HIGH RESOLUTION IMAGERY FOR MAPPING AND LANDSCAPE MONITORING

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ABSTRACT

An overview about available high and very high resolution space images and digital aerial images with some of their advantages and disadvantages is given, including information about sensor orientation and achievable object accuracy. Some problems of the sensors and type of scene orientation are mentioned.

Keywords: Satellite Imagery, digital aerial cameras, image orientation, object accuracy

INTRODUCTION

The number of high resolution satellites is growing permanently. With GeoEye-1, WorldView-1 and WorldView-2 optical images taken from space with a ground sampling distance (GSD) of 0.5m are available. Also the spectral information from these satellites has been improved to now 8 spectral bands for WorldView-2. Of course such very high resolution optical satellite images are expensive, so as alternative other space images with larger GSD should be used or aerial images. If satellite images free of charge cannot be used, lower price alternatives as RapidEye with 6.5m GSD and 5 spectral bands or even ASTER with 15m GSD should be taken into account.

Today aerial images and very high resolution optical satellite images are partially overlapping in their application and GSD. Only digital aerial cameras should be taken into account because of their better image quality and better defined spectral bands as in the case of film cameras.

In addition to optical images synthetic aperture radar (SAR) images are available with up to 1m GSD from space and even better resolution from air. But it should be mentioned, that the information contents of a SAR-image is not the same as for an optical image with the same GSD. The object interpretation of SAR-images is very difficult, needs a lot of experience and cannot be recommended for detailed mapping. Nevertheless Radar has the advantage of penetrating clouds.

OPTICAL SATELLITE IMAGES

Optical satellite images for forest application are used in two different manners. Based on high spectral information, but lower spatial information automatic multispectral classification is possible. Reverse for mapping purposes a higher spatial (smaller GSD) and lower spectral information is required. An overview about the high and very high resolution optical satellites, available for civil applications, can be seen in figure 1. In addition several military observation satellites are active, but the images can only be used by military. Of course the satellites available for civilian application are dominated by dual use – use for military and civilian application, but this is not limiting their availability.

The number of very high resolution satellite sensors (1m and smaller GSD) is growing permanently. This improves the use of less expensive images from image archives. Not only the technical details of the satellite sensors are important, also the imaging capacity and access to the images. For the latest satellites GeoEye-1, WorldView-1 and WorldView-2 the access is very simple, but the images are expensive. The scene price may change with the announced small satellite SSTL ART, which shall be launched in 2012. The images taken by this satellite with 0.6m GSD for panchromatic channel and 2.4m for red, green and blue shall be distributed for 0.2$ / km² or 51$ per scene 16km x 16km.

The relation of the geometric resolution between panchromatic and color channels of 1:4 is usual. For mapping purposes the lower multispectral resolution is not disturbing. By image fusion of 3 color channels with the panchromatic channel, color images with the geometric resolution as the panchromatic channel can be generated. Such color images for the human eye look as original color images taken with the same GSD because of the nature of the human eye which is more sensitive for grey values as for the color.

