High Resolution Imaging Satellite Systems

K. Jacobsen
University of Hannover, Germany

Keywords: high resolution space sensors, SAR

ABSTRACT: The number of existing and announced high and very high resolution imaging satellite systems is growing permanently. Not all systems are known very well even if they are powerful and images can be ordered. The announced systems are changing permanently – in general the number is growing, but also some do disappear mainly by financial reasons. In addition the sensor parameters are not published or fixed in any case. An overview of the existing and announced sensors and an explanation of important parameters will be given.

1 INTRODUCTION

The definition of high resolution satellite imaging systems is not fixed, it depends upon the application. So for meteorological satellites even 1km may belong to high resolution. Here it is used in relation to topographic mapping purposes, that means is starts approximately at a ground sampling distance (GSD) of 10m. Ground sampling distance is the distance of the centre of neighboured pixels projected to the ground. This appears as pixel size on the ground even if the real ground pixel size is influenced by over- or under-sampling.
Military reconnaissance was one of the first operational satellite applications. The US CORONA project started just 20 month after the launch of the SPUTNIK in October 1957. This presentation will be limited to civilian applications, but the images taken by the CORONA project are declassified and can be ordered over the internet. The Soviet Union followed this development and with the KVR-1000 they have had a very similar high resolution panoramic film camera. Also these photos can be ordered today.
The first digital images available for civilian application came from Landsat in 1972, but its GSD was not usable for topographic mapping; this was possible at first with SPOT 1 in 1986. The SPOT satellites have been designed especially for mapping with the potential of a stereoscopic coverage from neighboured orbits. The disadvantage of the time delay between imaging not from the same orbit was avoided at first by MOMS02 viewing to the nadir, forward and backward and generating a stereo coverage within the same orbit. The same principle is used by ASTER, SPOT5 HRS and will be used in the near future by ALOS and Cartosat-1. The IRS-1C was leading with 5.7m GSD to a better ground resolution, but the stereo view across the orbit by rotating the whole panchromatic camera was limited by using too much fuel.
A new class of optical satellites came with IKONOS-2, the flexible and fast changing view direction based on reaction wheels opened new possibilities. The TDI-sensor enabled the imaging with sub-meter GSD, which is now possible also by QuickBird and OrbView. EROS-A1, TES and the coming Cartosat 2 are not using TDI-sensors and have to enlarge the imaging time by a permanent rotation of the satellite.
Complete observation satellites today can be bought like the FORMOSAT-2 and the small satellites belonging to the disaster mapping constellation (DMC). The small satellites are using of the shelf components and so they can reduce the expenses. A high number of observation satellites are announced, enlarging the number of very high resolution systems. In the near future 6 countries will have satellites with 1m or smaller GSD. In total approximately 20 countries will have optical satellites. In addition very high resolution synthetic aperture radar systems will come, usable also for mapping purposes.

2 TECHNICAL DETAILS

The CORONA KH-4A and the KVR1000 photos already had a resolution between 2 and 3m GSD available for civilian space applications only 36 years later. Since 1962 the CORONA system was using 2 convergent mounted cameras allowing a stereoscopic coverage within the orbit. The most often used Corona KH-4A and KH-4B photos also today can be used for the generation of digital elevation models (DEMs).

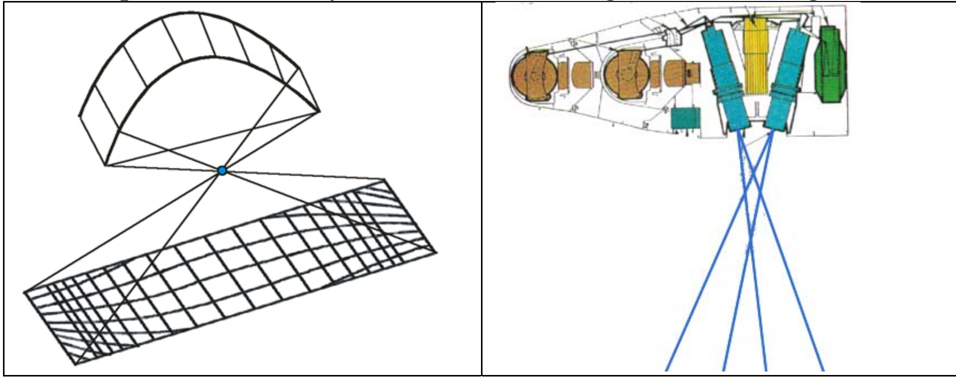


Figure 1: CORONA KH-4A
left: panoramic camera
centre: configuration of the 2 panoramic cameras in the satellite

Similar to the panoramic cameras, Landsat is scanning the imaged area by oscillating mirror. The first digital optical satellite system designed for civilian topographic mapping was SPOT. It was also the first high resolution system equipped with CCD-lines. The free electrons generated in the CCD-elements by the incoming light energy have to be shifted through the CCD-line to the read-out register. For a longer CCD-line not enough time is available for the read out up to the start of the next line of pixels, by this reason a combination of shorter CCD-lines is used. SPOT is equipped with a combination of 3 CCD-lines like IRS-1C / 1D and also IKONOS. QuickBird is even using a combination of 6 CCD-elements (figure 2b).
The exchange of the photographic material by digital images is leading in most cases to an improvement of the image quality. Film is influenced by the film grain and very often scratches are on the photos with negative influence to automatic image matching.

