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OPTICAL AND THERMAL SPACE-BORNE SENSORS - A REVIEW

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Abstract: *This paper discusses issues related to optical and thermal sensors with which the most common remote sensing satellites are equipped. Satellite sensors are core elements of the satellite system that take images in different wavelengths on Earth, natural resources, environmental monitoring and natural phenomena etc. In this direction are analyzed optical and thermal sensors, their main characteristics, bands in which they record and the type of images taken by them.*

Key words: *optical sensors, thermal sensors, satellite images.*

1. A Brief Introduction to Remote Sensing Sensors

For Earth observation, satellites are used to make several records with different frequency on surfaces of different sizes. Each satellite has on board one or more sensors that acquire records in different wavelengths, being sensitive to certain parts of the electromagnetic spectrum.

In taking remote sensing records are used two detection techniques, namely passive and active detection, depending on which the sensors (Figure 1).

Passive detection is the mean by which sensors measure the level of the energy that is naturally emitted, reflected or transmitted by details of the land. Passive sensors are designed to detect natural energy produced by sun, reflected or absorbed in the visible range and then emitted in the case of records in the thermal infrared. As such, these sensors can operate only when the natural energy is available, this limiting the ability of sensors to record at night. Also, limited are the small latitudes since in these areas the amount of solar radiation is often insufficient for sensors working in the visible. In addition, clouds, dust, smoke and other particles in the atmosphere prevent reflected energy to be recorded by the sensor.

These problems can be solved by remote sensing system design, so one way is to use a sensor capable of detecting radiation in many parts of the electromagnetic spectrum. For example, the combination bands in thermal infrared visible, meteorological satellites can take images on the type of clouds in both daytime and the night. A combination of visible and infrared bands can be used for bringing mathematical correction to image in terms of atmospheric interference caused by the interaction energy and its absorption of particles in the atmosphere before meeting the sensor [10], [11].

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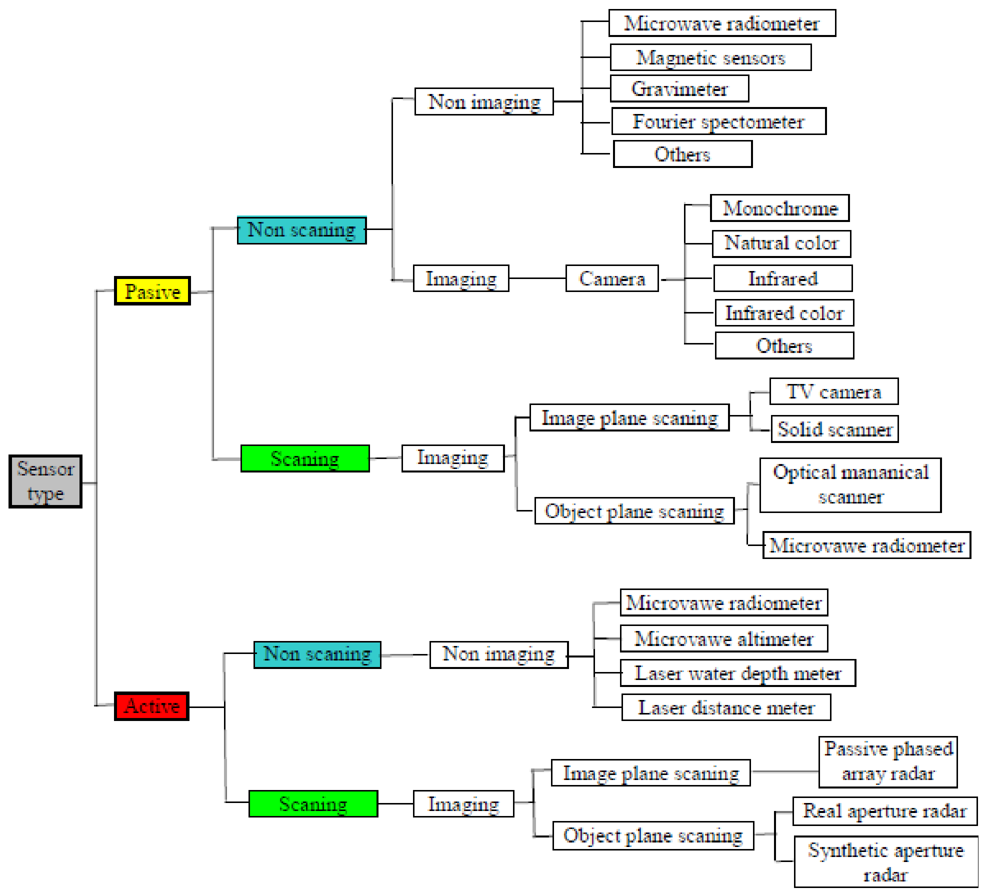

