CURRENT STATUS AND FUTURE TENDENCY OF SENSORS IN EARTH OBSERVING SATELLITES

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ABSTRACT

The number of sensors for Earth environmental observation is growing. Several new sensors have been announced for the near future and several proposals for smart sensors have been proposed. In particular, distributed sensors, sensor network and sensor integration are being taken into account, and smart sensors, intelligent sensors, sensor's autonomy, etc. is beginning to be used in future earth observing satellites. This paper investigates the development of sensors in Earth observing (EO) satellites, analyzes the current high-resolution EO satellites and presents the tendency of new imaging systems in future Earth observing satellite. The purpose of this paper is to contribute to the growing interest in knowing and keeping track of the details of the imaging system of earth observing satellites. This project is of particular interest to those who are developing the skills to measure and understand the detail of our Earth environment through analysis of satellite data.

1. INTRODUCTION

Since the first Landsat Multi-spectral Scanner System (MSS) was launched in 1972, after 10 years, four additional MSS systems, as well as the Landsat TM in 1982 and 1984 with 30 m spatial resolution and 7 spectral bands, and the SPOT HRV in 1986, 1990 and 1993 with 20m spatial resolution in 3 spectral bands, and 10m resolution in a PAN band were in orbit. In particular, by the middle of 1990s, the high-performance sensors developed by industries were able to produce imagery with resolutions as high as 1 m in PAN mode and 3 to 4 m in MS mode. The hyperspectral Imager were able to produce over 200 images of the same area with a spectral resolution of 10 nm wide over the solar reflective portion of the spectrum from 400 to 2500 nm. SAR sensors like ERS-1/2 operated by ESA, Radarsat 1 (using C-band) operated by CCRS and JERS-1 (using the L-band), operated by NASDA, have been used in space. These advanced sensors have largely improved the quality of information that can be gathered about the earth's surface and near environment, which have resulted in many new applications, e.g., wireless Personal Communications System (Fritz, 1999).

This paper investigates the development of imaging systems, and presents the tendency of new imaging systems in future Earth observing satellite. The purpose is to contribute to the growing interest in knowing and keeping track of the details of imaging system of earth observing satellites. This project is of particular interest to those who are developing the skills to measure and understand the detail of our Earth environment through analysis of the satellite data. Because of a large number of satellites, we only deal with Earth observation satellites with within 15 m GSD (ground sample distance) in PAN band, and 30 m GSD in Radar because these satellites have the ability to define human scale objects, which prove most useful for us to understand the details and scope of the interactions between man and his habitat. Other satellites will be beyond the scope of this paper.

2. HISTORY OF IMAGING SYSTEM DEVELOPMENT

The beginning of the space age (early 1960's thru 1970's)

CORONA, ARGON and LANYARD were the first three operational imaging satellite reconnaissance systems (McDonald, 1995), appeared at the beginning of the space age. They acquired data during the period of 1960 thru 1972, mostly black and white, but some in color and stereo. The three satellite imaging systems are basically similar to aerial photogrammetric photography (Zhou et al., 2002). The specification of the three operational satellites is list at http://leonardo.jpl.nasa.gov/msl/programs/corona.html. As we can see from this list, the best spatial resolution of the imagery is 6 feet (KH-6); the lowest resolution is about 460 feet (KH-5). The first photographs from space were taken on 18 August 1960 by the KH-1 system and the last of the imagery of this collection was acquired on 31 May 1972 by the KH-4B system.

Initial application (1972 thru 1986)

The Landsat 1, lunched on August 7, 1972, symbolized the modern era of earth remote sensing, making it possible for the earth science community to begin to use satellites for earth resource investigation (Lillesand et al., 2000). The satellite image data was directly delivered in digital form for the first time. Much of the foundation of multi spectral data processing was developed in the 1970s by organizations such as the NASA/JPL, USGS, ERIM, and LARS at Purdue University.

