Remote Sensing Systems - An Overview Focussing on Environmental Applications

Uwe Weidner[1]

Abstract

During the last decade, a number of new Earth observation systems were developed and put into operation. Some of these systems provide data with higher resolution than ever before. In this context, the term "higher resolution" is not only limited to the geometric resolution in terms of ground sampling distance (GSD), but also includes temporal und spectral resolution. These technical improvements allow for new applications of remote sensing techniques. In this contribution an overview of remote sensing systems is given focussing on those, whose data may be used for environmental applications. Acknowledging that this is a vague restriction due to the definition of the term "environmental applications", this overview does not claim to be complete, but nevertheless extensive and representative. It comprises classical multispectral space- and airborne sensors, high resolution satellite sensors, hyperspectral sensors, and active sensors for local and global applications.

1. Introduction

Remote sensing plays an important role for data provision for geoinformation systems (GIS). Both are closely related. Therefore, new developments in remote sensing concerning sensors and methods have direct impact on the domain of possible applications of both – remote sensing and GIS. During the last decade, a number of new Earth observation systems were developed offering data of higher resolution with respect to geometry and spectral information content. On one side, satellite systems like QuickBird are in orbit, which provide data with a ground sampling distance (GSD) of better than 1 m for the panchromatic channel and 4 m for multispectral channels. Such a geometric resolution like that of the panchromatic channel could formerly only be obtained by airborne systems, like photogrammetric cameras. On the other side, airborne hyperspectral systems are available which deliver almost continuous spectral information and thus allow to derive more detailed information about objects on the Earth's surface. Furthermore, the available digital photogrammetric cameras also offer more spectral information compared to film-based ones, because they register multispectral information in the visible and near-infrared (NIR) at a time. Therefore, high resolution optical satellite data and data from digital photogrammetric cameras show an almost seamless transition.

In this contribution an overview of remote sensing systems is given focussing on those imaging systems, whose data may be used for environmental applications. Due to the number of available systems, this overview does not claim to be complete, but nevertheless extensive and representative. It does not only cover new systems, but also well established multispectral systems, because data of these systems are available from the beginning of the 1970´s until present and thus allow for change monitoring over a longer period using (almost) the same type of data. Therefore, the focus is on optical sensors starting with multispectral sensors, namely those with more than just four channels, and discussing some hyperspectral

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[1] Institut für Photogrammetrie und Fernerkundung, Universität Karlsruhe (TH), Englerstraße7, 76131 Karlsruhe

sensors as well as high resolution satellite systems. The overview finally concludes with some remarks on active systems like RADAR and LIDAR.

2. Passive Remote Sensing Systems

Passive systems use the reflected and emitted radiance of the Earth's surface, normally ranging from the visible to the thermal infrared. The systems are often categorised by the number of recorded bands or by their geometric resolution as given in the following tables (cf. Ehlers et al. 2002):

	panchromatic	multispectral	hyperspectral	ultra spectral
number of bands	1	2 – 20	20 – 250	> 250
bandwidth	broad	broad	narrow	narrow

Table 1: Sensor categorization by spectral resolution

ultra high	very high	high	medium	low	very low
< 1 m	1 – 4 m	4 – 10 m	10 – 50 m	50 – 250 m	> 250 m

Table 2: Sensor categorization by spatial resolution

For the following presentation of systems this categorisation is used, but – although the high resolution satellite sensors belong to the group of multispectral sensors – a special section is dedicated to this group, thus using the categorisation given in Tab. 2.

