Army Hyperspectral R&D Consortium
The Way Forward

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Abstract

In early 2001 four Army laboratories signed a memorandum of understanding that signifies the Army's interest in focusing research interests on practical tactical applications of hyperspectral technology. The result of the focusing of these research interests will be actual applications of hyperspectral technology in the fielded Army. The AHR&DC has been meeting informally for about 3 years and exchanging information and ideas. The AHR&DC has two Science and Technology Objectives (STOs), IV.SN.2000.04 Spectral/Spatial Data Exploitation for Terrain Categorization and Target Identification and III.Q.05 Overhead Sensor Technology for Battlefield Characterization, which it manages among the four laboratories. Recently, IV.SN.2000.04 was captured under the Defense Technology Objective (DTO), Hyperspectral Technology. Each laboratory has research experience and practical experience in the area of hyperspectral, and through the STOs and DTO are moving the basic and applied research experience into practical applications for the Army. The AHR&DC has set goals of transitioning more hyperspectral technology into Army systems that may be used in Future Combat Systems and/or Objective Force Warrior. This paper details some of the collaborations and applications that the Army labs are considering for tactical applications of hyperspectral technology.

Introduction

The goal of the Army partners of the Army Hyperspectral R&D Consortium is to explore, develop, and transition tactical hyperspectral technology to Army customers. Recently, the Army laboratories realized that the Army research and development program in hyperspectral needed coordination and focus to achieve their technology goals. A Memorandum of Agreement was drawn up and signed by the Army partners. The four Army partners were already collaborating on two STOs, which are briefly described below. Each of the partners also have in-house R&D program with different scope and focus. The U.S. Army Engineer Research and Development Center, Topographic Engineering Center has the mission to develop technologies for rapid and accurate generation of topographic data. TEC works in concert with the national and intelligence communities to insure all available assets are utilized to generate accurate topographic data. TEC oversees and coordinates the development and application of spectral signal and image exploitation technologies across these communities to meet their needs. The Army Research Laboratory has the mission to perform fundamental, basic, and applied research programs in

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hyperspectral sensor and algorithm research conducted in the Army Research Office and the Sensors and Electron Devices Directorate. ARL research transitions to its Army RDEC partners. The Night Vision and Electronic Sensors Directorate of CECOM has the mission to develop technologies that meeting the Army's tactical requirements for reconnaissance, intelligence, surveillance, and target acquisition. NVESD conducts applied research and advanced development to lead the Army in the development of sensors that permit detection of targets in clutter. The Space and Missile Defense Command's mission is to provide space and missile defense and space technology research and development for the Ballistic Missile Defense Organization (BMDO), the U.S. Army, and the U.S. Air Force. These resources are the basis for the Memorandum of Understanding and the Consortium.

MOU and Army Hyperspectral Consortium

In early 2001, each of the four Army laboratories, Army Research Laboratory, Topographic Engineering Center of ERDC, Night Vision Electronic Sensors Directorate of CECOM, and Space Missile Defense Command Technical Center, signed a memorandum of understanding (MOU) that bound the organizations to cooperate in using hyperspectral technology in applications of interest to the Army. The Weapons Directorate of the Aviation and Missile Command (AMCOM) also participates in this Consortium through its connections with SMDC. This MOU is based on corporate knowledge and experience that exists in each of these organizations, but hopes to use the joint experience of these organizations to create a capability for the Army. Through cooperation and sharing of knowledge new opportunities can be created. The Memorandum of Understanding serves as the framework for cooperation and collaboration within the Army research and technology laboratories. The agreement addresses both multi- and hyperspectral sensing and servers to develop an Army requirement for spectral sensing. The agreement describes the procedures for collaboration and also the means for leveraging the Army's research and development efforts in spectral sensing, including the development of STOs in spectral sensing and coordination of the Army's efforts under the DDR&E DTO in hyperspectral sensing.

This MOU provides the Army with a unique opportunity to establish itself as a key player in the spectral sensing community and to support Defense and national security programs, as well as assisting in developing emerging Army requirements. This consortium serves as the Army agent to coordinate the definition and execution of an Army spectral sensing research and development program.

Each of the partners has representatives to the AHR&DC. They are TEC: Ms. Constance Gray, ARL: Dr. Patti Gillespie, SMDC: Mr. Adam Aberle, and NVESD: Mr. Christopher Simi. Mr. Wayne Davenport represents AMRDEC. These individuals form the steering committee for the AHR&DC, and facilitate communication among members. This steering committee neither constitutes a reporting chain nor has management authority over the programs executed by members. The steering committee meets a minimum of four times per year, to coordinate the member's research and development activities and exchange information. Informal communications occurs among the members more frequently. The AHR&DC is chaired alternately by each agency, with TEC, Ms. Gray, taking the first term for 2001. This MOU does not affect any pre-existing or independent relationships or obligations among the member organizations. Each partner will detail progress to date during that year in a letter report. The MOU lasts for 3 years and can be renewed or extended by agreement of the members.

Scientific and Technology Objectives

The Army manages two STOs on hyperspectral technology. One is IV.SN.2000.04, Spectral/Spatial Data Exploitation for Terrain Categorization and Target Identification, a joint STO between Army Research Laboratory and Topographic Engineering Center. This STO is under the DTO, SE.67, Hyperspectral Applications Technology. The second STO is III.Q.05, Overhead Sensor Technology for Battlefield Characterization, jointly held by SMDC and NVSED.

IV.SN.2000.04 Spectral/Spatial Data Exploitation for Terrain Characterization and Target Identification is an exploratory STO that hopes to combine the research efforts of both ARL and TEC to leverage some common capability that provides enhanced terrain categorization and target identification. The computational techniques used for both processes are similar in theory, but are often executed differently by people with different academic backgrounds.

The goal for TEC in this STO is to support the Army's need to deploy a force quickly into a hostile region with as much information about the terrain as possible. Knowledge of the terrain serves a critical role for the rapid projection of force providing the means to determine trafficability, develop lines of communication, and seek cover and concealment. Integrated knowledge of the targets and their relationship to the terrain will further increase the success of the mission. Once an engagement is ongoing, it becomes important to assess progress and anticipate hostile actions.

The TEC effort will implement spectral and spatial exploitation technologies that operate on multispectral/ hyperspectral imagery to support terrain categorization and target identification in an integrated way. The goal is to support military operations in a practical manner by implementing those technologies that degrade gracefully in non-optimal force deployment situations. Technologies that exploit various regions of the electromagnetic spectrum will be investigated and implemented, as appropriate, including the visible (VIS) through long-wave infrared (LWIR) wavelengths of light. Spatial information inherent in the primary image source is used, along with spectral and spatial information from secondary sources whenever available.

The Army Research Laboratory is pursuing the development of several algorithms that can be used with hyperspectral data in a tactical system. Algorithms developed thus far for this application are a PCA algorithm, a neural network algorithm, and a genetic programming technique. ARL has applied these algorithms to AOTF, SEBASS, and HYDICE data. Algorithms are still under comparison, and results have been reported in the literature. [Rauss 1999, 2000, 2001; Kwon et al. 200, 2001; Wellman, 2000] Besides development of a capability for a proposed tactical system, a goal for ARL is to show how the efforts for ATR can leverage results for terrain categorization. ARL will be using data from the NVESD efforts in the coming year.

