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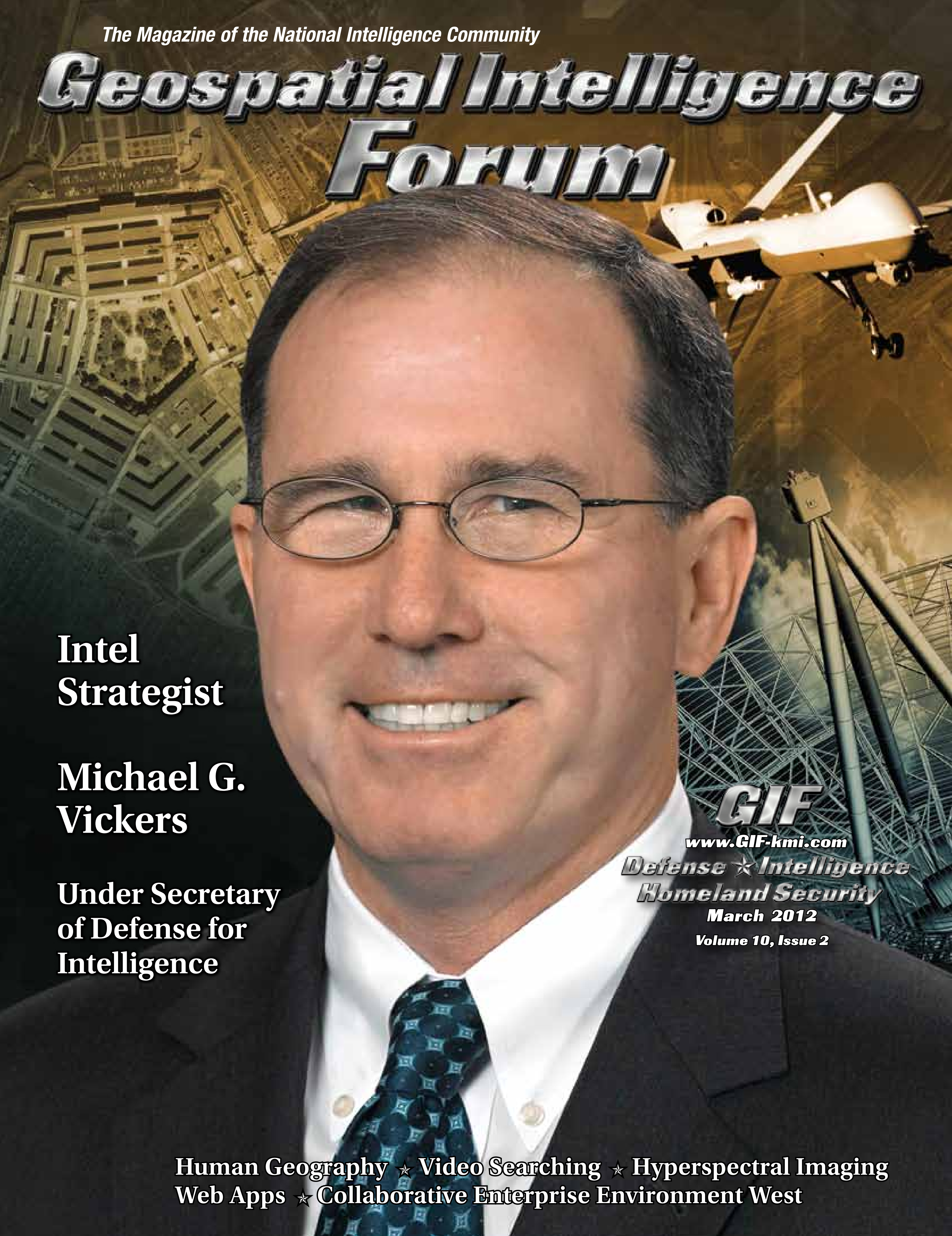

