3D-Remote Sensing, Status Report 2008

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ABSTRACT: Since the 27th EARSeL symposium 2007 in Bolzano with WorldView-1 and Cartosat-2A two more very high resolution optical satellites of a new group have been launched. Images with a ground sampling distance (GSD) of 0.45m, which will be distributed with 0.5m GSD, are operational available. In August 2008 GeoEye-1 shall be launched, having even 0.42m GSD. With CBERS 2B an additional high resolution is in space. The system of 5 RapidEye satellites shall follow. The high number of new satellites gives a strong push to the 3D-Remote sensing. The wide spread of the stereo systems Cartosat-1 and ALOS/PRISM has improved the possibility of generating detailed and accurate digital elevation models based on space images. An overview of the new optical systems, but also a short information about new radar satellites and in near future planned missions together with the influence to the practical application is given. Only systems available for civilian use are respected in this overview.

As new trend in aerial application we have with mid format digital aerial cameras and the combination of vertical and oblique images like from Pictometry and Multivision. The digital mid format are now completed by combinations of cameras, closing the gap to the large format digital cameras.

Digital height models can be generated by interferometric synthetic aperture radar (IfSAR) or by automatic image matching. The images used for image matching should be taken within a short time interval to avoid changes of the object and different shadows. Stereo systems generating stereo combinations in general have some advantages.

1 INTRODUCTION

Detailed earth observation determining or respecting the three-dimensional shape of the earth surface and usable for mapping purposes is dominated by the used sensors. Low or medium resolution systems like Landsat cannot be used for this task. The first civilian use of satellite images for 3D-mapping came with SPOT 1 in 1986, but with 10m ground sampling distance (GSD) the accuracy and identification of object details is limited. With IRS-1C in 1996 the GSD was improved to 5.8m, but the real break through of the use of space images for detailed information extraction came with IKONOS in 1999. Today we have several high and very high resolution optical satellites. The number is permanently growing and also the resolution is improving, just now images taken by WorldView-1 are distributed with 0.5m GSD. The Indian space organisation ISRO plans Cartosat-3, to be launched in 2011, with 0.35m GSD and the US company GeoEye made a proposal for GeoEye-2 with 0.25m GSD. The last requires a change of the US governmental limitation of the distribution of space images to currently at least 0.50m GSD. With stereo satellites like Cartosat-1 and ALOS/PRISM optimal conditions for the generation of digital elevation models (DEM) exist. In this presentation only civilian or dual use systems are respected. Most of these sensors are used for military and civilian application. Without military or secret service application we would not have such a variety of reconnaissance satellites, which we can use now also for civilian projects. Only a very limited number of systems are only based on civilian use like the German TerraSAR-X and the announced RapidEye. Sensors with medium resolution (above 10m GSD) are mainly used for land-use monitoring, they are also not included here. A special position has ASTER, allowing the generation of height models by the stereo system with 16m GSD. This sensor belongs to the overlap of the land-use monitoring and the mapping.

The optical space images are competing with aerial images. Of course the highest resolution is only possible from air, here a clear tendency to digital cameras exist. Beside the large format digital cameras also digital mid format cameras are becoming more important, supported by CCD-arrays with more pixels. In addition combinations of mid-format cameras are closing the gap to large format cameras. As platform of light weight cameras unmanned aerial vehicles are used more often, supported by partially automatic steering of these devices.

Beside very high resolution optical space images, now also very high resolution synthetic aperture radar (SAR) images are available with TerraSAR-X having the advantage of imaging through clouds. With interferometric SAR from aircraft large areas have been covered by DEMs for private companies. Such a competition to survey administrations is growing.

Laser scanning from air, also named LIDAR is used more and more for very precise and high resolution DEMs, also in not too dense forest areas.

2 SENSORS

2.1 Optical Imaging Sensors

2.1.1 Optical Satellites

Figure 1 gives an overview about the launch of the high and very high resolution optical satellites and their best ground resolution. All these systems are imaging with CCD-lines, generation the scenes by the movement and/or angular movement of the satellites. Today the majority of high and very high resolution optical satellites are flexible satellites, able to change the view direction fast and precise based on reaction wheels or control moment giros. The change of the view direction usually is precise enough to use it also during imaging without loss of accuracy.

