TERRESTRIAL IMAGING SPECTROSCOPY – SOME FUTURE PERSPECTIVES

K. Staenz

Alberta Terrestrial Imaging Centre/Department of Geography, University of Lethbridge, 400, 817-4th Avenue South, Lethbridge, Alberta, Canada T1J 0P3 – karl.staenz@imagingcenter.ca

KEY WORDS: Terrestrial Imaging Spectroscopy, Hyperspectral Remote Sensing, Hyperspectral History, Hyperspectral Space Missions, Algorithm Development, Data Processing, Applications Development, Future Needs, Outlook

ABSTRACT:

This paper covers 60 years of terrestrial imaging spectroscopy or hyperspectral remote sensing – 30 years each devoted to past and future developments. For this purpose, a brief history of imaging spectroscopy is given, covering civilian airborne sensor and spaceborne mission developments and associated data processing capabilities. Moreover, the paper reviews the existing and planned space systems, examines the current status in hyperspectral remote sensing in terms of data quality and availability, algorithm development, data processing, and applications development. Although many problems have been overcome since the advent of hyperspectral remote sensing, there are still major bottlenecks, as pointed out in this paper, which need to be addressed to further advance this area. Future needs in hyperspectral remote sensing are summarized in terms of space missions and the data products they provide, algorithm development, data processing, and applications development. The paper will conclude by speculating on civilian hyperspectral systems that might be in operation for terrestrial imaging 30 years down the road. In addition, an outlook of the data processing capabilities needed to analyse the increasing volume of data is given for the same time frame.

1. INTRODUCTION

Civilian terrestrial imaging spectroscopy or hyperspectral remote sensing has evolved over the last 30 years to a point where based on performance decent spaceborne missions can be deployed (Goetz, 2009). Along with the sensor system development, entire image analysis systems, such as ENVI, have emerged, which were able to handle the volume of data, pre-process these data, and extract information from these data. These activities have helped to advance the development of applications, such that without imaging spectroscopy, many environment and resource related issues faced today could not be properly monitored and understood (Schaepman et al., 2009). However, further development of this technology is required to fully exploit this kind of data and to reach, for example, a fully commercial system. In order to achieve this goal, hyperspectral systems need to be deployed which provide reliable and timely data, such that data are available when needed, and the information products can be retrieved with the highest possible accuracy. Timely delivery of these products is important in an operational/commercial setting and coupled with a drastic increase in the data volume in the future, near real-time processing is required either through on-board data processing or automation and parallelization of software tools, which are embedded in dedicated intelligent systems specific to an application. Moreover, most of these products will not only be generated from hyperspectral data alone, but include data from other sources. Therefore, data fusion to integrate these data properly for analysis and data mining to efficiently extract the data needed will become important in the future.

2. BRIEF HISTORY

The development of terrestrial imaging spectroscopy started in the late seventies by NASA's Jet Propulsion Laboratory (JPL) and a government of Canada/private partnership (Department of Fisheries and Ocean/Moniteq) leading to the Airborne Imaging Spectrometer (AIS; Vane and Goetz, 1988) in the U.S.A. and the Fluorescence Line Imager (FLI; Gower et al., 1987) in Canada with first data acquisitions in 1983 and 1984, respectively. These activities led in 1987 to the first visible and near-infrared (VNIR) and short-wave infrared (SWIR) sensor, JPL's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS; Vane et al., 1993) and in 1988 to the first commercial instrument, Itres' Compact Airborne Spectrographic Imager (*casi*; Anger et al., 1990). Many more airborne systems have been developed since that time (e.g., Buckingham, 2008; Birk and McCord, 1994).

The first successfully launched civilian hyperspectral satellite sensor, NASA's Hyperion on EO-1, has been in orbit since 2000 (Pearlman, 2003). A year later, the Compact High Resolution Imaging Spectrometer (CHRIS) on board ESA's Project for On-Board Autonomy (PROBA) platform was launched (Barnsley et al., 2004). Both systems are still operating today, providing imagery in the VNIR (CHRIS) and VNIR/SWIR (Hyperion). With the current launches of ISRO's VNIR Hyper-Spectral Imager (HySI) on board the Indian Microsatellite 1 (IMS-1) and the Chinese VNIR HJ-1A satellite sensor in 2008, new opportunities will arise for the use of hyperspectral data in various application areas due to the larger ground sampling distance (GSD) (≥100 m) combined with a larger swath width (≥ 50 km) of these sensors.

