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SATELLITE HYPERSPECTRAL EARTH OBSERVATION MISSIONS - A REVIEW

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Abstract

During the past 20 years the satellite hyperspectral earth observation missions proved their capability to provide critical information in numerous application areas as of military as of civilian origin. With the advancement of technologies for data acquisition, data storage, computation, and telemetry, it was made possible to decrease the cost of development of such systems and also to make them more readily available not only for scientific applications.

The article presents an overview of the past, present, and planned future hyperspectral remote sensing missions used for earth observation. The review revealed that the interest in developing such systems is growing continuously but is outpaced by the development of their airborne analogues. This is attributed to the fact that spatial and temporal resolution of the space systems is not competitive to the more readily deployed airborne (airplane or drone) hyperspectral systems.

1. Introduction

The ever growing demand for specific information for the remotest and inaccessible places on Earth, has driven the development of the satellite hyperspectral sensors. They come as successors of the multispectral sensors which were in development and operational use since the onset of the civilian space era with the launch of Earth Resources Technology Satellite-1 (ERTS-1, also known as Landsat 1 after renaming the program to *Landsat* in 1975) in 1972 (Landsat 1 History, 2014). Although the hyperspectral remote sensing systems provide markedly different capabilities for image acquisition they also introduce a whole new range of issues to be solved.

At present, there are many definitions of *hyperspectral imaging* or *imaging spectroscopy* (both terms are used interchangeably) but all of them could be narrowed down to the following two definitions.

The *imaging spectrometry* (or imaging spectroscopy) is defined as: ‘the simultaneous acquisition of spatially co-registered images in many spectrally contiguous bands’. *Hyperspectral (spectral) imaging* is defined also as imaging narrow contiguous spectral bands over a continuous spectral range, which produces the spectra of all pixels in the scene. In this sense a sensor with only 20 spectral bands each 10 nm wide can also be a hyperspectral when it covers the spectral range from 500 to 700 nm. The second definition for the hyperspectral imaging states is that a system is a hyperspectral if it acquires 40 or more narrow spectral bands (10÷20 nm) simultaneously (Van Der Meer and De Jong, 2006). However, the second definition with the threshold of 40 bands is only detailing the first one. Furthermore, the number of bands could not be a decisive for a system to be a hyperspectral since they can be few and scattered in farter parts of the spectrum where the absorption features of interest are located. The hyperspectral satellite systems can also be grouped according to the imager type, the acquisition type and other characteristics of the satellite itself into different groups which is not an objective of present study.

The hyperspectral satellite remote sensing systems for Earth observation are used primarily, but not limited to, to the following civilian applications: geology (mineralogy and mining activities), agriculture (crops identification, vegetation status, and stress), forestry (species identification and stress detection), and environmental monitoring (oceanic and land monitoring, coastal monitoring, and vegetation monitoring), security. However, the still developing hyperspectral technologies and the limited capabilities of the hardware and telemetry as well as the high volume of the hyperspectral sensors’ data, prevent their widespread and operational use.

The purpose of present study is not to provide a detailed classification of all the satellite hyperspectral imagers that have been flown in space but a review which later on can be built upon, debated, complemented, objected or even used as a basis for a more detailed investigation on the topic. The study does also aim specifically at Earth remote sensing satellite imagers since there are numerous examples used in studying the planets of the Solar system.

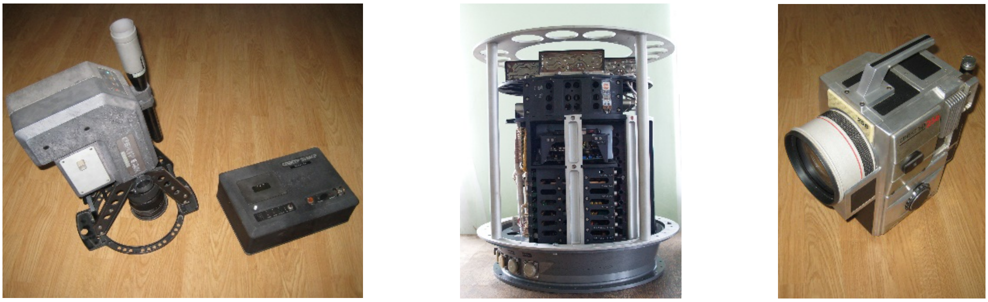
The main objective of the review is to study the developments of hyperspectral satellite missions for Earth remote sensing in the past decades until present and to study the future perspectives.