Wide application (1986 thru 1997)

The EO satellite family experienced significant development in technologies and applications during this period. The SPOT-1, launched on 22 February 1986, carrying two High Resolution Visible sensors, was another benchmark because it was the first to use a linear array sensor with push-broom imaging geometry. With its 10 m panchromatic band it was the first satellite capable of stereoscopic imagery in cross-track. The ERS-1 SAR, launched July 17, 1991 by the ESA, is an active microwave sensor satellite with 30 m spatial resolution in imaging mode. The Japanese JERS-1, launched in February 1992, added more width to the SAR application by adding an L-band to the configuration. These active microwave sensor satellites primarily provide data useful for improving the understanding of environmental and climatic phenomena and supporting a variety of operational applications, such as sea-ice charting and coastal zone studies.

High-resolution and hyperspectral age (1997 to "2010")

EarlyBird (Earth Watch Inc.), launched in 1997, providing 3 m GSD in panchromatic band, opened the new era of high-resolution satellites (Zhou, 2001a). High-resolution imaging systems here indicate their capability of identifying and measuring changes at the human scale of houses, roads and civil engineering projects at PAN band with ≤ 15 m (equal to the current Landsat-7). The products are dominantly used for mapping and GIS products at scales currently provided by the airborne sensors (Stoney, 1996).

3. INVESTIGATIONS AND ANALYSES OF CURRENT IMAGING SYSTEMS

With the analysis above, a significant stride in the technology of EO satellites happens every about 12 years (see Fig. 1). The current generation of satellites is just in the period of the fourth generation, i.e., the high-resolution age. The satellites group naturally falls into the two sensor types, optical and radar, which provide a wide variety of image features. The major features of interest are ground resolution, spectral coverage, revisit, stereo mode, etc.

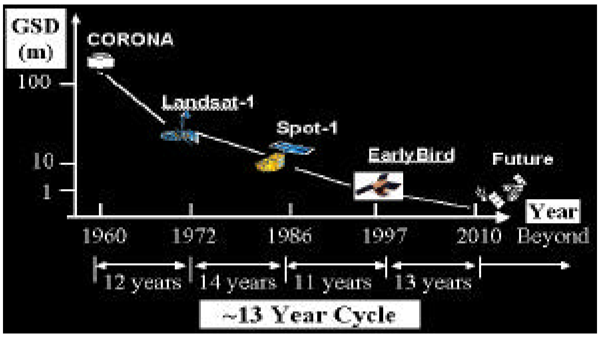

Fig. 1. Development of EO satellite development

3.1 Investigation and Analyses of Current Imaging System

High-resolution imaging system: The family of high-resolution satellites can be classified into four groups: (a) wide swaths, intermediate resolution, and broad spectral coverage, which is following closely in the footsteps of the Landsat system's broad coverage; (b) narrow swaths, very high resolution; (c) Hyperspectral sensors with 8~30 m GSD; and (d) Radar with 3 to 30 m GSD. As we can see from Zhou (2001a), the moderate resolutions imaging system of 5 to 15 m has a swaths of 60 to 185 km, while the high resolution imaging system of 0.6 to 5 m has 3 to 16.5 km swaths. However, SPIN-2's pan sensor with 2 m GSD has 40 km swaths. The GSD of multispectral images range from 4 to 20 m. Multispectral bands from all the satellites are, except for the EOS AM-1 and ASTER, very close to those used by Landsat. This is of course because the Landsat bands were placed in nearly all the wavelength windows free of severe atmospheric absorption. The Landsat-like satellites emphasize multispectral coverage, all of them having at least the lower SWIR band and three including both the upper SWIR and TIR bands. ASTER will provide even greater spectral definition in the upper SWIR and TIR regions.