Data handling and correction of sensor artefacts dominated software development in the early phases of imaging spectroscopy, followed by an intense period of algorithm development (AVIRIS, 2007). Innovative procedures, such as atmospheric correction and spectral linear unmixing, were developed (Staenz and Williams, 1997; Neville et al. 2008). These procedures together with the capability to handle hyperspectral data were incorporated into several hyperspectral image analysis systems by government and academic institutions and, ultimately, resulted in the release of the first commercial system, ENVI, in 1994 (Boardman et al., 2006). With the availability of ENVI, the development of applications increased significantly, making imaging spectroscopy an important tool in areas such as climate change, resource management, and environmental monitoring and assessment as, for example, shown in the AVIRIS Workshop proceedings (AVIRIS, 2007). Additional hyperspectral image analysis systems have emerged, such as the hyperspectral packages in ERDAS Imagine and in PCI Geomatica.

3. HYPERSPECTRAL MISSIONS

The hyperspectral missions can be categorized as follows (Buckingham and Staenz, 2008):

- Currently operating in space,
- Currently in funded development,
- Planned (waiting for full funding),
- Failed on launch, not launched, or not in operation anymore, and
- Terminated (never built).

The last two categories are of much less relevance today than the first three and, therefore, will be discussed only briefly in the following paragraph.

The sensors Lewis and Warfighter failed on launch and never acquired any data while NRL's Coastal Ocean Imaging Spectrometer (COIS) was built, but could never be launched. On the other hand, MightySat II.1, a military/civilian dual use sensor platform with a Fourier Transform Hyperspectral Imager (FTHS) onboard, operated successfully for about two years, but ceased operations in 2002. The "never built category" includes sensors which went through a design phase (phase A), but never made it into the detail design and building phases. It includes quite a number of initiatives such as HIRIS (NASA), HRIS (ESA), ARIES (CSIRO), PRISM (ESA), SPECTRA (ESA), and HERO (CSA).

3.1 Sensors Currently Operating in Space

Table 1 summarizes the major spatial and spectral characteristics of the hyperspectral sensors currently operating in space. These sensors, with the exception of the operational HJ-1A, were initially designed as technology demonstrators. Hyperion and CHRIS have now been in space way beyond their initially designed life time. Despite the data quality problem of these two sensors, they have made a great contribution to the advancement in the development of imaging spectroscopy. It should be noted that ESA's Medium Resolution Imaging Spectrometer (MERIS; Bézy et al., 2000) is by design a hyperspectral instrument, but it collects only a pre-defined set of bands.

Sensor	**Hyperion**	**CHRIS**	**HySI**	**HJ-1A**
Country and Organization	USA NASA	UK ESA	India ISRO/NRSC	China CAST
GSD (m)	30	17/34	506	100
Swath at Nadir (km)	7.65	13 (nominal)	129.5	≥50
Wavelength Coverage (nm)	357-2576	400-1050	400 - 950	450 - 950
Number of Bands	242	18/37/6	64	110 - 128
Spectral Res. (nm @ FWHM)	10	5.6-32.9	~ 10	5
Launch Date	2000	2001	2008	2008

Table 1. Current hyperspectral sensors/missions in space (GSD = Ground Sampling Distance, FWHM = Full Width at Half Maximum).

3.2 Sensors Currently in Funded Development

The sensors/missions, which are currently in funded development, are listed in Table 2. Out of these sensors, the US Air Force Advanced Responsive Tactically Effective Military Imaging Spectrometer (ARTEMIS) has been built and is scheduled to be launched May 5, 2009. The other sensors, the

Sensor	**EnMAP**	**PRISMA**	**MSMI**	**ARTEMIS**
Country and Organization	Germany GFZ/DLR	Italy ASI	S. Africa SunSpace	USA AF
GSD (m)	30	30	~15	5
Swath at Nadir (km)	30	30	~ 15	20 ?
Wavelength Coverage (nm)	420-2450	400 - 2500	440-2350	400-2500
Number of Bands	218	> 200	200	~400
Spectral Res. (nm @ FWHM)	5/10 VNIR 10 SWIR	~10	10	5 sampling
Launch Date	2013	2012	2010	2009

Table 2. Hyperspectral sensors/missions currently under construction or ready for launch.