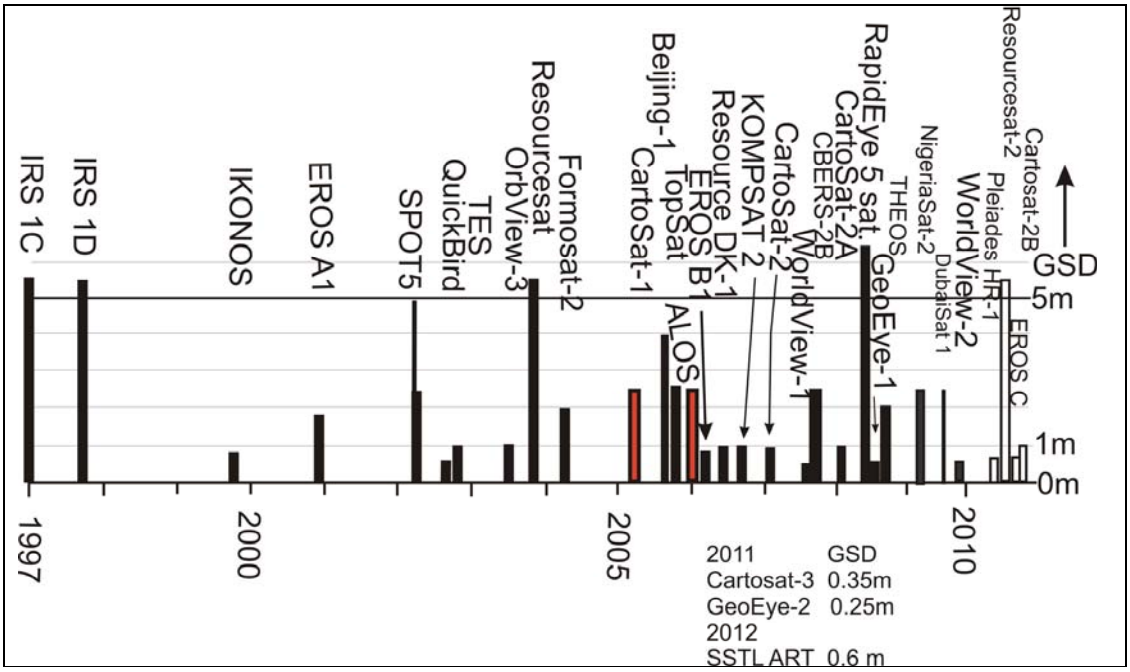


Figure 1: high and very high resolution optical satellites with their panchromatic GSD (vertical direction), depending upon launch time (horizontal direction)

An exception in figure 1 is the system of 5 Rapid Eye satellites. At first it is one of the first real commercial projects without any support by military and then it has no panchromatic, only 5 spectral bands with 6.5m GSD. The main purpose is the use for agriculture and forest application, for which the blue, green, red, red edge and near infrared spectral bands are designed. More multispectral information of the satellites shown in figure 1 has only WorldView-2, equipped with 8 spectral bands (figure 2). For forest applications especially the red edge band (700nm – 730nm) and the second near infrared band (900nm – 1050nm) are important. The yellow band (590nm- 640nm) just fills a niche, while the coastal band (423nm – 453nm) is only important for shallow water.

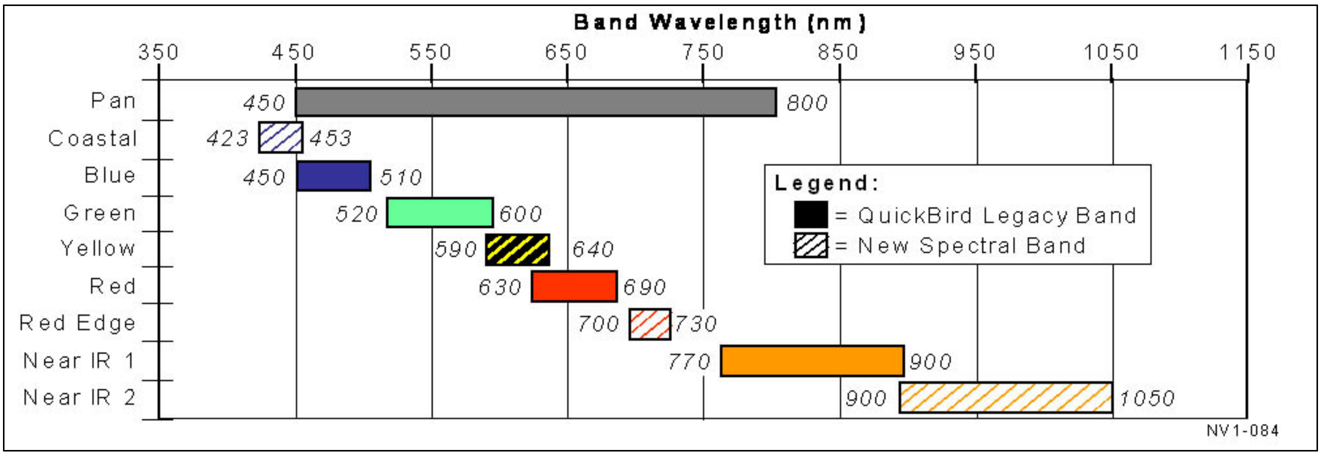


Figure 2: spectral bands of WorldView-2 in relation to QuickBird (courtesy Digital Globe)

Based on wide spread own tests a topographic mapping requires images with a GSD of approximately 0.1mm in the map scale e.g. for a map scale 1 : 10 000 as 0.1mm$*$ 10000 = 1m GSD. But in no case the GSD should exceed 5m to avoid a loss of some details which have to be shown in any case in the map. For thematic maps some variation from this rule is possible, but it depends upon the individual required topics.