The SMDC managed STO III.Q.05 , "Overhead Sensor Technology for Battlefield Characterization" has two main thrusts discussed here. Demonstrations of the ability to characterize, identify, and discriminate (CID) partially or fully concealed targets will be constructed during the last half of calendar year 2001 using the Real Time Measurement System (RTMS). The RTMS is an LWIR hyperspectral sensor that incorporates an acousto-optical tunable filter (AOTF) for waveband selection. The demonstrations will verify the concept that using a spectral filter approach for CID functions allows near real-time operation of the sensor with negligible degradation in CID performance. It is anticipated that sensor performance will actually improve due to increased dwell time, reduced processing of non-informational data, and the use of polarization data to reduce the effects of background clutter.

The second goal of the STO is to demonstrate the technology necessary to construct a sensor using this concept that can operate in the LWIR regime. To accomplish this, NVESD is developing a large focal plane array (1024x1024) suitable for a passive, staring sensor. Additionally, SMDC has funded the development and production of an AOTF constructed of Mercurous Chloride, a crystal suitable for operation in the LWIR and is considering a design in Tl_3AsSe_3. Demonstrations of these two technologies, coupled with the demonstration that the concept of using an AOTF to select desired bandwidths is viable, will lead to the development of an operational LWIR sensor for the characterization, identification, and discrimination of concealed , camouflaged, and disguised targets.

Laboratory Programs

Army Research Laboratory

Army Research Laboratory has several ongoing basic and applied research projects in hyperspectral sensor and algorithm development. ARL is contributing to the development of is the acousto-optical tunable filter (AOTF) sensor system, which has the advantages of being small and rugged, tunability, sensitivity throughout the visible and IR spectrum, and low cost. Today, ARL have AOTF sensor systems that are sensitive in the visible near IR (VNIR 400-1000μm), short wave IR (SWIR 800-1700 μm), midwave IR (MWIR 2-4.5 μm), and longwave IR (LWIR 8-12 μm). Research into AOTF technology is aimed at improving AOTF cell materials and design, as well as transducer design. As research on the AOTF sensor continues, the Collaborative Technology Alliance will be researching new crystals for the AOTR sensors in future ARL sensor systems. Shown here in Figure 1 is a series of AOTF images and one visible image showing how a hyperspectral imager, such as an AOTF, might be used to image hidden targets.[Gupta, 1999,2000] This research is being presented in a separate presentation at this workshop.[Gupta, 2001]

Fig. 1a Uncovered truck imaged at 660 nm

Fig. 1b Visible image of scene with truck covered camouflaged net

Fig. 1c Image at 660 nm with truck revealed under camouflage net

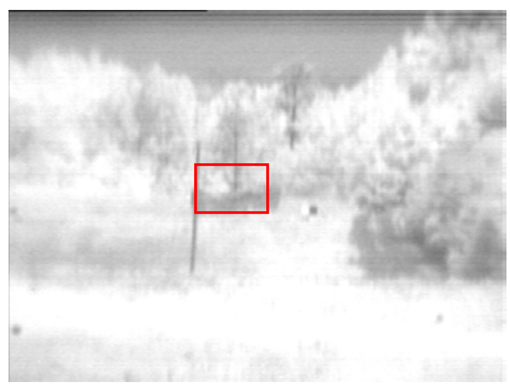


Fig. 1d Image at 780 nm revealing camouflage net against background

ATR algorithms for hyperspectral imagery are also under development at ARL. Thus far, PCA-EST (Principal Component Analysis-Eigenvector Separation Transform), neural net, and genetic algorithms have been developed for use with several different sets of hyperspectral imagery, including AOTF and SEBASS data. [Kwon, et al. 2000,2001; Rauss et al, 1999, 2000, 2001] Good preliminary results have been obtained with all three algorithms. Some of the hopes for the use of both the spatial and spectral information in hyperspectral imagery are that false alarms can be decreased, detection of certain materials can be enhanced, and detection can be made even in camouflage.

An adaptive segmentation algorithm using iterative local feature extraction has been used at ARL with AOTF hyperspectral imagery [Kwon, 2001]. The details of the work is in their paper, but some of the paper is summarized here. An image region filled with the same material tends to show strong spectral similarity, while different materials exhibit differences in spectral reflectivity. Segmentation of hyperspectral imagery is usually based on discrimination between materials using the spectral signature in thermal emission or solar reflection. Adaptive statistical classifiers have been used to effectively detect the spectral differences and the intensity differences in single band images. Spectral signatures, such as the means and covariances, of each region of the image are iteratively estimated to adapt to the local characteristics of the image. Local adaptation is desirable because spectral differences in illumination or atmospheric attenuation as well as material variation can cause pixels of the same material type to display different spectral signatures. As the spectral signatures are updated and re-estimated, the pixels were repeatedly segmented using a statistical classifier into more appropriate classes. The computational cost of this method is very high as the image size and spectral dimensionality increases. Kwon et al.[2000, 2001] propose the use of an adaptive segmentation technique based on the iterative use of a modified minimum-distance classifier, in which each cluster center is progressively updated to follow the local characteristics and does not assume a distribution type for each region. The reduced computational cost means that it can be applied to higher dimensionality and larger hyperspectral images with relatively little computational cost. It also improves segmentation performance over previous template matching methods due to its adaptation to the local context. The classifier uses a cost function, in which a spatial constraint term is added to the Euclidean distance between each pixel spectrum and the material centroid. Local adaptivity of the proposed algorithm is obtained by updating the feature vector of each material type over a local region that is defined by sliding a window whose size is progressively reduced by a factor of two [Kwon, 2001].

Figure 2 show the segmentation results of the non-adaptive method (b), and the proposed adaptive method (c) on one of the hyperspectral data cubes (a). The target is better segmented, and the new algorithm is more efficient in its computations [Kwon]. Improvement in classification results is shown in Table 1. ARL expects to refine its proposed technique, as additional data is available.

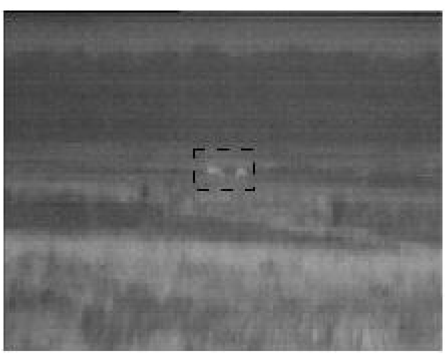


Figure 2a. Original hyperspectral image.