Hyperspectral sensing systems: Six typical hyperspectral imaging systems are listed in Table 1. The Orbview-4, launched on Sepeartber 2001, with a failure, is a commercial system driven by the requirements of the US Air Force. NASA's Earth Observing-l (EO-1) is a highly experimental system designed to prove a number of new technologies, especially two advanced hyperspectral sensors, one using a wedge filter and the second a grating spectrometer. The Naval EarthMap Observer (NEMO) will carry the Coastal Ocean Imaging Spectrometer (COIS). It was designed to demonstrate the use of hyperspectral data for characterisation of littoral battlespace environments and littoral model development as well as support of environmental and resource monitoring functions. ARIES is designed mainly for mineral exploration, resource mapping, and environmental monitoring. The wavelength of all satellites ranges from 0.4 to 2.5 μm. The spectral resolution is 10 μm with 200 bands, except ARIES-1 with 105 bands. All of these spacecrafts carry a higher resolution PAN sensor with 5~10 GSD that can be registered with the hyperspectral data. Because of the very high data rates required by the hyperspectral sensors, the resolution of these systems has been restricted to thirty meters, with the exception of Orbview-4, which is designed as 8 m. There is also a sense that thirty meters may well be more than sufficient to characterize the majority of natural targets.

Revisit: The satellites revisit each location on Earth in less than three days with an ability to turn from side-to-side up from a polar orbital path. The frequency of global repeat coverage is directly correlated with satellite resolution. For example, the MODIS & AVHRR like kilometer-level resolution, 1~2 day global repeat; Landsat-like with 10 to 30 m GSD, 2~3 week global repeat; and high resolution of 1 to 3 m, 4~12 month.

Inclination: All but one of the satellites revolve around the Earth in a sun synchronous polar orbit. The one exception is SPIN-2, which is in a 65 degree inclination orbit.

Stereo mapping capability: Almost all of imaging systems are capable of acquiring off-nadir data, in the cross-track or/and along-track lookings using linear imaging mode. This ability enables the collection of high-resolution stereo data that permits the efficient creation of accurate digital elevation models. The ability to simultaneously collect high resolution panchromatic data and multi-/hyperspectral data can create a data set containing structural information. Linear image sensors can be arranged to form a long linear array to cover the complete FOV of the objective lens of a telescope.

Sensor navigation: All satellites carry GPS receivers to maintain the precise position of sensor/orbit. Almost all satellites simultaneously carry attitude sensor, e.g., digital star trackers, gyro, and IRU to maintain attitude of sensor.

Resources of funding: Private sectors are more interested in sponsoring high resolution imaging systems because of commercially valuable products of the GIS global market.

Countries: The distribution of owners of high-resolution and hyperspectral satellites from 1997-2008 will migrate from developed countries to developing countries, from Europ and North America to Asia and South America. Another increasing trend is international (or country-by-country) cooperation such as USA/ISRAEL's EROS program, China/Brazil's CBERS program.

3.2 The Radar Imaging System

The three radar satellites providing a variety of resolution and swath combinations are listed in table 2. They have modes that provide full polarimetry, i.e. all possible polarisations are available, therefore, are capable of producing full polarisation response types of functions. The LightSAR presents an effective dual frequency system by placing that spacecraft in the same orbit as Radarsat-2 in such a way that they both illuminate the surface simultaneously or within a few minutes of each other. Radarsat-2 and LightSAR also have high resolution modes of operation, which permit the acquisition of data with 3-meter spatial resolution. All radar satellites can supply images with resolutions from 3 to 1000 m for swaths from 20 to 500 km and thus can cover a wide range of applications. All radar satellites are sun-synchronous orbit.

4. TENDENCY OF IMAGING SYSTEM

4.1 Constellation of Earth Observing Satellites

Since each individual satellite covers a small proportion of the Earth's surface, a rapid response using high-resolution satellites can only be achieved with several satellites operating simultaneously. In addition, to meet the many as yet unsatisfied needs of local decision makers for local environmental information, a low-cost and sustainable constellation of EO (small, mini and micro) satellites is thus required. The scheduled constellations of EO satellites in next few years have:

EROS constellation: ImageSat International features a constellation of at least one EROS A (EROS A1 launched on December 5, 2000, with 1.8-m GSD) and five EROS B. These satellites are planned to be placed in orbit in the next few years. For the current EROS-A1, the revisit is 1.8 days, while the maximum gap is 4 days. When a constellation of six EROS satellites is in space, imaging will be possible to allow a revisit at least twice a day for any specific site within the coverage area. Such a constellation, providing global coverage, plus the special feature of half-daily revisit of sites, ensure that decision makers make rapid changes to their local environments.