Fig. 1. *Different types of sensors*

In passive sensing are used passive sensors that measure the amount of radiation emitted by the Sun and reflected by the details from the Earth's surface.

Here we have the optical, thermal and hyperspectral sensors. In turn these include sensors that take records by scanning the land and sensors without scanning [10], [11] (Table 1) [15].

Active detection is the data acquisition method used in remote sensing using radiation emitted by detail. Fall within its active sensors that record directly the energy emitted by the detail and it measures the way it interacts with the energy. Active sensors have the ability to make measurements at any time of day, night or season. Active systems require a large amount of energy for adequate lighting of detail. In this category are RADAR (RAdio Detecting And Ranging) and LIDAR sensors (LIght Detecting And Ranging) which are becoming more used in taking records of remote sensing [13].

2. Optical Sensors

Optical sensors can records in the visible, near infrared and short wave infrared bands (0.30 mm - 15.0 mm), the radiation source being the Sun. Depending on the number of spectral bands that are

Major region of the electromagnetic spectrum Table 1

Region Name	**Wavelength**	**Comments**
Gamma Ray	<0.03 nanometers	Entirely absorbed by the Earth's atmosphere and not available for remote sensing.
X-ray	0.03 - 30 nanometers	Entirely absorbed by the Earth's atmosphere and not available for remote sensing.
Ultraviolet	0.03 - 0.4 micrometers	Wavelengths from 0.03 to 0.3 micrometers absorbed by ozone in the Earth's atmosphere.
Photographic Ultraviolet	0.3 - 0.4 micrometers	Available for remote sensing the Earth. Can be imaged with photographic film.
Visible	0.4 - 0.7 micrometers	Available for remote sensing the Earth. Can be imaged with photographic film.
Infrared	0.7 - 100 micrometers	Available for remote sensing the Earth. Near Infrared 0.7 to 0.9 micrometers. Can be imaged with photographic film.
Thermal Infrared	3.0 - 14 micrometers	Available for remote sensing the Earth. This wavelength cannot be captured with photographic film. Instead, mechanical sensors are used to image this wavelength band.
Microwave or Radar	0.1 - 100 centimeters	Longer wavelengths of this band can pass through clouds, fog, and rain. Images using this band can be made with sensors that actively emit microwaves.
Radio	>100 centimeters	Not normally used for remote sensing the Earth.

used, the optical systems can be:

- pancromatics, that are using a single band for recording radiation. In this case the electromagnetic spectrum is visible and the images that are taken are in black and white (SPOT HRV-Pan, Ikonos Pan);
- multispectrals, which are registered in several bands and record electromagnetic radiation in narrow wavelength (Landsat MSS, Landsat TM, SPOT HRV-XS, Ikonos MS);
- superspectrals, using more than 10 bands to obtain records with a small width and which permit the recording of fine spectral characteristics of details (MODIS and MERIS);
- hyperspectrals are the most advanced optical sensors that take records on more then one hundred spectrals bands. They allow recording the objects in details being used in geology, mineralogy, agriculture, forestry etc. (Hyperion).

The most parameters used to describe the characteristics of satellite images taken from optical satellite sensors are spatial, radiometric and temporal resolution (Table 2) [2-4], [6], [7], [9], [12-14], [16], [17].