Figure 2b. Non-adaptive segmentation method

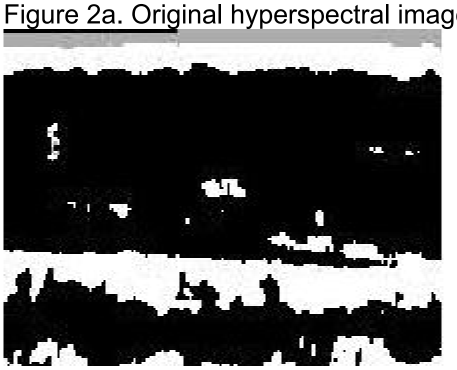


Figure 2c. Adaptive segmentation method

	Cube 1	Cube 2	Cube 3	Cube 4
Non-adaptive method (%)	**45.26**	**3.85**	**72.89**	**54.95**
Proposed Adaptive Method (%)	75.00	19.23	79.11	62.61
	80.53	71.43	89.78	72.97
	81.05	92.31	95.56	77.93
	81.32	96.15	96.89	82.88
	81.53	**98.35**	**97.78**	**83.78**

Table 1. Segmentation results of non-adaptive and adaptive algorithms.

Shown in Figure 3 is an AVIRIS image that has been segmented into various crops and vegetation using genetic programming. Both SEBASS and AVIRIS data have been used in a comparison of genetic programming and neural networks in material classification. Details on the genetic programming research project are being given in another talk at this conference by Rauss [2001b].

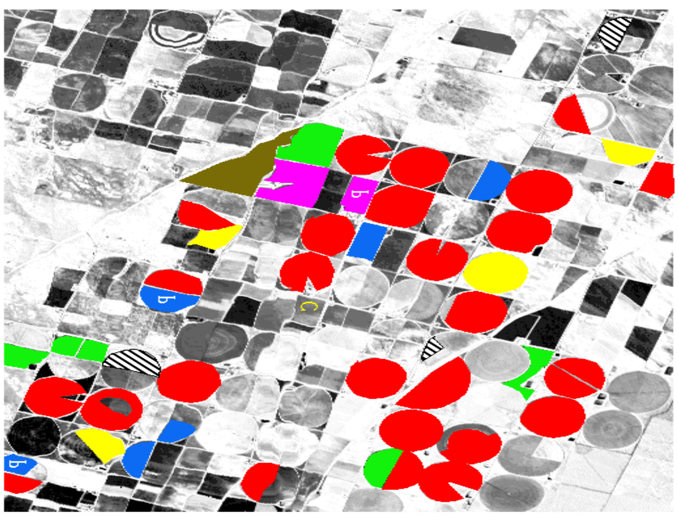


Figure 3. San Luis Valley, CO, vegetation distribution mapping using genetic programming

ARL has recently started a high performance computing project to parallelize an ATR algorithm, benchmark processing improvement, and compare with other algorithms from Navy and Air Force Laboratories. Initial parallelization techniques have been implemented and benchmarking has begun. Early results on this project have been reported at a recent High Performance Conference. [Stolovy, 2001]

Another algorithm that uses a spectral differencing technique, called the hyperspectral line pair (HSLP) algorithm, [Sola, 2000, 2001] has a patent disclosure and has been reported at a recent signatures conference. Different materials in a hyperspectral image have different spectral information. The idea behind this technique is to subtract images at specific wavelengths that are different wavelengths or polarizations. Current algorithm development is for the LWIR. This algorithm is going to be a feature in the ENVI algorithm package.

A technology being developed by ARL that is not precisely hyperspectral, but is spectral imaging, is dual band FLIR. The dual band or 2-color FLIR is sensitive in both the 3-5 and 8-12 µm wavelength range and images that it produces are fused images from both wavelength ranges. These devices will enhance the development of night vision devices that are highly sensitive, low cost, low maintenance, smart, multifunctional, and multispectral. They will demonstrate better recognition ability, faster decision times, higher operating temperatures, and better ability to function in all environments over currently available IR sensors.

The Army Research Office, a part of Army Research Laboratory, also has an interest in hyperspectral technology, and is starting a new MURI- Science of Land Target Spectral Signatures. Dr. David Skatrud of the Army Research Office will manage this new MURI.

Topographic Engineering Center

Current TEC research efforts accomplished to date include: Model and algorithms developed to combine spectral mixture and classification tasks [Rand and Keenan, July 2001]; two different and new unsupervised hyperspectral clustering algorithms based on a second-order statistical method [Bosch and Rand, 2001] and a Markov Random Field method [Rand and Keenan, April 2001]; a new algorithm for band subset selection on hyperspectral imagery[Bosch and Rand, 2001]; and enhancements to the HYPERCUBE tools kit developed at TEC. HYPERCUBE is a Macintosh and Windows application program specifically directed to the analysis and display of multi and hyperspectral imagery. This includes the static and dynamic display of the image cube, the generation of spectral classification overlays and matching within spectral libraries. In addition, HyperCube contains functions to filter, warp, mosaic, reformat, calibrate, combine, extract, graymap and statistically analyze images. Many operations have been included for the purpose of checking integrity of imagery. This software is available on the TEC website, www.tec.army.mil.

For the first year of the STO, TEC identified performance criteria, baselined VIS-to-SWIR terrain categorization algorithms, identified the appropriate physical and statistical models, and completed the initial design of some appropriate spectral/spatial algorithms.

In FY01, new algorithms were developed. Figures 4, 5, and 6 show the results of an experiment that demonstrates an advantage of two of the new algorithms. Figure 5 is a color abundance map generated by the basic Spectral Mixture Analysis (SMA) applied to the scene shown in Figure 4, as performed by existing commercial software (one of the baseline methods). Figure 6 is a color abundance map that demonstrates an enhanced SMA algorithm that uses prior input from a Gibbs-based partitioning algorithm applied to the same scene. The Gibbs-based method is an unsupervised algorithm that uses spectral information defined over a localized spatial neighborhood to partition the scene into homogeneous regions. These regions are subsequently used in the enhanced SMA to constrain the mixing simplex and corresponding candidate endmembers at each point in the scene. The blue, green, and red colors indicate the abundance of water, vegetation, and asphalt, respectively. Notice that the abundance map for the basic SMA displays a significant portion of the Potomac River with a reddish tint, incorrectly indicating the presence of asphalt in the water. This method also underestimates the abundance of water in the marsh regions -- the estimated abundance of vegetation is too high and a significant abundance of asphalt is incorrectly detected in these areas. The enhanced method eliminates the asphalt from both the Potomac River and the marsh areas. A description of the underlying spectral/ spatial model and the enhanced SMA algorithm is discussed in [Rand and Keenan, July 2001], and further work that is focused on characteristics of the partitioning algorithm is presented in [Rand and Keenan, April 2001].

Also, an effort performed under contract with the University of Puerto Rico, Mayagüez Campus, executed a research study titled “Clustering and Subset Selection Research for Hyperspectral Data Analysis”. In this study the researchers have effectively used first and second order statistics to perform unsupervised clustering of hyperspectral data. The analysis takes into account both spectral and spatial information. As part of the effort the researchers have implemented a band reduction technique based on the singular value decomposition of the hyperspectral data set. The objective of the dimension reduction algorithm is to selectively discard redundant information ultimately allowing the clustering algorithm to process less data and obtain faster results. The algorithm produces a subset of the original bands, optimum in the sense that they are closely aligned with those of the Principal Component Analysis (PCA). The resulting bands are a permutation of the original bands, unlike those produced by the PCA that are a linear combination of the original hyperspectral bands, so spectral physical information is not lost in the transformation. TEC scientists further investigated both the clustering and dimension reduction algorithms through additional experiments [Bosch E. and Rand R].

