HIGH RESOLUTION SATELLITE IMAGING SYSTEMS - OVERVIEW

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ABSTRACT:

More and more high and very high resolution optical space sensors are available. Not in any case the systems are well known and the images are distributed over popular distributing channels or are accessible for any user. Several imaging satellites are announced for the near future. Not every announced satellite finally will be launched and some starts are failing. In most cases the launch has or will be postponed. In the following, mainly the characteristics of systems usable for topographic mapping are shown, limiting it to sensors with a ground sampling distance (GSD) of approximately 15m and better.

Not only the GSD of the imaging system is an important value for the characteristics, also the type of imaging with a transfer delay and integration sensor (TDI) or by reducing the angular speed with a permanent rotation of the satellite during imaging is important, like the accuracy of the attitude control and determination unit. The radiometric and spectral resolution has to be taken into account. For operational use the swath width, viewing flexibility and imaging capacity has to be respected. The very high resolution optical satellites can change the view direction very fast, allowing a stereoscopic coverage within the same orbit, but this is reducing the amount of scenes which can be taken from the same orbit. On the other hand stereo combinations taken from neighboured paths are affected by changes in the object space, atmospheric conditions or different length of shadows. With Cartosat-1 we do have the first accessible stereo systems like the existing, but restricted SPOT 5 HRS sensor, generating a stereoscopic coverage within some seconds by viewing forward and afterward in the orbit direction.

Synthetic Aperture Radar (SAR) sensors with up to 1m GSD are announced for the near future, allowing an imaging independent upon the cloud coverage. Of course the information contents of SAR-images are not the same like for optical images with the same GSD, but nevertheless we are coming into the range of interest for mapping applications.

An overview about the existing and planned high resolution satellite imaging systems will be given together with the required parameters for a comparison of the images for mapping purposes.

1. INTRODUCTION

With the higher resolution and unrestricted access to images taken by satellites, a competition between aerial images and space data exists, starting for a map scale 1:5000. Based on experiences, optical images should have approximately a ground sampling distance (GSD) of 0.05mm up to 0.1mm in the map scale corresponding to a map scale of 1:20000 up to 1:10000 for a GSD of 1m. GSD is the distance of the centre of neighboured pixels projected on the ground. Because of over- or under-sampling, the GSD is not identical to the projected size of a pixel, but for the user, the GSD appears as pixel size on the ground. An over- or under-sampling cannot be seen directly in the image, it is only influencing the image contrast, which also may be caused by the atmosphere.

Mapping today is a data acquisition for geo-information systems (GIS). In a GIS the positions are available with their national coordinates, so by simple theory a GIS is independent upon the map scale, but the information contents corresponds to a publishing scale – for a large scale more details are required, for a small scale the generalisation is stronger. In no case the full information is available in a GIS, for a large presentation scale the generalisation starts with the size of building extensions which are included, while for small scales the full effect of generalisation is required. This includes comprehension, selection and reduction, simplification of type, change to symbols and classification with underlining and shift. So for large presentation scales more details have to be identified in the images while for smaller scales a larger GSD may be sufficient. Independent upon the mentioned relation of GSD and publishing scale, there is a limit for the GSD-size. If the GSD exceeds 5m, not all details, usually shown in the corresponding publishing scale can be identified. So for example a single railroad line sometimes cannot be seen.

Not only optical images have to be taken into account, in the near future high resolution synthetic aperture radar (SAR) images will be available. Of course the information contents of a SAR-image is not the same like for an optical image with the same GSD, but radar has the advantage of penetrating clouds, so a mapping is possible also in rain-forest areas.

Within few years there will be an alternative between the satellite images and aerial images coming from high altitude long endurance (HALE) unmanned aerial vehicles (UAV) with an operating altitude in the range of 20km.

Several satellites carry more than one sensor, often a high resolution sensor together with low resolution, wide field sensor. The wide field imagers are small and not expensive. In the following, the low resolution wide field sensors are not respected. Not from all systems images are accessible, they may not be classified, but sometimes no distribution system exists and it is difficult to order images.

