

An Enterprise Architecture for Transferring Remote Sensing Algorithms from Research to Operations - Hyperspectral applications in the littoral zone

Response to CASIS Request for Information/Proposal:
Utilization of Existing ISS Hyperspectral Imaging for Commercial Product Development

Expanding Return on U.S. Investments in Earth Observation

The geospatial market is a high growth industry, with substantial investments made in sensor development and instrument deployment. However, the associated implementation and application of innovative new processing algorithms, needed to transform remote sensing data into value-added products and services, is often hindered by a number of barriers.

We propose an enterprise architecture for image processing that leverages existing investments in Earth observation data acquisition and enables the remote sensing community to more effectively transform research ideas into functional software applications.

We will demonstrate the capabilities of this technology by creating an initial prototype for processing data from the HICO instrument on the ISS.

*“Empower the individuals ...
... and you inspire the community”*

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Abstract

Inspiring innovation and facilitating technology transfer are important components of economic success in the global high-tech marketplace. And the geospatial industry is no exception to the need for improving this process in the United States. Consider the amount of money invested by government and commercial organizations to develop, launch and operate remote sensing instruments. Also consider the amount of funding distributed to research centers for the development of novel techniques to utilize this data for answering important societal questions, such as those related to resource utilization, climate change and ecological assessment. Contrast this with the limited amount of investment being made in transforming these existing datasets and processing techniques into functional applications with public benefits and commercial value. When combined with the conventional barriers to software development, this dichotomy in investment strategy has hindered the efficient implementation of new remote sensing applications. Fortunately, in what was previously the domain of select software companies and large research organizations, there has been a movement in the software industry to offer development tools enabling application development to flourish in the hands of the community. We propose demonstrating the functionality of this paradigm shift as it applies to remote sensing. Specifically, using the newly released ENVI Services Engine from Exelis VIS, and using the HICO instrument as an example prototype, we propose an enterprise architecture for rapidly implementing new remote sensing algorithms and applications, and for making these applications readily available to the global user community. The resulting framework will demonstrate an improved pathway for advancing the field of remote sensing, which has both scientific and commercial benefits.

Project Overview

The objective of the proposed project is to develop a prototype implementation of the ENVI Services Engine, thereby *demonstrating a framework for the acceleration of technology transfer in the remote sensing marketplace*. While the project will use the HICO instrument as the basis for the prototype, it is important to note that the resulting framework is equally applicable to any number of other remote sensing instruments, including those on the ISS as well as those on airborne and satellite platforms. Steps used to accomplish the project objective will include the following:

- Use HICO data as basis for transforming remote sensing algorithms into operational applications.
- Develop applications using ENVI and IDL, commercial-off-the-shelf (COTS) software from Exelis VIS already familiar to the remote sensing community.
- Engage existing HICO user community in application development.
- Focus initial development on littoral zone applications, while still highlighting that the resulting framework is broadly applicable across a host of sensors and applications.
- Transform no less than 2-3 existing hyperspectral algorithms into IDL modules for ENVI and then into enterprise applications using the new ENVI Services Engine.
- Build a prototype web-enabled, scalable, geospatial data processing architecture for HICO, and demonstrate the functional capability for building and deploying enterprise applications using the ENVI Services Engine.
- Host the resulting prototype on a publically-available password-controlled server, with access provided for testing and evaluation by members of the HICO science community, for a period of up to 6 months or more.

Science and Technology

HICO: Our proposal is in response to the CASIS RFI entitled “*Utilization of Existing ISS Hyperspectral Imaging for Commercial Product Development.*” As such, science requirements for the proposed project are a function of the unique imaging capabilities and sensor characteristics of HICO (Hyperspectral Imager for the Coastal Ocean). HICO was integrated into the HICO and RAIDS Experimental Payload (HREP), which is part of the first U.S. experiment payload on the Japanese Experiment Module - Exposed Facility (JEM-EF) on the International Space Station (ISS).

As indicated by its name, HICO is a hyperspectral instrument designed specifically for imaging the coastal zone. HICO is the first space borne instrument of its kind, built on the proven heritage of the PHILLS airborne imaging spectrometer and optimized for acquisition of dark aquatic targets (Corson et al. 2008). HICO measures the spectral range from 400-900 nm at

a sampling interval of 5.7 nm (full range is 353-1080 nm prior to cropping for quality control). The instrument has a high signal-to-noise ratio (>200:1 for water penetrating wavelengths from 400-600 nm) and low polarization sensitivity (< 5%) for the majority of wavelengths (Lucke et al. 2011). Its nominal ground sampling distance is 90 m, with 500 x 2000 pixels per scene covering an area 42 x 192 km. HICO was launched and installed on the ISS in mid-September 2009, and collected its first imagery later the same month. Since that time HICO has acquired 1000s of coastal scenes from around the world.