Environmetal Mapping Program (EnMAP; Stuffler et al., 2007), the Hyperspectral Precursor of the Application Mission (PRISMA; Galeazzi et al., 2009), and the hyperspectral portion of the Mulit-Sensor Microsatellite Imager (MSMI; Van Aardt and Coppin, 2006), are in different development stages of which the MSMI is the most advanced in this sense with a planned launch in 2010. EnMAP and PRISMA, which are very similar in the spatial and spectral characteristics, are scheduled to operate in space in the 2012/13 time frame. These sensors will have a much higher data acquisition capacity than the technology demonstrators, Hyperion and CHRIS, allowing better data provision capabilities for the civilian community to feed initial operational applications on a regional basis.

3.3 Sensors Planned

There are quite a few hyperspectral initiatives in the planning stage worldwide, and only selected programs are listed in Table 3. NASA's Hyperspectral Infrared Imager (HyspIRI; Green et al., 2008), which focuses on ecosystems changes due to human land management practices and climate variability, is anchored in NASA's decadal survey and planned for an implementation in 2013 – 2016. Since HyspIRI is a global mission with a swath width of 145 km, it complements the EnMAP and PRISMA targeting missions which both have a swath width of 30 km. Although similar in spectral characteristics to HyspIRI, the hyperspectral mission of the Japanese Ministry of Economy, Trade and Industry (Takahashi, 2009) is a targeting mission with spatial and spectral characteristics similar to MSMI. These two hyperspectral initiates are covering the VNIR/SWIR wavelength range while ESA's Fluorescence Explorer Visible (FLEX-VIS) hyperspectral instrument is sensitive to the VNIR only (Ward and Berger, 2007). The latter instrument was proposed to complement the Earth Explorer mission FLEX, which in its current form is not pursued further by ESA. This also means that FLEX-VIS will not be developed in the near future. Other examples of hyperspectral initiatives pursued are Surrey Satellite Technology's CHRIS-2, a VNIR/SWIR sensor, and a hyperspectral instrument on the Korea Multi-Purpose Satellite platform (KOMPSAT-6).

Sensor	**HyspIRI**	**not specified**	**FLEX-VIS**
Country and Organization	USA JPL, NASA	Japan METI	ESA
GSD (m)	60	15	300
Swath at nadir (km)	145	15	390
Wavelength Coverage (nm)	380 – 2500	400 - 2500	400 - 1000
Number of bands	> 200	185	> 60
Spectral Res. (nm @ FWHM)	10	10 for VNIR 12.5 for SWIR	5-10
Launch Date	~2013-2016	~ 2013	~ 2016

Table 3. Hyperspectral sensors/missions in the planning stage.

4. CURRENT STATUS

4.1 Data

Most hyperspectral data available from the current airborne and spaceborne sensors have quality issues mainly due to sensor artefacts and erroneous calibration. Issues such as banding, low signalto-noise, spectral smile/frown and keystone are common in hyperspectral data acquired with pushbroom sensors such as Hyperion and CHRIS. These issues need to be addressed in order to maximize the accuracy of information to be extracted from such data (e.g., Khurshid et al., 2006). Other issues are data coverage and availability. With Hyperion/CHRIS, the intention was to provide data to the scientists, but left the broader community without a hyperspectral data source with the exception of airborne remote sensing. The latter has filled some of these gaps in the past, but is expensive. It is hoped that some of these issues can be addressed with the spaceborne sensors, HySI and HJ-1A, launched in 2008. Although these sensors provide a vastly improved coverage, the GSD is an order of magnitude larger than that oft Hyperion/CHRIS (30 m). Another issue is the different data formats used by the various data providers, which can be dealt with by scientific groups, but will be more challenging for the broader remote sensing and end user communities.