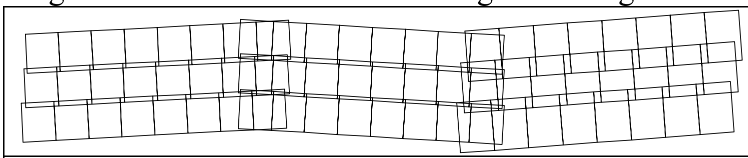


Fig 2a: calibration situation of IRS-1C sub-scenes

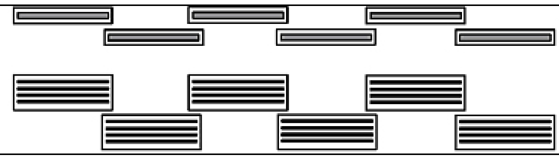


Fig. 2b: arrangement of CCD-lines in focal plane of QuickBird
above: panchromatic below: multispectral

Usually the combination of the sub-scenes generated by the individual CCD-lines belongs to the inner orientation and will be handled by the satellite image vendors. For the IRS-1C the sub-images have been available and the calibration could be made based on ground control points (Jacobsen 1998). The alignment as well as the shift have been far outside the system accuracy and had to be improved. After calibration, which was also depending upon the nadir angle, accuracy in the range of one GSD has been reached. The separation of the panchromatic from the multispectral CCD-lines is causing a time delay of the colour images. So pan-sharpened images (merge of high resolution panchromatic and lower resolution multispectral images to a high resolution colour image) do show this for fast moving objects the colour with a delay against the grey values – the black and white part of cars on highways is in front of the colour.
The high resolution space sensors usually do have a combination of a higher resolution panchromatic band with lower resolution multispectral bands. By definition panchromatic shall cover the visible range without spectral separation. In no case the so called panchromatic band of the satellite systems follows this definition. Usually the sensitivity is reduced for the short wavelength (blue) and it is extended to the near infrared. The short wavelength is influenced by the stronger scatter effect, by this reason the blue band is not available for all sensors. On the other hand the extension to the near infrared improves the object contrast for the vegetation and leads to a better image quality. Figure 3 shows the system sensitivity for IKONOS and QuickBird, equipped with the same Kodak CCD-elements. The effective sensitivity respects the overall effect of the sun energy depending upon the wavelength, the transmission of the atmosphere, the filters and the

CCD-sensitivity. The imaging systems with mid-infrared band (SWIR) do compensate the lower sun energy for this spectral range with larger GSD.

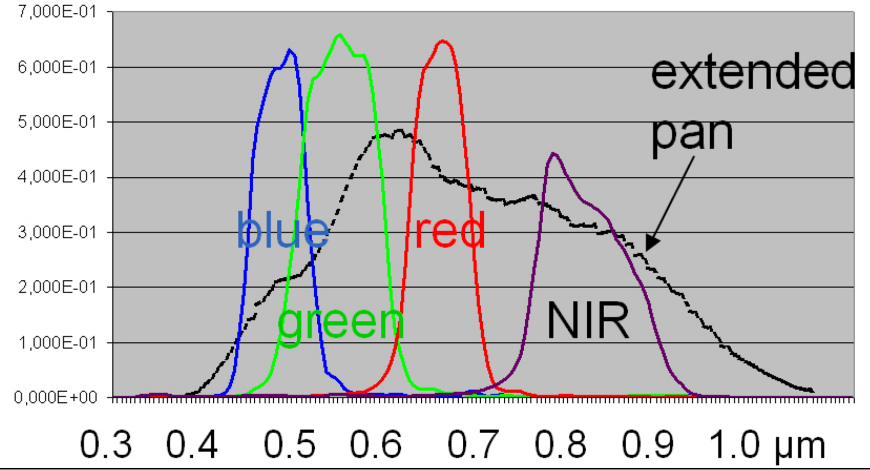


Figure 3: effective spectral quantum efficiency of the optical system for IKONOS and QuickBird

horizontal axis: wavelength
vertical: effective sensitivity of CCD-elements

Very often the pixel size of the multispectral images is 4 times as much like for panchromatic. This is an acceptable relation for the generation of pan-sharpened images. For the human eye the colour information must not have the same resolution like the grey value information – this corresponds to the situation of the human eye with a higher number of grey value sensible rods and a smaller number of colour sensible cones in the human retina.
Because of the usually higher resolution, the geometric handling like automatic image matching will be made in most cases with the panchromatic band. This has disadvantages in the forest areas, where the near infrared has quite better contrast (figure 4).