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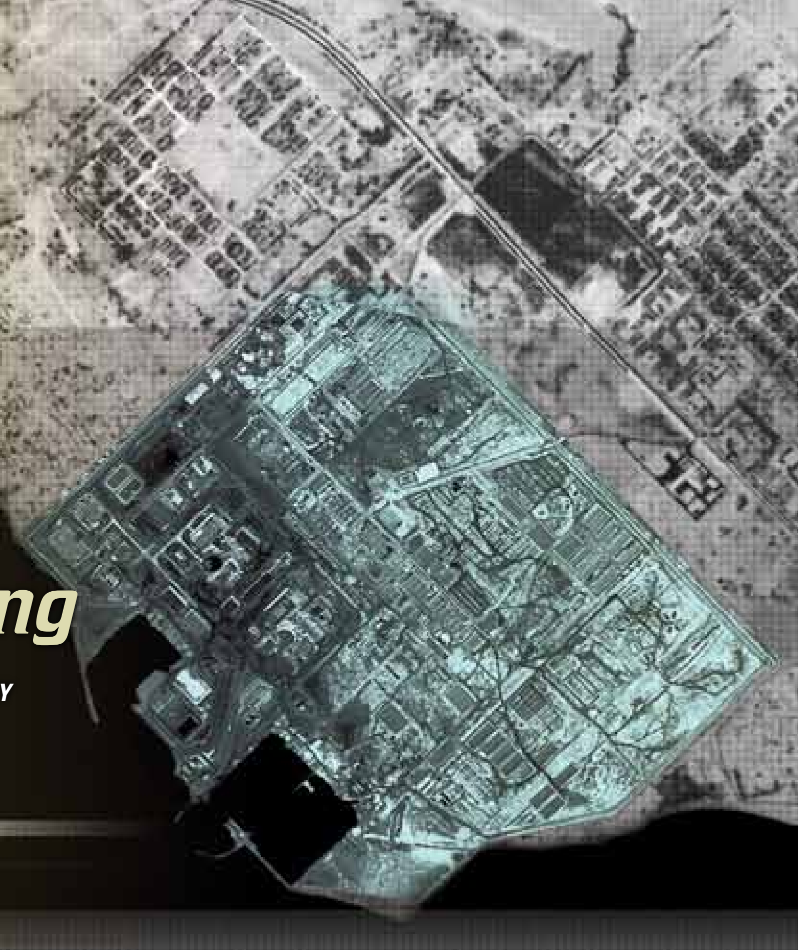


Scanning the Spectrum with Hyperspectral Imaging

Advances spur military and intelligence use of technology that can define, distinguish distant objects precisely.

By Cheryl Gerber, GIF Correspondent

Bolstered by developments in software and computing power, with its unmatched ability to capture key fine details invisible to the human eye, hyperspectral imaging is gaining value in military and intelligence operations.

The high cost and expert scientific knowledge required to create and use hyperspectral technology had been barriers to its broader use until recent years.

Today, automated hyperspectral workflows, fast, multi-core processors and lower-priced, tactical, hyperspectral sensors and cameras all work to bring actionable intelligence to troops on the ground.

"This is under the category of 'complicated stuff that's been automated,'" noted Derrold Holcomb, technical director, product development, Intergraph Corp., ERDAS geospatial product line.

Hyperspectral imaging is one of the most complex yet crucial geospatial technologies to traverse from scientific labs into theaters of operation. It captures many narrow, contiguous bands of the electromagnetic spectrum with separations of color so fine that the human eye cannot see them. Yet once the data has been post-processed or analyzed in near real time, hyperspectral sensors can define the chemical composition of distant objects precisely.

Ranging from subatomic to universal radiation with light waves from nanometers to meters in length, the electromagnetic spectrum is immense. Hence, there are many different spectral regions and associated wavelengths (speed of light divided by frequency), such as infrared, ultraviolet and X-rays, most of which are invisible to the human eye. Regardless of wavelength, radiation energy quantity in the spectrum boils down to photons.

Sunlight reaches across the entire spectrum, but humans can see only a minuscule segment, called visible light, with a wavelength range of only 400-700 nanometers, and a color range of violet through red. Infrared, for example, has a longer wavelength than red light and is outside the humanly visible portion of the spectrum.

To detect and analyze a wider range of the electromagnetic spectrum than is humanly visible, astrophysicists use spectroscopes to view and record hyperspectral images, that is, the detailed chemical characteristics of objects, gases and stars. Spectrometers measure what is viewed.