4.2 Algorithms/Data Processing

To date, hyperspectral tools for data processing and analysis are on a level of sophistication to allow the extraction of information mainly in a scientific sense. These tools include algorithms for data handling, data preprocessing and information extraction. Especially the latter area has seen a significant advancement over the last decade. With algorithms, such as spectral matching and derivative approaches (e.g., Staenz et al., 1999), wavelet-based procedures (e.g., Rivard et al., 2008), spectral unmixing/endmember selection (e.g., Boardman, 1993), kernel-based classification / detection approaches (e.g., Camp-Valls et al., 2004), and vegetation transfer modelling inversion (e.g., Zarco-Tejada, 2001), it is possible to generate information products in a number of applications. Development of algorithms with focus on combing the spectral and spatial information has begun, which will further improve the exploitation of hyperspectral data (e.g., Plaza et al., 2005). For the same reason, a variety of data preprocessing algorithms, such as for the removal of sensor/data artefacts as described in section 4a and data reduction are available. These algorithms and their implementation into comprehensive image analysis systems, such as ENVI, provide the remote sensing community with easy access to hyperspectral processing and analysis capabilities. The current trend in system development is to automate the whole processing chain and make use of parallel processing and grid-computing capacity, allowing cost-effective and timely data processing.

4.3 Applications

Within the last decade, significant advancements have been made in the development of applications using hyperspectral data. This was mainly possible due to extensive airborne programs such as JPL's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), ESA's CHRIS, and NASA's Hyperion spaceborne initiatives, which made hyperspectral data freely available or at a modest cost. Figure 1 indicates some of the major applications areas where imaging spectroscopy has made inroads up to various degrees. It is clear from the numerous studies carried out that imaging spectroscopy has significantly advanced the use of remote sensing in different applications (e.g., AVIRIS, 2007). Especially the capability to extract quantitative information made imaging spectroscopy a unique remote sensing tool. For example, this technology has been adopted by the mining industry for exploration of natural resources, such as the identification and mapping of abundances of specific minerals. It is also recognized that imaging spectroscopy is a tool, which is required to successfully carry out ecosystem monitoring, especially the mapping of changes due to human interaction and climate variability. This technology plays also an important role in the monitoring of coastal and inland waters. Other capabilities include the forecasting of natural hazards, such as mapping the variability of soil properties, which can be linked to landslide events and monitoring of environmental disturbances, such as due to resource exploitation, forest fires, insect damage and slope instability in combination with heavy rainfall . Imaging spectroscopy can also be used for mapping of snow parameters important for characterizing the snow pack and its effect on the water run-off. Moreover, it showed potential to be utilized for national security, such as in surveillance and target identification, treaty compliance verification (e.g., Kyoto Accord on Greenhouse Gas Emission), and disaster preparedness and monitoring.

Figure 1. Overview of application areas where hyperspectral imaging has contributed significantly.

4.4 Bottlenecks

Since the development of imaging spectroscopy began in the early eighties, many difficulties have been overcome in areas such as in sensor development, data handling, and data processing. However, there are several main issues (bottlenecks) today, which require solutions to move this technology towards operational use. These issues are as follows:

- There is a lack of operational reliable data sources. Quasi error-free data with a high SNR are required to retrieve the desired information.
- Analysis tools are readily available today, but there is a lack of robust automated procedures to process data quickly with a minimum of user intervention.
- A lack of operational products is obvious, since most efforts up to date have been devoted to the scientific development of imaging spectroscopy.
- The cost to derive the information products is too high, since the analysis of hyperspectral data is currently too labour intensive (not automated yet).

5. FUTURE NEEDS

5.1 Mission/Data

An operational AVIRIS-like spaceborne mission is needed providing 20/30-m data. Such a mission must cover an adequate area on the ground with a daily data acquisition capacity of at least

1,000,000 km^2 and has a revisit time of less than 5 days to ensure data are readily available and can fulfil the requirements of the users such as large-scale mapping. With EnMAP and PRISMA currently under development, some of these requirements will be met in the 2012/13 time frame. However, the data quality level of these sensors does not quite match the one of AVIRIS since their SNR is lower. Despite this fact, there will be quite an improvement in performance compared to Hyperion and CHRIS, and the data acquired with these sensors will be of sufficient quality to further advance imaging spectroscopy, especially towards its operational use. The proposed HyspIRI mission with its global focus on the other hand will definitely meet the data quality and coverage requirements but at the cost of a larger GSD (60 m).