EO-1 and Landsat Formation Flying: The Earth Observing One (EO-1) Satellite, launched on November 21, 2000, is designed for a formation flying with Landsat-7. The EO-1 orbit is slightly to the east of Landsat-7, with an equatorial crossing time one minute later than that of Landsat-7. This results in EO-1 passing over the same ground-track as Landsat-7, one minute later. In a broader sense, EO-1 is not merely formation flying with Landsat-7, but joins a constellation of earth observing satellites, including SAC-C and TERRA, all examining electromagnetic radiation along the same ground track with different swath widths and with a range of spatial and spectral resolution.

RADARSAT constellation: The RADARSAT-3 satellite is planned to be operated in tandem with RADARSAT-2 (Canada's next generation earth observation satellite, co-funded by the Canadian Space Agency (CSA) and MacDonald Dettwiler) as an interferometric mission to collect very high precision detailed data about the global terrain and elevation characteristics of the Earth's surface.

COCONUDS constellation: The COCONUDS (Co-ordinated Constellation of User Defined Satellites) constellation is performed in the framework of a European Union project by an international consortium (Geosys, NRI, SSSL, and NLR). This constellation consists of 9 satellites, which observe the Earth from a LEO orbit with a resolution of 30 meters, four spectral bands, and a swath width of 350 km. Thus, the constellation ensures a daily global coverage to meet the demands of local decision-makers for high temporal resolution.

RapidEye Constellation: The RapidEye Inc., Germany is building a 7-year lifetime RapidEye constellation of four advanced Earth observation mininsatellites. The constellation, scheduled in orbit in 2003, will provide 6.5-metres resolution wide-swath multispectral imaging with a daily revisit. Each of the satellites carries a CCD-based imaging system. The camera's imaging swath of approximate 150 km combined with an off-track angle of ±22° ensures daily global accessibility. The satellites will be equally spaced in the same sun synchronous orbit. Each satellite also has the capability of performing an off-track rotation and can be redirected any time through the telemetry, tracking and command unit. A data handling and storage unit is situated onboard each satellite as well as a high-speed X-band communication system capable of downloading the acquired images.

Disaster Monitoring Constellation (DMC): Surrey Satellite Technology Ltd. (SSTL), UK is building a Disaster Monitoring Constellation (DMC). The constellation consists of five micro-satellites to provide daily imaging worldwide for the monitoring and mitigation of natural and man-made disasters as well as dynamic Earth observation. Every satellite will carry a CCD-based earth imaging system, which captures images in 6 spectral bands (including visible, near infra-red and panchromatic). Each system also consists of two cameras allowing the generation of images of up to 150 km x 1000 km at a resolution of 6.5 meters. The satellite platform of this constellation is fully three-axis stabilized using star sensors, reaction wheels and magnetic torquers. Orbital determination and control is provided via GPS receivers and a nitrogen cold-gas system. Algeria and the United Kingdom have committed to the acquisition of the first two DMC satellites, with launches planned for 2002 or 2003.

Other EO Satellite Constellation: ***COSMO-SkyMed*** (COnstellation of Small satellite in the Mediterranean basin Observation), currently funded by the Italian Space Agency (ASI), is performed by Alenia Aerospazio. This constellation, consisting of 7 small satellites, is for risks management, coastal zone monitoring and sea pollution application. ***WATS*** (Water vapor in Atmospheric Troposphere and Stratosphere) constellation consists of 12 small satellites for monitoring variations of global atmospheric water vapor distribution. The distribution of constellation consists of two arrays, with six satellites each at two different altitudes of 650 km and 850 km. Each satellite of an array is in a different plane with the same inclination. ***COSMIC constellation:*** NASA and Taiwan are building a satellite constellation, called *ROCSAT-3/*COSMIC. The constellation, scheduled in orbit in early 2005, consists of six microsatellites to collect atmospheric data for weather prediction and for ionosphere, climate, and gravity.