The objective of the current project is to focus predominantly on end-user applications. Project development will therefore focus on applications that operate using atmospherically corrected Level 2 data. This means that the only project requirement related to ISS facility/hardware is access to select examples of HICO Level 2 data and/or Level 1b data, where HySpeed Computing will handle atmospheric correction in-house.

HICO Applications: Because HICO spectral performance was optimized for dark targets, the sensor represents a unique opportunity to focus on applications in the littoral zone. Such coastal applications have received far less attention than their terrestrial counterparts, in part due to the additional complexities inherent to the water surface, water column, and shallow substrate, as well as limitations of terrestrial-optimized sensors. As a result, significant opportunity exists for algorithm and App development in this environment.

The majority of reported HICO investigations have focused on applications related to water properties and its constituents, as well as benthic composition and water depth. These algorithms all have relevant research directions and science objectives, but they also have additional societal and commercial importance with respect to derivative products and utilizing output for other related applications. For example, consider the importance of bathymetry in modeling coastal storm surge and tsunami inundation, which in turn impacts coastal development and risk management valuations by insurers. Similarly, declining water quality impacts the health and productivity of marine fisheries, which influences resource management decisions and subsequent economic revenue in the coastal zone. Improvements in sensor technology and image processing algorithms can thus have significant reach, but leveraging these improvements requires that applications become available for use.

Algorithms to be considered for implementation in this project include a combination of those already available in-house at HySpeed Computing, those solicited from the HICO user community and those available in the literature. Hence, as stipulated in the CASIS RFI, the project is not reliant on access to any existing NRL algorithms. Instead, we will demonstrate the capabilities of the enterprise architecture using an independent collection of algorithms. Note that, wherever appropriate, intellectual property related to the individual algorithms will remain with the algorithm developer. Examples to be considered for inclusion in the project include:

- *AquaCor*. This is an in-house implementation of the inversion model originally developed by Lee et al. (1999, 1998) as adapted from work by Dr. Goodman (Goodman et al. 2008, Goodman and Ustin 2007). The algorithm is thus an independently programmed version of the HOPE algorithm, and an excellent opportunity to demonstrate the functionality of the proposed architecture using this highly successful, yet computationally complex, algorithm. As with the original, this version of the model uses a non-linear numerical optimization scheme to derive information on water properties, water depth and bottom albedo from hyperspectral imagery. AquaCor is already programmed in IDL as a plug-in module for ENVI, making it readily available for implementation using the ENVI Services Engine.
- *Sunglint correction*. This is a collection of various published sunglint correction algorithms, including those reported in: Goodman et al. (2008), Hedley et al. (2005), Hochberg et al. (2003), Kutser et al. (2009) and Lee et al. (1999). As was the case with AquaCor, a majority of the code for these algorithms already exists in IDL, facilitating relatively straightforward implementation in this project. The sunglint algorithms all function to remove the effects of specular reflection from aquatic imagery, and in some cases also help normalize reflectance from multiple scenes.
- *Algal blooms*. A number of HICO researchers are also investigating algorithms to detect and characterize high biomass bloom events in coastal waters (e.g., Ali, Binding, Kudela). For example, Kudela is using HICO imagery from Monterey Bay to compare the efficacy of various sensors and algorithms for assessing bloom dynamics, including evaluation of the spectral shape algorithm proposed by Dierssen et al. (2006).
- *Water quality*. There are numerous examples of hyperspectral algorithms related to the assessment and monitoring of water quality parameters (e.g., Govender et al. 2007). While some of these are based on existing multispectral

algorithms, many represent innovative approaches that leverage the spectral resolution of hyperspectral imagery. A number of HICO researchers are exploring the relative merits of a number of these water quality algorithms, as well as developing their own novel approaches (e.g., Davis, Dogliotti, Garfagnoli, Moreno).

- *Submerged aquatic vegetation.* Differentiating water column chlorophyll from submerged aquatic vegetation is another example where hyperspectral imagery can contribute significant advantages over multispectral data. With this objective in mind, Cho and Mishra are building on past work (e.g., Cho and Lu 2010; Lu and Cho 2011; Mishra and Mishra 2012) to develop a novel algorithm for mapping seagrass and algae in the Indian River Lagoon.