1.1.Early days

The onset of satellite hyperspectral remote sensing era comparing to the explosive developments of their multispectral counterparts was slow. This may be explained with the fact that the technology for the first was slowly developing. The main reason for that could be chiefly attributed to the huge volume of spectral imaging data being stored onboard and the broadband telemetry which was not available at that time to downlink the data to Earth. Therefore the beginning of the hyperspectral satellite remote sensing era was hampered and started first with testing of non-imaging hyperspectral systems followed by the development of prototypes of airborne hyperspectral imagers. The airborne hyperspectral systems were the necessary step due to the limiting factor of limited data storage and telemetry capacity. About the time of first airborne systems the first software systems, such as *Spectral Analysis Manager (SPAM)* by Jet Propulsion Laboratory (JPL), for handling the big amounts of data were developed based on pioneering algorithms for information extraction.

One of the first non-imaging examples of hyperspectral remote sensing systems is the Bulgarian spectrometric system *SMP-32* launched onboard of Meteor-Priroda "Bulgaria-1300-II" satellite from Plesetsk on 7 August 1981. The instrument has 32 spectral bands (λ=457÷888 nm; 14 nm spectral resolution, 280 m) Ground Sampling Distance (GSD) (Serafimov, 1984; Ivanova, 2011). The gathered data is stored on two tape recorders, each with a capacity of 60 megabit. The main transmitter radiates 10 W in the 130 MHz band. The spectrometric system was developed at Space Research and Technology Institute at the Bulgarian Academy of Sciences (SRTI-BAS) (formerly the Space Research Institute at the BAS) and as its predecessors, i.e. *Spektar-15* which has 15 spectral bands flown on Salut-6 space station, is a non-imaging spectrometer (Serafimov, 1984). The principle of acquisition is of a whisk broom nadir-looking detector but without a scanning mechanism to reconstruct an image. The "INTERCOSMOS 22" satellite, which is carrying the instrument onboard, is still in orbit and is classified by NORAD under an ID 12645, Int'l Code NSSDC/COSPAR: 1981-075A (INTERCOSMOS 22, 2014). During the 80s of 20th century, based on the experience gained from the development of

SMP-32, the *Spektar-256* spectrometer was developed by SRTI-BAS and the Institute of Technical Cybernetics and Robotics at the BAS. The spectrometer was collecting the spectra in two modes: 1) 128 bands and 2) 256 bands, in the spectral range (λ=480÷810 nm). It was actively used onboard of MIR space station for over 12 years (Getsov, 1999). The experiments onboard of MIR were carried out using jointly a topographic photo camera KATE-140 with the *Spektar-256* spectrometer. The camera frames were used to locate the GSD of the spectrometer in order to identify the land-cover type. For that purpose the pointing-mode instrument was affixed so that the GSD was positioned precisely at the center of the frame acquired by the KATE-140 camera. Some of the scientific experiments carried out with the instrument from Bulgarian scientists were: *Stara planina*, *Ocean*, *Contrast and Pollution*, *Colour and Colour Perception* with a principal investigator (PI): Acad. D. Mishev; *Trakia*, *Mizia* with a PI: Prof. H. Spiridonov (Mishev, 1986; Mishev and Dobrev, 1987; Getsov, 1999; Ivanova, 2011).



a) **b)** **c)**

Fig. 1. a) Spektar-15; b) SMP-32, and b) Spektar-256
(Photos courtesy: Prof. DSc G. Mardirossian)