grey value histogram SPOT 5 panchromatic | grey value histogram ASTER near infrared

Figure 4: grey value histograms of the same forest area

ASTER has also the advantage in having a nadir and a backward viewing camera generating the stereoscopic coverage within few seconds while the standard SPOT images like IRS 1C /1D, Resourcesat, KOMPSAT 1 and CBERS only can generate the stereo model in viewing from neighboured orbits. Under optimal conditions the second image can be taken one day later, but if the weather conditions do not allow this, a longer time interval may happen with problems of the change of the imaged object. So the stereoscopic coverage within the same orbit has advantages. SPOT 5 has respected this with the additional HRS camera (high resolution stereo), viewing forward and backward. Before MOMS has used this principle by viewing forward, backward and to the nadir. In near future PRISM on ALOS will do it in the same manner and Cartosat-1 will have two view directions. The satellites with flexible view direction also can generate a stereoscopic coverage within the same orbit, but it is reducing the possibility in taking other images from the same orbit.
Today the observation satellites are equipped with reaction wheels – fast rotating gyros (figure 5). If they are accelerated of slowed down, a moment goes to the satellite and it is rotating. With one reaction wheel for every axis, the satellite can rotate in any direction just based on electric power coming from the solar cells. The rotation of the satellites can be fast and are controlled very accurate, so it is possible to rotate the satellite during imaging for example to enable a scene parallel to the ground coordinate systems or in the extreme case the image can generated in the opposite direction to the movement within the orbit.
The speed of the satellites projected to the ground is in the range of 7km/sec. The very high resolution systems like IKONOS with 1m GSD do have only 0.14ms integration time for one pixel. Even with the large optics and large CCD-elements this is a too short time for getting a good image quality. EROS-A1, TES and

the coming Cartosat-2 do change the view direction during imaging continuously to reduce the speed of the image forward motion (figure 6).


Figure 5: reaction wheels

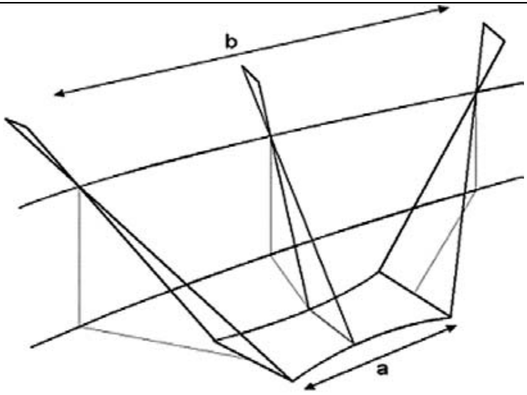


Figure 6: enlargement of integration time with factor b/a by continuous change of the view direction

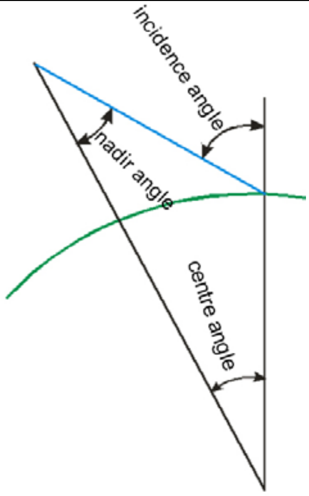


Figure 7: nadir angle – incidence angle

IKONOS, QuickBird, OrbView-3 and Formosat-2 are equipped with time delay and integration (TDI) sensors. They do have not only a CCD-line but a small array. The free electrons generated by the energy reflected from an object element are shifted with the speed of the image motion to the neighboured CCD-element, there more charge is generated and the sum of free electrons are shifted to the next CCD-element and so on. IKONOS and QuickBird are usually using 13 CCD-elements for the sum up of the energy (see figure 8).

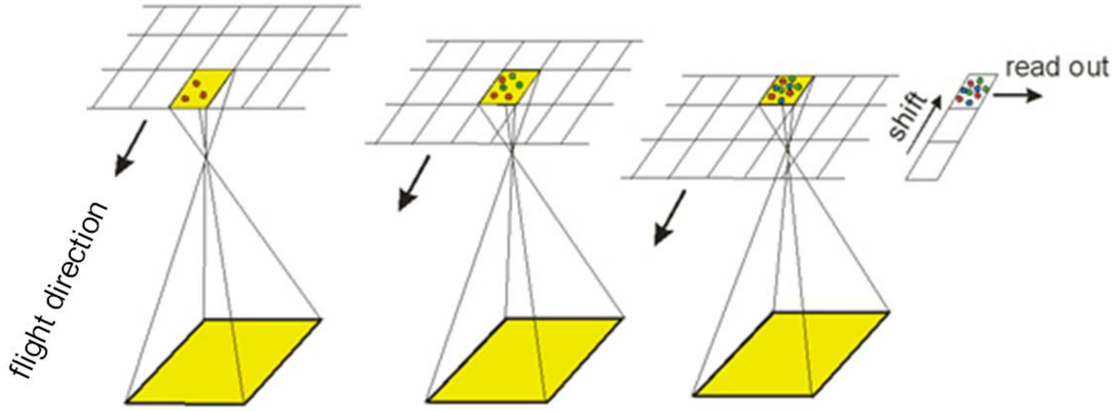


Figure 8: time delay and integration sensor (TDI)

