0 SYSTEM OVERVIEW

Over the past 10 years or so, multiple field tests and deployments have shown the operational utility of HSI systems. Current developments are aimed at migrating these manned systems into unmanned systems, so as to increase their operational flexibility. Along these trends, NRL and Corning are developing of a prototype HSI system that could meet the requirements for flight from small manned and unmanned air vehicles. This goal was chosen to provide HSI collections and analysis to a lower echelon than is possible using current and near-term HSI systems.

The CHSI HSI sensor system is composed of multiple sub-systems, these are broadly shown in Figure 1 as the sensor can, enclosing the two cameras; the electronics and HSI processor; and the pod support structure. The sensor can is also integral to the CHSI pointing and stabilization system.

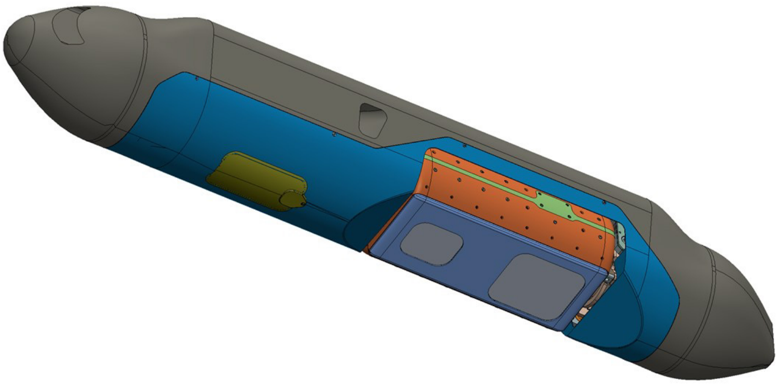

Figure 1: CHSI sensor system overview.

The CHSI program began with a broad trade-study approach aimed at identifying technical approaches that could yield the size, weight and power (SWAP) reductions desired for use from small aircraft. The selected technologies include: monolithic block spectrometers; small pitch InAs and strained layer superlattice (SLS) focal plane arrays (FPAs); and floating point gate array (FPGA) based HSI processing. Only through a combination of these technologies is the SWAP goal possible while still preserving the system's technical performance.

The CHSI system is currently projected to have a full system weight of <60 pounds (<28 kg) in the pod configuration shown in Figure 1. The total CHSI system power is estimated to be <250 Watts sustained. The designed ground resolution, coupled with the estimated spectral sampling and resolution, are predicted to achieve the material sensitivity and detectability needed for the planned CHSI missions.

3.0 SENSOR CAN AND OPTICAL BENCH ASSEMBLY

The sensor can encloses the optical bench, carrying the two separate HSI cameras, capture electronics boards, and provides an environmentally-protected space to house the optical assemblies, as shown in Figure 2. Note that in Figure 2, the camera electronics boards are not shown. The size of the final sensor can is approximately the size of a large shoebox. The two cameras are designed, and will be assembled, aligned, and tested as independent camera units; these cameras are then married onto the common optical bench for final alignment and test. The flexibility of this approach allows the program to proceed through camera manufacture and test with the cameras on independent timelines. This also makes the CHSI system more flexible to future improvements as either camera can be upgraded without impact to the other.

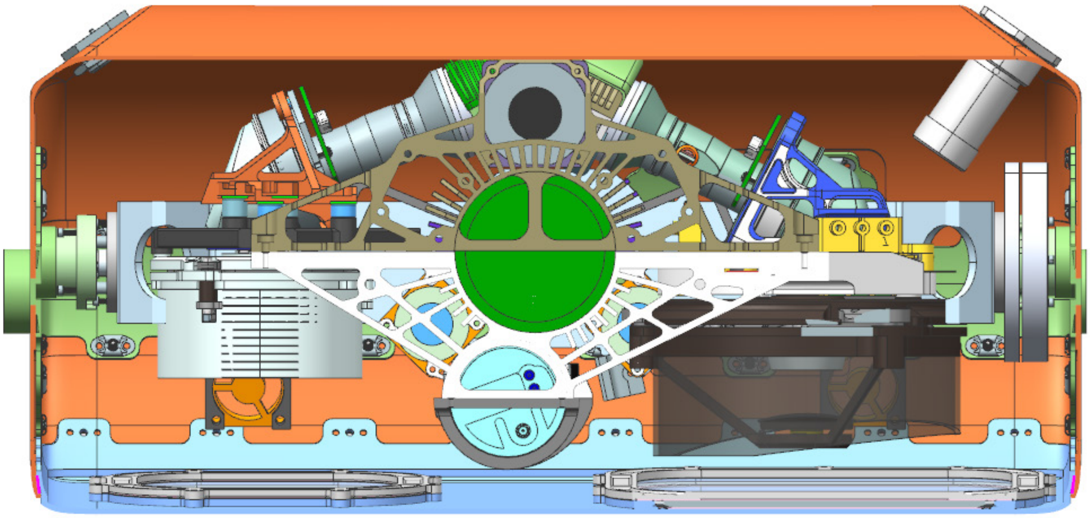

Figure 2: Sensor can assembly.