ENVI Services Engine: As the demand for access to geospatial information grows, the need for new and more efficient ways to deliver information to those who need it most becomes more important. This is why Exelis VIS created the ENVI Services Engine, a cloud-based image analysis solution that allows an organization to create, publish, and deploy advanced ENVI image and data analytics to any existing enterprise infrastructure.

Using ENVI- or IDL-based image processing services, the ENVI Services Engine allows deployment of traditional ENVI/IDL desktop capabilities into on-line, on-demand environments. The ENVI Services Engine presents a simple HTTP REST interface that supports integration into a wide variety of environments such as Java Enterprise Environments, OGC, ArcGIS for Server and custom batch workflows. Once an ENVI/IDL routine is developed, it is simple to wrap it as a service and deploy it in the Services Engine for consumption by remote end users or other Apps and services running in the enterprise. Results are delivered back from the Services Engine and can be saved as data or files, or displayed in a variety of clients including web browsers, desktop apps and mobile devices, depending on the specific implementation.

Figure 1 below provides a conceptual view of the ENVI Services Engine in a Cloud or Enterprise Environment. Application developers create ENVI routines or functions using the proven image and data analytics available in the ENVI COTS product. These functions are wrapped and deployed as web services in the ENVI Services Engine which is integrated into an Enterprise architecture providing a cloud-based image analysis solution that is then made available to a variety of clients. The same web-services can be leveraged in a variety of clients supporting multiple platforms and levels of user capabilities. Very simple web-based clients can be developed for new or novice users, while complex thick clients that leverage the desktop and the cloud can put significant capability in the hands of advanced users. In this model, analytic services and data are centralized and exposed to a variety of different uses through multiple clients.

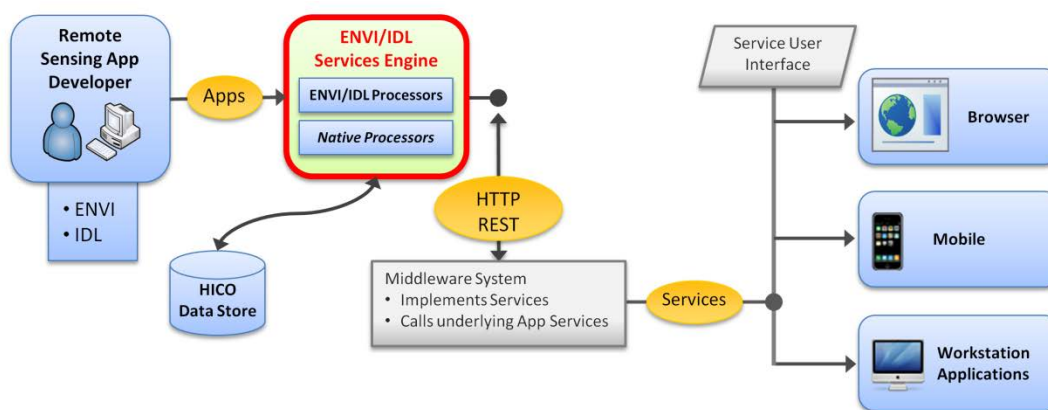


Figure 1. Schematic of the connection between developers, data and Apps with remote sensing users enabled through ENVI/IDL and the ENVI Services Engine.

Project Impacts

Technology Transfer: The objective of the proposed project is to generate an enterprise architecture for accelerating technology transfer in the remote sensing marketplace. Since this objective has relevance beyond HICO and the ISS, the project has *considerable significance and potential impact throughout the geospatial industry, particularly with respect to the domains of algorithm development, image processing and applied remote sensing.*

Beyond the remote sensing imagery itself, it is also the value-added information and products derived from this imagery that has such enormous potential. Remote sensing scientists are developing innovative new remote sensing algorithms and applications at a remarkable pace. Their efforts continue to expand the realm of what is possible for deriving scientific, commercial and societally important information from this imagery. HySpeed Computing is building an innovation community to embrace and empower these achievements (Figure 2); and through this project demonstrate a pathway to rapidly transfer remote sensing technology into the community and into the marketplace. By basing this project on the ENVI Services Engine, customers can utilize their existing investment in ENVI and IDL in a new, services-based deployment model, and application developers can readily deploy their own ENVI- or IDL-based services. Additionally, as the architecture becomes more firmly established, the efficiency of follow-on development will be greatly improved and time to market will therefore decrease with increasing App development.