2. DETAILS OF IMAGING SENSORS

2.1 View Direction

The first imaging satellites have had a fixed view direction in relation to the orbit. Only by panoramic cameras, scanning from one side to the other, the swath width was enlarged. For a stereoscopic coverage a combination of cameras with different longitudinal view directions was used, like for the CORONA 4 serious and later MOMS and ASTER. With SPOT by a steer able mirror the change of the view direction across the orbit came. IRS-1C and -1D have the possibility to rotate the whole panchromatic camera in relation to the satellite. This requires fuel and so it has not been used very often. IKONOS launched in 1999 was the first civilian reconnaissance satellite with flexible view direction. Such satellites are equipped with high torque reaction wheels for all axes. If these reaction wheels are slowed down or accelerated, a moment will go to the satellite and it is rotating. No fuel is required for this, only electric energy coming from the solar paddles.

2.2 TDI-sensors

The optical space sensors are located in a flying altitude corresponding to a speed of approximately 7km/sec for the image on the ground. So for a GSD of 1m only 1.4msec exposure time is available. 1.4msec is not a sufficient integration time for the generation of an acceptable image quality, by this reason, some of the very high resolution space sensors are equipped with time delay and integration (TDI) sensors. The TDI-sensors used in space are CCD-arrays with a small dimension in flight direction. The charge generated by the energy reflected from the ground is shifted with the speed of the image motion to the next CCD-element and more charge can be added to the charge collected by the first CCD-element. So a larger charge can be summed up over several CCD-elements. There are some limits for inclined view directions, so in most cases the energy is summed up over 13 CCD-elements. IKONOS, QuickBird and OrbView-3 are equipped with TDI-sensors while EROS-A and the Indian TES do not have it. They have to enlarge the integration time by a permanent rotation of the satellite during imaging (see figure 1). Also QuickBird is using this because the sensor originally was planned for the same flying altitude like IKONOS, but with the allowance of a smaller GSD, the flying height was reduced, resulting in a smaller pixel size. The sampling rate could not be enlarged and this has to be compensated by the change of the view direction during imaging, but with a quite smaller factor like for EROS-A and TES.

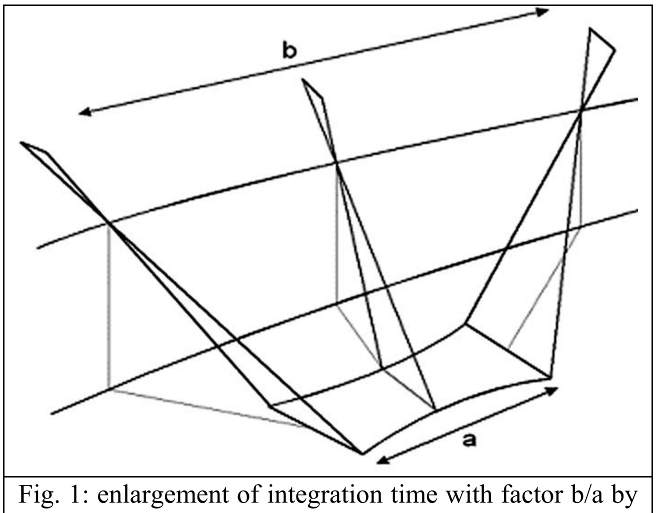

Fig. 1: enlargement of integration time with factor b/a by continuous change of view direction

2.3 CCD-configuration

Most of the sensors do not have just one CCD-line but a combination of shorter CCD-lines or small CCD-arrays. The CCD-lines are shifted against each other in the CCD-line direction and the individual colour CCD lines are shifted against the panchromatic CCD-line combination in the sampling direction (figure 2).