The optical satellites today are usually equipped with positioning systems like GPS, gyros for the attitude determination and star trackers for the absolute determination of the satellite attitude (figure 2). Based on this equipment the exterior orientation of the sensor can be determined. In the case of IKONOS this is possible with a standard deviation of 4m without use of control points, for WorldView-1 Digital Globe talks about 2.5m. The other sensors are not so accurate, requiring in any case control points for the correct geo-reference, but this is also recommended for IKONOS and WorldView-1 at least for a check and for a correct handling of the national net datum – the relation between the national coordinates and WGS80 in ITRF (international terrestrial reference frame).

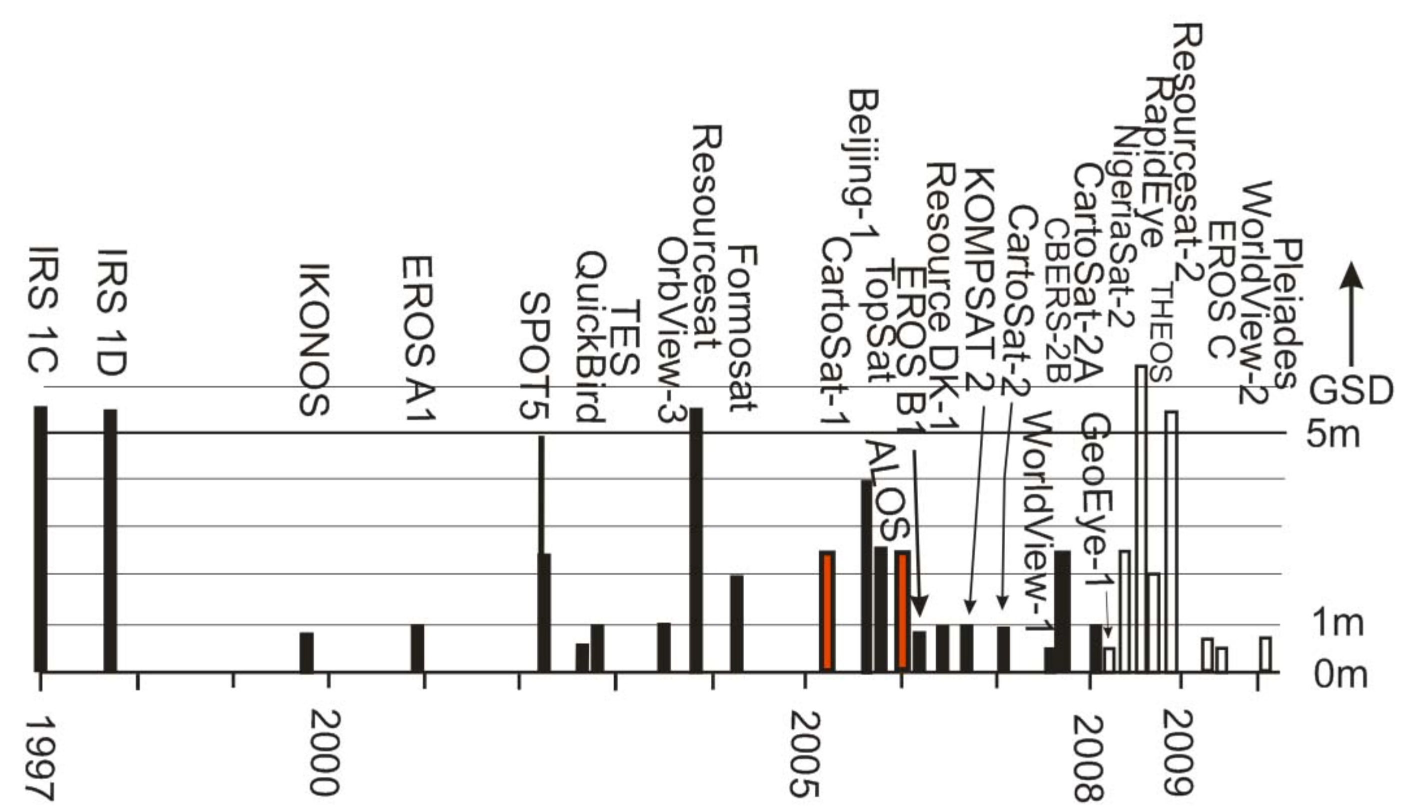


Fig. 1: high and very high resolution optical satellites available for civilian use in sequence of launch with their best GSD

As obvious in figure 1, the number of launches of such systems stays on a high level, the number of very high resolution optical sensors is growing permanently and with WorldView-1 0.45m GSD has been reached (figure 3). Because of a legal restriction in the USA only images with 0.5m GSD are distributed by US companies. This limitation will be used also for GeoEye-1, scheduled for launch in August 2008. GeoEye-1 will have 0.42m GSD for nadir view.