There is also a need to go beyond the traditional data products, such as atmospherically and geometrically data sets. It is necessary to move towards higher information products (EOS levels 3 and 4), such as those distributed by the MODIS/MERIS programs. It is also important that the data products are delivered timely with a latency of less than a week and in case of an emergency response within 12 to 24 hours of tasking the satellite. The cost structure of these products needs to be such that the end user can afford them, i.e., having a viable business case using hyperspectral imaging technology in a government/private operation.

Combining hyperspectral data with other remotely sensed data and data from other sources is needed to solve the issues of today and in the future. Data management, including distribution and archiving, becomes important together with data mining to access and receive the various data efficiently and quickly. For this purpose, standardization of data (formats) and derived higher-level data products become more and more important. For example, the accuracy of the same product, generated by two different satellite data distributors, means not much without standardized accuracy assessment protocols (methods).

An open data policy is desirable, meaning that data can be shared within a specific organization. This might not be the most viable business model, especially if industry owns and operates a mission. For the research community it is important to have access to data at a modest cost (free if possible), since it is mainly this community which will further advance the science in imaging spectroscopy. This will ultimately benefit the end users.

5.2 Algorithm Development/Data Processing

Another phase of algorithm development is required to further advance imaging spectroscopy. For example, potential areas are in classification/quantitative parameter retrieval (e.g., spectral unmixing, especially to improve the endmember selection from scenes with only mixed pixels), radiative transfer modelling in vegetation canopy with special emphasis on the improvement of the model inversion, bridging different scaling levels (e.g., leaf to canopy), and real-time target detection. Other attention needs to be directed towards algorithms, which incorporate the spectral and spatial information inherent in the hyperspectral data and procedures for fusion of these data with data from various other sources. An example of the latter is hyperspectral and LiDAR data, a powerful combination, which is currently used to better characterize the surface heterogeneity and canopy structure, but needs more development in the future to fully utilize this capability.

In order to move towards the operational use of hyperspectral data, fast and easy-to-use processing systems are required. Meeting these requirements necessitates first the automation of hyperspectral image processing/analysis tools followed by parallelizing them, allowing the tools to run in a distributed fashion (grid-computing). These steps might involve the development of new algorithms since not all algorithms can be automated or parallelized. Moreover, not only the tools, but entire processing chains need to be automated and implemented into dedicated systems to be effective. An example of such a system would be one which monitors coastal waters. These systems need to be intelligent and have a learning capability built in to improve their capability over time (expert systems). This will help to ease user interaction.

Due to the high data volume produced from hyperspectral missions, on-board data processing will be one of the options to overcome the bottleneck to download all these data. For this purpose, automated procedures, as mentioned in the previous paragraph, are required to successfully create on-board products. For example, raw data can be calibrated on board to generate an at-sensor radiance data product, which can be further converted into surface reflectance using an automatic atmospheric correction procedure. Such a procedure could be implemented today (Zhang et al., 2009). There is also a need to move from these traditional data sets to higher-level products such as land cover, vegetation indices, and target material abundance maps. These higher-level products will also play an important role in emergency events since on-board processing will cut significantly the response time.

5.3 Applications

Despite the inroad imaging spectroscopy has made into the different application areas, the breakthrough in this area has not really occurred yet. Although the most successful application of hyperspectral remote sensing so far is in geology (mineral identification/mapping), the mining industry, which adopted this technology for their exploration purposes, has not provided to date the money to support a hyperspectral spaceborne mission. Based on this fact and the other efforts in applications development so far, it seems that the ‘killer” application has not been found yet. Since the strength of hyperspectral remote sensing is to serve multiple applications (Figure 1), this so-called “killer” application might never be found. This strength of imaging spectroscopy is also its weakness when it comes to the funding of hyperspectral spaceborne missions as, for example, experienced in the Canadian context.

Despite the advances in applications development, it is necessary that the remote sensing community increases its effort in this area. An increased emphasis in this area needs to be especially directed towards contemporary issues, such as those related to the carbon and water cycles and their effects on the environment. Within this context, an improvement of the assimilation of parameters extracted from hyperspectral data into forecast models is required. ESA’s SPECTRA would have made an impact in this area, but was unfortunately not moved into the building phases. Although considerable progress has been made in the understanding of the photon-matter interaction, this mission would have further advanced this area especially related to the surface heterogeneity of vegetation canopies. This is an area which needs increased attention in the future to generate improved/new applications products in forestry and agriculture. It is clear that contemporary issues of today can only be properly addressed using an integrated multidisciplinary approach. Hyperspectral data have the potential to play an important role in this area, but increased efforts are required to fully exploiting these types of data.