1.2. Hyperspectral imagers

Before the beginning of the satellite era for the hyperspectral imagers there were at least 20 years of development of their aircraft equivalents. In the beginning of 1980s at the Jet Propulsion Laboratory (JPL) (Pasadena, CA) was developed the *Airborne Imaging Spectrometer (AIS)* (128 spectral bands, λ=1.2÷2.4 μm, 10 nm spectral resolution, 8 m SR). Later on, based on its legacy, NASA and JPL developed the *Airborne Visible/InfraRed Imaging Spectrometer (AVIRIS)* imaging spectrometer (224 spectral bands, λ=0.4÷2.45 μm, 10 nm spectral resolution, 11 m SR for an 11 km × 11 km scene). The instrument was tested in 1987 and began operations in 1989 (Baret and Curtis, 1997; Campbell, 1996).

In the beginning of 90s of the 20th century NASA and TRW corporation co-developed a spectrometric system *HyperSpectral Imager (HSI)* for the mission *LEWIS*, which was designed to shoot in 128 bands in the spectral range λ=0.4÷1 µm and another 256 bands in λ=0.9÷2.5 µm, or in total 384 bands, Figure 2a (Van Der Meer and De Jong, 2006). The spectral resolution in both spectral ranges were respectively 5 nm and 6.5 nm, which comparing to the present-day satellite hyperspectral systems is still unravelled. Three days after the launch on 23 August 1997 the control of the satellite was lost and subsequently entered the Earth atmosphere in September 1997 (Lewis (SSTI 1), 2014).

Another imaging spectrometer developed by the U.S. Air Force Research Laboratory at that time was *Fourier Transform Hyperspectral Imager (FTHSI)* of MightySat II (Sindri P99-1) satellite, Figure 2b. The instrument was designed with 256 bands operating in the range λ=0.35÷1.05 µm. The satellite was launched on 19 July 2000 from VAFB, CA and re-entered the Earth atmosphere on 12 November 2002 with 100% mission success for FTHSI (Mightysat, 2014).

a) (image credit: NASA)

b) (image credit: General Dynamics)

Fig. 2. a) An artist rendition of LEWIS in space and b) MightySat-II spacecraft without FTHSI instrument

Another hyperspectral earth observation mission, which also was unsuccessful and developed by U.S. Air Force, was *Naval Earth Map Observer (NEMO)*, Figure 3. Unlike the existing hyperspectral satellite sensors, such as *EO-1/Hyperion* and *CHRIS/PROBA*, *NEMO* has a dual purpose of military and civil emergency. It was designed to carry on-board *Coastal Ocean Imaging Spectroradiometer (COIS)* instrument which was designed to acquire images in the spectral range λ=400÷2 500 nm with a spectral resolution of 10 nm. The designed width of the scene was 30 km, with a pixel size of 60 m × 30 m SR. It featured also an improved Signal-to-Noise ratio (S/N ratio) compared to the previous similar systems such as *High Resolution Imaging Spectrometer (HIRIS)*. *NEMO* was planned for launch in 2000, but the program has been put on hold and subsequently cancelled (NRL to Develop Navy Earth Map Observer (NEMO), 1997; NEMO, 2014).

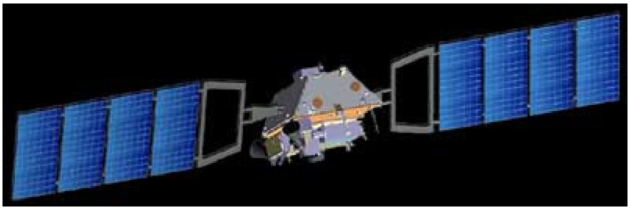
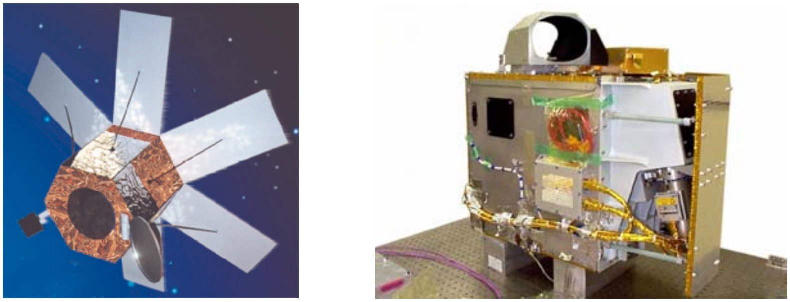