3. Thermal Sensors

Thermal sensors are part of passive sensors that record out in the thermal zone. In contrast to the visible region of the electromagnetic spectrum, the infrared is dominated by thermal emission. This allows sensors to operate in good condition in the same way both night and daytime. Hyperspectral thermal infrared sensors are able to detect details, to classify land and materials etc. using different thermal detectors. They can make such records by examining differences in emissivity of the details in the same way that the visible hyperspectral sensors examine differences in solar reflectance (Table 3) [8].

Thermal sensors use one or more reference temperatures to compare the detected radiation, so they can be tied to absolute radiant temperature. Data are generally recorded in digital form and temperature sensors resolution can reach 0.1°.

Images obtained from the use of thermal sensors are called thermogrammes and they restore the image of relative radiant temperatures that is displayed in grey scale

Principal characteristics of common optical sensors Table 2

Platform	**Sensor name**	**Launch**	**Wavelengh**	**Spatial resol.**	**Radiometr. resolution**	**Revising time**		**Swath Width**	**Operator**	**Country**
						a nadir	off nadir			
Landsat 5	Landsat TM	1984	7 bands - RGB, NIR, Thermal SWIR	30 m, 120 m (B6)	8 bit	16 days	-	180 km	USGS	USA
IRS 1C	IRS LIS-SIII	1995	GB, NIR, Mid IR	23 m, 70 m (MIR)	8 bit	-	-	140 km	ISRO	India
IRS 1C	IRS LIS-SIII	1995	Pan	5.8 m, 23 m, 140 m	6 bit?	24 days	5 days	70 km	ISRO	India
IRS 1D	IRS LIS-SIII	1997	GB, NIR, Mid IR	23 m, 70 m (MIR)	8 bit	-	-	140 km	ISRO	India
IRS 1D	IRS Pan	1997	Pan	5.8 m, 23 m, 140 m	6 bit	-	-	70 km	ISRO	India
-	Spot 4	1998	Pan	10 m	8 bit	-	-	60-80 km	Spot Image	France
NOAA 15	AVHRR3	1998	6 bands, RGB, NIR, IR	1100 m	10 bit	1 day		2600 km	NOAA	USA
Terra Aqua	MODIS	1999	36 bands, RGB, NIR, SWIR, MWIR, LWIR	250 m, 500 m, 1000 m	12 bit	16 days	1-2 days	2330 km	NASA/ USGS	USA
Terra	ASTER	1999	RGB, NIR (VNIR), SWIR, TIR	15 m, 30 m, 90 m	8, 12 bit	16 days	1-2 days	60 km	JPL/ METI	USA/ Japan
Landsat 7	Landsat ETM+	1999	8 bands – Pan, RGB, NIR, Thermal IR	15 m (B8), 30 m	8 bit	-	16 days	180 km	USGS	USA
-	IKONOS-2	1999	Pan, RGB, NIR	1 m, 4 m	11 bit	-	<3 days	11 km	Space Imaging	USA
EO-1	Hyperion	2000	220 bands	30 m	16 bit	16 days	-	7,7 km	NASA/ USGS	USA
EO-1	Advanced land Imager (ALI)	2000	10 bands, Pan, RGB to SWIR	10 m (B1), 30 m	16 bit	16 days	-	30 km	NASA/ USGS	USA
-	EROS A1	2000	Pan	1.8 m	16 bit	-	2 days	-	Image-SAT int	Nether-land
-	Quickbird	2001	Pan, RGB, NIR	0.6 m, 3 m	11 bit	-	3-7 days	16.5 km	Digital Globe	USA
PROBA	CHRIS Compact High Resolution Imaging Specto-meter	2001	63 bands, Hyper-spectral	36 m (63 bands) 18 m	12 bit	-	7 days	14 km	SSTL/ESA (managed by)	EU

Table 2 (*continuous*)