4.2 Sensor autonomous navigation and control

The navigation tendency for imaging systems will be autonomous via on-board performance using positioning sensors and attitude sensors, such as high-accuracy autonomous double-head star tracker, GPS receiver, reaction wheels, three-axis magnetometer, magneto-torquers, and gyroscopes. The main attitude determination sensor is an autonomous star tracker that provides the full-sky coverage and achieves the high-pointing accuracy required in Earth observation and in astronomy. The sensor can autonomously reconstruct the spacecraft's inertial attitude starting from a 'lost in space' attitude. This is done with a typical performance of a few arcseconds to an arcminute, depending on the sensor's characteristics and the measurement conditions. Orbital position determination via GPS receivers can reach centimeter level of accuracy. Landsat 7 and Resource21 systems have sun and moon based calibration capabilities for autonomous navigation. EO-1 instruments use the sun and moon to maintain consistent calibration. In the solar calibration, each of the three instruments views the sun through some sort of diffusing mechanism. The lunar calibration, which allows the detector system to view the lunar surface through the same optical path as when viewing the earth, can be used to measure overall detector system stability and thus will serve the role of solar diffuser monitor.

4.3 On-board image processing via advanced sensors

Another tendency in EO satellites is strong capabilities for on-board image processing, especially change detection capability via advanced sensors. Currently, several advanced satellite systems, e.g., NEMO (Naval Earth Map Observer) developed by the US Navy, PROBA (PRoject for On-Board Autonomy) developed by the European Space Agency (ESA) and BIRD (Bispectral Infrared Detection) developed by the German Space Agency (DLR), successfully launched on 22 October 2001, have the capabilities of on-board image processing. The NEMO satellite will provide automated, on-board processing, analysis, and feature extraction using the Naval Research Laboratory's (NRL's) Optical Real-Time Adaptive Signature Identification System (ORASIS). The real-time feature extraction and classification will reach greater than 10x data reduction. Proba is an ESA mission conceived for the purpose of demonstrating new on board technologies and the opportunities and benefits of on-board autonomy, which will perform a number of mission operations functions with minimum ground involvement (Teston, et al., 1997). The basic functions of the on-board data processing can be reviewed at (http://telecom.esa.int/artes/artes2/fileincludes/multimedia/multi.cfm). BIRD is a small satellite mission dedicated to hot spot detection and evaluation using an infrared detector (http://www.uni-freiburg.de/fireglobe/iffn/tech/ tech 9. htm). Main on-board data processing capabilities are (1) a thematic on-board neural network classificator for disaster warning and monitoring; and (2) radiometric and geometric on-board correction of sensor signals (Halle et al., 2000; Gill et al., 2001). Some analysis and investigation for low-level of data processing capabilities, high-level data processing capabilities, and higher-level on-board processing can be found in Zhou (2001a).

5. FUTURE IMAGING SYSTEM BEYOND 2010

As demonstrated in the 12 years cycle of EO satellite development, it is estimated that the current generation of earth observing satellites will be replaced by another generation by 2010. What is new generation of EO satellites? We think that the next generation of satellites will be intelligent. The intelligent system envisioned will be a space-based configuration for the dynamic and comprehensive on-board integration of earth observing sensors, data processors and communication systems. It will enable simultaneous, global measurement and timely analysis of the Earth's environment for real-time, mobile, professional and common users (Zhou, 2001a). This presents new challenges for the next generation of technology development. These challenges are described in Zhou (2001a; 2001b). Here we focus on the imaging system.