In general, the remote sensing community must increase its focus on applications development in all areas, new or currently under development, to establish this technology not only from a scientific perspective, but also within the market place. The former is well underway, but the latter needs a lot of attention in the future and will become critical for the funding of future hyperspectral space missions. Therefore, it is of paramount importance to better inform the stakeholders and potential end users about the capability of this technology and include them in collaborative projects early on. In order to be able to move towards operational/commercial products, large continuous data coverage with a high revisit time as mentioned in section 5.1 are crucial prerequisites.

6. OUTLOOK

After 30 years of hyperspectral development, a 30-year speculative outlook, where imaging spectroscopy might be going in the future, is given in the following sections. This is done in increments of 10 years, leading to tie points in the years 2020, 2030, and 2040 with respect to space missions, data accessibility and data processing.

In general, it is expected that the hyperspectral spaceborne instrument technology will further advance not only to increase performance, but also to shrink the instruments in weight and size so smaller platforms can be used. This will decrease the cost of building entire space missions, making data readily available at a reduce cost and, ultimately, will lower the price for information products.

International cooperation will be the key in further advancing imaging spectroscopy. Especially the area of mission coordination will require the different space agencies world-wide to work together, for example, to maximize area coverage and repetition frequency. Other areas include sharing of platforms, calibration of sensors and also in the scientific development of imaging spectroscopy. Organizations like the Committee on Earth Observation Satellites (CEOS) or the International Spaceborne Imaging Spectroscopy Working Group (ISIS WG) will play an essential role in the future.

2020: The remote sensing community can expect the follow-on missions to EnMAP and PRISMA either in orbit or under construction. These targeting systems will likely have an AVIRIS-like performance with a 20-m GSD and a 60 km swath width covering the VNIR and SWIR wavelength regions in less than 10-nm wide bands. In addition, there will still be a need for global missions with a higher GSD (≥60 m) to replace current missions such as the Chinese HJ-1A and planned HyspIRI. It is also foreseen that the first commercial hyperspectral satellite mission will appear within this time frame. However, this strongly depends on different factors, such as a reduction in space hardware cost and advancement in operational applications development and data processing. Also a thermal hyperspectral system will be launched complementing VNIR/SWIR instruments, as for example, demonstrated in the planned HyspIRI mission. There will be also a trend from the governments to promote progressive partnerships in hyperspectral missions with the goal to eventually hand off the responsibilities to industry and buy the data back from the industry partner(s).

These data will become easier accessible using web-based technologies and the trend will be to continue to sell data on a pixel basis as currently offered by RapidEye. Distributed versus centralized approaches related to data reception, distribution, and processing will continue. On-board processing will be an integrated part of the overall processing chain and will be especially used in cases of emergency response.

2030: The data volume will increase drastically towards 2030 not only due the increased number of hyperspectral satellites available, but also due to the individual mission’s capability to acquire repetitive consistent data over large areas with an increasing number of bands. Telemetry and computational capacities will be able to handle the increased data volume. Also the trend towards a better spatial resolution will continue and leads to AVIRIS-like systems with 5 or 10-m GSD and 50 km swath width. Within this context, there are likely commercial systems available, which include clusters of several satellites to achieve decent area coverage with the objective of targeting specific market segments. The trend to move the responsibility for remote sensing missions more and more from the government to industry over the past two decades will have finally paid off and resulted in fully commercial systems.

Due to the dramatic increase of the data volume, data compression and on-board processing will be much more common than today. For example, data will be processed on-board into sophisticated applications products using comprehensive processing chains. Downloading, distributing, and processing of data will be decentralized further to meet the requirements of the end user to guarantee timeliness of data or information products. Data fusion across time, scale, and space with other remotely sensed imagery and data from other sources will be common for problem solution. Not only hyperspectral data and associated products, but remotely sensed data in general, will be part of entire data warehouses which contain information from various disciplines focusing on specific issues of the day. These warehouses will have links to the data providers and will be interlinked with each other. These databases will become the cornerstone to carry out multidisciplinary approaches for solving contemporary issues. For this purpose, data mining and timely access to information as mentioned earlier will be crucial.