QuickBird originally was designed for a flying altitude of 680km like IKONOS. Later it was decided to reduce the flying altitude to 450km for getting a GSD of 0.61m, but it was too late to enlarge the sampling rate of 6900 lines /sec. By this reason QuickBird is using the TDI in combination with an enlargement of the integration time by continuous change of the view direction with a factor b/a of approximately 1.6.
The reduction of the flying height has a second disadvantage – the viewing range from the orbit is reduced. For a limited incidence angle (definition see figure 7) the range from the nadir line to the side is smaller for a lower flying altitude. The range limit from the nadir point for an incidence angle not exceeding 10° for IKONOS is 109km while it is 74km for QuickBird and 77km for OrbView 3. This is also determining the revisit time.

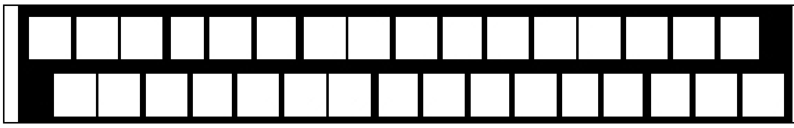
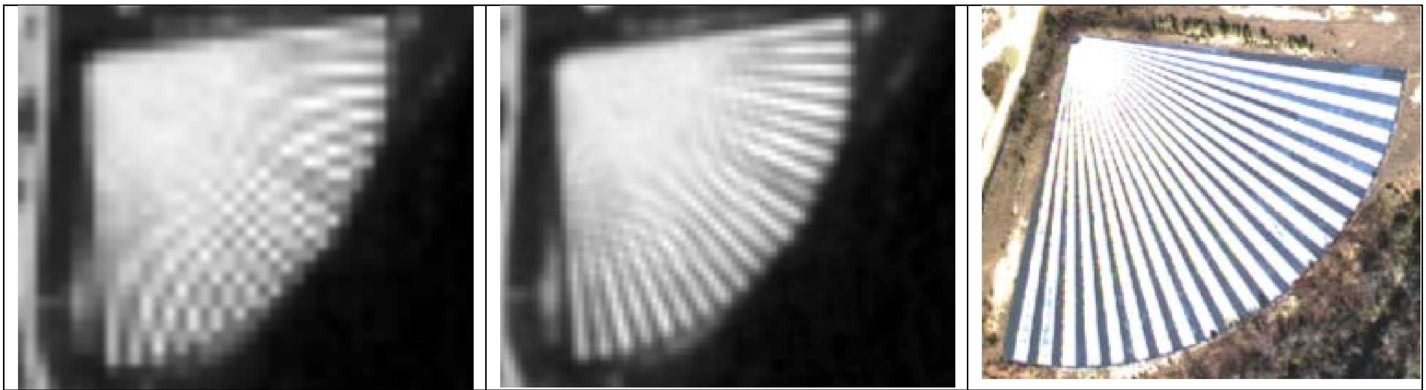


Figure 9: staggered CCD-lines

SPOT5 and OrbView 3 are using staggered CCD-lines to reduce the GSD. The original 5m ground pixel size of SPOT 5 is not requiring TDI, but the 2.5m GSD of the supermode could not be reached without. Staggered CCD-lines are two lines just shifted half a pixel against each other (figure 9). The sampling rate is also enlarged by the factor 2. This information can be used for the generation of an image with half the GSD; that means the ground pixel size for the nadir view is 5m and the neighboured pixels are over-sampled in X- and Y-direction by 50%, so the GSD is 2.5m. This really improves the image quality – by theory the SPOT 5 supermode corresponds to a usual image with 3m GSD. The images of the Stennis Space Flight Center test pattern (figure 10) show the improvement by the supermode against the usual panchromatic SPOT image. The largest width of the strips are approximately 4m and this cannot be separated with 5m GSD, but with the 2.5m GSD of the supermode. The test pattern leads to a ground resolution of 3m which corresponds to the theoretical resolution.