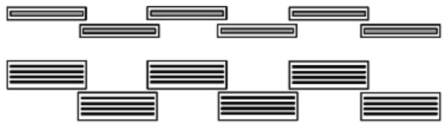

Fig. 2: arrangement of CCD-lines in focal plane
above: panchromatic below: multispectral

The merging of sub-images achieved by the panchromatic CCD-lines belongs to the inner orientation and the user will not see something about it. Usually the matching accuracy of the corresponding sub-images is in the lower sub-pixel range so that the geometry of the mosaiced image does not show any influence. This may be different for the larger offset of the colour CCD-lines. Not moving objects are fused without any problems during the pan-sharpening process. By theory only in extreme mountainous areas unimportant effects can be seen. This is different for moving objects – the time delay of the colour against the panchromatic image is causing different locations of the intensity and the colour (figure 3). The different colour bands are following the intensity. This effect is unimportant for mapping because only not moving objects are used.

Fig. 3: pan-sharpened IKONOS image

caused by the time delay of the colour imaging, the colour of moving objects are shifted against the grey value image

2.4 Staggered CCD-lines

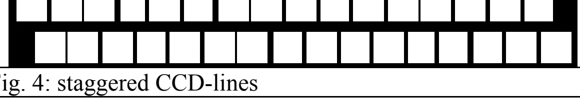

Fig. 4: staggered CCD-lines

The ground resolution can be improved by staggered CCD-lines (figure 4). They do include 2 CCD-lines shifted half a pixel against the other, so more details can be seen in the generated images. Because of the over-sampling, the information content is not corresponding to the linear double information. For SPOT 5 the physical pixel size projected to the ground is 5m, while based on staggered CCD-lines the super-mode has 2.5m GSD. By theory this corresponds to the information contents of an image with 3m GSD.

2.5 Multi Spectral Information

Sensors usable for topographic mapping are sensitive for the visible and near infrared (NIR) spectral range. The blue range with a wavelength of 420 – 520nm is not used by all sensors because of the higher atmospheric scatter effect, reducing the contrast. In most cases the multispectral information is collected with a larger GSD like the panchromatic. With the so called pan-sharpening, the lower resolution multispectral information can be merged with the higher resolution panchromatic to a higher resolution colour image. For example after IHS-transformation (transformation of red, green, blue (RGB) to the colour model intensity, hue, saturation (IHS)) and after linear enlargement of the number of pixels, the intensity channel coming from RGB is exchanged by the panchromatic channel and IHS is transformed back to higher resolution RGB. This pan-sharpening is using the character of the human eye which is more sensitive to grey values like for colour. A linear relation of 4 between panchromatic and colour GSD is common.

Because of the lower sun energy in the mid-infrared range, the GSD is larger for this like for the visible and NIR range. The panchromatic range does not correspond to the original definition – the visible spectral range. Often the blue range is cut of and the NIR is added to the spectral range of approximately 500nm to 900nm.

2.6 Imaging Problems

The human eye is able to separate approximately 64 grey values (6 bit), but it can adapt very well to the brightness. The imaging sensors cannot change the sensitivity very fast without influence to a homogenous image quality, by this reason they must be able to separate quite more grey values. Modern CCD-sensors used in space do have a radiometric resolution up to 11 bit, corresponding to 2048 different grey values. Usually there is not a good distribution of grey values over the whole histogram, but the important part can be optimised for the presentation with the 8bit grey values of a computer screen. The higher radiometric resolution includes also the advantage of an optimal use of the grey values also in extreme cases like bright roofs just beside shadow part. By high pass filter the important information for mapping can be optimised. Also for 11bit-sensors, there are some limits. If the sun light will be reflected by a glass roof directly to the sensor, an over-saturation will occur and the generated electrons will flow to the neighboured CCD-elements and the read-out will be influenced over short time. The over-saturation (figure 5) is not causing problems, but the human operator should know about it to avoid a misinterpretation of the objects.

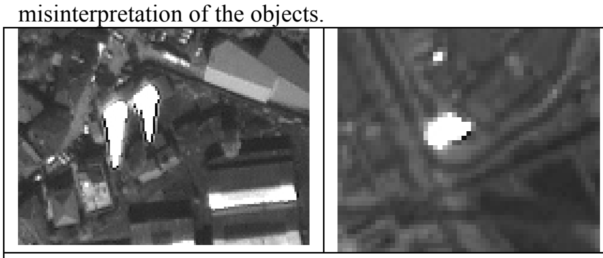

Fig. 5: over-saturation left: IKONOS right: ASTER

Some sensors do have only a limited radiometric calibration and improvement of the delivered images, visible in a striping effect. The human eye is very sensitive for this. For example the part of an ASTER image shown in figure 6 has only an average grey value difference of neighboured lines of 3.4 in relation to the mean grey value of 67, but this is disturbing the impression and also the object identification. By a simple shift of the grey values by half the mean difference of neighboured lines the effect can be removed.