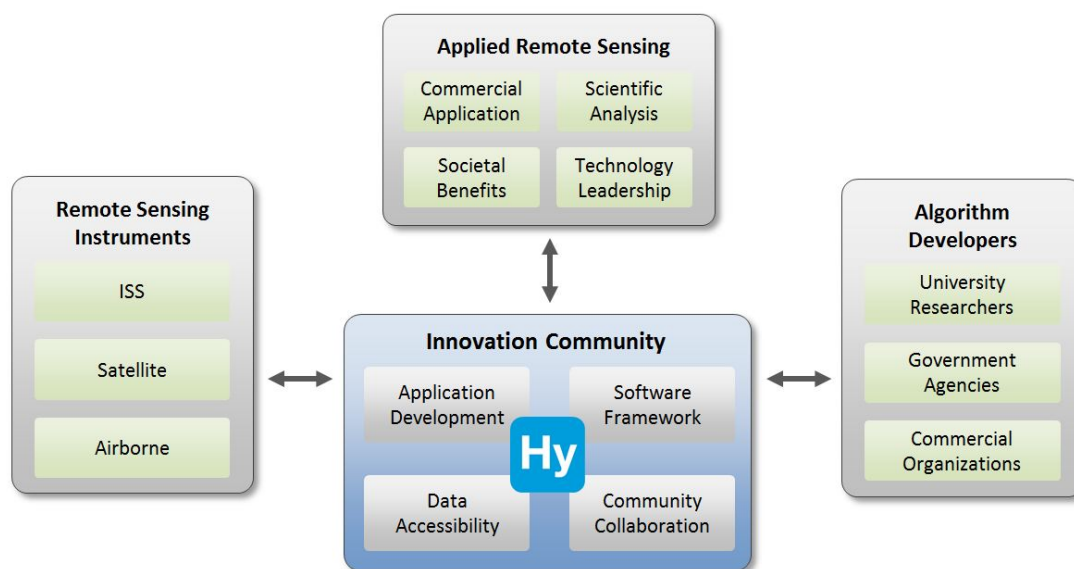


Figure 2. The HySpeed Computing vision: building a community of technology innovation.

Beyond HICO and the ISS: The ability to readily integrate remote sensing Apps in an enterprise architecture has significant relevance beyond just HICO. For example, outcomes from this project are applicable to other hyperspectral missions, such as HyspIRI and EnMAP, as well as other ISS instruments (e.g., CATS, ISSAC, ISS-RapidScat). This same architecture can also be extended to accommodate the entire image processing chain for any given instrument, from calibration and pre-processing to intermediate processing steps and end-user applications. Implementation is therefore not constrained to just the applications demonstrated in this proposal, nor is it limited by any particular spectral and spatial characteristics. It can in fact *serve as an end-to-end image processing framework* for any number of current and future remote sensing missions. For example, the proposed enterprise architecture can be used to step through a standardized sequence of processing steps (e.g., from raw imagery, through radiometric, geometric and atmospheric corrections, to higher order output products), while also being capable of dynamically integrating different algorithms and applications. This allows significant processing flexibility, from a production viewpoint, from a research position, and from an application perspective.

There is a compelling need for such processing systems, particularly those that are accessible to the user community and can be dynamically modified with new algorithms. Using ENVI and the ENVI Services Engine as the foundation, we will *demonstrate the ability to move from algorithm to desktop application to enterprise service*. This algorithm deployment model will be exposed via new capabilities in the ENVI+IDL Workbench, allowing researchers to easily deploy new algorithms for exploiting remote sensing data as enterprise services. The resulting capability has the potential to open ISS-based remote sensing to a global audience, demonstrating the value of the ISS as a platform for testing and developing sensors and systems as well as addressing big questions in the Earth sciences.

Biographical Sketches

Dr. James Goodman is the founder and President/CEO of HySpeed Computing LLC, a technology company specializing in developing advanced algorithms and analytic tools for the scientific community. He previously worked as a consulting engineer, a software developer for decision support systems, and an academic researcher. His cross-disciplinary expertise includes remote sensing, image analysis, mathematical modeling, imaging spectrometry, and high-performance computing. Dr. Goodman maintains academic affiliations with the University of Puerto Rico at Mayaguez and the University of Miami, where current research is focused on remote sensing of coastal ecosystems. He has been awarded grants for his research from NASA, NSF and NOAA, and collaborated on projects with investigators around the world. He is also active in the scientific community, publishing research articles and leading sessions at international conferences.