SPOT 5 panchromatic, 5m GSD	SPOT 5 supermode, 2.5m GSD	test pattern

Figure 10: images of Stennis Space Flight Center test pattern

3 HIGH RESOLUTION SPACEBORN OPTICAL IMAGING SYSTEMS

system	launch	GSD [m] pan / MS	swath [km]	remarks
SPOT 1 France	1986	10 / 20	60	+/-27° across orbit
SPOT 2 France	1990	10 / 20	60	+/-27°
SPOT 3 France	1993	10 / 20	60	failed
SPOT 4 France	1998	10 / 20	60	+/-27°
SPOT 5 France	2002	5 / 10 (2.5) HRS 5*10	60 120	+/-27° (staggered) 23° fore, 23° after
JERS-1 Japan	1992	OPS 18	75	+ SAR
MOMS 02, Germany	1993	4.5 / 13.5	37 / 78	nadir + 21.5° fore + 21.5° aft
MOMS-2P Germany	1996	6 / 18	48 / 100	like MOMS 02
IRS-1C India	1995	5.7 / 23	70 / 142	+/-26° across orbit
IRS-1D India	1997	5.7 / 23	like IRS-1C	
IRS P6 India Resourcesat	2003	5.7 MS	24 / 70	+/-26° across orbit
KOMPSAT-1, South Korea	1999	6.6 pan	17	+/-45° across orbit
CBERS-1, China + Brazil	1999	20	113	+/-31° across orbit
CBERS-2	2003	like CBERS-1		
Terra USA / ASTER Japan	1999	15, 30, 90 all MS	60	nadir + 24° aft
IKONOS-2 USA SpaceImage	1999	0.82 / 3.24	11	free view direction, TDI
EROS A1, Israel, Imagesat	2000	1.8 pan	12.6	free view direction
TES India	2001	1 pan	15	free view direction
QuickBird-2 USA DigitalGlobe	2002	0.62 / 2.48	17	free view direction, TDI
OrbView-2 USA OrbImage	2003	1 / 4	8	free view direction, TDI
FORMOSAT-2 (ROCSAT-2) Taiwan	2004	2 / 8	24	free view direction, TDI

Table 1: larger optical space sensors
MS = multispectral fore = view forward in orbit direction aft = backward in orbit direction

Only the high resolution photos taken with the CORONA 4 serious and the combination of the Russian TK350 with the KVR1000 do play a role. Especially the CORONA images available for a handling fee are used as base for change detection and archaeological purposes. In addition they are still useful for the generation of detailed height models.
Not from all satellite systems listed in table 1 actual images are available. At first some of the sensors are not anymore active or even existing like the first SPOT satellites, JERS-1, MOMS and CBERS-1 or they are not in an image distribution system like KOMPSAT-1 and TES. The distribution of the FORMOSAT-2 images by SPOT Image has not really started. ASTER scenes are often used for several purposes because of the regular imaging program, the good distribution system and the low price of a little above 60 US$ for a scene combination. The satellite images from the commercial companies SpaceImage, Imagesat, DigitalGlobe and OrbImage are well distributed and operational, but still expensive. In a similar manner SPOT Image and India are distributing their products.
FORMOSAT-2, before named ROCSAT-2, has been made by EADS Astrium for Taiwan. Today it is possible to order the whole systems with satellites and ground stations including image processing. The launches since longer time are still in strong international competition and it is absolutely not a problem to launch satellites.

	IKONOS	QuickBird	OrbView-3
GSDnadir pan / ms	0.82m / 3.28m	0.61m / 2.44m	1m / 4m
number of pixels pan	13 816	27 552	8 000
swath	11 km	16.8 km	8 km
flying height	681 km	450km	470 km

Table 2: comparison of very high resolution satellites

Table 2 shows a comparison of the very high resolution commercial satellite images. IKONOS images in the first years have been distributed only with 1m GSD, but today they are also available with the full resolution of 0.82m GSD in the nadir. One of the differences between the image types is the swath width, beeing largest for QuickBird, but QuickBird has also some capacity limitations in the orbit direction caused by the enlargement of the integration time by permanent satellite rotation.

system	launch	GSD [m] pan / MS	swath [km]	remarks
UOSAT 12 UK	1999	10 / 20	10 / 30	CCD arrays
KITSAT 3, South Korea	1999	15 MS	50	
SunSAT, South Africa,, commercial	2000	15	52	
Alsat 1 Algeria	2002	32 MS	600	DMC
BilSat 1 Turkey	2003	12 / 28	24 / 53	DMC, CCD arrays
BNSCSat UK	2003	32 MS	600	DMC
NigeriaSat Nigeria	2003	32 MS	640	DMC

Table 2: small optical space sensors

The required hardware components for the satellites are becoming smaller and smaller, so today it is not any more necessary to have very heavy satellites for reconnaissance purposes. A weight of 100kg to 300kg should be enough for satellites with ground resolutions usable for topographic mapping purposes. Such satellites also can be equipped with of the shelf components for cost reduction. A group of small earth observation satellites have been launched during the last years (table 2). With exception of KITSAT and SunSAT the small satellites listed in table 2 are produced by Surrey Satellite Technologies (SSTL) in the UK. These satellites can and have been ordered as complete solutions including also the ground stations with the required equipment. Most of the listed countries are cooperating in the disaster monitoring constellation (DMC) – in the case of natural disasters the affected area shall be mapping within 24 hours by at least one of the satellites. Only the UOSAT 12 and the BilSat 1 do have a GSD in the range of importance for topographic mapping, but they do not have a regular imaging and image distribution system.