2.7 Film Cameras

The first imaging satellites have been equipped with film like the US CORONA and the different Soviet cameras. The US brought back only the film capsular, while the Soviets got back the whole satellite and launched it again. Film in space now belongs to the history, used by Russia up to 2000. The old military reconnaissance photos have been released for civilian purposes. They are used especially for archaeological projects and change detection. The stereoscopic coverage by the high resolution CORONA KH-4-serious is helpful for accurate DEM generation.

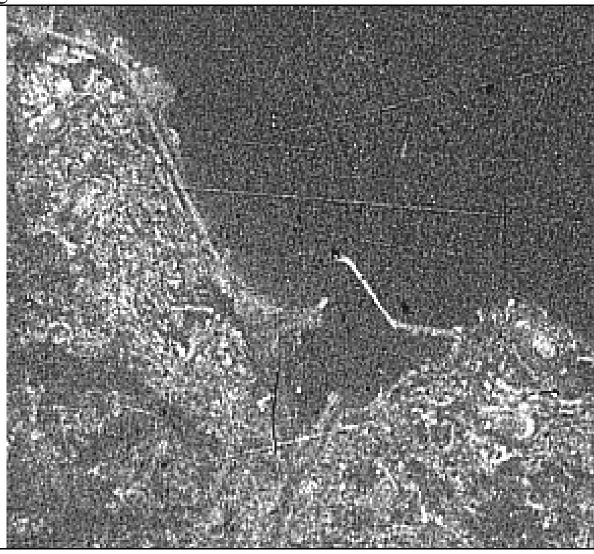

Fig. 6: scratches and film grain of a TK350 photo

Film has the disadvantage of the photographic grain limiting the resolution and sometimes also disturbing the interpretation. In addition some of the handled photos have been disturbed by a high number of scratches (Figure 6). So for a TK350 photo model the automatic matching of scanned images was nearly impossible without scratch removal by filtering.

2.8 Direct Sensor Orientation

The satellites are equipped with a positioning system like GPS, gyroscopes and star sensors. So without control points the geo-location can be determined with accuracies depending upon the system. For example IKONOS can determine the imaged positions with a standard deviation of approximately 4m. Often more problems do exist with not well known national datum.

3. IMAGING SATELLITES

Imaging satellites at first have been used for military reconnaissance reasons; this was one of the first satellite applications. So 20 month after the launch of SPUTNIK in October 1957 the US tests with the CORONA system started in 1959, but only the 11th launch was successful in August 1960 (McDonald 1997). The state of the art in that time allowed only the use of film with the difficult recovery. For reconnaissance the USA used film up to 1963 while the Soviet Union and later Russia made the last satellite photo flight in 2000. The historical images have been declassified by the USA in 1995, but also Russia is selling now the old images.

Based on film for civilian purposes, two Space Shuttle missions have been made. In 1983 the German Spacelab 1 mission Metric Camera (MC) used an only slightly modified Zeiss RMK 30/23 for taking images from space. This was the first civilian application especially made for mapping purposes. It was followed by the large format camera (LFC) test of the USA in 1984 using the especially designed camera with 23cm x 46cm photo format.

For civilian or dual use (use for military and civilian applications) the digital imaging from space started with Landsat 1 – at first named ERTS-1 – in 1972, but the GSD was not sufficient for mapping purposes. This changed with the French SPOT satellite, at first launched in 1986. With the stereoscopic possibilities and 10m GSD this system was used for the generation and updating of topographic maps up to a scale 1 : 50 000 but not with the same information contents of traditional maps in this scale. This has been improved with the Indian IRS-1C in 1995 having a GSD of 5.7m. The next big step came with the very high resolution IKONOS in 1999. Today there is a large variety of imaging sensors in space including not so expensive small satellite systems operated by a growing number of countries.