2.1 Multispectral Systems

Prototyping and testing of system configurations are often done by using airplanes as sensor platforms. Thus, it is not surprising that a number of similarities of sensor characteristics between airborne and spaceborne sensors can be found. One example is given by the DAEDALUS and LANDSAT sensors. The spectral bands of these multispectral sensors are compiled in Tab. 3. Both sensor systems cover the visible, near- (NIR), shortwave (SWIR) and thermal infrared (THIR) and therefore their data can be used for a large number of applications including land cover/use and vegetation monitoring as well as applications dealing with the topic of heat islands in urban areas. The advantage of a spaceborne system is the global availability of data on a regular basis dependent on the orbit parameters and of course weather conditions. Airborne systems show a greater flexibility and allow for the capturing of data of higher geometric resolution – both for the price of higher costs.

Besides the DAEDALUS systems, there are other airborne systems like e.g. the ATLAS system (Advanced Thermal and Land Applications Sensor) with 15 channels from visible to THIR, the CAMS (Calibrated Airborne Multispectral Scanner) with 9 channels ranging also from visible to THIR, and the TIMS (Thermal Infrared Multispectral Scanner) with 6 channels in THIR only, all flown by NASA Stennis Space Center.

The LANDSAT family of systems (landsat.gsfc.nasa.gov) provides data since the early 1970's until today. The last satellite was launched in 1999 carrying the ETM+ providing 30 GSD of the multispectral channels from visible to SWIR, 60 m for THIR and 15 m for the panchromatic channel. Despite the sensor problems, the system still delivers data, but due to the failure of the scan line corrector, there are gaps in the data. In order to fill these gaps, data from earlier overflights may be used. Of course, this filling and fusing of data from different acquisition times has an impact on the suitability of the data for applications depending on time synchronous data capture for a scene. Although the geometric resolution of the LANDSAT sensors is only medium, the data archive offers valuable data for long-term analyses of environmental changes. A continuation of the program is announced and the launch of the carrier is scheduled for late 2009.

One drawback of the LANDSAT system compared to the French SPOT system (www.spotimage.com), whose first satellite was launched in 1986 providing multispectral data in four channels (cf. Tab. 3 for SPOT4), is the fact that it does not provide stereoscopic capability. A combination of the characteristics of LANDSAT and the stereoscopic capability of SPOT provides the ASTER system (asterweb.jpl.nasa.gov): 14 channels from visible green to THIR with resolutions of 15 m (VNIR), 30 m (SWIR) and 90 m (THIR) including sensors (band 3) in nadir/backward configuration and thereby allowing stereoscopic use for derivation of DEMs.

Besides the mentioned systems, a number of other systems are available including also small satellite configurations with several similar systems in orbit. An overview is given in Jacobsen (2005).

	Airborne systems	Spaceborne systems		
	DAEDALUS	LANDSAT (ETM+)	ASTER	SPOT4
pan		520 – 900 nm		510 – 730 nm
blue	420 – 450 nm			
	450 – 520 nm	450 – 520 nm		
green	520 – 600 nm	520 – 600 nm	520 – 600 nm	500 – 590 nm
	605 – 625 nm			
red	630 – 690 nm	630 – 690 nm	630 – 690 nm	610 – 690 nm
NIR	695 – 750 nm			
	760 – 900 nm	760 – 900 nm	760 – 860 nm	
	910 – 1050 nm			
SWIR	1550 – 1750 nm	1550 – 1750 nm	1600 – 1700 nm	1580 – 1750 nm
			2145 – 2185 nm	
	2080 – 2350 nm	2080 – 2350 nm	2235 – 2285 nm	
			2295 – 2365 nm	
			2360 – 2430 nm	
THIR			8125 – 8475 nm	
			8475 – 8825 nm	
			8925 – 9275 nm	
	8500 – 13000 nm	10400 – 12400 nm	10250 – 10950 nm	
			10950 – 11650 nm	
GSD pan	depending on velocity and flying height above ground	15 m		10 m
GSD VNIR		30 m	15 m	20 m
GSD SWIR		30 m	30 m	20 m
GSD THIR		60 m	90 m	
stereo	–	–	+	+