Dr. Goodman has a B.A. in engineering from Dartmouth College, a M.S. in civil and environmental engineering from University of Colorado at Boulder, and a Ph.D. in hydrologic science from University of California at Davis. He is also a licensed Professional Engineer. His Ph.D. dissertation, supported through the prestigious NASA Graduate Fellowship Program, established an innovative methodology for hyperspectral remote sensing of submerged coral reef ecosystems. He spent six years working with the Center for Subsurface Sensing and Imaging Systems, an NSF Engineering Research Center, as a lead investigator on algorithm development for spectral discrimination and subsurface remote sensing of coastal environments. These research projects included work with a variety of hyperspectral sensors, including AVIRIS, CASI, AISA and HYPERION. Dr. Goodman is lead editor on the recently released book entitled Coral Reef Remote Sensing. He is also currently a member of NASA's HypIRI Aquatic Data Products and Applications Working Group and collaborating with scientists from the German EnMAP hyperspectral mission to simulate satellite-based coastal hyperspectral scenes. His expertise in hyperspectral coastal remote sensing and algorithm development is therefore directly aligned with the proposed commercial project involving the HICO instrument on the ISS.

HySpeed Computing is all about accelerating innovation and technology transfer. We recognize that innovators are everywhere, but that many different challenges can hinder transforming ideas into reality. Fortunately we live in a remarkable age where the intersection of technology and communication is continually opening exciting new pathways and opportunities. HySpeed Computing embraces this evolution and offers the scientific community a platform for achieving their goals of innovation. We provide a community framework for scientific innovators to purchase advanced software, sell user-created applications, and collaborate with other developers. Our initial community centers on geospatial applications, with particular emphasis in remote sensing and imaging spectrometry.

HySpeed Computing was founded in 2010 with the vision of redefining the paradigm by which researchers collaborate and expand their impact on society. This is being achieved by becoming a leader in the development of advanced remote sensing applications, as well as establishing an unprecedented means for scientists to sell and purchase their own applications. HySpeed Computing has already been awarded a grant from the NSF SBIR/STTR and ERC Collaboration Opportunity to use high-performance GPU computing to accelerate a remote sensing tool for the analysis of submerged marine environments. We are also currently partnering with universities, government agencies and commercial companies to expand their impact through open sharing of high-quality remote sensing datasets. HySpeed Computing is dedicated to connecting and empowering the remote sensing community; it is together that we can achieve great things.

Exelis Visual Information Solutions (VIS) is an industry leading provider of geospatial and scientific software, committed to creating state-of-the-art remote sensing tools and facilitating the efficient integration of user-developed algorithms. At Exelis VIS, the mission is to empower people to easily extract useful information from complex data in the pursuit of discovery. Exelis VIS has a vision is to be the leading supplier of desktop and enterprise solutions for image and data access, exploitation, and dissemination in the defense and commercial geospatial information markets, and to remain the data analysis and visualization tool of choice in our core scientific markets. Exelis VIS produces, supports and continues to develop world-class scientific and image analysis products, including IDL, ENVI, ENVI LiDAR, and the recently released ENVI Services Engine.

The Exelis VIS Professional Services Group has been providing custom solutions and products for more than 20 years. Exelis VIS has extensive experience handling data in many complex formats from a variety of scientific and government sources. In addition, Exelis VIS has developed a solid understanding of the typical data processing chain, from request and

acquisition of data to calibration and validation to data display, enhancement and analysis, final output and storage/archival. Exelis VIS has a staff of scientific programmers who build custom, commercial-grade applications and productivity tools. Our software development expertise includes IDL, C, C++, and Java in addition to algorithm development, research and phenomenology. Most Exelis VIS Professional Services staff hold a PhD or a Masters degree in a field such as Earth Sciences, Physics, Meteorology, Mathematics, Geophysics, Chemistry, Astronomy, Environmental Engineering, Geology, Biophysics, or Computer Science.

Exelis VIS Professional Services offerings include: custom software design & development, enterprise development, commercialization services, creation of custom workflow and UI design, process and program automation, optimization and tuning of IDL & ENVI applications, software testing/validation and verification, on-site contracting support, algorithm development in imaging spectroscopy and spatial feature extraction, and professional training in the use of IDL and ENVI. As the IDL / ENVI developers, Exelis VIS is uniquely positioned to provide enhancements to our commercial products to support specific program needs while controlling cost and risk.

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