With the synthetic aperture radar (SAR) imaging radar systems are available which are independent upon the cloud coverage. Because of the speckle and quite different imaging conditions, the SAR images cannot be compared directly with optical images having the same GSD. So up to now only in tropical rainforest areas SAR has been used for the generation of topographic maps but this may change with the coming very high resolution SAR satellites.

system	first launch	GSD	swath / coverage [km]	stereo
military reconnaissance, USA				
Corona KH-1	1959	8-12m	17 x 260	-
Corona KH-2	1960	8-12m	17 x 260	-
Corona KH-3	1961	8-12m	17 x 260	-
Corona KH-4	1962	8m	17 x 260	2 cameras
Corona KH-4A	1963	2.7m	17 x 260	2 cameras
Corona KH-4B	1967	1.8m	17 x 260	2 cameras
Corona KH-5	1962	140m	285	frame
Corona KH-6	1963	0.15m	13 x 72	-
military reconnaissance, Soviet Union				
Zenith-2	1961	15-20m		60%
Zenit-4	1963	1m		60%
KATE-140		60m	440	60%
KATE-200		20m	240	60%
MKF-6	1978	20m	150-220	60%
MK-4	1988	8m	120-220	60%
KFA-1000	1988	5-10m	66-105	60%
KFA-3000		3m	22-35	-
KVR-1000	1981	2-3m	40*180	-
TK350	1984	10m	200*300	80%
civilian missions				
MC Germany	1983	30m	190	60%
LFC USA	1984	15m	190*380	60%

Table 1: imaging space missions based on film

Especially in the beginning several space missions failed. So from the 10 launches of CORONA KH-1 only one was successful while for the CORONA KK-4A only 3 of 52 missions failed. The highest ground resolution was possible with panoramic cameras like the CORONA serious without KH-5 and the similar KVR-1000. Also for military reconnaissance a stereoscopic coverage was important, so the most often used CORONA 4-serious was equipped with 2 convergent mounted cameras. The Soviet Union preferred frame cameras for getting the 3rd dimension – they used for example the KVR-1000 in combination with the TK-350. The swath and the ground coverage especially for the Soviet cameras was not always the same because of different flying altitudes.

system	launch	GSD [m] pan / MS	swath [km]	remarks
SPOT 1 France SPOT 2 SPOT 3 SPOT 4	1986 1990 1993 1998	10 / 20	60	+/-27° across orbit
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
IRS-1D India	1997	5.7 / 23	like IRS-1C	
IRS P6 India Resourcesat	2003	5.7 MS	24 / 70	+/-26° across
KOMPSAT-1 South Korea	1999	6.6 pan	17	+/-45° across
CBERS-1 China + Brazil	1999	20	113	+/-31° across
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 dir., TDI
FORMOSAT-2 Taiwan	2004	2 / 8	24	free view dir., TDI
IRS-P5 Cartosat-1 India	2005	2.5 pan	30	-5°, +26° in orbit

Table 2: larger optical space sensors
MS = multispectral fore = view forward in orbit direction
aft = backward in orbit direction

The space images got a growing market share in photogrammetry. They have been established as a completion and partially as replacement of aerial images. They can be used in remote locations and "no-fly"-zones. In several countries aerial images are classified and a commercialisation is complicate or impossible. Because of the availability of very high resolution space imagery there is no more justification of such a classification, but some governmental organisations like to keep their importance by such restrictions. Space images can be used by private companies for the generation of the different photogrammetric products even if some countries still try to restrict it.