Scientists refer to spectral signatures or chemical fingerprints to describe the characteristics of objects based on how they absorb or reflect light in different electromagnetic bands and wavelengths. Hyperspectral imaging captures and measures these signatures by taking hundreds of simultaneous pictures at nanometer intervals from hundreds of electromagnetic bands—scanning wavelength bands similar to how a pushbroom sweeps a wide area of a floor. The result is a large data cube with pixel-level accuracy—and complexity—unparalleled by other modalities. Libraries of established spectral signatures provide a basis for comparison and identification.

"The real value of hyperspectral imaging is in detailed spectral signatures and material distinctions. Our users often require specific information with unique signatures only hyperspectral imaging can see. You can extract evidence of materials that you can't with any other modality, so it becomes important in solving well-defined problems. But it's expensive and the data sets are bulky," said Gerald Kinn, Esri imagery architect, national imaging accounts.

Often the questions asked of hyperspectral imaging have been derived from the results of other sensors used with hyperspectral sensors. "The question has to be well defined with hyperspectral imaging. It's like fingerprint matching. If you've got the fingerprint, you've got the person," said Holcomb.

Surveillance Breakthrough

Hyperspectral sensors and cameras have been on aircraft and in satellites for 30 years. But they are now small enough to fit in the hand and thus, are being deployed tactically as ground-based handheld instruments within DoD. With a heritage in astrophysics and geology, hyperspectral imaging typically carries terabytes of data, requiring time-consuming computations. Slow processors once were an obstacle to practical use, but that is no longer the case.

A breakthrough in the practical use of hyperspectral sensors by the Department of Defense came in May 2009, when the Air Force Research Laboratory launched Raytheon's Advanced Responsive Tactically Effective Military Imaging Spectrometer (ARTEMIS) aboard the TacSat-3 satellite to demonstrate the sensor's tactical ability to download actionable information directly to troops. ARTEMIS showed it could collect, process and download imagery during a single 10-minute pass—bringing hyperspectral space surveillance to combatant commanders.

The Air Force Space Command took control of TacSat-3 for operational use in 2010. ARTEMIS now produces about 100 hyperspectral imagery products per month, delivering key intelligence within hours after sensor tasking.

Last year the Air Force deployed the Raytheon Airborne Cueing and Exploitation System-Hyperspectral (ACES-HY) in the aft of its MQ-1 Predator UAVs, along with multispectral sensors. The ACES-HY provides the Predators real-time detection and geolocation of tactically significant targets for cueing the onboard multispectral targeting system. Operating in the short-wave infrared section of the spectrum, the hyperspectral sensors can distinguish between natural terrain and camouflage (indicating hidden objects) and identify areas of disturbed earth (indicating possible IEDs).

Hyperspectral sensors are used most often with other sensors or cameras such as multispectral, light detection and ranging (LiDAR) and panchromatic cameras. Multispectral imagery is produced by sensors that measure light in broader, fewer bands than hyperspectral. LiDAR illuminates a target with light, often using laser pulses. Panchromatic remote sensing cameras are the most widely used in satellite imaging applications.

"Rarely do we use hyperspectral sensors independent of any other sensor. We use multiple sensors to achieve our goals," said Trey Howell, Merrick and Co. defense solutions manager.

"The more sensors you use, the more you weed out false positives," added Matt Bethal, Merrick manager, system engineering.

Other geospatial experts agree. "A combination of different sensors and cameras provides the most robust actionable result," said David Bannon, chief executive officer of Headwall Photonics.

Multispectral sensors seem to be the workhorses for building general maps of terrain or oceans while hyperspectral sensors are used to find specifics. "It's ironic. For the sensor with the most amount of information—hyperspectral—you seek specific information, whereas the sensors with less information—multispectral—you seek general information," noted Kinn.

Kinn has observed progress in recent years in the use of hyperspectral imaging. "It's now affordable to answer one specific question out of many possible questions using new sensors and algorithms that are emerging for hyperspectral," he said.

Ground-based, handheld tactical instruments represent another major advance in the use of hyperspectral imaging. Current field requirements and the reality of constrained budgets have mandated the deployment of hyperspectral sensors for enhanced ISR (intelligence, surveillance and reconnaissance) missions. The small, less costly hyperspectral sensors operate like cameras and are packaged for imaging in harsh environments such as unmanned aerial vehicles and unmanned ground vehicles.