Fig. 3. An artist rendition of NEMO in space

The satellite *OrbView-4*, a.k.a. *Warfighter*, developed by Orbimage, was scheduled to have one panchromatic band with 1 m GSD, a multiband system with 4 m GSD and 200 bands in the spectral range λ=0.4÷2.5 μm, with 8 m GSD but for civil and scientific purposes the data was planned to be provided only as a resampled product with 24 m GSD, Figure 4a. *OrbView-4* had the ability to shoot at different angles - with a tolerance of ±45º from nadir look angle. The *OrbView-4* was lost during a launch failure on September 2001 when the Taurus-2110 carrier rocket suffered a loss of control which was recovered but the orbit was not achieved (Boucher, 2001; OrbView-4, 2013).



a) (image credit: OSC) **b)** (image credit: NASA)

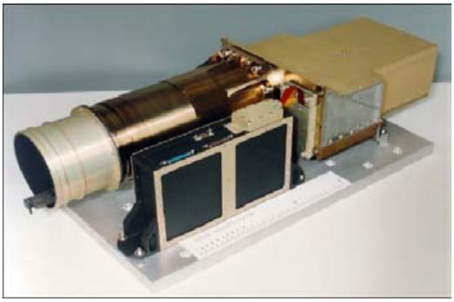
Fig. 4. a) An artist rendition of OrbView-4 in space, b) EO-1/Hyperion hyperspectral imager

Only after the emergence of the new satellite platforms developed under the *New Millennium Program (NMP)* by National Aeronautics and Space Administration (NASA), such as Earth Observer-1 (NMP/EO-1), with the spectrometer *Hyperion* on board, and *PRoject for OnBoard Authonomy (PROBA*), with the hyperspectral instrument *Compact High Resolution Imaging Spectrometer (CHRIS)*, developed by the European Space Agency (ESA), launched in 1999 and 2001 respectively, the satellite imaging spectrometry for civil and scientific applications became possible (Van der Meer, de Jong, 2006).

The NMP/EO-1 mission carries on-board three radiometers: 1) the *Advanced Land Imager (ALI)* – a multispectral pushbroom radiometer with 1 panchromatic and 9 multispectral bands; 2) the *Hyperion* – an imaging specroradiometer, Figure 4b; and 3) the *Linear Etalon Imaging Spectrometer Array (LEISA) - Atmospheric Corrector (LAC)*. The *EO-1/Hyperion* is a grating imaging spectrometer with a 30 m Ground Sampling Distance (GSD) and 7.7 km swath width. It provides 10 nm (sampling interval) contiguous bands of the solar reflected spectrum λ=400÷2 500 nm. The *LAC* is an imaging spectrometer operating in the spectral range λ=900÷1 600 nm, which was suited for the EO-1 Science Validation Team to monitor the atmospheric water absorption lines for correction of atmospheric effects in multispectral imagers during the first year of the mission (Beck, 2003; EO-1, 2013; Earth Observing 1 (EO-1) Sensors, 2014).

The *CHRIS/Proba* imaging spectrometer objective is the collection of Bidirectional Reflectance Distribution Function (BRDF) data for a better understanding of spectral reflectance, Figure 5 (PROBA instruments, 2014). The *PROBA* mission carries onboard also a panchromatic camera HRC, a miniaturized telescope of Cassegrain type with an aperture size of 115 mm and a focal length of 2 296 mm, which can acquire images with an area of 25 km^2 with a 5/8 m GSD. The *CHRIS* was flown onboard of the PROBA-1 satellite, in 2001 (Figure 3). The *CHRIS* instrument provides 18 spectral bands in Mode 2, 3, and 4 and 37 spectral bands in Mode 5 in the VNIR range (λ=415÷1 050 nm) at a GSD of 17 m. CHRIS can be reconfigured to provide 63 spectral bands (the instrument is fully programmable to up to 150 bands) at a GSD of about 34 m in Mode 1 (PROBA-1/CHRIS, 2014). Each nominal image forms a square sized scene (13 km × 13 km) at perigee. Each scan is executed at different view angles (-55°, -36°, 0°, 36°, and 55°), 5 consecutive pushbroom scans by the single-line array detectors, to the target within a 55º cone centred at the target zenith (PROBA Instruments, 2014). The mission is in now in extended mode and offers only to registered users, Category-1 Proposals using Third Party Mission (TPM) data, tasking and archived images from ESA's image archive.