In addition in 2009 WorldView-2 shall be launched, it will have the same panchromatic resolution like WorldView-1, but also 8 spectral channels. In addition to the classical blue, green, red and near infrared a costal channel, yellow, red edge and a short-wave-infrared channel will be available.

The high resolution systems Resourcesat and RapidEye have a good spectral resolution with 4, respectively 5 spectral bands. They are more directed to land use monitoring, but with 5.8m and 6.5m GSD they are at the limit for mapping purposes.

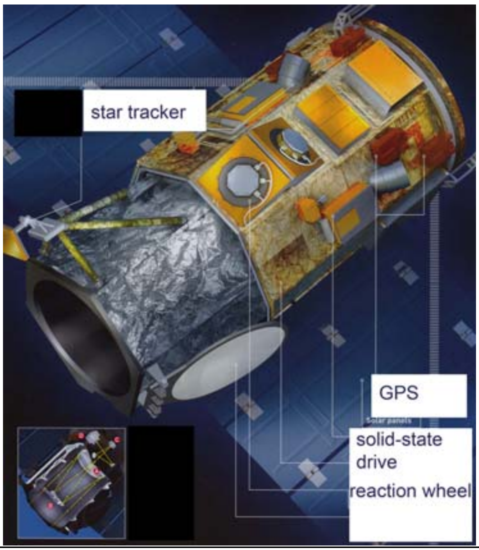


Fig. 2: GeoEye-1; Typical hardware components of a high resolution optical satellite courtesy: GeoEye

Fig. 3: Dolmabace palace, Istanbul in WorldView-1 image 0.5m GSD

sensor	country	GSD (nadir) [m]	swath [km]	pointing in-track	pointing across
SPOT 1-4	France	10 / 20	60	-	+/-27°
SPOT 5	France	5 (2.5) / 10	60	-	+/-27°
SPOT 5 HRS	France	5 x 10	120	+20°, -20°	-
MOMS-02 / -P	Germany	5.8 / 16.5	37 / 78	-27°,0°,27°	
IRS-1C/1D	India	5.8 / 23.5	70 / 142	-	+/-26°
Resourcesat	India	- / 5.8	70	-	+/- 26°
KOMPSAT	S. Korea	6.6	17	-	+/-45°
Terra ASTER	Japan	15 / (30, 90)	60	0°, 27.2°	
IKONOS	USA	0.82 / 3.2	11.3	free view direction	
EROS A	Israel	1.8	12.6	free view direction	
QuickBird	USA	0.61 / 2.44	16.4	free view direction	
OrbView 3	*USA*	*1 / 4*	*8*	*free view direction*	not active
EROS B	Israel	0.7	14	free view direction	
FORMOSAT 2	Taiwan	2 / 8	24	free view direction	
IRS-P5 Cartosat-1	India	2.5	30	26° fore, 5° after	free view to side
TopSat	UK	2.5 / 5	15 / 10	free view direction	
Beijing-1	China	4 / 32	/ 600	free view direction	
ALOS	Japan	2.5	35 (70)	-24°, 0°, +24°	free view to side
KOMPSAT-2	S. Korea	1 / 4	15	free view direction	
Resource DK1	Russia	1 / 3	28	free view direction	
IRS Cartosat-2	India	<1	9.6	free view direction	
WorldView-1	USA	0.45	15.8	free view direction	
CBERS-2B	China/Brasil	2.5 / 20	27 / 120	free view direction	
IRS Cartosat-2A	India	1	10	free view direction	

table 1: high and very high resolution optical satellites available for civilian use