4.0 HSI CAMERAS

A diagram of one of the camera assemblies is shown in Figure 3. This assembly marries the monolithic block spectrometer and FPA (attached to the cold finger inside the cooled Dewar) with the fore optic telescope. The Dewar is mated to the fore optic using two sets of athermal compensation stages. These are designed to compensate for defocus and spatial shifting of the Dewar and fore optic as the temperature of the camera changes. Baffling is also introduced throughout the optical train, both within the fore optic and internal to the Dewar, to reduce effects from stray light and internal radiation.

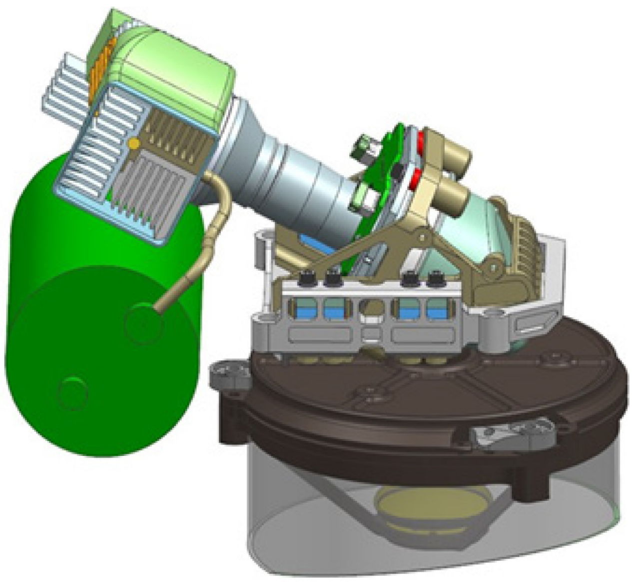

Figure 3: Hyperspectral camera assembly.

Each monolithic block spectrometer consists of a single crystal block cut to form an internally folded Offner-Chrisp spectrometer [1]. In the CHSI design, shown in Figure 4, the entrance slit is placed between the M1 and M3 focusing mirrors. Fold mirrors are then used at each end to bring the optical path from the slit to the M1 mirror and to align the path from the M3 mirror out to the FPA. The blazed grating is cut into the convex surface on the back of the block. This design achieves very low F/# while preserving the small size and wide spectral bandwidth needed for this application. The first block is currently in the final coating process with full optical testing to commence in Summer 2023.

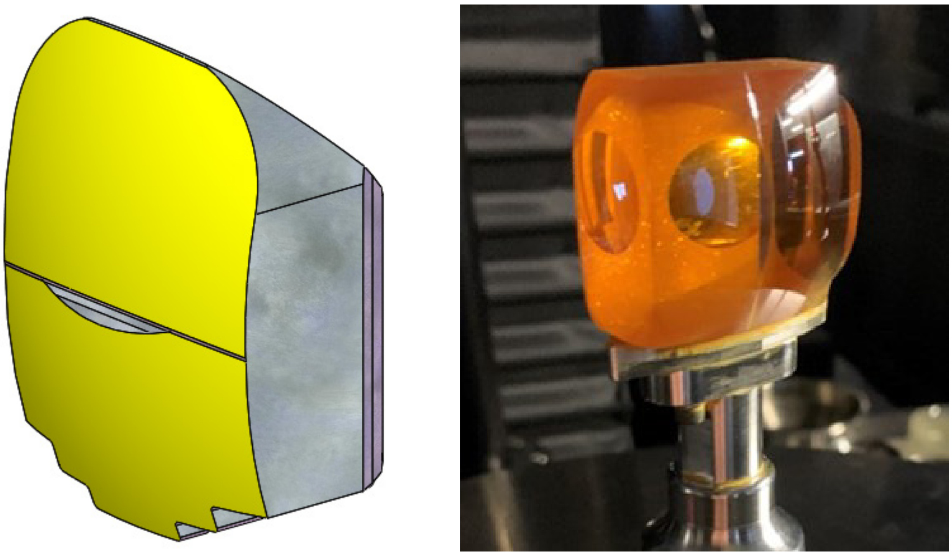

Figure 4: HSI monolithic block spectrometer design (left) showing the entrance slit between the primary and tertiary mirrors and diamond machined block (right) showing the same two curved mirrors and the ledge for the entrance slit.

The final spectrometer block is then bonded, via a Ti frame, to the FPA and cold finger, all of which is held at the FPA operating temperature. This assembly has been developed in a test configuration and is now in final alignment evaluation prior to completion of the first block spectrometer. The FPA has completed initial testing and is ready for integration with the block and the Dewar.