a) (image credit: ESA)

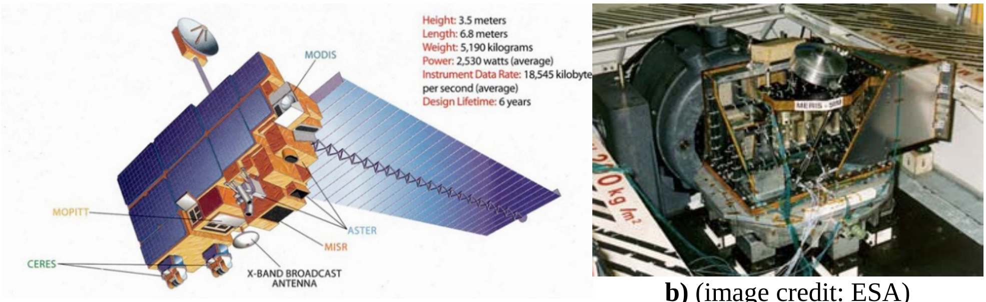


b) (image credit: ESA)

Fig. 5. a) Artist rendition of CHRIS/PROBA multi-angle acquisitions and b) CHRIS/PROBA instrument

In the late 80s and early 90s of 20th century within the *Earth Observing System (EOS)* Programme of NASA were planned two hyperspectral instruments, *High Resolution Imaging Spectrometer (HIRIS)* and *Moderate Resolution Imaging Spectrometer-Nadir (MODIS-N)*. The *High Resolution Imaging Spectrometer (HIRIS)* was designed to capture 192 bands with a spectral resolution of λ=9.4÷11.7 nm (nominal 10 nm) in different areas of the electromagnetic spectrum in the range λ=0.4÷2.5 μm (Dozier, 1988). The swath width was 30 km with 30 m SR and a viewing area of 25 off track and +60/-30 in track (Barrett and Curtis, 1997). If we compare *HIRIS* with the successful *EO-1/Hyperion* mission it can be easily seen that *EO-1/Hyperion* bears some of this instrument characteristics.

Within the EOS program, which provides for developing of several satellites EOS designed for 15 years of work, the *MODIS* instrument was launched on board of EOS-AM1 satellite, Figure 6a. It began operation on February 2000. The *MODIS* covers a swath width of 2 300 km, with almost daily acquisition, running in 36 bands in the spectral range λ=0.4÷14.4 µm. Two bands have a SR of 250 m (VNIR), five bands 500 m SR, and the remaining feature 1 000 m SR (Kramer, 2002).



b) (image credit: ESA)

a) (image credit: NASA)

Fig. 6. a) An artist rendition of EOS-AM 1 (Terra) with the instruments on-board and b) MERIS in the testing facilities of ESA

Another example of a hyperspectral imaging system is the 14-band *Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)*, working on the same satellite as MODIS, Figure 6a. It was developed jointly by a US-Japanese group and is with less revisit capabilities (60 km), but features a better SR. Three bands in the VIS range have a SR of 15 m (spectral resolution of 6-10 nm), 6 bands in the NIR are with 30 m SR and 5 bands in the TIR - with 90 m SR (ASTER, 2014).