The traditional multispectral classification with images taken by such geometric high and very high resolution satellites is very difficult – as it can be seen in figure 3. With increasing resolution of remote sensing data more and more details and structures of landscape objects are observable. With lower geometric resolution the grey value structure is averaged in the individual pixels, simplifying the multispectral situation and for most of the object classes the sole analysis of their spectral signature is sufficient, because that allows to directly infer the object classes. A classification with geometric high resolution satellite images requires the use of improved methods for object extraction (Pakzad 2007). This situation requires a separation of the high and very high resolution satellites useful for mapping and the geometric lower resolution satellites with a satisfying number of spectral channels for multispectral classification.

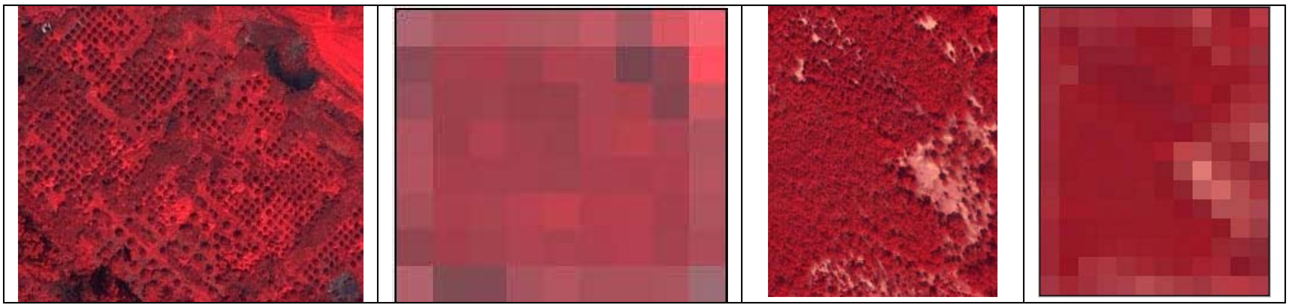


Figure 3: false color infrared images of 2 forest areas with 1m GSD and with 30m GSD

The civilian use of satellite images and multispectral classification started with Landsat (at first named ERTS) in 1972. With Thematic Mapper (TM) 30m ground resolution was available with the exception of the thermal infrared. For long time Landsat images have been the standard for multispectral classification, but with the failure of the scan line correction (SLC) in 2003 and the availability of other satellite sensors this changed. In the meantime a fast growing number of multispectral satellite scanners exist with the tendency to higher geometric and also spectral resolution. For Brasilia the free available CBERS images have large advantages. An alternative are also the serious of small satellites organized in the frame of the disaster mapping constellation (DMC) by Surrey Satellite Technologies (SSTL). For higher resolution multispectral images the French SPOT, the Indian Resourcesat or German RapidEye can be used. In the frame of the Global Monitoring for Environment and Security (GMES) program of the European Union the super-spectral Sentinel-2 shall be launched in 2013 having 13 channels in the visible, near and mid infrared with 10m / 20m and 60m GSD. With EnMAP the German DLR will launch in the same year a hyper spectral sensor with 30m GSD and a spectral resolution of at least 10 nm over the wide range from 420 nm up to 2450 nm with a VNIR (96 spectral channels) and a SWIR (136 spectral channels) detector.

AIRBORNE CAMERAS

camera	View direction	pixels	Pixel size	Focal length	GSD from 5000m hg	h/b	bands	Line cycle
ADS 80, Leica Geosystems	+27°, +2°, -16°	12000	6.5µm	62.5mm	52cm	1.25	R G B NIR + pan	800 lines/sec
Jenaoptronic JAS-150	0°, +/-12°, +/-20.5°	12000	6.5µm	150mm	22cm	1.34	R G B NIR + pan	800 lines/sec

Table 1: high performance aerial line scan cameras

camera	f	Pixel in flight	Pixel across	Pixel size	h/b	GSD from 5000m hg	Frame cycle
UltraCamX	100 mm	9420	11310	7.2µm	3.7	36 cm	1.6 sec
UltraCamXp	100 mm	11310	17310	6.0µm	3.7	30 cm	2 sec
UltraCamXpW	70 mm	11310	17310	6.0µm	2.6	43 cm	2 sec
DMC	120 mm	7680	13824	12 µm	3.2	50 cm	2 sec
DMC II 140	95 mm	11200	12096	7.2 µm	2.8	39 cm	2 sec
DMC II 230	92 mm	14400	15104	7.2µm	2.2	30 cm	1.7 sec
DMC II 250	111 mm	14656	17212	5.6 µm	3.4	25 cm	1.7 sec

Table 2: large format digital frame cameras

In several countries analogue aerial cameras using film are replaced by digital aerial cameras. The digital cameras have better image quality, well defined spectral bands and lead to higher geometric accuracy as a test organized by the German Society of Photogrammetry, Remote Sensing and Geoinformation stated (Jacobsen et al. 2010). The digital aerial cameras can be grouped into line scan (table 1), large format frame (table 2) and mid-format cameras (table3). Mid-format cameras partially are used as a system of 2, 3, 4 and even 5 cameras for covering a larger area.