Table 3: Examples of multispectral systems

2.2 Hyperspectral Systems

The principal idea of hyperspectral remote sensing is to gather data with high spectral resolution using a large number of non-overlapping bands with small width and thereby sampling the spectrum almost continuously. The development of hyperspectral sensors started about 25 years ago. The data was first used for geologic exploration. During recent years, the application field enlarged and the data is now used for other applications like material identification in urban areas as well. Such a task requires data of high spectral and geometric resolution in order to deal with the complexity and variability in such environments. The first hyperspectral sensors were airborne and the availability of data improved during the last years. Besides airplanes satellites are also used as platform. Although the geometric resolution of these satellite sensors may also reach up to 20 m like e.g. the airborne AVIRIS sensor flown on an ER-2, the SNR ratio reduces and limits the distinction and separability of classes (Kruse et al. 2003). Nevertheless, satellite hyperspectral sensors with low geometric resolution provide significant information, e.g. for monitoring oceans and their pollution and allow to distinguish more spectral classes than multispectral sensors. Tab. 4 indicates some hyperspectral system examples, including airborne and spaceborne systems.

System	Spectral range [nm]	Number of bands	Bandwidths [nm]	Year
Airborne Systems				
AVIRIS	380 – 2500	224	10.0	1987
CASI	400 – 1000	288	2.2	1989
HyMap	400 – 2500	128	10.0 … 20.0	1997
DAIS 7915	498 – 1010	32	16.0	1994
	1500 – 1800	8	100.0	
	1970 – 2450	32	15.0	
	3000 – 5000	1	2000.0	
	8700 – 12300	6	600.0	
MIVIS	400 – 800	20	20.0	1994
	1100 – 1500	8	50.0	
	1900 – 2500	64	9.0	
	8200 – 12700	10	35.0 … 45.0	
HYDICE	400 – 2500	210	10.0	1995
Spaceborne Systems				
MOS	400 – 1000	17	2.0 … 5.0	1996
MODIS	400 – 14400	36	15.0 … 300.0	1999
Hyperion	400 – 2500	220	10.0	2000
CHRIS	415 – 1050	63	2.0 … 12.0	2001
MERIS	400 – 1035	15	4.0 … 20.0	2002

Table 4: Examples of hyperspectral systems

The AVIRIS (Airborne Visible / InfraRed Spectrometer) is operated by the Jet Propulsion Laboratory and NASA. The predecessors AIS1 and AIS2 (Airborne Imaging Spectrometer) were operated from the early 1980´s. Since 1987 the AVIRIS sensor is flown on an ER-2 collecting data in 224 bands with a width of approx. 10 nm. In this configuration with a velocity of 730 km/h over ground and a flying height of about 20,000 m, the data sets provide a ground sampling distance of about 20 m and a swath width of approx. 11 km. The AVIRIS is a whisk-broom-scanner. Each scene covers 512 lines with 614 pixels. Further information is provided on www.jpl.nasa.gov, also including information about the AVIRIS workshop held every year focussing on developments and applications of its data.

The Compact Airborne Spectrographic Imager (CASI) was developed by ITRES, Calgary in Canada (www.itres.com). The system is a push-broom-scanner and captures data in up to 288 bands with a nominal bandwidth of 2.2 nm. Swath width and GSD depend on the flying height and velocity above ground. The sensor is programmable, i.e. from the 288 bands a subset may be selected in order to reduce the amount of data. The CASI2 sensor is designed for the spectral range between 400 and 1000 nm using 1480 sensor elements for 12 bit registration. CASI3 uses 1548 sensor elements and 14 bit registration to acquire data in the spectral range from 400 to 1050 nm. Further technical details can be found on the website.