The European analogue of MODIS, but primarily oriented towards ocean studies, was *MEdium Resolution Imaging Spectrometer (MERIS)* onboard of ENVISAT, Figure 6b. MERIS provided regular acquisitions until the ENVISAT stopped transmitting data in 2012. The imager consisted of 15 band system, operating in the VIS and the NIR ranges (λ=390÷1040 μm) with 300÷1200 m SR. The 7-band *AATSR* system, also onboard of ENVISAT, acquired with a 1 km SR in the VS, NIR, and TIR spectra, which allowed solving the problem of monitoring the concentration of phytoplankton biomass of vegetation, surface temperature of the water and the land (MERIS, 2014).

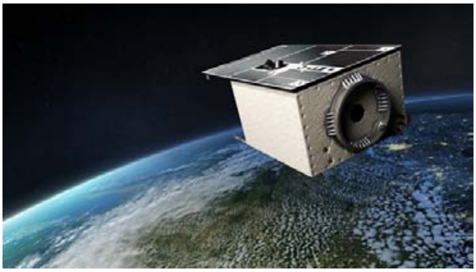
The planned *Australian Resource Information and Environment Satellite (ARIES)* was designed to cover the visible (VIS) and near IR spectral (NIR) range (or VNIR) λ=400÷1 050 nm, spectral sampling 20 nm, and subsequent continuation in Short Wave InfraRed (SWIR-2) spectral range λ=2000÷2 500 nm with a minimum distance of 16 nm between bands, for a total of 105 bands at 30 m SR for a swath of 15 km (Roberts et al. 1997; Merton, Huntington, 1999; Van der Meer, de Jong, 2006; ARIES, 2009). The instrument was also envisaged to acquire scenes between ±30º which give it a multi-angle acquisition capability similarly to the German's

EnMap satellite. Even though the concept of the mission was of a good standing it was cancelled.

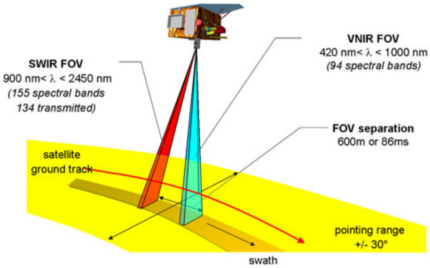
The *Hyperspectral Imager for the Coastal Ocean (HICO)* camera on board of International Space Station (ISS) is part of the *HICO* and RAIDS Experiment (HREP-HICO). This instrument is currently flown onboard of the ISS since 2009, to study the composition of water and land along the coasts. Each scene covers an area of about 48 km × 200 km, which captures features like river outflow plumes or algae blooms, and lets scientists do environmental characterization of coastal regions (HREP-HICO, 2014). Only in 2009 the instrument acquired more than 1700 images with 95m^2 GSD.

1.3. Future missions

Within the *Environmental Mapping and Analysis Program (EnMap),* a mission of DLR, is prepared the *HyperSpectral Imager (HSI)* instrument, Figure 7. Designed to record bio-physical, bio-chemical and geo-chemical variables on a global basis and thus, to increase the understanding of biosphere/geosphere processes and to ensure the sustainability of our resources (EnMap, 2013). It is also a new generation of hyperspectral imager which offers a multi-angle acquisitions in ±30º off nadir, see Table 1 for mission characteristics.



a) (image credit: DLR/Kayser-Threde)



b) (image credit: DLR)

Fig. 7. a) An artist rendition of EnMap is space, and b) EnMap satellite ground track with acquisition modes

The mission of *Hyperspectral Infrared Imager (HyspIRI)* satellite, see Figure 8b, will be to be used to study the world's ecosystems and provide critical information on natural disasters such as volcanoes, wildfires, and drought, i.e. similarly to what the *EO-1/Hyperion* is used for in its Extended Mission. The imaging spectrometer will be acquiring its images in the spectra range from the VIS to SWIR (λ=380÷2 500 nm) in 10 nm narrow contiguous bands along with a multispectral imager acquiring from 3 to 12 µm in the mid and thermal infrared (TIR) (HyspIRI, 2013).


a) (image credit: IOCCG)


b) (image credit: JPL-CalTech)