PROBA	HRC (High Resolution Camera)	2001	N/A	N/A	N/A		7 days	-	SSTL/ ESA	EU
Meteosat Second Generation (MSG)	SERIVI (Spinning Enhanced Visible and InfraRed Imager)	2002	12 bands, RGB IR Thermal IR (8 bands)	1 km, 3 km	N/K	15 min	-	Europe Africa Atlantic Ocean	EU-METSAT	EU
-	SPOT-5	2002	Pan, RGB, NIR	2.5 m, 5 m	8 bit	-	2-3 days	120 km	Spot image	France
DMC (part of DMC)	AISAT-1	2002	7 bands - RGB, NIR, Thermal SWIR	32 m	8 bit	-	-	600 km	CNTS (Algeria)	Algeria
DMC (part of DMC)	BILSAT-1	2003	Pan, multi 4 bands, hyperspectr. 9 bands	12 m, 26 m	8 bit	-	-	-	TUBITAK research council	Turkey
DMC (part of DMC)	NIGERIA-Sat-1	2003	7 bands – RGB, NIR, Thermal SWIR	32 m	8 bit	-	-	600 km	Federal Ministry of Science and Technol.	Nigeria
BNSCSat-1	DMC-1	2003	-	32 m	8 bit	-	-	600 km	Survey Satellite Technology Ltd. (SSTL)	UK
-	ORBVIEW-3	2003	Pan, RGB, NIR	1 m, 4 m	11 bit	-	<3 days	8 km	GeoEye	USA
-	FORMOSA T–2	2004	Pan, RGB, NIR	2 m, 8 m	12 bit	1 day	1 day	24 km	NSPO	Taiwan
Cartosat-1	IRS P5	2005	Pan	2.5 m	6 bit	-	5 days	30 km	ISRO	India
TOPSAT	RALCam 1	2005	Pan, RGB	2.8 m, 5.6 m	8 bit?	-	4 days	15 km (pan) 10 km (RGB)	QinetQ/ SSTL/ RAL/ InfoTerra	UK
DMC (part of DMC)	BEIJING-1	2005	Multi, Pan	32 m, 4 m	8 bit	-	-	-	Beijing Landview Mapping Information Tecl	China
ALOS	AVNIR	2006	RGB, NIR	10 m	8 bit	46 days	2 days	70 km	Earth Observ. Research and Application Center/ JAXA	Japan
ALOS	PRISM	2006	Pan	2.5 m	8 bit	46 days	2 days	70 km	Earth Observ. Research and Application Center	Japan
-	EROS B	2006	Pan	0.7 m (Pan)	16 bit	-	N/K	7 km	Image-SAT int	Nether-land
-	Worldview 1	2007	Pan, RGB, NIR	0.5 m, 2.6 m	11 bit	-	1.7 days	17.6 km	Digital Globe	USA

Table 2 (*continuous*)

-	Cartosat-2A	Late 2007	Pan (2 sensors)	<1 m	6 bit	-	4 days	10 km	ISRO	India
-	DMC-2	2008	RGB	22 m	8 bit	-	-	600 km	SSTL	UK
-	Demios-1	2008	RGB	22 m	8 bit	-	-	600 km	Demios SL	Spain
-	(Q2) Geoeye-1	2008	Pan, Multi	0.41 m, 1.65 m	11 bit?	-	8 days at 0.42 GSD	15.2 km	Geoeye	USA
-	Worldview-2	Late 2008	8 bands, Pan, Multi	0.46 m-0.52 m	11 bit	-	-	16.4 km	Digital Globe	USA
-	Pleiades 1 and 2	2009	Multi, Pan, stereo	0.7 m, 2.8 m	-	-	-	20 km	CNES	France
-	En-MAP	2010	Hyper-spectral, 420-2450 nm, 20+ bands	30 m	N/K	5 days	-	30 km	DLR	Germ.
Sentinel 2	GMES	2011	Multi (RGB, NIR, SWIR)	10 m	N/K	N/K	-	280 km	European Space Agency	EU