5.1 Earth Observing Satellite Network

It is apparent that no single satellite can provide all of the measurement features needed by all of the user community. In addition, the past design of Earth observing satellite systems focused on placing numerous scientific instruments on relatively large and expensive space platforms (Prescott et al., 1999). This requires that the instruments, the spacecraft, and the space transport system have multiple redundant components that are built with expensive failure-proof parts because of the risk of launch or in-orbit failure (Schetter et al., 2000; Campbell et al, 1999; and Zetocha, 2000). The future EO satellite system will overcome these drawbacks by using an Earth Observing Network imagined as integrating a constellation of EO satellites into a cohesive network of measurement instruments. It is similar to the Internet in that scientists and other users will be able to access any on-orbit sensors and be able to direct and control those sensors in the same manner as we access information on the Internet today (Schoeberl et al., 2001).

We simulated a two-layer EO satellite network (see Fig. 2, Zhou, 2001a). The first layer, which consists of hundreds of EO satellites viewing the entire earth, is distributed in low orbits ranging from 300 km to beyond. Each EO satellite is small, lightweight, and inexpensive relative to current satellites. These satellites are divided into groups called *satellite groups*. Each EO satellite is equipped with a different sensor for collection of different data and an on-board data processor that enables it to act autonomously, reacting to significant measurement events on and above the Earth. They collaboratively work together to conduct the range of functions currently performed by a few large satellites today. There is a lead satellite in each group, called *group-lead*; the other satellites are called *member-satellites*. The group-lead is responsible for management of the member-satellites and communication with other group-leaders in the network (constellation) in addition to communication with the geostationary satellites. This mode of operation is similar to an *intranet*. The group-lead looks like a local server, and the member-satellites look like the computer terminals. The local server (group-lead) is responsible for internet (external) communication in addition to management of the intranet (local) network. This design can reduce the communication load and ensure effectiveness of management and coverage of data collection. The second layer is composed of geostationary satellites because not all EO satellites are in view of or in communication with worldwide users. The second layer satellite network is responsible for communication with end-users (e.g., data downlink) and ground control stations, and ground data processing centers, in addition to further processing of data from group-lead satellites. All of the satellites are networked together into an organic measurement system with high speed optical and radio frequency links. User requests are routed to specific instruments maximizing the transfer of data to archive facilities on the ground and on the satellite (Prescott et al., 1999). Thus, all group-leads must establish and maintain a high-speed data cross-link with one another in addition to uplink with one or more geostationary satellites, which in turn maintain high-speed data cross-links and down-links with end users and ground control stations and processing centers.