"The goal is to enable tactical CONOPS to bring the sensor to the warfighter to enable a rapid flow of actionable reconnaissance," said Bannon. "Coupled with fast processors for real-time target detection, this represents a significant shift in deployment strategy from previous generations of large, expensive hyperspectral platforms requiring teams of imagery analysts evaluating terabytes of data," he said.

Analysis Software

The advances gave geospatial image processing companies such as BAE Systems, Exelis Visual Information Solutions (VIS) and Intergraph ERDAS opportunities to upgrade their hyperspectral data analysis software. "We routinely make sure we can properly read the data, including the metadata, of any new format coming from a new sensor. When Raytheon launched ARTEMIS, it created a resurgence of interest in the use of hyperspectral data," said Cherie Darnel, Exelis VIS senior solutions engineer. "Now we have a wide variety of users who take advantage of this."

In the past, hyperspectral data was reserved for highly trained image analysts and considered too complex for most users. However, in recent years, Exelis has worked with DoD to provide easier to use, faster exploitation and analysis of hyperspectral imagery. The work resulted in the Exelis ENVI tools known as Tactical Hyperspectral Operational Resource (THOR), a set of automated hyperspectral workflows, including for ARTEMIS imagery.

"The THOR tools provide different types of workflow-based analysis, each with wizards that guide users through processing," said Darnel.

THOR, which provides target detection, material identification, stress vegetation, change detection, anomaly detection and other workflows, was released in 2010 in ENVI 4.7 Service Pack 1.

"These types of automated THOR workflows did not exist before 2010, so it marked an advancement in hyperspectral image analysis capability," she said. THOR also provides a Spectral Library Viewer and Builder within its software to match a query about incoming hyperspectral images with established signatures in the libraries.

"ENVI comes with a handful of spectral libraries, but users have access to other libraries which they can import into ENVI using the THOR spectral library builder," noted Darnel.

The THOR tools support data written in National Imagery Transmission Format (NITF), including metadata from ARTEMIS NITF data. Used in the defense and intelligence communities, NITF data storage allows for the combination of images, graphics and metadata in a single file.

There are no file size limitations in ENVI, which works with multiple processing cores. "Even to display these large data sets takes a lot of processing power but hardware advancements have made it easier. The more cores you have, the faster the data can be processed and produce results. More memory, faster processing and more processing cores available on the machines have all helped to advance hyperspectral in recent years," said Darnel.

THOR can be used on a laptop in theater, and since ENVI can exist on an enterprise cloud, a rugged tablet user can access it as well. THOR tools also work with Esri's ArcGIS. "ENVI has hyperspectral algorithms that we are able to call in ArcGIS. The model builder can directly call routines in ENVI that have these algorithms for hyperspectral data," said Kinn.

Various algorithm improvements have expedited the processing of massive hyperspectral data. As an example, Intergraph ERDAS added improved signature handling algorithms to speed up the process of comparing new hyperspectral image data with existing signatures in libraries.

"In the latest ERDAS Imagine software, the signature-handling library capability is more organized and user friendly. Improved signature handling is the result of improved algorithms that are more computationally efficient," said Holcomb.

"Matrix math applied to algorithm writing has sped the process of matching signatures. Searching one million pixels is a lot of comparing to do. But matrix computations can handle massive hyperspectral data. By interfacing two matrixes looking for commonalities, you can process the massive data sets faster now," he explained.

Matrix Math

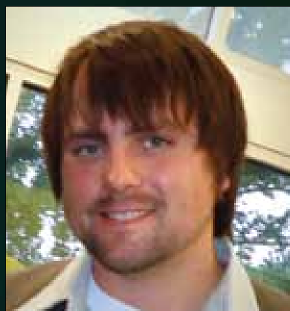
Matrix mathematics is based on a rectangular array of numbers, symbols or expressions. When the arrays are matched in certain ways, they can be added, subtracted or multiplied to simplify or expedite computations.

"Faster computers combined with advanced algorithms, particularly the application of matrix algebra to the analysis of hyperspectral data sets, have made high speed analysis possible," Holcomb said. "In addition, sophisticated algorithms have improved atmospheric correction in Intergraph's ERDAs Imagine software." Atmospheric correction eliminates the atmospheric effects that distort hyperspectral images.