sensor	country	proposed launch	GSD (nadir) [m]	swath [km]	remark
GeoEye-1	USA	August 2008	0.42 / 1.64	15	
RapidEye	Germany	July 2008	- / 6.5	78	5 satellites
Resourcesat-2	India	2008	5.8 / (23.5)	70/140	+/-26°
NigeriaSat-2	Nigeria	2009	2.5 / 5		
WorldView-2	USA	2009	0.45 / 1.8	15	pan + 8 spectral
THEOS	Thailand	2009	2 / 15	22 / 90	
EROS C	Israel	2009	0.7 / 2.8	11	
Pleiades	France	Begin 2010 + 11	0.7 / 2.8	20	Follow on of SPOT
Cartosat-3	India	2011	0.35 / -		
ResourceSat-3	India	2011	2.5 / 5.8	25	
GeoEye-2	USA		0.25 /		proposal

table 2: proposed high resolution optical satellites available for civilian use

The development of the optical sensors is continuing as shown in table 2. The resolution will be improved and more systems will come, which will not just replace old systems. Table 2 is not a complete list, in addition the proposals may be changed and very often the launch is postponed. Also additional countries, like Turkey, will launch very high resolution optical satellites, but no clear specifications are available yet.

There is a clear tendency to smaller satellites, reducing the overall cost. The electronic components are getting smaller and most new systems are limited to just one camera. From table 1 TopSat, Beijing-1, the not more active OrbView-3 and the EROS-satellites are belonging to the group of satellites with a weight below 500kg, while ALOS has a weight of 4 tons and Resource DK1 even 6.8 tons.

The Indian space organisation ISRO has the most complete program for earth observation satellites from very high up to low resolution systems. It has a dense program for the development of improved optical and radar satellites and replaces also old systems. From 1995 up to 2007 ISRO launched successful 9 earth observation satellites and this program will be continued with 3 more systems in the next 2 years and 4 satellites in 2011.

The distribution of the satellite images is an important factor, causing a sharing of different satellite products to major distributors. For example SPOT Image is also distributing Formosat-2 and KOMPSAT-2 images and enlarging so the product group over 5m, respectively 2.5m GSD (for supermode) panchromatic SPOT images to 2m and 1m GSD. For longer time it was difficult to get images from the Disaster Monitoring Constellation (DMC), constructed by Surrey Satellite Technologies Ltd (SSTL), UK. SSTL has build satellites with 32m GSD for the multispectral range for Algeria, China, Nigeria, Turkey and the UK, Spain will follow soon. Beijing-1 belongs to this group, but it is equipped in addition with a 4m panchromatic camera. The Images are now distributed by DMC International Imaging, UK. SSTL has build also the TopSat satellite having 2.5m panchromatic GSD. All these satellites are belonging to the group with less than 500kg weight. The DMC constellation will be continued with the Deimos Satellite for Spain, having an improved resolution of 22m instead 32m like the group before; it shall be launched 2008. For Nigeria a second satellite shall be launched 2009 with 2.5m GSD for the panchromatic band.

To manage large disasters like caused by earthquakes, floods, forest fires and oil spills, with social and economic relevance for Earth and mankind, the International Charter "Space and Major Disasters" was initiated at the UNISPACE III in Vienna in 1999. The major earth observation organizations are participating and after official declaration of a disaster, they are trying to get images of the affected area, so that organizations like the Center of Satellite Based Crisis Information of the DLR are able to generate very fast ortho-maps of the affected regions as support for the local operating help organizations.

2.1.2 Aerial Cameras

New aerial cameras are digital cameras. The large format digital cameras Z/I Imaging DMC, Vexcel Imaging UltraCamD and UltraCamX like also the line scan camera Leica ADS40 are well established and are taking over the imaging from standard photogrammetric film cameras. The change from film to digital systems is faster than expected few years ago. As new development we have the growing use of mid format digital cameras, equipped with just one CCD-array, using a Bayer pattern for generating colour images. With the new Kodak CCD-array having 5412 x 7216 pixels a capacity of 39 Mpixels has been reached. This CCD-array is also used in the UltraCamX, leading to the improved number of pixels against the UltraCamD.