In FY02, TEC will complete implementation of the above algorithms, and additional spectral/spatial algorithms will be investigated for VIS-to-SWIR and LWIR processing of hyperspectral data.

Figure 4. Color IR Composite of Northern VA Scene.

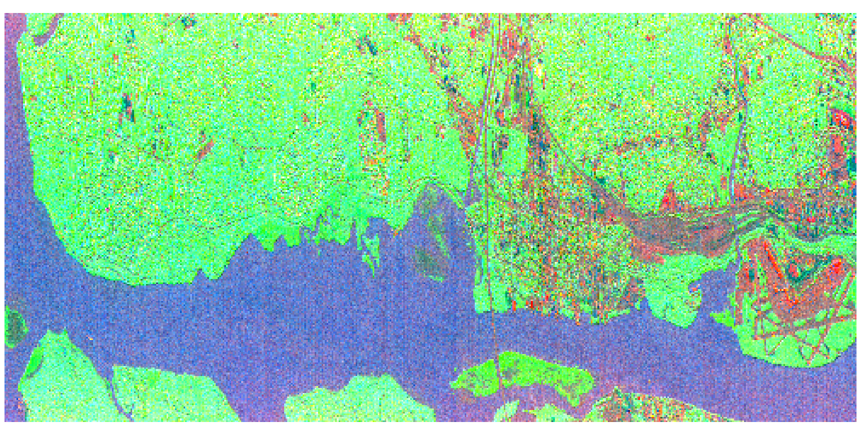


Figure 5. Color Abundance Map - Basic Spectral Mixture Analysis.

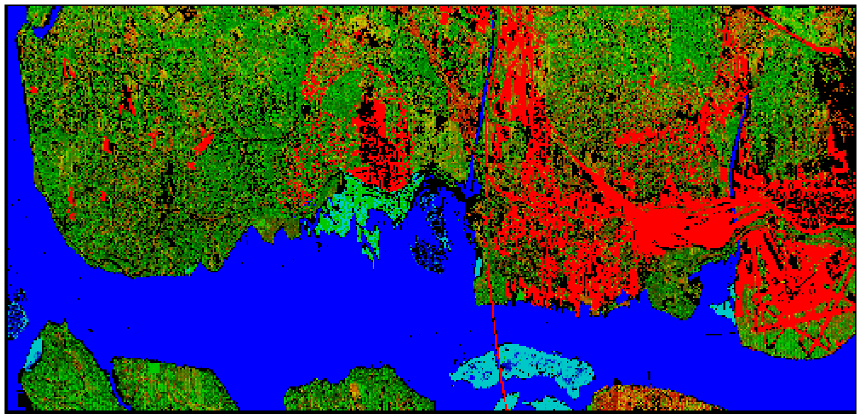


Figure 6. Color Abundance Map - Enhanced Spectral Mixture Analysis.

TEC is actively involved in support of the Air Force Warfighter 1 post-launch image technical validation and TERCAT product generation. TEC has developed the Spectral Database Structure to be used in the Tech Val and the TERCAT product generation by the Mission Data Center (MDC) at Chantilly, VA. TEC is also charged with supplying the terrain and land cover data for populating the TERCAT database. Warfighter 1 has selected primary terrain imaging test sites representing varying climatic and topographic conditions. All are located on military posts and include Eglin AFB, FL, Fort Hood, TX, Fort Huachuca, AZ, Yuma Proving Grounds, AZ, Camp Pendleton, CA, and Camp Ripley, MN. In addition to collecting the terrain and ground cover data for these sites, TEC is also monitoring the spectral characteristics of image spectral calibration panels and targets located at several sites. Figure 7 shows Tech Validation panels constructed to give a 40% pixel fill of CARC green paint.

Figure 7. Tech Validation panels constructed to give a 40% pixel fill of CARC green paint.

The paper titled "Evaluation of a matrix factorization method for data reduction and the unsupervised clustering of hyperspectral data using second order statistics", written by Bosch and Rand (2001), was presented at the SPIE Conference in Orlando, Florida in April, 2001.

TEC scientists are actively pursuing the emerging and promising fluorescence technology. Research has been directed towards all aspects of the fluorescence phenomena including both active and passive techniques. Bench top measurements utilizing spectrofluorometers capable of obtaining 3-D excitation-emission matrices (EEMs) in the ultraviolet, visible, and near-infrared spectral regions are forming the basis of fluorescence understanding. These laboratory measurements are being used to establish basic relationships between fluorescence response and feature attribution. This research is exactly synonymous to the collection of reflectance signatures in support of multispectral and hyperspectral imagery.

In order to further determine the mechanisms of fluorescence at a finer spatial detail, TEC scientists have begun research into fluorescence microscopy. This technique, more commonly found in the field of molecular biology, allows researchers to pinpoint the exact source of fluorescence radiation. Knowledge of this information is critical for the future design of camouflages, paints, and tagents, which may need to defeat/exploit fluorescence systems.

The newest area of research within active fluorescence technology is the maturation of Laser Induced Fluorescence Imaging (LIFI) systems. TEC has sponsored the construction of a prototype portable LIFI system capable of obtaining 6-band emission imagery under any conditions. This instrument will allow TEC researchers to collect remotely obtained fluorescence imagery in both laboratory and field conditions (figure that I will send on LIFI images of garden soil). Effort expended in this area is critical in extending fluorescence technology to airborne and spaceborne systems.

TEC is looking at three areas of research to exploit fluorescence images they are: 1) stand-off contaminant (UXO) detection 2) air and waterborne biohazards 3) topographic information collection using vegetation indicators.

TEC plans to vigorously pursue its fluorescence research in the coming years. Support of ongoing DOE research at Epcot Center will continue, especially in the field of fluorescence signature database development design and exploitation. Support from DARPA and ARO is also continuing.

Night Vision and Electronic Sensors Directorate (NVESD)

NVESD is developing airborne day and day/night hyperspectral sensors to provide detection of Camouflage, Concealment and Deception (CC&D) and other difficult to detect targets(Colandene et al., 2000). The Compact Airborne Spectral System (COMPASS) is a daytime visible/near infrared (VNIR) to shortwave infrared (SWIR) spectral imager. The Hyperspectral Longwave Imager for the Tactical Environment (HyLITE) is an 8 to 11 micron spectral imager utilizing closed cycle cooling for tactical deployment. NVESD is also pursuing spectral algorithm and processor development to provide real-time hyperspectral data exploitation. Automated real-time processing allows hyperspectral imagers onboard Unmanned Aerial Vehicles (UAVs) to meet time critical targeting schedules and reduces datalink bandwidth requirements.