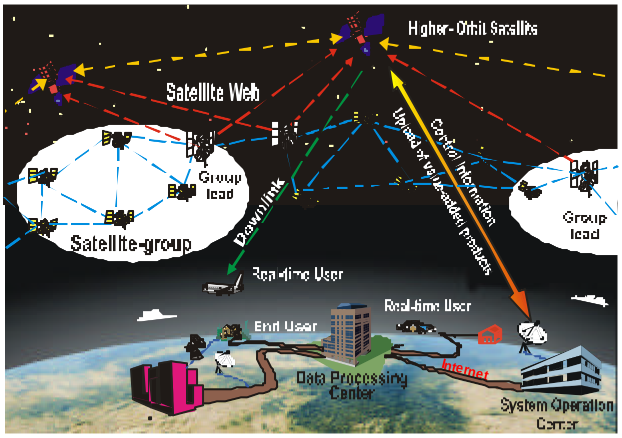

Figure 2. The architecture of a future EO satellite system

5.2 Event-driven observation

The normal operating procedure is for each programmed sensor to independently collect a different datum, such as temperature, humidity or air pressure, land use, etc., even like an electronic nose (Enose) for sniffing out different types of gases, analyze and interpret data using its own sensors and on-board processors. These collected data will *not* be transmitted to ground users, the ground station, or geostationary satellites unless they detect changed data. When an EO satellite detects an event, e.g., a forest fire, the sensing-satellite rotates its sensing system into position and alters its coverage area via adjusting its system parameters in order to bring the event into focus (Schoeberl et al., 2001). Meanwhile, the sensing-satellite informs member-satellites in its group, and the member-satellites adjust their sensors to acquire the event, resulting in a multi-angle, -sensor, -resolution and -spectral observation and analysis of the event. These data sets are merged to a geostationary satellite that assigns priority levels according to the changes detected. Following a progressive data compression, the data is then available for transmission to other geostationaries. The links between the geostationary satellites provide the worldwide real-time capability of the system. Meanwhile, the geostationary further processes the data to develop other products, e.g., predictions of fire extend after 5 days, weather influence on a fire, pollution caused by a fire, etc. These value-added products are then also transmitted to users.

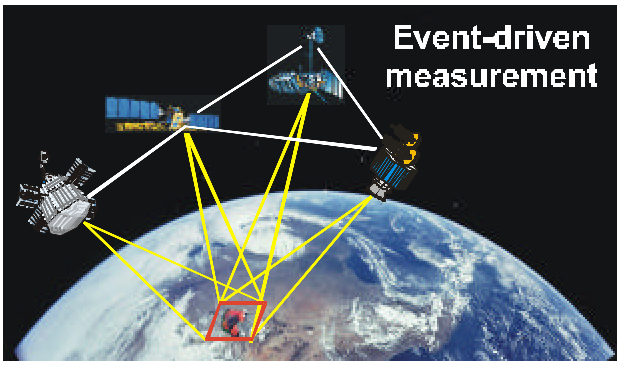

Fig. 3. Event-driven observation

5.3 Advanced sensors and their application in EO

A space-borne remote sensor, using electromagnetic radiation technology to sense physical variables such as temperature, atmospheric gases and water vapor, wind, waves and current, or land use, etc. provides an alternative solution to environmental research. This technology is already quite mature, but data interpretation remains more of a problem than sensor performance. Also, limitations in spectral, spatial, and temporal resolution are likely to remain a problem. Therefore, conventional sensors using electromagnetic radiation technology are no longer adequate for monitoring our environment (e.g., using hyperspectral satellite imagery for toxic chemicals and pollution analysis). The necessity for real-time monitoring these environments by advanced sensor has highly been required in future EON. Currently funded advanced sensors have the following:

Biological Sensors: Biosensors use biological techniques for environmental science investigation in earth observation. The biosensors are typically used in automated, continuous, and in situ monitoring of toxic chemicals and pollutants both in waters and in soils.

Chemical Sensors: Chemical-sensors use chemical techniques for environmental science, atmospheric science, and aquatic science. The chemical sensor can be used in (1) analyzing atmospheric particles, such as their size and chemistry; (2) understanding the transport, dispersion and deposition of heavy metals, the formation of cloud condensation nuclei, and the fate of volatile organic compounds after gas-particle reactions; (3) understanding distributions and fluxes of trace gases and organic vapors for pollution studies.

Neural network Sensors: Neural network sensors use neural network technology to deploy large arrays of small sensors. An advanced neural network technique to increase the level of detail captured in Landsat satellite images has been developed by ONR researchers. Using neural net algorithms can improve resolution on Landsat satellite images and solve the problem pixel by pixel in real time, independent of the image size. Thus, neural network sensors essentially increase the resolution of satellite images.

ATR Sensor: The ONR, since the 1980s, has researched an automatic target recognition (ATR) sensor. The sensor combines different passive and active sensors for autonomous detection of spot targets. Such sensors are capable of the "unsupervised learning" exhibited by the human brain and can dig out the nuggets of information even if they're buried in garbage. Remote sensing will be the first real-world application of ATR sensor because it will provide autonomous classification of our environment.