Fig. 8. Artist renditions of a) ARIES and b) HyspIRI in space

The *Infrared Atmospheric Sounding Interferometer (IASI),* is a Michelson Interferometer, and according its very narrow bands of acquisitions it belongs to the ultraspectral imagers. It measures the spectral distribution of the atmospheric radiation, is a key payload element of the MeTop series of European meteorological polar-orbit satellites. Developed jointly by Centre National D'Études Spatiales (CNES) and EUMETSAT it was flown onboard of the meteorological satellite MeTop-A in 2006 and MeTop-B in 2012 (IASI – the project main steps, 2014). The last one of series is to be launched on MeTop-C in 2015-2016, see Table 1. Its main purpose of the instrument is to temperature, moisture and trace gases across the atmospheric column (Bioucas-Dias et al 2013).

The most recent *PRISMA (PRecursore IperSpettrale of the application mission)* mission, developed by the Italian Space Agency (ASI), is scheduled for launch by the end of 2015, see Table 1.

The Canadian Aerospace Agency (CAA) is also developing its own hyperspectral satellite mission *Hyperspectral Environment and Resource Observer (HERO)*, which is designed to be used on an operational basis, see Table 1 (Jolly et al 2002; Buckingham et al 2002).

The *VENµS (Vegetation and Environment monitoring on a New Micro-Satellite)* mission is jointly developed by CNES and Israeli Space Agency (ISA) and is expected to be launched and operational in 2016. The VENµS scientific objective is the provision of data for scientific studies dealing with the monitoring, analysis, and modelling of land surface functioning under the influences of environmental factors as well as human activities (Vegetation and Environment monitoring on a New Micro-Satellite, 2014).

Last but not least, it is important to note the emergence of some commercial mixed-type multi- and hyperspectral systems such as WorldView-2 and WorldView-3, which bear some of the characteristics of hyperspectral systems, such as narrow bands dedicated to specific application studies, such as ocean colour and vegetation stress (WorldView-2, 2014; WorldView-3, 2014).

2. Future prospects

The review of the development of the past, contemporary, and planned future hyperspectral satellite systems for Earth observation revealed that the interest in developing such systems is growing steadily. However at present the developments of space systems are outpaced by the development of their airborne analogues. This is attributed due to the fact that the spatial scale of the area covered as well as the temporal resolution of the space systems is not competitive to the more readily deployed airborne (airplane or drone) systems. The relatively higher costs, necessary human capital, and facilities to develop and deploy into orbit and to maintain a hyperspectral satellite remote sensing system are still decisive factors for the observed phenomenon. Nevertheless, there are some signs that some leading space agencies, such as CAA and ASI, are taking steps to use the hyperspectral satellite systems on an operational basis.

3. Acknowledgements

The author is deeply appreciated to all that helped him to carry out this study. Special thanks to Prof. DSc G. Mardirossian for providing photos of the *Spektrar-15*, *SMP-32*, and *Spektar-256* spectrometers. All the used photos, figures, and renditions of satellites in space are copyright of the respective owners.

Table 1. A comparative table for the main sensor and satellite characteristics of some past, present, and planned future satellite hyperspectral remote sensing missions for Earth observation (Sources: Kramer, 2002; Ward, 2012 with modifications)