There is a general tendency in the development of high resolution optical space sensors: the resolution is improving and the new systems do have a flexible view direction. By reaction wheels the whole satellites can change the attitudes in a controlled manner very fast and precise enough to generate images also during the rotation. This has advantages against the change of the view direction just across the orbit direction – a stereoscopic coverage can be generated within some seconds, while for the view direction across the orbit, the second image has to be taken from another orbit; that means under optimal conditions at the following day. If the weather conditions do not allow an imaging during the next days, it may happen that the imaged objects do change and a stereoscopic impression is getting more difficult or will become impossible. So for example in the case of a SPOT stereo pair of the Hannover region the first image has been taken in June when the grain was green and the second in August, when the grain became yellow. So in the rural areas a stereoscopic handling was impossible. SPOT Image reacted to this problem with the additional HRS-sensor on SPOT5 viewing with two optics 23° forward and 23° backward in the orbit direction, allowing a stereoscopic coverage within approximately 100 seconds. A similar solution is also available for ASTER and based on 3 view directions it has been used by MOMS before. The backward view of Japanese ASTER instrument, located on the US Terra platform, has only the red channel, which can be combined with the red nadir channel. ASTER has no panchromatic band. Reverse with KOMPSAT-1, EROS A1 and TES three of the listed systems in table 2 do have only a panchromatic band – they are mainly designed for mapping purposes.

The very high resolution systems IKONOS, QuickBird, OrbView and EROS A1 are operated by private companies. Without financial support by military contracts they would not survive, so in reality they are belonging to dual use – the used is dominated by military, but the free capacity is commercially available. So there are still some restrictions – the images from the US companies are not released within 24 hours of its collection and for EROS A1 images the military has the priority of data collection. This is similar for most of the systems.

The very high resolution systems EROS A1 and TES are not equipped with TDI-sensors, so they have to enlarge the exposure time by continuous change of the view direction (see figure 1). This has only a limited influence to the radiometric and geometric image quality, but it is reducing the imaging capacity. QuickBird originally was designed for the same GSD like IKONOS, but before launch the USA reduced the restriction for the GSD from 1m to 0.5m and DigitalGlobe reacted with a reduction of the flying height from 680km to 450km leading to a GSD of 0.62cm. But it was not possible to increase the sampling frequency, which is respected by a factor b/a = 1.5 (see figure 1).

SPOT 5 with the super mode and OrbView are improving the GSD by staggered linear CCDs. An edge analysis of both image types did lead to a GSD identical to nominal resolution. But the analysed images have been edge enhanced like most of the space images and this is leading to optimistic results.

The access to the images is well organised by the commercial companies, but also SPOT Image and India based on distribution over a net of commercial distributors. For the FORMOSAT-2 (before named ROCSAT-2) SPOT Image got the exclusive distribution right. The ASTER images are available Web-based for a handling fee over US administration. Also Japan has solved the distribution of the not more active JERS-1 images like Germany for the existing MOMS-images via the DLR. Only for KOMPSAT and CBERS the distribution is more difficult, but possible. TES-images are not available.

The required technical knowledge and the access to the required components was limiting the imaging satellites to just few countries, but today the major components and partially the whole systems can be ordered. So the FORMOSAT-2 satellite has been made by the European EADS ASTRIUM. A similar cooperation exists for the small satellites (table 3). The launch is also not a problem – there is a strong competition. Because of the lower price Russia is dominating the launches, followed by the USA, China, Europe, the private Sea Launch and India.

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	2000	15	52	
Alsat 1 Algeria	2002	32 MS	600	DMC
BilSat 1 Turkey	2003	12 / 28	24 / 53	DMC
BNSCSat UK	2003	32 MS	600	DMC
NigeriaSat Nigeria	2003	32 MS	640	DMC

Table 3: small optical space sensors

With the reduced size and weight of electronic components, the imaging satellites can be smaller today, leading to small satellites with a weight below 200 kg (table 3). These systems have been separated from the previously listed because of the limited access to the collected images mainly used only by the owning countries. A strong position in this field has the Surrey Satellite Technologies (SSTL), a spin-off of the Surrey University, UK. SSTL made the UOSAT12 and all the satellites belonging to the disaster monitoring constellation (DMC). In the case of natural disasters the DMC satellites are cooperating to generate as fast as possible images from the affected area. The satellite constellation guarantees a daily coverage of the earth by images having the Landsat-ETM bands 2, 3 and 4. SSTL is using off-the-shelf components and so the price for a satellite system including launch and ground station today may be in the range of 10 million US$. The small satellites do have a free view direction. Partially they are equipped with CCD-arrays instead of CCD-line. The designed life time of the small satellites is with 2 to 4 years shorter like for the large systems.