For metric application fix-focus systems are required like the Applanix DSS, IGI DigiCam and Rolleimetric AIC. All these cameras are equipped with the just mentioned Kodak CCD-array. The gap between the mid-format and the large size digital cameras is closed by combinations of more than one mid-format system. DIMAC is using like IGI (figure 4) a combination of 2 cameras with shifted principal point, allowing the merge of 2 parallel used single camera images to a homogenous larger virtual image. Rolleimetric is offering beside a combination of 2 AIC-cameras also the use of 4 oblique mounted AIC (figure 4). The combination of vertical and oblique images got very fast a widespread use by companies like Pictometry and Multivision. The required images can be taken by cameras like Track'Air MIDAS, viewing to the nadir and into 4 oblique directions, partially not with overlap to the nadir image.

		
combination of 2 IGI DigiCam	Rolleimetric AICx4	Track'Air MIDAS camera system

Fig. 4: combinations of digital mid-format cameras

2.2 Laser scanner (LIDAR)

The use of laser scanners became standard for very precise and detailed digital elevation models in several countries. The range for the flying height has been enlarged, limiting the possible pulse rate because of the time of flight, but the first systems have reduced this problem by handling more than one pulse during the time interval required for sending up to receiving again the same pulse. Of course the point spacing is influenced by the flying height, but this can be fitted to the requirements.

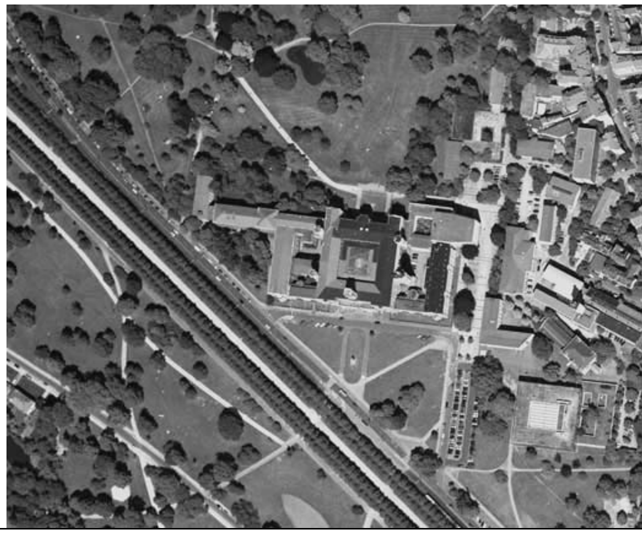
For very high accuracy specifications in the range of 10cm standard deviation of the height, the orientation of the point clouds for every flight line has to be improved by a procedure similar to the former model block adjustment.

2.3 Synthetic Aperture Radar (SAR)

SAR is used from space and from aircraft. With the German TerraSAR-X and the Canadian Radarsat-2 the possible ground resolution from space has been improved drastically. The ground resolution and the swath of SAR are depending upon the imaging mode. TerraSAR-X has in the SpotLight mode 1m GSD, in StripMap mode 3m GSD and in ScanSAR 16m GSD, while Radarsat-2 has in total 11 different modes from Ultra-Fine with 3m GSD up to ScanSAR Wide with 100m GSD. Corresponding to the GSD the swath width of Radarsat-2 varies between 20km and 500km.

The information contents of SAR-images having the same ground resolution like optical images cannot be compared directly (figure 5). At first the imaging is totally different – the object reflection of the spectral range used by optical images is mainly depending upon the chemical situation of the object, while radar is mainly depending upon the physical situation of the surface. The interpretation of SAR-images requires a special training and understanding of SAR-imaging. Special problems exist in build up areas with the radar lay over – the return signals from the facades and partially roofs are mixed with the return signal from the ground in front of the buildings. In addition total reflections by corners are causing problems like also the speckle. Of course the speckle can be reduced by filtering, but this causes also a loss of information. On the other hand some special objects like railroads with the metallic rails can be seen clearer like in optical images. The main advantage of SAR images is still the penetration through clouds – for SAR-images the partially painful waiting for cloud free weather does not exist.

TerraSAR-X SpotLight image



Optical image

Fig. 5: comparison of SAR-image with optical image – both with 1m GSD; main building University Hannover

Fig. 6: multi polarization (HH/VV) TerraSar-X SpotLight image reduced by factor 2
city of Dresden

The information contents of SAR-images can be improved by multi polarization like shown in figure 6. By the combination of HH and VV polarization the image interpretation is improved.