TIR spaceborne hyperspectral instruments Table 3

Instrument	**Mission**	**Launch**	**Termal detector**	**Spectral resolution [μm]**	**No of bands**	**Spatial resolution**	**Δλ [nm]**	**Swath [km]**	**Cooling**	**Operator**
TES	Mars	Nov 1996	MTC	6-50	143	3 km	2	65	Active	NASA
THEMIS	Mars	Apr 2001	InSb	0.425-0.860 6.5-15.5	5 9	19 m 100 m	1000	32	Passive	NASA
MODIS	EOS-PM1	2002	MTC	0.620-0.876 0.459-2.155 0.405-0.965 3.660-7.475 8.400-14.385	2 5 12 9 8	250 m 500 m 1000 m	10-500	2330	Passive	USA
GLI	ADEOS-2	Dec 2002	MCT	0.380-2.2 3.7-12	29 7	250 m 1 km	10-1000	1600	Active	NASDA Japan
MiniTES	Mars	June 2003	InSb	5-29	50	20 mrad	480	N/A	Passive	NASA
VITRIS-H	ROSETTA	2003	MTC	2.0-5.0	N/A	1 mrad	1-2.5	N/A	Active	ESA
VITRIS-MIR	ROSETTA	Mar 2004	MTC	0.95-5.0	N/A	1 mrad	70-360	N/A	Active	ESA
VIIRS	NPOESS	2006& 2009	MTC	0.412-0.865 1.240-4.050 8.550-12.010	11 8 4	750 m	40	3	Passive	NASA/ IPO
Warfighter 1	Warfighter	Lunch felt	MTC	0.45-0.905 0.83-1.74 1.58-2.49 3.0-5.0	40 80 80 80	8 m 8 m 8 m 8 m	11.4-25	5	Active & Passive	US-mil

levels [5]. Thus, high temperatures are represented in open tones and dark temperatures in low tones. Regarding the absolute temperature, it can be measured but requires an accurate calibration, determination of the reference temperature and detailed knowledge of thermal properties of detail, geometric distortions and radiometric effects.

Thermal sensors are using detectors which are sensitive to direct contact of photons with their surface for detecting the thermal radiation which is emitted. The sensors are cold, with temperatures close to absolute zero, to limit their own thermal emission. Thermal sensors measure, essentially, the surface temperature and thermal properties of the details.

Because the wavelength of thermal radiation relatively high compared with the visible radiation, atmospheric scattering is minimal. However, due to absorption of gases in the atmosphere it restricts the thermal sensitivity in two specific areas i.e. 3 to 5 μm and 8 to 14 μm. As energy decreases with increasing wavelength, thermal sensors generally have an instantaneous field of view (IFOV) high to ensure enough power to the detector in order to achieve reliable measurements. However, the spatial resolution of thermal sensors is generally lower, relative to the visible spatial resolution [1]. Thermal sensors can acquire images during the day or night because the radiation is emitted and not reflected, being used for a variety of applications such as military recognitions, disaster management (forest fire mapping) and heat loss monitoring.

4. Conclusions

Satellite sensors are increasingly used to download data on the Earth and of phenomena in progress. Given the growth of the need for information, it was intended to achieve an ideal system for remote sensing satellite that includes the following components:

- the use of a uniform source of energy for all wavelengths at a high, known and constant level;
- the lack of interference with the atmosphere, which means an atmosphere that does not change the energy received from the source, whether it comes from the Sun or Earth;
- a unique series of energy/matter interactions in the Earth's surface. These interactions will generate reflected or emitted signals that are not selected according to wavelength, but are known, invariant and unique for each type of feature and under feature on the land's surface;
- the use of a super sensor that requires a high sensitivity at all wavelengths, acquisition of detailed spatial data regarding glow or radiant scene (depending on wavelength). This super sensor should be simple, should not require high power, to be economical and safe in operation;
- the use of an operating system with real-time satellite data. Thus the spectral response of the details recorded will be processed into a interpretable format which will be recognized as unique. This processing will be done in real time, providing immediately the recorded data. Derived data can be used in the various sectors;
- multiple data users that will need to acquire both expertise, specific to their work, and knowledge regarding the acquisition and processing techniques of remote sensing images.

Regarding the choice of sensor it should be considered the nature of the application depending on which the radiometric, space and time resolutions and cost records are established.

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