Main characteristics	EO-1/Hyperion (NASA)*	HJ-1/HIS (CAST)*	PROBA/CHRIS (ESA)*	SumbandilaSat ZASat/MSI (S. Africa Sun Space)*	ARTEMIS (US Air Force)**	METOP-SG/IASI** (CNES/EUMETSAT)	EnMap (DLR/OHB Systems)**	PRISMA/HYC (ASI)**	HyspIRI (NASA**	ARIES (CSIRO)**	Venµus** (CNES & Ben Gurion State University)	HERO (CASI)**
Spectral range (λ)	*VIS, NIR & SWIR* 0.4÷2.5 µm	*VIS & NIR* 0.45÷0.95 µm (128 bands)	*VIS & NIR* 0.415÷1.05 µm (5÷12 nm) 1:200 S/N	*VIS, NIR & SWIR* 0.44÷2.35 µm (~10 nm)	*VIS, NIR & SWIR* 0.4÷2.5 µm	3.62÷15.5 (645÷2760 cm^{-1}) (0.5 cm^{-1})	*VIS & NIR* 0.42÷1.03 µm (5÷10 nm) *NIR & SWIR* 0.95÷2.45 µm (10÷20 nm)	*VIS & NIR* 0.4÷0.9 µm (0.4÷1 µm) *NIR & SWIR* 0.9÷2.5 µm (10 nm)	*VIS, NIR & SWIR* 0.38÷2.5, 7.5÷12 µm (4÷12 µm)	*VIS, NIR & SWIR* 0.4÷ 2.5µm	*VIS & NIR* 0.415÷0.91 µm	*VIS, NIR & SWIR* 0.4÷2.5µm (10 nm)
Panchromatic band	-	-	1	-	-	-	-	-	-	1	-	-
VIS bands (380÷700 nm)	35	3	15	440÷510 nm 520÷540 nm 520÷590 nm 620÷680 nm 690÷730 nm	-	-	89 (0.42÷1 µm)	30	-	0.4÷1.0 µm	8	-
NIR bands (750÷1400 nm)	35	2	4	840÷890 nm	-	-	89 (0.42÷1 µm)	30	-	1.0÷2.0 µm	4	-
SWIR bands (1.4÷3 µm)	172	1	0	-	-	-	155 (0.9÷2.5 µm)	160	-	2.0÷2.5 µm	-	-
MIR bands (3÷8 µm)	0	1	0	-	-	-	0	0	-	-	-	-
LWIR bands (8÷15 µm)	0	1	0	-	-	-	0	0	-	-	-	-
Spatial resolution (m)	30	30; 150 (300) / 100	18/37/63 (150)	15	5	V: 1÷2 km H: 25 km	30	30	60	10 (pan) 30 (hyper)	5.3 (nadir)	30
Swath (km)	7.5	360, 720 / 50	14	-	-	-	30	30	-	15 (at nadir)	27.5	30
Altitude (km)	705	649	556	504	-	817	653	614/720	626	500	410 (technology)/ 720 (scientific)	~700
Radiometric resolution	cont. 16 bit	discrete	discrete 12 bit	discrete	discrete	discrete	discrete	discrete	discrete	discrete	discrete	discrete
No of bands	220[1] (242)	136	19÷63	200	400	8461 (16921)	228 (248)	220 (238)	217	105	12	>200
No of satellites	1	2	1	1	1	2(3)	1	1	1	-	1	1
Temporal resolution (days)	200	31	2 (mid latitudes)	-	-	29	27 (VZA≤5°) 4 (VZA≤30°)	29	5/19	7	2 (±30° view mode)	3
Launch date	21/11/2000	5/09/2008	22/10/2001	17/09/2009	-	2020-2021	-	end of 2015	-	-	2016	-
Lifetime (years)	1[2]	≥3	2	≥3	-	5 (METOP) 8.5 (METOP-SG)	-	5	-	-	3.5	5
Orbit Inclination	98.21°	97.95°	97.9°	98°	-	98.704°	97.96°	98.19°	-	-	98.27°	-

[1] Calibrated bands
[1] An Extended Mission
*ongoing mission
**planned mission

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РАЗВИТИЕ НА СПЪТНИКОВИТЕ СПЕКТРОМЕТРИЧНИ ДИСТАНЦИОННИ ИЗСЛЕДВАНИЯ – ОБЗОР

Л. Филчев

Резюме

В настоящата статия е направен обзор на миналите, настоящи и някои планирани бъдещи спектрометрични спътникови системи за дистанционно наблюдение на Земята. През последните 20 години системите за спектрометричните спътникови системи за наблюдение на Земята се установиха, като надежден източник на информация в множество приложни области, както с военно, така и гражданско предназначение. С напредването на технологиите за събиране, пренос и съхраняване на данни, стана възможно да се намалят разходите за развитие на спектрометричните спътникови системи, а също и да станат по-достъпни извън техните строго научни приложения. Направена е сравнителна характеристика на съществуващите спектрометричните спътникови системи и са дискутирани тенденциите в развитието им.