Optical images only can be taken under cloud free condition and with sufficient sun light. So all systems listed in tables 2 and 3 do have sun-synchronous orbits with imaging between 9:30 and 11:00 pm - the day time with the best viewing condition. This is different for radar satellites. Radar can penetrate the clouds and is an active system, independent upon the sun light. The GSD of 10m and larger is not sufficient for topographic mapping – the information contents of SAR-images is below the information contents of optical images with the same size. So only in tropical rain forest areas SAR-images have been used for topographic mapping. But in interferometric constellation (IfSAR) SAR-image combinations can be used for the generation of height models. So ERS-1 and ERS-1 have been operated for a period of approximately 1 year in the tandem constellation for DEM generation. By the Shuttle Radar Topography Mission (SRTM) a homogenous and qualified DEM covering the earth from 56° southern up to 60.25° northern latitude has been generated (Jacobsen 2005).

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 IfSAR
ENVISAT ESA	2002	30-1000	100-405	C-band 5.6cm full polarisation

Table 4: SAR space sensors

system	launch	GSD [m] pan / MS	swath [km]	remarks
IRS Cartosat-2, India	2005	1 pan	10	free view direction
ALOS, Japan	2005	2.5 / 10	35 / 70	-24°, nadir, +24° in orbit
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 dir., TDI
EROS C Israel	2009	0.7 / 2.8	11	free view dir., TDI
RazakSat Malaysia	2005	2.5 / 5	20	free view dir inclin. 7°
CBERS 2B China, Brazil	2005/ 2006	2.5 / 20		+/-32° across
CBERS-3 + 4 China, Brazil	2008	5 / 20	60/ 120	“
WorldView 1 DigitalGlobe	2006	0.5 / 2		free view dir. TDI
OrbView 5 OrbImage	2006	0.41 / 1.64	15	free view dir. TDI
THEOS Thailand	2007	2 / 15		free view dir. TDI
Pleiades 1 + 2 France	2008 2009	0.7 / 2.8	20	free view dir. TDI
KOMPSAT-3 South Korea	2009	0.7 / 2.8		free view dir. TDI

Table 5: announced larger optical space sensors

A higher number of optical satellite systems are announced (tables 5 – 7). The proposed launch time often is delayed and some systems may disappear or the launch may fail. The specification of the systems may change or in some cases they are not fixed or published jet. But today it is not any more so time consuming to assemble qualified reconnaissance satellites, so additional systems may come. There is a general tendency – the GSD is getting smaller, the weight is reducing, TDI will become standard, very high resolution SAR sensors will come and dual use is reducing the expenses for the countries and is enabling a commercial use. Nearly all satellites will be equipped with reaction wheels leading to high agility and free view direction. Two systems – ALOS and Cartosat-1 – are designed especially for 3D-mapping based on three or two cameras having different nadir angles in orbit direction for the generation of stereo models with only some second difference in time. Of course also the satellites with free view direction can generate stereo models within the same orbit, but this is reducing the imaging capacity.

Within the NextView program of the USA contracts have been made with DigitalGlobe and OrbImage for operating satellites with at least 50cm GSD in the panchromatic range. The GSD for nadir view will be smaller, but the USA is restricting the GSD to at least 50cm, so the commercial available images will be limited to this. More and more countries are entering the field of commercial very high resolution optical systems. A GSD of at least 1m will be supported by the USA, India, Israel, France, South Korea and Russia. Up to 2.5m GSD in addition there are Malaysia, China, Brazil, Thailand and the UK. Of course there are also military systems available or will come, but they are not respected here.

Some of the systems will carry also low resolution wide field sensors, they are small, not heavy and do need only limited satellite resources. These systems are not listed.