COMPASS

COMPASS is a technical development program that will move hyperspectral technology towards operational status. The COMPASS program will demonstrate a solar reflective device, which utilizes new technological innovations. The program will deliver a broad area coverage, compact, ruggedized device for demonstration. Since the programs execution in May 2000, the program has gone through a design study, preliminary design review (PDR) and a critical design review (CDR). Several system configuration modifications have been required along the way, which were not originally anticipated. As a result, a mild cost increase will have to be endured to achieve the final system configuration required to successfully demonstrate this technology.

The COMPACT Airborne Spectral Sensor (COMPASS) design is intended to become the core design of all solar reflective hyper spectral systems in the DOD. Capitalizing from recent focal plane developments, the COMPASS system utilizes a single FPA to cover the 0.4-2.35μm spectral region. This system also utilizes an Offner spectrometer design as well as an electron-etched lithography curved grating technology pioneered by NASA/JPL. This paper also discusses the technical trades, which drove the design selection of COMPASS.

Although the COMPASS program is actually a technology demonstration, emphasizing high performance spectrometer and a unique FPA approach, a significant amount of robustness has been added to the system design. The consideration of both environmental and structural issues will greatly reduce the amount of retro engineering required to transition the COMPASS base design to an operational system. The COMPASS system requirements have been specifically developed and its performance modeled with two airframes in mind. One being the Predator, the other is the Army's ARL system. It should be explained that the COMPASS performance goals were drawn from DARPA's (VISNIR/SWIR) Counter CC&D studies (1). System parameters such as NESR, ground-sampling distance (gsd), spectral resolution, smile, and keystone were all derived from these reports. This connection provides a clear, well-defined pedigree of Government requirements.

It was determined very early in the program that this approach would be more desirable in that it provided greater swath coverage without the need of a very large FPA. NVESD's and TRW had successfully demonstrated the TRWIS-B (c. 1995) in this same configuration. Certain optical design advantages in this scan approach are also noteworthy. Specifically, imaging spectrometer designs tend to show better blur performance and lower distortion effects when the field of view is kept relatively narrow. This is especially true for low F/# systems such as COMPASS

The cross track scan mode allows for very large swath coverage (up to 30°@ 16,500’ agl). The spectrometer is oriented such that its FOV (5.5°) is in the direction of flight. Data is collected in a series of sequential swatches. Attitude information is provided from the Boeing C-MIGIT INS, which is mounted on the spectrometer housing. For this demonstration, only a single cross track scan mirror will be used. This mirror will be roll compensated using information from the C-MIGITS. In addition to the hyperspectral imager (HSI), the COMPASS will also include a 6000 or 12000 element high- resolution imager (HRI) , which is push broom scanned utilizing the forward motion of the A/C.

Figure 1: COMPASS HSI/ HRI Scan

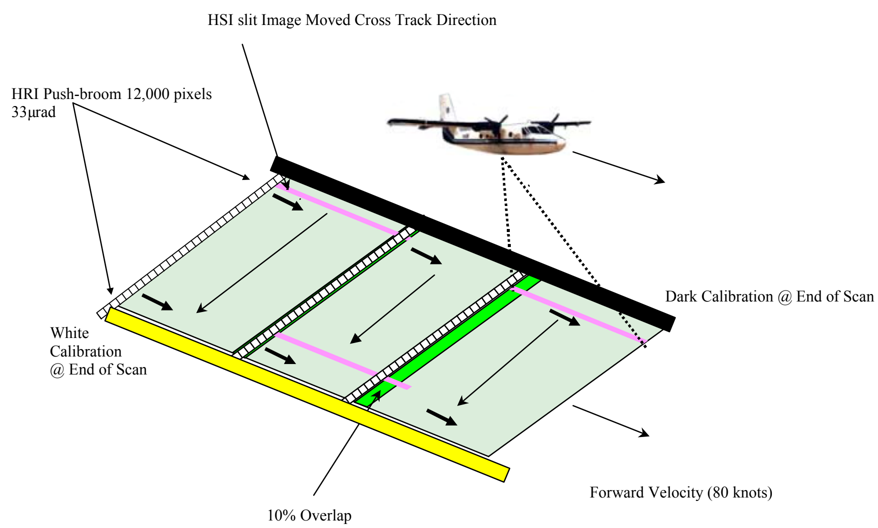


Figure 8. COMPASS HIS/HRI Scan

Description	Specification
Scan Configuration	Whisk-broom
Spectrometer FOV, Cross Track Scan FOV	5.5°, 15-30°
Spectrometer IFOV	0.35 µrad
Number of Crosstrack Pixels per swatch	256
Spectral coverage	0.5-2.35 µm
Number of spectral channels	256
Frame rate	100-300 Hz
GSD	0.85m@8000’, 1.65m@14,500’
INS-D-GPS	Boeing C-MIGITS role, pitch, yaw, alt, UTC, lat, long, provided per frame of data
Ground coverage rate (km/hr)	133@8kft,>500@16.5kft

Weight	60 lbs.
Preprocessing	Dark subtraction, gain, bad pixel map, radiance calibration performed on data
Stabilization mode	Roll compensation of cross-track scan
Digitization	14 bits

Table 2. COMPASS System Performance Characteristics

A design analysis was performed to compare the performance of the two main candidate spectrometer designs, the prism and the grating. Upon completion of the design trades for the COMPASS program, it was determined that the grating Offner relay design would probably be the best approach. Much also has been published concerning the many attributes of the Offner design (3,4). Within the last 4 years, the use of the Offner spectrometer design has grown. The design of the spectrometer itself can be quite compact, consisting of only a slit, one or two spherically reflective surfaces and one reflective grating element etched onto a third spherical surface. The Offner design has been utilized in several of the Governments space programs including NASA's Lewis and EO-1, the AFRL's Warfighter-1, and the NRL's NEMO program. Currently, a split Offner will be utilized in the NVSED/ Lockheed Martin HYLITE program (5). Many other key attractions of this spectrometer design are low keystone and smile distortion. Very high MTF and excellent throughput are also chief characteristics of the Offner design

Based on the optical design analysis, it was constructive to develop a performance prediction matrix to compare performance of a prism design to that of the Offner system. The following matrix explains the design trades considered in the ultimate selection process.

Design Characteristic	TMA/Triplet Prism Spectrometer	Offner Grating Spectrometer	Preferred Design
Distortion	Meets minimum requirement	Better than minimum requirement	Offner
Image Quality	Meets requirement	Meets requirement	Equal
Average Throughput	65%	35%	Prism
Size/Weight	0.5 cu ft	0.05 cu ft	Offner
Ease of fabrication (mirrors)	Moderate	Simple	Offner
Dispersion linearity	+/- 3 nm per pixel	Limited only by grating accuracy	Offner
Order sorting filters	Not required	Required	Prism
Polarization uniformity	Limited by prism AOI	Limited by grating AOI	Equal
Dispersive element fabrication issues	Standard optical component	E-beam fabrication	Prism
Added risk		Sole source grating supplier, dual blaze not exhaustively tested	Prism
Room for white-light imager	No	Maybe	Possibly Offner

Table 3: Design Trade

The prism design attributes are mainly, its superior throughput and the lack of a need for an order-sorting filter. The prism design provides sufficient image quality and meets distortion requirements. As stated earlier, the extremely compact nature of the Offner system, coupled with the sufficient image quality, and superior distortion characteristics, makes this grating design more attractive. However, the whiskbroom scanning nature of the COMPASS system requires that the throughput be extremely good in order to achieve high frame rates, which results in larger swath widths and greater ground coverage per hour. Originally, the grating design was set for F/3.0, which lead to an extremely compact package. To achieve the same throughput performance of the F/3.0 prism design, the Offer design had to be made to be F/2.5, which made the spectrometer volume increase somewhat. The large volume of glass in the prism element used in the prism design may lead to variations of index of refraction as a function of temperature. This issue would require a heating element to be used to maintain a constant temperature of the prism and would add complexity to an operational system. Both the smaller size and avoiding the prism temperature stability requirements lead to the selection of the Offner grating spectrometer.