2040: Hyperspectral remote sensing will be commercially fully established in 2040 with several high-performance missions operating in space. These missions, including targeting and synoptic sensors, will cover an entire spectrum of applications delivering information products in near-real time. They are networked together, but also linked to extensive sensor webs on the ground and are a fully integrated portion of larger satellite networks such as the Global Earth Observation Systems of Systems (GEOSS) or the system for Global Monitoring for Environment and Security (GMES). The trend towards more bands will result eventually in the first operational ultraspectral mission, which will take the data volume and, subsequently, processing of these data to new levels.

Data complexity and volume have further increased, which require new approaches to data access and processing. It is envisaged that data will be processed remotely and just the result will be delivered to the end user. For example, a sophisticated user will access the hyperspectral imagery and data from other sources in one or several data warehouses and generates the desired products using image analysis tools available on the web. Accordingly, these data would not be electronically shipped to the end user in this scenario. Other users might flip through a product catalogue and order an information product through one of the product warehouses. Many of these products will be generated through on-board processing, which has reached a stage of sophistication that many information products can be generated near-real time. Products that require integration of both hyperspectral data and data from other sources will be generated on the ground using application-dependent intelligent image analysis systems provided by industry, specialized in these services.

REFERENCES

Anger, C.D., Babey, S.K., and Adamson, R.J., 1990. A new approach to imaging spectroscopy. Proc. SPIE Conference on Imaging Spectrometry of Terrestrial Environment, Orlando, Florida, Vol. 1298, pp. 72-86.

AVIRIS, 2007. AVIRIS Workshop Bibliographies. http://aviris.jpl.nasa.gov/html/aviris.biblios.html (accessed April 20, 2009).

Barnsley, M.J., Settle, J.J., Cutter, M.A., Lobb, D.R., and Teston, F., 2004. The PROBA/CHRIS mission: a low cost smallsat for hyperspectral multiangle observations of the earth surface and atmosphere. IEEE Trans. Geosci. Remote Sens., 42(7), pp. 1512-1519.

Bézy, J-L., Delwart, S., and Rast, M., 2000. MERIS-A new generation of ocean-colour sensor onboard Envisat. *ESA Bulletin*, Vol. 103, pp. 48-56.

Birk, R.J., and McCord, T.B., 1994. Airborne hyperspectral sensor systems. IEEE Aerospace and Electronic Systems Magazine, 9(10), pp. 26-33.

Boardman, J.W., 1993. Automating spectra unmixing of AVIRIS data using convex geometry concepts. Summaries of the 4th Annual JPL Airborne Geoscience Workshop, JPL Publication 93-26, Pasadena, California, Vol. 1, pp. 11-14.

Boardman, J.W., Biehl, L.L., Clark, N.N., Kruse, F.A., Mazer, A.S., Torson, J., and Staenz, K., 2006. Development and implementation of software systems for imaging spectroscopy. Proc. Int. Geosci. Remote Sens. Symp. (IGARSS'06), Denver, Colorado, pp. 1969-1973.

Buckingham, R., and Staenz, K., 2008. Review of current and planned civilian space hyperspectral sensors for EO. Can. J. Remote Sens., 34(Supplement 1), pp. S187-S197.

Camps-Valls, G., Gomez-Chova, L., Calpe-Maravilla, J., Martin-Guerrero, J.D., Soria-Olivas, E., Alonso-Chorda, L., and Moreno, J., 2004. Robust support vector method for hyperspectral data classification and knowledge discovery. IEEE Trans. Geosci. Remote Sens., 42(7), pp. 1530-1542.

Galeazzi, C., Varacalli, G., Longo, F., Lopinto, E., Garramone, L., and Capentiero, R., 2009. Overview of the PRISMA mission. Proc. 6th EARSel SIG Workshop on Imaging Spectroscopy, Tel Aviv, Israel (in this proceedings).

Goetz, A.F.H., 2009. Three decades of hyperspectral remote sensing of the Earth: A personal view. Remote Sens. Environ., doi: 10,1016/j.res.2007.12.014.

Gower, J.F.R., Borstad, G.A., Gray, L.H., and Edel, H.R., 1987. The Fluorescence Line Imager: Imaging spectroscopy over water and land. Proc. 11th Can. Symp. on Remote Sens., Waterloo, Ontario, pp. 689-697.