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 dir., TDI
X-Sat Singapore	2006	10 MS	50	
RapidEye Germany commercial	2007	6.5 MS	78	free view direction, 5 satellites

Table 6: announced small optical space sensors

Again the small satellites are listed separately because of in most cases missing distribution systems. Most of the small optical satellites are assembled by SSTL including also Rapid Eye. Rapid Eye will be a system of 5 small satellites, mainly for use by high tech agriculture. It will be the first commercial system outside the area of dual use.

system	launch	GSD [m]	swath [km]	remarks
SAR-X Cosmo-Skymed-1 Italy	2006	1- several 10th	10-few hundreds	X-band 3.1cm
RADARSAT-2,	2006	3 –	20-500	C-band

Canada		100		5.6cm, full polarisation
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 7: announced SAR space sensors
ppp = private public partnership

With SAR-X Cosmo-Skymed-1 and TerraSAR-X two radar systems with a GSD of 1m are announced. SAR images with such a resolution can be used for mapping purposes. A comparison of mapping with high resolution SAR and optical images was leading to an identification of 60% up to 100% of the elements in SAR-images in relation to optical images with the same GSD (Lohmann et al 2004). So the information contents of the 1m SAR-images may be in the range of optical images with 2m GSD. SAR-images do have the big advantage of being independent upon the cloud coverage – this is important for regions like Germany having only few cloud free days. With RADARSAT-2 and RISAT two systems with a GSD of 3m will come in addition. Export restrictions of the USA delayed the completion of the RADARSAT-2 satellite which was now constructed with Italian support.

Terra SAR-X will be operated under private public partnership of the German Aerospace Center DLR and EADS ASTRIUM. SAR-X Cosmo-Skymed-1 will be operated by Italy in cooperation with France within the dual use ORFEO program. Under this cooperation France will operate two very high resolution optical system Pleiades and Italy four SAR-system.

The Tandem X project is under investigation which shall include a second TerraSAR-X in tandem configuration for the generation of digital elevation models fulfilling the DTED-3 specifications with better than 12m DEM point spacing and a vertical accuracy of 2m and better. For the SAR-X Cosmo-Skymed-1 the so called Cartwheel is studied, it could include one active SAR-satellite together with 3 to 4 passive micro satellites for the generation of DEMs with a standard deviation of 1m.

4. HALE UAV

High altitude long endurance (HALE) unmanned aerial vehicles (UAV) may be in future a completion, on the contrary also a competition to space and aerial images. Up to now UAVs are mainly used for military reconnaissance, but like for the reconnaissance from space it seems to lead also to civilian application. With Pathfinder Plus the NASA made the first tests in 1998. It is powered by sun energy and able to stay for long time in high altitude.

Fig. 7: HALE UAV Pegasus – design model

The Belgian Flemish Institute for Technological Research VITO plans the first test flight of its HALE UAV Pegasus for 2006. 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 at 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 conditions for mapping with high and very high space images are improved permanently. More and more sensors are entering the field leading to better coverage and the possibility to select the optimal solution. The image data bases are becoming more and more complete, allowing a fast access corresponding to the requirement. The competition between the different distributors has improved the order conditions and partially was leading to reduced prices. On the other hand the high expenses for the large systems cannot be covered by civilian projects. Without dual use the private companies in this field cannot survive. This may change with the raising capacity of small satellites.

Not only the optical images, also synthetic aperture radar has to be taken into account. With the very high resolution of the announced systems, SAR is becoming important for mapping purposes. With IfSAR accurate digital surface models can be generated. Only in mountainous areas IfSAR and also SAR do have some problems by lay over.

The operation of high resolution satellites is not any more restricted to few countries with advanced technology. More and more components of the shelf can be used and in addition satellites can be ordered from different manufacturers. So in the above listed tables in total 22 countries are mentioned.

With the improving ground sampling distance space images do come into competition with aerial images. Because of classification of aerial photos, in some regions space images became more important than in countries without restrictions. In near future with the HALE UAV there will be a stronger overlap of the applications. Very high resolution space images are not only a supplement or competition to aerial photos; they are also in use for new applications.

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