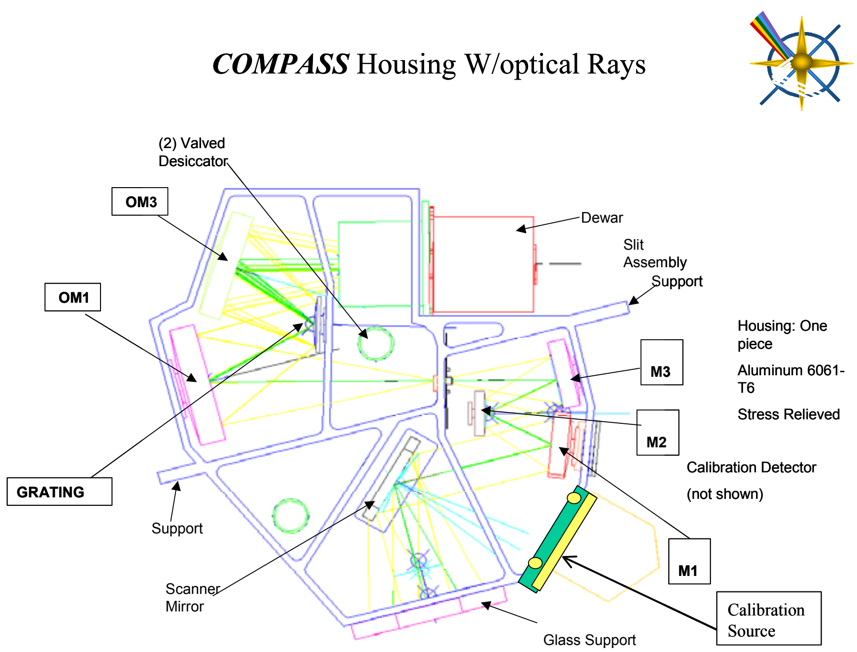


Figure 9. COMPASS Housing and optical rays

COMPASS Offner Optical Layout

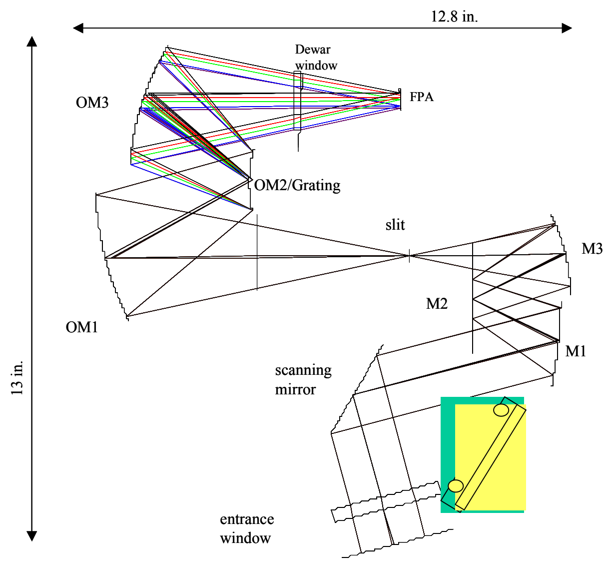


Figure 10. COMPASS Offner Optical Layout

E-Beam Grating

The significant advantage of the Offner design is the curved reflective grating element. Specifically, NASA/JPL has pioneered the fabrication technique that has made it possible to build compact high performance spectrometers. JPL's ability to fabricate curved grating elements through an electron beam lithographic technique allows the production of grating elements, which not only disperse the in-coming light, but also provide corrections to optical aberrations. Other system designs usually use refractive elements to provide correction to aberrations, but this almost always decreases optical throughput and adds complexity to the design and alignment. The JPL E-beam gratings have shown efficiencies as high as 50% average, with peak values >80%. As mentioned earlier, the single FPA design of COMPASS requires that the grating efficiency perform well over the entire spectral range from 0.4-2.4µm.

NIRFPA

The COMPASS system will make use of a significant focal plane development that resulted directly from the DARPA/NVESD NIRFPA Program. Rockwell Science Center (RSC) was the technical lead for the detector fabrication process. The NIRFPA uses Rockwell's standard planar hybrid architecture modified by removing the CdZnTe substrate to allow the same detector material to detect light from the visible to the SWIR spectral region. Under this development, Rockwell Science Center (RSC) successfully developed and delivered a 256x256 (40um pitch) MCT FPA which provides >60% quantum efficiency from 0.4-2.08µm (**Figure 11**). Although 0.9-2.5µm MCT FPAs are quite common, the ability to gain good responsivity into the visible region is significant. The upper spectral range is controlled through a special doping process that allows a tailored wavelength cut-off. In this way, unwanted emissive photon leakage can be avoided by appropriate selection of the cut-off wavelength. The two advantages of the NIRFPA technology to provide a single FPA, which provide the required spectral range, are the decreased complexity of both the optical design and the data-handling burden.