4 ANNOUNCED OPTICAL IMAGING SYSTEMS

Several high resolution optical satellites systems are announced for the next years (table 3). The proposed launch time in most cases has been and will be delayed, in addition some systems may fail and others may be cancelled, but also additional systems may come. In general the number of high and very high observation systems will be enlarged very soon. The tendency goes to higher resolution and lower weight; that means also in most cases to a lower price. In addition the tendency of international cooperation for the component assembly is growing. It is not any more necessary to develop all the components in the own country, they can be bought or even the whole systems can be bought for a reasonable price.

system	launch	GSD [m] pan / MS	swath [km]	remarks
IRS-P5 Cartosat-1 India	2005	2.5 pan	30	-5°, +26° , 2 cameras in orbit
IRS Cartosat-2, India	2005	1 pan	10	free view direction
ALOS, Japan	2005	2.5 / 10	35 / 70	-24°, nadir, +24°, 3 cameras in orbit direction
KOMPSAT-2 South Korea	2005	1 / 4	15	free view direction
Resurs DK1 Russia	2005	1 / 2.5-3.5	28	free view direction
Monitor-E Russia	2005	8 / 20	94 / 160	free view direction
EROS B, Israel	2005	0.7 pan	14	free view direction, TDI
EROS C, Israel	2009	0.7 / 2.8	11	free view direction, TDI
RazakSat, Malaysia	2005	2.5 / 5	20	free view direction, inclination 7°
CBERS 2B, China, Brazil	2005/ 2006	2.5 / 20		+/-32° across
CBERS-3, China, Brazil	2008	5 / 20	60/ 120	"
CBERS-4, China, Brazil	2008	5 / 20	60/ 120	"
WorldView 1 DigitalGlobe	2006	0.5 / 2		free view direction, TDI
OrbView 5, OrbImage	2006	0.41 / 1.64	15	free view direction, TDI
THEOS Thailand	2007	2 / 15		free view direction, TDI
Pleiades 1 , France	2008	0.7 / 2.8	20	free view direction, TDI
Pleiades 2, France	2009	like Pleiades 1		

Table 3: announced larger optical space sensors

Two systems, Cartosat-1 and ALOS have been especially designed for the generation of digital elevation models (DEMs) in having 2 or 3 optics with different nadir angles in view direction. The ground resolution of 2.5m can lead to DEMs with height accuracy in the same range. Most of the systems will have a flexible view direction allowing also the generation of stereo models within the same orbit. 8 systems will have a GSD ≤1m. TDI will be used in most of the very high resolution systems. Pleiades will be the follow on system for SPOT with higher resolution and lower weight; that means also for lower cost. THEOS will be made by EADS Astrium for Thailand.

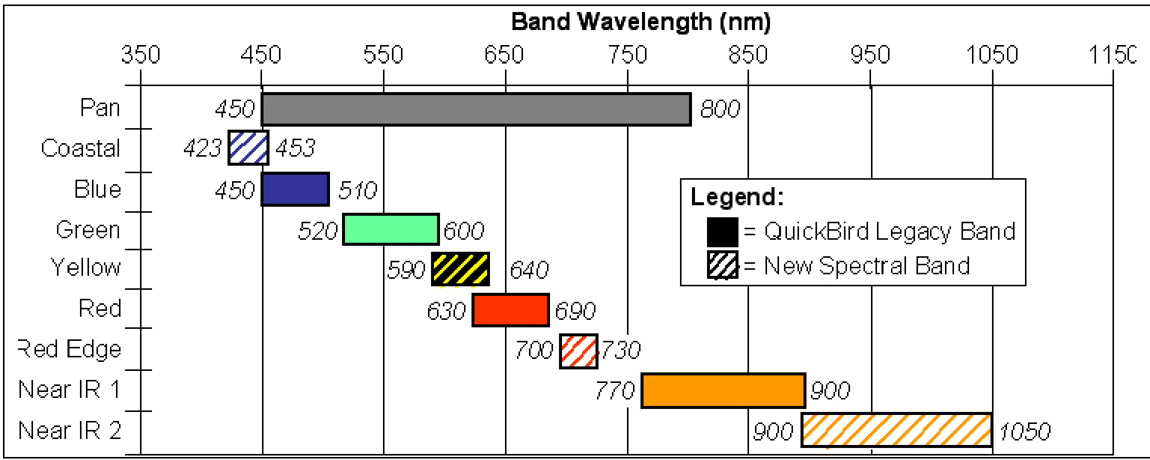


Figure 11: spectral bands of WorldView 1

WorldView 1 and OrbView 5 are based on contracts within the NextView program of US military. Not only these satellites, most of the high resolution observation satellites are based on dual use – the highest percentage of the required funds is coming from military and the remaining free capacity is available for commercial applications. WorldView 1 and OrbView 5 will lead to 0.5m GSD. In addition to the bands used by QuickBird four new spectral bands are included (figure 11). The main reason for the higher spectral resolution is based on military requirements, but it is also useful for civilian application. Especially the coastal band with its possibility of water penetration may be useful in shallow water.