ERDAS Imagine provides remote sensing analysis and spatial modeling with the ability to view 2-D, 3-D, movies and

Hyperspectral Sensing Offers Actionable Intelligence

Hyperspectral sensors have lost weight and size as they have gained accuracy and resolution during the past 10 years. "The 300-pound, refrigerator-sized hyperspectral sensors of yesteryear now weigh only 20 to 30 pounds. And they perform better," said Sean Anklam, chief technology officer for the SGS division of SpecTIR, a hyperspectral solutions company.



Sean Anklam

A decade ago, hyperspectral sensors primarily were flown on large aircraft. Today, they can be integrated into the smallest unmanned aerial vehicles or ground vehicles. "The newest generation of sensors requires significantly less power and maintenance as the manufacturing materials and techniques have grown more sophisticated," he said.

SpecTIR created processing and analysis algorithms specifically for ground-based sensing. "We built prototype hyperspectrals in mobile, ruggedized containers. They are turnkey plug-and-play systems that take a hyperspectral picture, process the image and prepare it for immediate use as tactical, actionable intelligence," Anklam said. "We built some of the first ground-based hyperspectral imagers that will be deployed in Afghanistan within the next couple of months."

The systems are imaging in the humanly visible as well as the invisible, near-infrared and short-wave infrared portions of the electromagnetic spectrum, which are valuable for tactical applications. "It increases your accuracy to have information from that expanded portion of the spectrum when looking for key chemical signatures associated with insurgent activities," he said.

To overcome the complexity, the company provides training and education in spectral analysis and remote sensing on-site and off-site, including specialized concept of operations) and tailored mission development.

Another leap forward in hyperspectral image analysis is the ability to integrate the information into other intelligence formats and GIS, such as Esri geo-databases and shape files, Google Earth KMLs, LiDAR or thermal imagery with HUMINT or SIGINT. SpecTIR's own GAIA database integrates these formats and is both temporally and spatially enabled in a 3-D environment for a common operating intelligence picture.

As a result of these developments, the actionable intelligence derived from hyperspectral imaging is more valuable today. "The detailed information you can discern about a material or an object's chemical composition in hyperspectral imagery can now be explicitly linked to a significant event, a thermal emission or even the location of a cell phone call—all within a common operational or common intelligence picture," said Anklam.

cartographic quality map compositions. It scales from Imagine Essentials to Advantage up to Professional, with authoring of geospatial content in more than 100 different formats. Each tier of the software can be expanded with add-on modules.

Ortho-rectification provides sensor adjustment and image orientation to render geo-location as accurate as possible. The Imagine Image Interpreter provides a list of imagery enhancement tools for spectral imaging, filtering, resolution merge and others.

The Advantage level provides batch and parallel processing, change detections and GIS analysis of remote sensors for decision support. Professional offers mosaic terabytes of imagery with ERDAS ER Mapper and spectral classification tools. Imagine Model Maker builds upon a Spatial Modeling capability with the ability to blend remote sensing and GIS data. Radar Interpreter provides radar analysis. The spectral analysis tools enable hyperspectral image processing to extract material mapping information with minimal user interaction and without the need to learn hyperspectral image processing theory.

ERDAS Apollo is an enterprise level data management delivery and collaboration suite that scales through clustering to handle large data archives.

Processing Speed

The enormity of the hyperspectral data package has led industry to focus on improving the speed of processing. "In the 2012 version of ERDAS Imagine we are changing the way we read and handle image data, changing core pieces that will speed up the processing of hyperspectral data yet again," Holcomb said.

"To determine if your targets are accurate, you need very fast processors and high speed data links," said Bannon.

Headwall Photonics has provided hyperspectral sensors to the military for years, starting when its predecessor, American Holographic, provided defractive optics, a key optical component of hyperspectral sensors, to the Navy.

Headwall offers space-qualified satellite sensors for small satellite payloads, airborne and ground-based sensors, which are handheld or unattended reconnaissance sensors for checkpoint control or unmanned ground vehicles for enhanced ISR.

"The complexity is being engineered out of the technology," said Bannon. "Hyperspectral sensors now can be exploited cost-effectively for the boots on the ground."

The top two hyperspectral sensors Headwall provides to the military are the High Efficiency Hyperspec airborne sensor and the MicroHyperspec sensor. "The High Efficiency Hyperspec sensor offers extremely high signal-to-noise target detection and imaging capability that allows for scanning a wide field of view without image aberrations. The product has been widely adopted for high-end airborne deployment just as it has been ruggedized and light-weighted at a unique price/performance for DoD applications," Bannon said.