5.0 ELECTRONICS AND HSI PROCESSING

The CHSI electronics and control system is divided into three major segments as shown in Figure 5: sensors & sensor control, HSI processing & system control, and ground control. Each of these sub-systems comprises independent electronics hardware and software suites.

The sensor electronics system comprises the analog to digital converter (ADC) hardware and the FPA control software along with the sensor cooler controller and digital signal conditioning boards to enable efficient transmission of the signals from the sensor to the system control electronics. These components are all housed within the sensor can. The sensor control system also includes the global positioning system (GPS) and the inertial navigation system (INS) controllers.

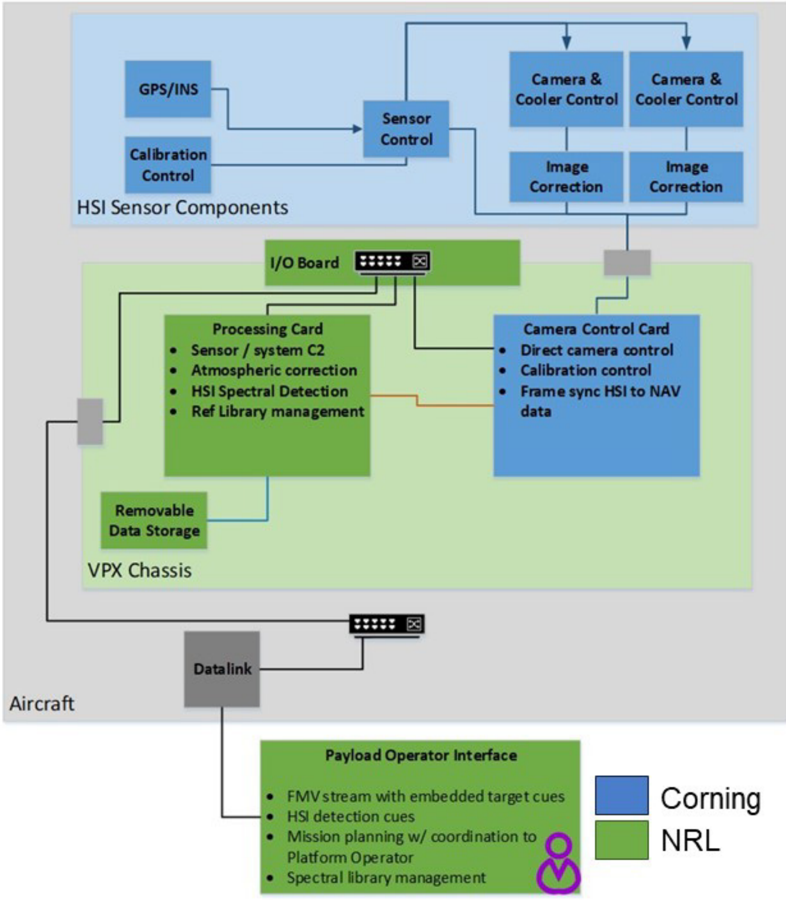

Figure 5: Electronics and controls diagram for CHSI system.

HSI processing and system control system is a VPX card-based system. The HSI pre-processing, HSI processing, and system controls function are resident on two commercially-available multi-purpose system on a chip (MPSOC) cards. These combined ARM/FPGA devices provide enough computing resources to enable full HSI collection and processing while maintaining very low overall power budget.

The HSI processing system is based on prior NRL HSI processing developments and on commercially-available industry standard HSI processing routines but has been augmented to the needs of the CHSI program. Calibrated HSI data enters the processing chain, these data are corrected for detector and system non-linearities, gain & offsets, and have had bad-pixels corrected. For some sensor channels gain and offset corrections are calculated based on HSI data collected with the sensor looking at uniform temperature reference sources.

The HSI processors utilize independent paths to prepare the data into a common spectral format so that can then utilize the same HSI detector code. Both chains consist of atmospheric compensation followed by covariance equalization. The details depend on the bands used for each of the two processing pathways.

The CHSI ground control system adapts the modular Midnight ground user interface (GUI) that was developed by NRL under a prior program. This adaptable GUI uses the Cesium 3D geospatial engine with modules to control creation and management of flight lines and spectral libraries. The Midnight GUI also manages sensor calibration timing and controls sensor and platform configurations for each imaging run. The user interacts with Midnight via a web interface while the Midnight web server then coordinates with the aircraft using the SIGMA multi-sensor coordination architecture.

6.0 CONCLUSION

The CHSI program requirements have driven the development of a novel, compact HSI data collection and processing system. This capability is currently in the manufacturing stage, with critical components and sub-systems to be assembled and tested during 2023. Following this, the full system will be integrated and undergo field testing during 2024.

7.0 REFERENCE

[1] M. P. Chrisp, "Convex diffraction grating imaging spectrometer," U.S. patent 5880834 (9 March 1999).