In contrast to the two sensors above, the HyMap (Hyperspectral Mapper) sensor covers the range from 400 to 2500 nm, thus also including SWIR. The system was developed by Integrated Spectronics, Baulkham Hills, Australia (www.intspec.com) and is operated by HyVista (www.hyvista.com). The system delivers 16 bit data of 128 bands with a band width of 10 to 20 nm, excluding absorption bands. The GSD and swath width of the whisk-broom-scanner depends again on the flying height and velocity above ground. Further technical details and application examples are given on the named web-sites and www.hymap.com. The new sensor generation of the HyMap is designed to capture also information in the THIR using 32 narrow bands, thus following the configuration of the Digital Airborne Imaging Spectrometer (DAIS 7915) operated by DLR (German Aerospace Centre): This scanner acquires data over a larger range of the electromagnetic spectrum than the other sensors available at the time of its design. In comparison to the new HyMap generation, DAIS 7915 provides data of THIR in six channels with larger bandwidths. Detailed information about the sensor can be found on www.op.dlr.de/dais.

Besides the mentioned systems MIVIS (Multispectral Infrared and Visible Imaging Spectrometer, 1994), HYDICE (Hyperspectral Digital Imagery Collection Experiment, 1995) and ROSIS (Reflective Optics System Imaging Spectrometer, 1992) are further examples of airborne hyperspectral systems. With respect to the availability of data covering larger areas worldwide spaceborne hyperspectral systems are of interest. One of the first examples of such spaceborne systems is the MOS (Modular Optoelectronic Scanner), carried by IRS-P3 launched in 1996. The geometric resolution of the systems is 500 m with a swath width of approx. 200 km. Other examples are the MODIS (Moderate Imaging Spectroradiometer, modis.gsfc.nasa.gov) on the TERRA and AQUA missions launched in 1999 and 2002, and the MERIS (Medium Resolution Imaging Spectrometer, www.envisat.esa.int/instruments/meris) on ENVISAT launched in 2002. Some of the bands of the MODIS in THIR are not as narrow as one may expect for a hyperspectral sensor. Nevertheless, the sensor can be categorized as hyperspectral because of the number of bands. Following the categorization given in Table 1, MERIS may still be classified as multispectral. In comparison to other sensors of that group, MERIS bands are narrow and therefore the sensor is named here. The geometric resolutions for MODIS are 250 to 1000 m and for MERIS 300 m respectively, thus they both provide very low geometric resolution. An example of a medium resolution hyperspectral spaceborne sensor is the Hyperion on EO-1 launched in November 2000. Like the AVIRIS, the Hyperion captures data in 220 bands of 10 nm bandwidth in the spectral range of 400 to 2500 nm with a ground sampling distance of approx. 30 m. A quiet similar geometric resolution is provided by CHRIS (Compact High Resolution Imaging Spectrometer) on PROBA launched in 2001. The spectral range from 415 to 1050 nm is covered by a smaller number of bands. If data is captured in all 63 bands, the geometric resolution is limited to approx. 36 m. A ground sampling distance of about 18 m is possible, in case only 19 bands are selected for data capture.

In 2008, the launch of a Canadian system called HERO (Hyperspectral Environment and Resource Observer) is scheduled. The specifications include a geometric resolution of 30 m and a swath width of approx. 30 km based on an orbit like LANDSAT. The observable spectral information will cover the range from 430 to 2450 nm with band width of 10 nm. The system will be designed for a life time of 5 years.

2.3 High Resolution Satellite Sensors

The era of commercial high satellite remote sensing systems started at the end of 1990´s. Some characteristics of the most prominent systems are compiled in Tab. 5. IKONOS is the first spaceborne high resolution remote sensing system delivering digital data. After the failed launch to orbit of IKONOS-1 in April 1999, the second system was launched in September 1999. The system is operated by SpaceImaging (www.spaceimaging.com) and provides optical data in one panchromatic channel with a geometric resolution of approx. 1 m and in four channels in the visible and near-infrared range of the spectrum with a geometric resolution of approx. 4 m. The web-site provides more detailed information about the sensor and available products. Furthermore, examples of imagery can be found.