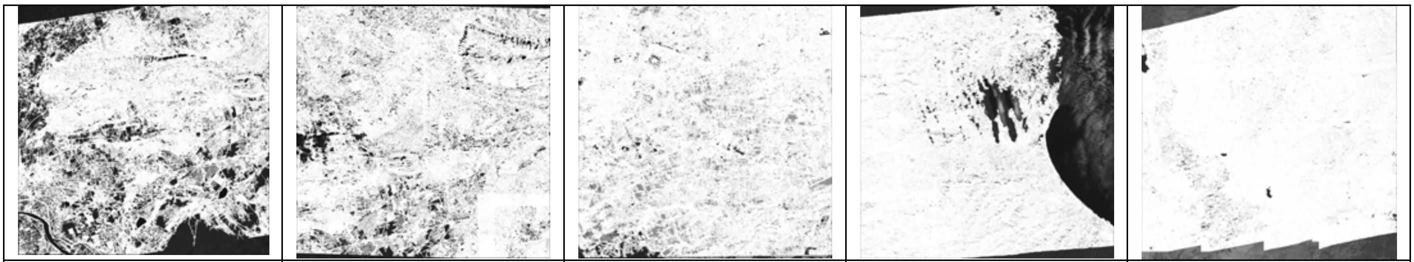
An important advantage of SAR-images is the combination of 2 images, taken with a small base length, to interferometric SAR (IfSAR), allowing the determination of digital height models. From space this has been done with the Shuttle Radar Topography Mission (SRTM), generating a nearly worldwide coverage (Passini et al 2007). The height models of SRTM are available free of charge in the internet, having a spacing of 3 arcsec, corresponding to ~92m at the equator. The standard deviation of the height values is in the range of 4m up to 12m depending upon the terrain inclination and the land cover – the highest accuracy is reached in flat and open areas. The used C-band of SRTM cannot penetrate the vegetation, so not digital elevation models with the height of the bare ground, but digital surface models (DSM) with the height of the visible surface are generated.

TerrSAR-X will be completed by a second, identical satellite to a tandem configuration in 2009. Both SAR-satellites are joint together to the TanDEM-X configuration, where both satellites will have a base between 0.5km and 2km. Based on this configuration worldwide height models shall be generated with 12m point spacing and a standard deviation of 2m (Pitz 2006).

The Canadian company Intermap has generated height models of the USA, Great Britain and Western Europe as NEXTMap USA, NEXTMap Britain and NEXTMap Europe by IfSAR from aircrafts operating in 6km up to 9km flying height. The NEXTMap products have a point spacing of 12m and shall have a vertical standard deviation of 1m and a horizontal accuracy of 2m. Intermap generated these height models without contract from governments. The sold height models in most countries are less expensive than height models from survey administrations.

3 HEIGHT MODELS FROM OPTICAL IMAGES

Height models are a basic requirement for geo information systems (GIS). They have to be used for the most often generated product, the ortho image. If the available height models are not accurate enough, have not sufficient point spacing or if existing height models are too expensive or not distributed, height models have to be generated. One possibility is the generation of height models by automatic image matching. This requires stereo models where both images have to be taken under similar conditions. Optimal is the imaging of both used scenes during the same path, avoiding changes of the object and different illumination conditions. With the today dominating flexible satellites in most cases the acquisition of a stereo pair from the same orbit is possible. Nevertheless only a limited number of stereo pairs are available in the image archives because of economic reasons; this is different for the stereo systems like ASTER, SPOT-5 HRS, Cartosat-1 and ALOS/PRISM. Based on 2 or 3 optics, they are generating permanently stereo models. The images taken by SPOT-5 HRS cannot be ordered, SPOT Image only likes to distribute height models based on it. The SPOT-5 HRS height models over forest areas should be handled with care because of the limited spectral range of the images between 0.48µm and 0.70µm. This is not leading to sufficient image contrast in forest areas (Büyüksalih et al 2008). ASTER stereo pairs are taken in the near infrared spectral range, optimal also for matching in forest areas, but the 15m GSD limits the vertical accuracy to approximately 15m (Sefercik et al 2007). ASTER/PRISM images have some problems with the image quality, but this seems not to influence the results of the image matching. In addition the orientation based on sub-images requires more control points than the orientation of a full scene. Very good results have been achieved with Cartosat-1 stereo pairs. The images are covering a spectral range from 0.50 up to 0.85µm, including the near infrared, leading to good contrast in forest regions. Even in difficult regions a good coverage by matched points has been reached (Jacobsen, 2007, Büyüksalih et al 2008, Jacobsen et al 2008).