"Previously the cost of a high-performance hyperspectral airborne sensor had been a budget-buster, at more than $6 million, inhibiting the adoption of the technology. Headwall has been successful supplying high performance hyperspectral sensors at much lower cost—$200,000—so the technology can be deployed in volume," he said.

Headwall's Micro-Hyperspec sensor is a reduced size and weight to fit onto a wider range of operational vehicles such as small UAVs and robotic platforms. Designed for harsh environments, the Hyperspec RECON handheld sensor allows DoD users to load mission-specific target sets onto an SD-card (Secure Digital memory card, like a camera), and scan and view identified targets on the sensor's LCD screen at distances of 1.5 kilometers.

"You just load your algorithms and your particular target signatures onto a neutral SD card and plug it into the sensor and now you've got a mission specific hyperspectral sensor. It's used for surveillance and reconnaissance purposes and doesn't require training. The soldier simply points it and takes a picture," said Bannon.

"It can detect a six-inch-by-six-inch target (a human face) at a distance of a mile in one to three seconds. The idea is to collect a large data set and process it quickly to take action on it," he said.

The Army Night Vision and Electronic Sensors Directorate (NVESD) at Fort Belvoir, Va., is evaluating the Hyperspec RECON handheld sensor/camera for missions such as camouflaged sniper detection and to spot explosives concealed on approaching people. NVESD is developing mounted hyperspectral imaging sensors for vehicles that can detect explosives and related chemicals at speeds as fast as 12 miles per hour from four to 330 feet away during the day, at night and in bad weather.

Updated Algorithms

BAE Systems SOCET GXP geospatial intelligence software also contains many updated algorithms for hyperspectral image processing that allow analysts to extract information quickly in multiple bands. "Analysts match pixels in an image to known materials in real time with a single button click, define signatures of interest, adjust the thresholds for determining matches and snapshot to Powerpoint in a matter of minutes now, as opposed to legacy systems that could take hours," said Nick Rosengarten, product manager, BAE Geospatial eXploitation products.

In addition, the SOCET GXP software now is easier to use by a wider variety of users. "Previously this data analysis was considered a specialized field using niche applications that required processing by spectral scientists using complex stovepipe systems," he noted.

SOCET GXP can process multiple data types including hyperspectral imaging, multispectral, synthetic aperture radar and LiDAR. SOCET GXP version 3.2 added more new algorithms and increased flexibility to let users add and remove spectral signatures in real time using in-scene spectra, adjust thresholds and switch algorithms. The U.S. Geological Survey spectral library is included in the software.

Hyperspectral imaging is used to detect chemical warfare, uranium processing, smelting radioactive materials, roasting ores and exhaust gases. "It looks at molecules in exhaust plumes to understand what's going on in that facility," Holcomb said.

The technology also helps to locate IED manufacturing sites. "There are very specific chemicals and minerals used to contruct the explosive portion of the IED. Hyperspectral sensors are extremely successful in detecting the chemicals used to create IEDs and to locate IED manufacturing sites. These chemicals—or any chemical for that matter—emit a specific signature within a certain band that you can't find with other sensors," said Merrick's Howell.

Data fusion is a growing area of interest. "We are looking at data fusion to take advantage of the many different types of data. Within ENVI's feature extraction tool, for example, we can combine hyperspectral and LIDAR data for that type of analysis," said Darnel.

"The concept of data fusion is discussed a great deal in the intelligence community and SOCET GXP has taken a significant step towards making this a reality," said Ronsengarten.

Many hyperspectral experts are eagerly awaiting the placement of more hyperspectral sensors into space orbit. "There are still not enough airborne and space-borne hyperspectral sensors available. It's expensive to launch satellites. There are no commercially available satellite-borne hyperspectral sensors and data, so there is there's still no big commercial market for this yet," noted Holcomb.

However, further development of hyperspectral imaging is expected. "Within the next few years, hyperspectral will be critical for solving specific problems that our users face on a daily basis, so it will be more widely applied," said Kinn. ✯

For more information, contact *GIF* Editor Harrison Donnelly at harrisond@kmimediagroup.com or search our online archives for related stories at www.gif-kmi.com.