QuickBird-1 met a similar fate than IKONOS-1. QuickBird-2 is operated in orbit since October 2001 by DigitalGlobe (www.digitalglobe.com). The spectral ranges of the channels (one panchromatic channel and four multispectral channels ranging from blue to near-infrared) are comparable to those of IKONOS, but the nominal geometric resolution at nadir is superior with approx. 0.6 m for the panchromatic channel and approx. 2.4 m for the others. More information is again available on the web-site of DigitalGlobe.

The last system of the North American trio is the OrbView system launched in June 2003 by ORBIMAGE (www.orbview.com). This sensor delivers data in five channels like the two systems mentioned above with geometric resolutions of 1 m for the panchromatic and 4 m for the other channels. Therefore, it matches with the technical data given for the IKONOS system.

The French system SPOT5 belongs to the SPOT-family launched until 1986. The SPOT 5 system captures data since 2002. It has two panchromatic sensors with a geometric resolution of 5 m. Data of these two sensors are combined, finally leading to a nominal geometric resolution of 2.5 m. The other sensors capture data in the spectral ranges from 500 to 590 nm (green), 610 to 680 nm (red), and 780 to 890 nm (NIR) with a geometric resolution of 10m , and from 1580 to 1750 nm (SWIR) with a geometric resolution of 20 m, thus offering other spectral information than the North American sensors. Detailed information about sensors and available data is compiled on the web-site of SPOTIMAGE (www.spotimage.com).

All four systems are able to deliver stereoscopic data, thus height information about the Earth’s surface in form of digital elevation models can be derived (see e.g. Baltsavias et al. 2005). Besides these four prominent high (geometric) resolution sensors, a number of systems are already operated or developed. For an extensive overview, please refer to Jacobsen (2005). As one example, the launch of the German system RAPIDEYE (www.rapideye.de) is scheduled for 2007. The final system consists of 5 satellites delivering data in 5 optical bands ranging from 440 to 850 nm with a ground sampling distance of 6.5 m at nadir. RAPIDEYE is an example for the group of small satellites. The principle idea is to use (more or less) COTS-components leading to inexpensive systems and to install a number of (possibly) identical systems in orbit. Although, the geometric resolution of RAPIDEYE will not be as high as for the other high resolution systems, the temporal resolution is high because of the 5-satellite-configuration. Furthermore, data availability is given also in case one satellite may fail – a fact which is a prerequisite for time-critical applications like vegetation growth or disaster monitoring. All systems mentioned above belong to the group of passive sensors delivering optical images. Therefore, the systems have sun-synchronous orbits in order to have optimal and similar imaging conditions. Nevertheless, the time window for imaging is small and furthermore restricted by weather conditions.

	IKONOS	QuickBird	OrbView	SPOT5
pan	450 – 900 nm	450 – 900 nm	450 – 900 nm	480 – 710 nm
blue	455 – 516 nm	450 – 520 nm	450 – 520 nm	
green	506 – 595 nm	520 – 600 nm	520 – 600 nm	500 – 590 nm
red	632 – 698 nm	630 – 690 nm	625 – 695 nm	610 – 680 nm
NIR	757 – 835 nm	760 – 900 nm	760 – 900 nm	780 – 890 nm
SWIR				1580 – 1750 nm
GSD pan	1.0 m	0.6 m	1.0 m	(2.5) / 5.0 m
GSD VNIR	4.0 m	2.4 m	4.0 m	10.0 m
GSD SWIR				20.0 m
stereo	+	+	+	+