6. CONCLUSION

Because of the exponentially growing number of announced and proposed sensors for use in space, we cannot list all sensors, but we did discuss the major, influence specifications of satellites. On the other hand, not all proposed systems will survive; some of them will fail and many of them are or will be delayed. Furthermore, the information of some satellites cannot be collected. However, we can see from the analysis above that the spaceborne imaging system by 2010 will significantly increase in four categories:

- High spatial resolution imagers: having spatial resolutions of less than one meter.

- Hyperspectral imagers: having of the order of over two hundred spectral bands with spectral resolutions of the order of 10 nanometers.
- Imaging radar polarimeters: having spatial resolution of 1~5 m with complete polarization state of backscattered energy.
- Multi-imaging system integration via satellite constellation: having capability of daily global coverage, high resolution, hyperspectrial and integrating active and passive sensing system.

In recent years, many advanced sensors, such as smart sensors, neural network sensors, human brain sensors, computerized sensors, etc. have been emerging. Especially, NASA is developing a space-based "sensor web" - an internet-like connectivity for future earth observing satellites. Therefore, the concept of the sensors will have to be extended into those sensors whose response to a biological, chemical or physical stimulus is a signal, which at this point is usually electrical. Beyond 2010, the new generation of earth observing satellites will probably use these advanced sensors for our Earth environment observation. To this end, the key is the real-time information system that are required to solve the grand challenges associated with on-board processing, intelligent sensor control, high data rate transmission, network control, intelligent platform control, and information production, distribution and storage.

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Table 1. Currently funded hyperspectral satellite systems

SPACECRAFT	NEMO	EO-1	ORBVIEW-4	ARIES-1			SIMSA	PRISM	
Owner	NRL	NASA	Orbimage	ARIES Consortium			ESA	ESA/French	
Sensor	COIS	Hyperion	Warfighter	Spectrometer			HIS		
GSD (m)	30/60	30	8	30			25	50	
Wavelength Range	0.4 - 2.5	.48 – 2.4	0.4 – 2.5	.4 – 1.1	2.-2.5	1.-2.	.43 – 2.4	.15-.2	.45-.2.35
No. of bands	210	220	200	32	32	32	220	8	158
Spectral Res (nm)	10	10	10	22	16	31	10	12	12
Swath width	30 km	7.5 km	8 km	15					
Altitude	605	705	470	500					
Inclination	87.8^0	98	97.3^0	polar					
Pan Sensor GSD	5 m	10	1	10 (Pan, 0.4-0.7)			10 (Pan, 0.4-0.7)		
Anticipated launch	2002	11/21/00	9/21/01(Failed)	2002			Rejected	2002	

Table 2. Radar imaging system

	RADARSAT-2			**ENVISAT ASAR**				**LIGHTSAR**					
Orbit	Sun-synchronous			Sun-synchronous				Sun-synchronous					
Altitude (km)	798			780-820				600					
Inclination (°)	98.6			98.6				97.8					
Operational Mode	UF	Standard	Wide	Image	WS	GM	AP	HR	SM	QP	DP	RP	SS
Spatial Res. (m)	3	28	100	30	150	1000	30	3	6-10	50	25	25	100
Swath Width	20	100	500	100	405	405	100	20	22	50	50	100	250
Frequency Band	C-band (5.4GHz)			C-band				L-Band (1.26GHz)					
Polarizations	HH, HV,VH,VV			HH, HV,VH,VV				HH, HV,VH,VV					
Operational Mode	12 types			4				6					
Looks	1~4			4				3~10					
Swath (km)	10~50			65~405				20~250					
Coverage (km), [angle (°)], {steps}	125~1000, [10~60], {1~10}			400~750, [14~45], {5~7}				200~500, [20~52], {2~8}					
Repeat cycle (days)	24			35				10					
Launch	2003			2/28/2002				2002					

(UF=ultra-fine WS=wide swath, GM=global monitor, AP=altering polarization, HR=High resolution, SM=strip map, Q.=Quad, D=Dual RP=Repeat Pass, ScanSAR=SS)