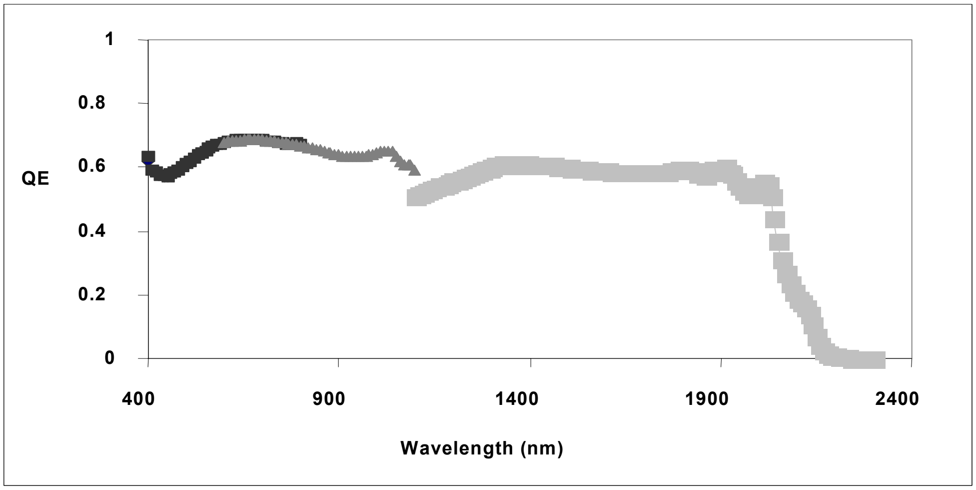


Figure 11. Quantum efficiency of MCT FPA

A basic performance prediction analysis of the COMPASS instrument has been undertaken. A common paint reflectance spectrum was used as a “target” sample. Radiance input levels were calculated using GENPSPEC, which is a GUI front end to MODTRAN specifically developed for airborne hyperspectral analysis. The scenario parameters used were; mid-latitude, 9 am, summer, 15-km visibility, at an altitude of 8000’ above ground. GENSPEC can calculate the radiance (combined reflected and scattered) at the sensor aperture predictions for full sun, partial illumination, and full shadow conditions. This spectral radiance shown in (**Figure 12)** was used as the COMPASS input. Using the predicted system throughput, which considers all reflective surfaces and the grating efficiency, FPA quantum efficiency, MUX readout levels (120es), nominal calibration error, and some thermal background photo electron generation due to emission from inside the COMPASS spectrometer housing, the SNR performance was calculated for the worst case scenario of “target” in shadow (**Figure 13)**. The calculation also took into consideration a nominal residual pattern noise (RPNU) value of 0.15 %.

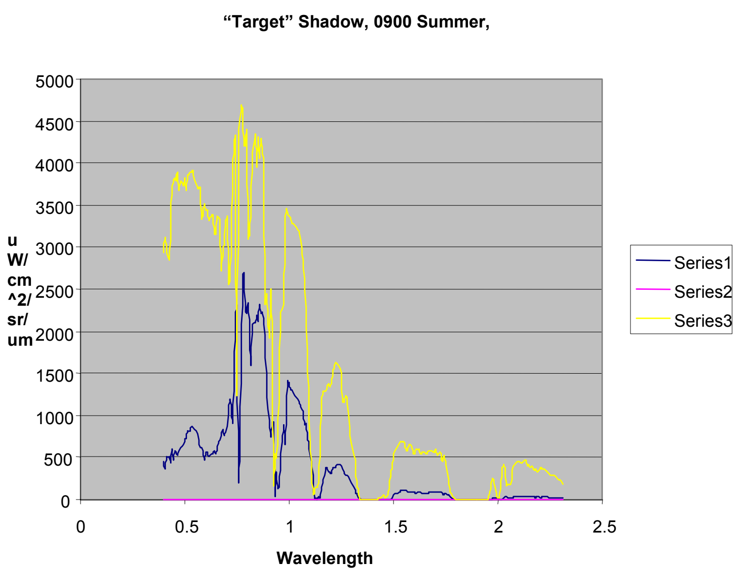


Figure 12 : Compass Radiance Model Inputs

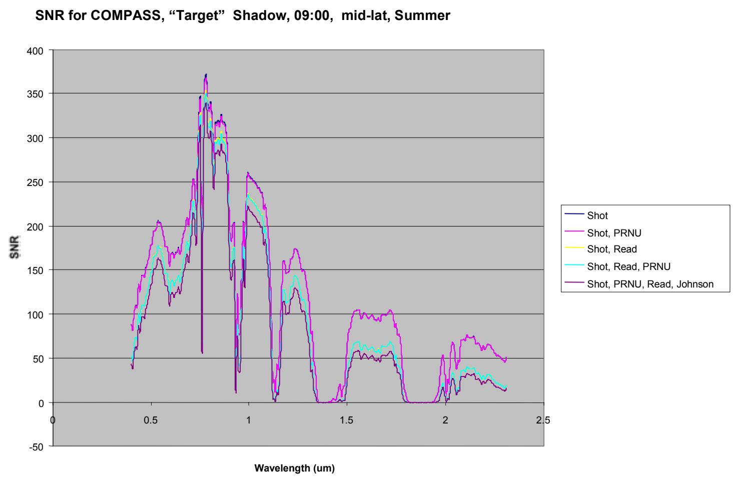


Figure 13 :COMPASS SNR Predictions

HYLITE

HyLITE is the result of the sensor development thrust of the DARPA Adaptive Spectral Reconnaissance Program (ASRP) [Tousley et al., 2001]. Air Force and Joint Multi-Spectral Program studies were used to develop HyLITE sensor specifications. Tactical operation was a key performance parameter necessitating day/night operation, reduced weight and volume, and closed cycle cooling. This led to the selection of an Offner based spectrometer design that provides compactness with low spectral and spatial distortion and utilization of critical background suppression techniques to decrease self-emission photon levels. The sensor is being developed by BAE Systems in Syosset, NY.

HyLITE is designed for operation in pushbroom or whiskbroom scanning modes. The sensor's primary specification is a Noise Equivalent Spectral Radiance (NESR) in the range of 0.25 to 0.5 μflicks over a 200nm bandwidth. A secondary sensor goal was the simultaneous development of a midwave IR high-resolution imager (HRI) to provide NIIRS 6.5 imagery, which would be used in tandem with the LWIR hyperspectral system. Based on the ASRP real-time hyperspectral imaging system concept, HyLITE provides spectral target detection and cues the HRI to provide image chips of the detected targets for an image analyst. This cued image chip approach allows image analysts to perform target identification with greater accuracy and speed by focusing their attention on the individual target areas rather than on the entire area of search, enabling timely, wide area search with reduced workload. The chip approach also minimizes data communications bandwidth requirements and allows the HSI system components to operate on platforms with modest data communications capabilities. The complete HyLITE design was carried to the Preliminary Design Review at that point due to funding constraints development of the scanning mirror and midwave HRI were put on hold and only the longwave spectrometer is in fabrication.

HyLITE operates in the 8-11μm band, with 180 spectral bands. The spectra will typically be binned by three, to provide 60 channels, each 50nm wide. Target detection algorithms will run on subsets of the 60 channels. In the absence of a stabilization/scanning system HyLITE will run in the pushbroom mode. The HyLITE FOV is approximately 6 degrees, providing a swath of 500m at 14,500 feet AGL, with 1m ground sampling distance (GSD). The need for frequent calibration to maintain high NESR performance requires that the field of view of the pushbroom system will have to be diverted away from the ground from time to time in order to perform onboard calibration.

One of the key design considerations of the HyLITE system is the use of the all-reflective Offner spectrometer design (see figures 14 and 15). Offner designs are noted for providing good throughput. The Offner spectrometer lends itself to designs of F/3 and lower. HyLITE demonstrates an F/2 design. Offner designs provide extremely low keystone and smile distortion characteristics, and excellent MTF. Optical design predictions indicate <0.1 spatial pixel keystone and spectral channel smile. The Offner design yields a very compact package. The crucial curved grating element makes the Offner spectrometer possible.