The large format digital frame cameras (table 2) DMC are from Intergraph Z/I Imaging, developed and produced in Germany, and the UltraCam from Microsoft Vexcel Imaging, developed and produced in Austria. These cameras are system cameras, each with 4 color sub-cameras and with the exception of the DMC II-serious, 4 panchromatic sub-cameras. The lower resolution color images can be merged together with the joined panchromatic image to high resolution color images. All these cameras have blue, green, red and near infrared spectral bands. As mentioned above, for manual mapping purposes the lower resolution color information corresponds to the sensitivity of the human eye. For multispectral classification of course the original color resolution counts; but for a classification with the GSD taken by the digital aerial cameras, the structure information included in the panchromatic band should be respected as it is automatic done by a human operator. In the case of the line scan cameras the color has the same GSD as the panchromatic bands.

The new DMC II is based on one large, new developed Dalsa CCD array for the panchromatic band, avoiding geometric problems by merging the sub-images together, which still can be seen on high accuracy level especially in case of the UltraCam.

The large format digital frame cameras are equipped with transfer delay and integration (TDI), which can be explained as digital forward motion compensation - this improves the sensibility of the cameras and allows imaging under low sun angle. Such a TDI does not exist for the line scan cameras.

camera	f	Pixel in flight	Pixel across	Pixel size	h/b	GSD from 5000m hg	Frame cycle
Z/I RMK D	45 mm	5760	6400	7.2 µm	2.7	80 cm	1.1 sec
UltraCam L	70 mm	6588	9735	7.2 µm	3.7	51 cm	2.5 sec
Trimble AIC-x1	80 mm	5420	7160	6.8 µm	5.5	42 cm	2 sec
Trimble AIC-x4	80 mm	2 x 5420	2 x 7160	6.8 µm	-	42 cm	2 sec
IGI DigiCAM	82 mm	5412	7216	6.8 µm	5.5	41 cm	2 sec
IGI Quattro DigiCAM	82 mm	2 x 5412	2 x7216	6.8 µm	-	41cm	2 sec
Applanix DSS	40 mm 60 mm	5412	7216	6.8 µm	2.7 4.1	85 cm 57 cm	2 sec
DIMAC	60 mm-120 mm	(2 x) 5412	7216	6.8 µm	3.1 – 6.1	57 cm – 28 cm	2 sec

Table 3: mid format digital frame cameras

The mid-format cameras, listed in table 3, are just a selection of the high number of digital mid-format, but they include the typical types. A must for metric application of such cameras is the fixed focus; with changing focus or even with a zoom lens, the image geometry including the inner orientation is not stable. The mid-format cameras RMK D from Intergraph Z/I Imaging and UltraCamL from Microsoft Vexcel Imaging are also system cameras with 4 spectral sub-cameras (R G B NIR) and in the case of UltraCamL also separate panchromatic band. They are equipped with TDI, improving the image quality in case of longer exposure interval. The other mid-format digital cameras have only one CCD-array, so the color information can only be generated with a Bayer pattern (figure 4).

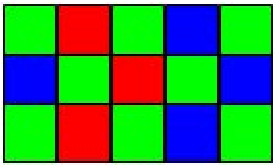


Figure 4: Bayer pattern
= filter in front of any pixel in the CCD
50% green, 25% blue, 25% red
or 50% red, 25% green, 25% near infrared

The output of a CCD equipped with a Bayer pattern is an image with the full color bands. The grey values of the pixels not available in the original color are computed by a more complex interpolation respecting also of the grey values of the other spectral bands. Of course this cannot be the same information contents as with images based on separate spectral bands. In addition only 3 color bands are possible with a Bayer pattern, so it has to be selected between red, green and blue (RGB) or green, red and near infrared (GR NIR). If all 4 spectral bands are required, 2 mid format cameras have to be used in parallel.