system	launch	GSD [m] pan / MS	swath [km]	remarks
DMC China	2005	4 / 32	600	DMC
VinSat-1 Vietnam	2005	32 MS	600	DMC
ThaiPhat, Thailand		36 MS	600	DMC
TopSat UK, BNSC	2005	2.5 / 5	10 / 15	free view direction, TDI
X-Sat Singapore	2006	10 MS	50	
RapidEye, Germany, commercial	2007	6.5 MS	78	free view direction, 5 satellites

Table 4: announced small optical space sensors

Also a group of small satellites shall be launched. Partially they will have a higher resolution. Rapid Eye is one of the first totally commercial applications without financial support by dual use. The system of 5 low cost satellites will be constructed by SSTL and operated by RapidEye, a spin-off of the German Aerospace Centre DLR, in cooperation with Mc Donald Dettwiler, Canada. The main application shall be in the field of precision farming.

5 SYNTHETIC APERTURE RADAR

Images can be generated by synthetic aperture radar (SAR). Radar has the advantage of penetrating the clouds and as active systems they are independent upon the sun light. The physics of imaging is quite different to optical images, so also the object identification is different. A comparison of the information contents of SAR-images in relation to optical images having the same GSD (Lohmann et al 2004) was leading to the identification of 60% to 100% of the objects in SAR-images in relation to optical images. In general with the same GSD in SAR-images not so many objects can be identified. In addition SAR has problems with layover in steep regions and also in city areas. But nevertheless SAR may be an important alternative especially for time critical mapping and areas with permanent cloud coverage. Especially in the case of flood mapping SAR is very helpful.

system	launch	GSD [m]	swath [km]	remarks
ERS-1 ESA	1991	10-30	100	C-band 5.6cm
ERS-2 ESA	1995	like ERS-1 1995 – 96 used in Tandem configuration		
JERS-1 Japan	1992	18	75	
RADARSAT-1, Canada	1995	9-100	50-500	C-band 5.6cm
SRTM USA , Germany, Italy	2000	30 30	225 45	C-band 5.6cm X-band 3cm, InSAR
ENVISAT ESA	2002	30-1000	100-405	C-band 5.6cm full polarization

Table 5: SAR sensors in space

From the SAR-sensors listed in table 5 only RADARSAT-1 and ENVISAT do have the full function. ERS-2 has the first problems and probably will be shut down this year. The GSD is not in the range for being a real alternative to topographic mapping based on optical images, so SAR-images have been used for this purpose only in areas with permanent cloud coverage. Another application for SAR is the use for DEM generation by interferometric SAR (InSAR). ERS-1 and ERS-2 have been used over one year in the tandem configuration for this purpose and the Shuttle Radar Topography Mission (SRTM) was especially made for this. Based on the SRTM for the areas from 56° southern up to 60.25° northern latitude DEMs have been generated with accuracy up to 4m for open and flat parts. With the announced very high resolution SAR-systems topographic mapping may be possible.

system	launch	GSD [m]	swath [km]	remarks
ALOS, PALSAR, Japan	2005	7 - 100	40 - 350	L-band, 24cm
SAR-X CosmoSkymed-1 Italy	2006	1-several 10th	10-few hundreds	X-band, 3.1cm
RADARSAT-2, Canada	2006	3 – 100	20-500	C-band, 5.6cm, full polarization
TerraSAR-X Germany, ppp	2006	1/3/16	10/30/100	X-band, 3.1cm
RISAT India	2006	3 – 50	10 – 240	C-band
Surveyor SAR, China	2007	10 / 25	100 / 250	C-band, 5 satellites

Table 6: announced SAR space sensors ppp = private public partnership

SAR-X CosmoSkymed-1 and TerraSAR-X will allow a GSD up to 1m. TerraSAR-X will be operated in a private public partnership between the German Aerospace Center DLR and EADS Astrium. It is not belonging to dual use because in parallel Germany is building with SARLupe military SAR-satellites with a similar specification. For SAR-X CosmoSkymed-1 with the cartwheel concept (1 active and a group of passive SAR sensors) and for TerraSAR-X with the TandemX there is a discussion for InSAR-configurations which may lead to accurate DEMs.