Internal reference sources provide on-board calibration capability with a blackbody assembly for non-uniformity correction and a spectral filter assembly for channel alignment verification (as shown in Figure 16). Three blackbodies at different temperatures allow for three-point non-linear calibration needed to achieve the desired NESR. The operator can select each blackbody as desired or automatically run calibration algorithms. The spectral filter is imaged against the blackbodies and spectral shifts of narrow notches in the filter material are used to correct the band assignments

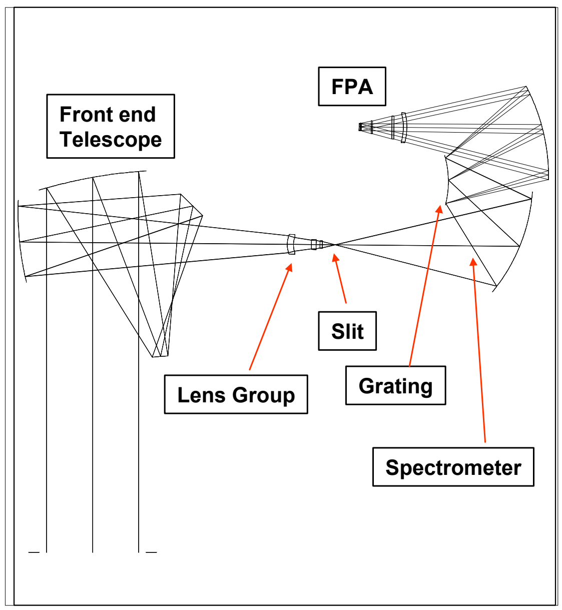


Figure 14. HyLITE TDS Optical System

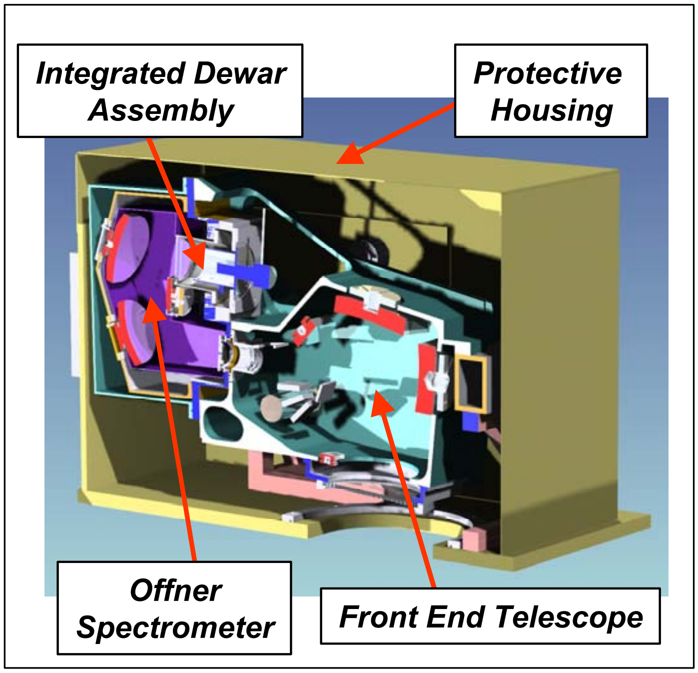
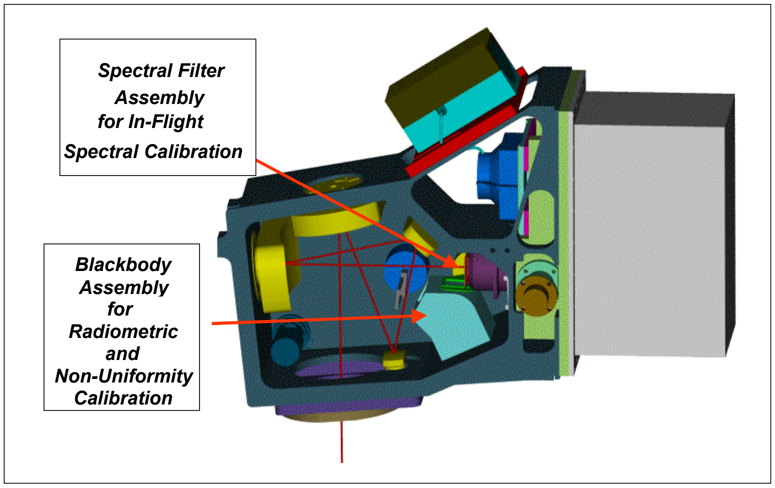


Figure 15. HyLITE ISA/OBA

Figure 16. Calibration System



For demonstration of COMPASS, HyLITE and other DoD spectral sensors NVESD operates several airborne testbed platforms. In particular the Hyperspectral Airborne Reconnaissance Platform (HARP) (Girata, et al., 2000) is a Twin Otter providing system mounts, power, INS/GPS and onboard processing and storage for hyperspectral systems. Standard 19-inch rack mounts allow for additional sensor related equipment and processors. HARP will be the testbed for the spectral sensors, processors and algorithms currently under development at NVESD. Plans are underway for a general purpose-scanning mirror to support phenomenological studies of off-nadir imaging for algorithm and processing development

NVESD is developing both day-only and day/night hyperspectral sensors. Day-only sensors such as COMPASS provide more low cost, compact packages and are therefore attractive for fielding in larger numbers on smaller platforms. Day/night tactical sensors such as HyLITE provide around the clock operation but require larger platforms, Predator and above with current technology. NVESD is providing spectral systems for manned and unmanned aerial platforms to defeat CC&D over wide areas through development of sensors, processors and algorithms.

SPACE MISSILE DEFENSE CENTER

The laboratory program for SMDC is presented in another paper at this workshop. [Filegar, 2001] SMDC is developing an operational AOTF system, including development of both the instrument and data analysis. Shown here in Figure xx is a schematic of their system.

AVIATION AND MISSILE COMMAND R&D CENTER

AMCOM provides assistance in calibration and testing of the AOTF hyperspectral sensor system being built by SMDC and NVESD for the Passive Overhead Sensor Technology for Battlefield Characterization STO. They have supported research into hyperspectral technology through various means, including hosting this Workshop annually. Both AMCOM and NVESD have invested in ATR technologies over the last 25 years, but with very different focus for missile ATR and RSTA FLIR ATR. AMCOM is investigating the concept of wide FOV spectral search and narrow FOV spectrally enhanced spatial ATR system. Most current systems have wide FOV spectral search, but only broadband (panchromatic) high-resolution spatial imagery. AMCOM thinks that the spectral enhancement in the narrow FOV will improve target contrast by simple band subtraction, ratioing, or other simple algorithm and therefore improve segmentation algorithms.

Coordination with TRADOC

TRADOC recognizes the potential benefits of spectral sensing for Army applications. TRADOC issued an HIS (Hyperspectral Information) Integrated Concept Team Report in July 1999, identifying 28 existing Future Operational Capabilities having spectral solutions.

Potential New Applications and Summary

DoD applications of hyperspectral sensors have been for overhead assets until now. Army scientists are working to develop conceptual uses of hyperspectral sensors that will benefit the land army. Potential uses include aircraft landing strip mine removal, bomb damage assessment, and UGV RSTA capability. This paper shows a brief highlight of a number of projects that are various stages of this proposed capability. Through the coordination and collaboration of the several Army laboratory efforts, this effort is enhanced.

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