Green, R.O., Asner, G., Ungar, S., and Knox, R., 2008. NASA mission to measure global plant physiology and functional types. Proc. IEEE Aerospace Conference, Big Sky, Montana, pp. 1-7

Khurshid, S., Staenz, K., Sun, L., Neville, R.A., White, H.P., Bannari, A., Champagne, C.M., and Hitchcock, R., 2006, Preprocessing of EO-1 Hyperion data. *Can. J. Remote Sens.,* 32(3), pp. 84-97.

Neville, R.A., Sun, L., and Staenz, K., 2008. Spectral calibration of imaging spectrometers by atmospheric absorption feature matching. Can. J. Remote Sens., 34(Supplement 1), pp. S29-S42.

Pearlman, J.S., Barry, P.S., Segal, C.C., Shepanski, J., Beiro, D., and Carman, S.L., 2003. Hyperion a space based imaging spectrometer. IEEE Trans. Geosci. Remote Sens., 41(6), pp. 1160-1173.

Rivard, B., Feng, J., Gallie, A., and Sanchez-Azofeifa, A., 2008. Continuous wavelets for the improved use of spectral libraries and hyperspectral data. Remote Sens. Environ., 112, pp. 2850-2862.

Schaepman, M.E., Ustin, S.L., Plaza, A.J., Painter, T.H., Verrelst, J., and Liang, S., 2009. Earth system science related imaging spectroscopy – An assessment. Remote Sens. Environ., doi: 10,1016/j.res.2009.03.001.

Staenz, K., and William, D.J., 1997. Retrieval of surface reflectance from hyperspectral data using a look-up table approach. Can. J. Remote Sens., 23(4), pp. 354-368.

Staenz, K., Schwarz, J., Vachon, F., and Nadeau, C., 1999. Classification of hyperspectral agricultural data with spectral matching techniques. *Proc. Int. Symp. on Spectral Sensing Research*, Las Vegas, Nevada, U.S.A., CD-ROM (8 pages).

Stuffler, T., Kaufmann, H., Hofer, S., Förster, K.-P., Schreier, G., Müller, A., Eckardt, A. ,Bach, H., Penne, B., and Haydn, R., 2007. The EnMAP hyperspectral imager - An advanced optical payload for future applications in Earth observation programmes**.** Acta Astronautica, 61(1-6), pp. 115-120.

Takahashi, D., 2009. The world's first commercial hyperspectral data service from Japanese ALOS-3 satellite. http://www.isiswg.org/documents/Hyper-X%20v%204%204%20090302.pdf (accessed May 11, 2009).

Van Aardt, J.A.N., and Coppin, P.R., 2006. Current state and potential of the IS-HIS Project – Integration of *in situ* data and hyperspectral remote sensing for plant production modeling. *Proc. IUFRO International Precision Forestry Symp.*, Stellenbosch, South Africa, pp. 33-42.

Vane, G., and Goetz, A.F.H., 1988. Terrestrial imaging spectroscopy. Remote Sens. Environ., 21(1), pp. 1-29.

Vane, G., Green, R.O., Chrien, T.G., Enmark, H.T., Hansen, E.G., and Porter, W.M., 1993. The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). Remote Sens. Environ., 44, pp. 127-143.

Ward, S., and Berger, M., 2007. ESA's activities supporting hyperspectral remote sensing. http://www.isiswg.org/meetings/isiswg1/materials/ISIS_WS_Hawaii_2007ppt.pdf (accessed April 20, 2009).

Zarco-Tejada, P. J., Miller, J.R., Noland, T.L., Mohammed, G.H., and Sampson, P.H., 2001. Scaling-up and model inversion methods with narrow-band optical indices for chlorophyll content estimation in closed forest canopies with hyperspectral data. IEEE Trans. Geosci. Remote Sens., 39: 1491−1507.

Zhang, J., Staenz, K., Rochdi, N., Teillet, P.M., Ren, X., Lowe, D., and Eddy, P., 2009. Automatic surface reflectance retrieval from SPOT data using a MODTRAN-based look-up table. Proc. Can. Symp. on Remote Sens., Lethbridge, Alberta (in press).