6 HALE UAV

With the high altitude long endurance (HALE) unmanned aerial vehicles (UAV) an alternative between space and airborne systems will come. The HALE UAV are using solar energy and may stay for month in the air. With Pathfinder-Plus the NASA always made a successful test. The Belgian Flemish Institute for Technological Research VITO plans the first test flight of its HALE UAV Pegasus for 2005, it is constructed by QinetiQ, UK. The sun powered Pegasus is designed for continuous operation over several month in up to 55° latitude from March to September (Biesemann et al 2005). It shall operate in a height of 20 000m, over night it will go down to 16 000m and raise again in the next morning. This altitude is above the aeronautic control, avoiding safety problems. In a partially autonomous flight it can be directed to the area for imaging. Starting from 2006 it shall carry a digital camera with 4 spectral bands and 12000 pixels having a GSD of 20cm. This later shall be extended to 10 spectral bands and 30 000 pixels and SAR and LIDAR may be included.

CONCLUSION

The increased ground resolution has caused a competition between space born and aerial sensors for mapping in the scale 1 : 5000 and smaller. With the availability and easy access to very high resolution space images the use for classical, but also new applications is growing fast. The number of accessible sensors is increasing in the near future. Most systems are based on dual use, but the free capacity is still pushing the development in the commercial sector. Also very high resolution SAR-systems will play an important role. More and more countries are entering the field, so in near future 22 countries will have their own sensors. The still existing gap between space and aerial application may be filled with HALE UAV, so in near future a quite larger variety of systems can be used.

REFERENCES

Baudoin, A., 2004: Beyond SPOT5: Pleiades, Part of the French-Italian Program ORFEO, ISPRS Istanbul IntArchPhRS. Vol XXXV, B1. pp 260-267

Biesemann, J., Everaerts, J., Lewyckyj, N., 2005: Pegasus: Remote Sensing from a HALE-UAV, ASPRS annual convention Baltimore, 2005, on CD

Büyüksalih, G., Kocak, M.G., Oruc, M.*, Akcin, H., Jacobsen, K, 2003a: Handling of IKONOS-images from Orientation up to DEM Generation, Joint Workshop "High Resolution Mapping from Space 2003", Hannover 2003– see also http://www.ipi.uni-hannover (publication)

Büyüksalih, G., Kocak, M.G., Oruc, M., Akcin, H., Jacobsen, K: DEM Generation by ASTER and TK350, Joint Workshop "High Resolution Mapping from Space 2003", Hannover 2003– see also http://www.ipi.uni-hannover (publication)

Epiphanio, C., 2005: CBERS-2, Joint China-Brazil Remote Sensing Satellites, GIM 2005, Vol. 19, Issue 2, pp68-71

McDonald (editor) 1997: CORONA Between the Sun & the Earth, ASPRS, Bethesda, Md, USA, 440 pages

Jacobsen, K., 1998: Geometric Potential of IRS-1C PAN-Cameras, ISPRS Com I Symposium, Bangalore 1998

Jacobsen, K. 2005: DEMs based on space images versus SRTM height models, ASPRS annual convention Baltimore, 2005, on CD

Lohmann, P., Jacobsen, K., Pakzad, K., Koch, A., 2004: Comparative Information Extraction from SAR and Optical Imagery, Istanbul 2004, Vol XXXV, B3. pp 535-540

McDonald, R.A., editor, 1997: CORONA Between the Sun and the Earth, the first NTO Reconnaissance Eye in Space, ASPRS 1997

Schroeder, M., Suckfüll, E., Todd, G., Lohmann, P. 1988: Spacelab 1 – Metric Camera User Handbook and Data Catalogue, DLR, Oberpfaffenhofen, Germany

Internet References

ASTRONAUTIC, Malaysia:
http://www.atsb-malaysia.com.my/news-eng.asp
Digital Globe: http://www.digitalglobe.com/
DLR – German Aerospace Center: http://www.dlr.de/
ImageSat Intl.: http://www.imagesatintl.com/
ISRO: http://www.isro.org/index.htm
ITC Launch schedule: http://www.itc.nl/research/products/ sensordb/Launch_Schedule.aspx
NASA SpaceWarn Bulletin: http://nssdc.gsfc.nasa.gov/spacewarn/
NSPO: FORMOSAT-2 Spacecraft: http://www.nspo.org.tw/e60/menu0402.html
JAXA EORC: http://www.eorc.jaxa.jp/en/index.html
KARI, Korea Aerospace Research Inst.: http://www.kari.re.kr/
Orbimage: http://www.orbimage.com/
RapidEye: http://www.rapideye.de/
RADARSAT International.: http://www.rsi.ca/
Sovinformsputnik: http://www.sovinformsputnik.com
SpaceImaging: http://www.spaceimaging.com/
SPOT Image: http://www.spotimage.com
SSTL: http://www.sstl.co.uk/
Stoney, W.E., 2004: ASPRS Guide to Land Imaging Satellites, http://www.asprs.org/news/satellites/