Table 5: Examples of high resolution satellite systems

3. Active Systems

In contrast to the passive (optical) sensors discussed above, active sensors can acquire data independently of illumination and also (almost) independently from weather conditions. One type of active sensors uses microwaves: RADAR or SAR (Synthetic Aperture Radar) sensors respectively. The signal is emitted and the reflected signal recorded. The used electromagnetic waves can penetrate clouds. Different configurations are possible – either polarimetric or interferometric. Polarimetric SAR is used for classification applying different combinations of polarization of emitting and receiving antenna: both horizontal, both vertical, or a combination of horizontal and vertical. Interferometric SAR is used for the derivation of height information providing the height of the ground or vegetation, e.g. by use of different wavelengths. Both types of SAR are used on different platforms: airplanes, shuttle and satellites. One example is the SRTM (Shuttle Radar Topographic Mission) in 2000 working as interferometric SAR (InSAR). The results are DEMs of different resolution and coverage. The mission was also intended as technical demonstrator for the upcoming mission of TerraSAR-X (Bamler et al. 2003, www.terrasar.de), which is scheduled for launch in April 2006 (Hermann et al. 2005). The highest geometric resolution of this SAR system will be about 1 m. Also in 2006, the launch of RADARSAT-2 as successor of RADARSAT-1 by RADARSAT International (www.rsi.ca) is scheduled. RADARSAT-2 will provide full polarization capabilities and a GSD of up to 3 m, thus improving the geometric resolution of RADARSAT-1 by a factor of 3. Nevertheless, optical data are easier to interpret and may provide more information than SAR imagery with the same GSD in case of a high number of bands is available. Of course, the information content is not really comparable, because optical and SAR sensors gather different characteristics of the Earth's surface, raising the topic of data fusion.

LIDAR systems constitute the second type of active sensors. It is not as independent from the acquisition conditions, because the wavelength used is normally in the infrared range of the spectrum and the strength of the signal may be attenuated by weather conditions. LIDAR systems are known for providing range measurements and therefore, 3D coordinates of the surface can be captured, if the position and the viewing direction are known by GPS and INS. In the past, there were ideas to use a satellite as platform for a LIDAR profiler with 5 beams called VCL (Vegetation Canopy LIDAR) and the launch was scheduled for 2000, but these plans have been abandoned (essp.gsfc.nasa.gov/vcl/ (July 2005)). Thus, airplanes are used as platform. Besides the measurement of the pure running time of reflected pulses allowing geometric analyses, LIDAR systems also provide information about the strength of the pulses and therefore also spectral information. Geometric analyses to derive DEM and to extract objects and/or object information in LIDAR data have been shown to be operational, partly feasible. The use of spectral information from the LIDAR measurements is not really exploited.

4. Conclusion

In this contribution an overview of remote sensing systems was given focussing on environmental applications. The developments of the last decade show an increase of sensor resolution – geometrical and spectral. Based on these developments of sensor technology, new fields for the application of remote sensing are opened, namely remote sensing of urban areas. Multispectral sensors of medium resolution and their data can be used for a variety of applications in rural and large areas. Examples are the monitoring of vegetation and/or land cover as tools for the monitoring of desertification and land use. Without the improvements of sensor technology during the last decade, remote sensing of urban areas would be impossible – at least at the scale and resolution normally required. Besides the high geometric resolution of data provided by high resolution satellite imagery, airborne systems like digital photogrammetric cameras, and LIDAR systems, high spectral information of the surfaces is required in order to classify materials for environmental applications in urban areas, thus requiring hyperspectral data and data fusion techniques for the analyses.

The developments of the last decade also show another effect: In former times, large satellites were designed as platform for a number of sensors for different applications. The advantage was that data of different sensors were acquired simultaneously. One of the last examples for such a platform is ENVISAT. Such large missions are dangerous in case of failures, sometimes leading to a total loss. Therefore, small satellites have been designed in recent years as specialized systems. Hand in hand with developments towards small satellites, the number of nations implementing systems and programs of their own increased. The advantage of small satellites is the fact, that not only one satellite may be put into orbit, but a configuration of several satellites with similar specifications leading to a higher redundancy in case of failure and higher temporal resolution of data acquisition. The temporal resolution and the (almost) guaranteed availability of data are crucial for the end user and for the acceptance of remote sensing techniques.

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