Mausanne Jan.	Mausanne Feb.	Warsaw	Istiranca	Jordan

Fig. 7: Cartosat-1 - overlay of matched points (white) to after scenes

The gaps in matching Cartosat-1 scenes (figure 7) are caused in the case of Mausanne by missing contrast in fields without vegetation, in Warsaw by areas covered by snow, in Istiranca by clouds and in Jordan by lakes and fields without vegetation. No other optical satellite could lead to completer matching results. The automatic image matching leads to the height of the visible objects, that means to digital surface model. If a mixture of points located on the ground and located on objects, like trees and buildings, is given, the points not belonging to the bare surface can be filtered. By filtering the standard deviations of the height values have been improved in any case (table 3).

		SZ	bias	SZ as F(terrain inclination α)
Mausanne January	open areas	4.02	-0.51	$3.91 + 1.64 * \tan \alpha$
	open areas filtered	3.30	0.48	$3.17 + 3.14 * \tan \alpha$
Mausanne February	open areas	4.13	-1.16	$3.96 + 3.06 * \tan \alpha$
	open areas filtered	3.39	-0.58	$3.22 + 1.97 * \tan \alpha$
Warsaw	open areas	3.23	-0.54	$3.16 + 1.19 * \tan \alpha$
	open areas filtered	2.43	0.44	$2.39 + 8.80 * \tan \alpha$

Table 3: accuracy of Cartosat-1 height models checked by precise reference DEMs

As it can be seen in table 3, the height accuracy is depending upon the terrain inclination. For flat and open terrain after filtering root mean square differences of the DEMs based on Cartosat-1 against reference height models are 3.17m, 3.22m and 2.39m. For 2.5m GSD and the base to height relation of 1.6 this corresponds in the average to a standard deviation of the x-parallax of 0.7 GSD, this is a very good result for DEMs. If a DEM is analysed against check points, the results would be too optimistic because check points have usually a good object contrast and are not so much affected by terrain inclination. For getting realistic information about the accuracy of height models, reference height models have to be used. As point spacing 3 GSD, identical to 7.5m, are justified, so detailed and precise DEMs can be generated by automatic image matching of Cartosat-1 images.

5 CONCLUSION

Caused by the improving ground resolution the competition between aerial and space images is growing. Medium scale maps can be generated based on aerial or space images. With WorldView-1 images, maps in the scale 1:5000 can be generated by on-screen digitizing of ortho-images. The DEM required for such ortho-images can be achieved by automatic matching of Cartosat-1 images if the satellite elevation does not exceed 20° under the condition of a required geometric accuracy of 0.2mm in the map scale. Not in any case such a large map scale is requested, so also space images with larger GSD can be used. As rule of thumb for mapping, 0.1mm GSD in the map scale is required, corresponding to 1m GSD for the map scale 1 : 10 000, but the GSD should not be quite larger than 5m to allow the identification of objects which have to be shown in any small scale map.

The high number of high and very high resolution space systems is improving the situation for mapping – in most cases images are available in the archive, avoiding a waiting time for acquisition. Only if the latest object information is required, new images have to be ordered. The variety of space images also has a positive influence to the financial side, the images just required for the actual project can be ordered, avoiding higher price for a higher ground resolution.

Aerial images are taken more and more by digital cameras. The digital mid format cameras are playing an important role for several projects. The gap between the mid format and the large format cameras is closing by combinations of 2 and 4 mid-format cameras.

SAR images have growing importance, supported by the very high resolution TerraSAR-X and Radarsat-2. Of course the information contents of SAR-images is not on the same level like the information contents of optical images, nevertheless today a mapping based on SAR images taken from space is possible. A big advantage of radar is the penetration through clouds, so images can be taken in any case at the planned time without respecting the weather conditions. Only very strong rain may degrade the SAR image quality. A further advantage is the use of IfSAR for the generation of height models. This can be done from space and air. The coming TanDEM-X constellation is announced with 2m vertical standard deviation, while the NextMAP, taken from air, is specified with 1m standard deviation. DEMs also can be generated without problems based on optical space models taken from the same orbit.

The actual overview over the optical space systems is mainly based on internet information. This is a little painful - any information has to be confirmed seriously because there is still a lot of not precise, partially wrong information about the systems in the WEB. Even several information shown by operating organizations, is not updated if some parameters have been changed in the meantime.

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