CCD-arrays with a Bayer pattern cannot use the electronic forward motion compensation TDI because the TDI shifts the free electrons, generated by a pixel, with the speed of the forward motion to the next CCD and integrates so more energy. This would merge the spectral information in a Bayer pattern. So the images may be influenced by forward motion, reducing the image quality. The only exception is the DIMAC camera having a mechanical forward motion of the CCD, shifting the whole CCD during imaging by Pieco-elements.

The Trimble aerial camera AIC (former Rolleimetric AIC) can be joined together to a 4-camera configuration AIC-x4 as well as the DigiCAM from IGI to the Quattro DigiCAM. The slightly convergent arrangement of 4 cameras is covering an area similar to the large format digital frame cameras, but no homogenous virtual images are delivered. The DIMAC is an exception it can use 2 cameras with the CCDs in the same plane, but with shifted principal points, enlarging the field of view. The images of the DIMAC ore joined together to a larger virtual image.

CAMERA ORIENTATION

The camera orientation of space and aerial images are quite different. Space images are covering a large area, so in most cases just a single scene or a single stereo arrangement is used. Only for covering very large areas a combination of scenes is used. Opposite, aerial images are covering only smaller parts, requiring as standard an aerial triangulation.

The satellites are equipped with a positioning system as GPS and attitude information systems based on gyros and stellar cameras. So the approximate scene orientation is known without ground control points (GCPs). The accuracy of the orientation just based on the direct sensor orientation varies from satellite to satellite, but in general it is permanently improved. GeoEye-1 today delivers the scene orientation with a standard deviation in the range of 3m on the ground; WorldView-1 and WorldView-2 are not far away from this. IKONOS and QuickBird are in the range of a standard deviation of 4 to 10m. Of course the possible scene orientation based on GCPs is better.

Today the very high resolution space images are delivering the orientation information in form of rational polynomial coefficients, describing the image position by the relation of two polynomials of third degree as function of the ground coordinates X, Y and Z. With 80 coefficients the geometric relation is approximated. For reaching the possible full accuracy the relation between the image and the object coordinates have to be improved by a 2-dimensional affinity transformation or even just a shift, named as bias corrected sensor oriented RPC-solution. So by theory with just 3 or even one GCP a pixel- or sub-pixel-accuracy is possible. Of course not just the minimum of GCPs should be used for being able to identify control point errors. Control point errors cannot be avoided, in most cases they are based on problems of the point identification in the satellite images. Another possibility of scene orientation is the reconstruction of the imaging geometry based on the delivered geometric information which can be quite different from satellite to satellite. In addition also the type of image is important – it can be the close to original Basic geometry (in case of SPOT level 1A) or the image projected to a plane with constant elevation height in the object space, named for example as ortho-ready standard or in the case of SPOT level 1B. The naming of the image types is different from satellite to satellite. Mostly it is simpler to use the images projected to a plane with constant height – so for example from IKONOS only this image type is available and not the Basic imagery.

Another possibility is the use of approximations as the 3D-affine transformation, direct linear transformation (DLT) or the use of a reduced number of RPC-coefficients just based on GCPs, also named terrain dependent RPCs. The terrain dependent RPC-solution should never be used, even if it is included in some commercial software packages, it is just a polynomial interpolation and cannot guarantee the accuracy outside the three-dimensional range of the GCPs and also in areas with not even distribution of GCPs. The residuals of the terrain dependent RPC-solution may be very small, not indicating large errors of the orientation or even errors at single GCPs.

The mathematical model of the DLT is a perspective image, but satellite image have perspective geometry just in the sensor line. The 11 unknowns of the DLT have to be determined with at least 6 control points. The small field of view for high resolution satellite images together with the limited object height distribution in relation to the satellite flying height is causing problems with correlation of unknowns. Even if the results achieved by this method are not poor in any case, there is no justification for the use of this method for the orientation of satellite images having more unknowns as required.

The three-dimensional affine transformation is also not using available sensor orientation information. The 8 unknowns for the transformation of the object point coordinates to the image coordinates have to be computed based on control points located not in the same plane. At least 4 well distributed control points are required. The 3D-affinity transformation is based on a parallel projection which is approximately given in the orbit direction but not in the direction of the CCD-line. An extension of the basic 3D-affine transformation has been made in (Jacobsen 2010), leading to a similar accuracy as with the sensor oriented RPC-solution or the geometric reconstruction, but requiring more and also 3-dimensional well distributed GCPs.

With the latest very high resolution satellite images from WorldView and GeoEye-1 the orientation based on sensor oriented RPC, improved by GCPs are slightly more precise as the geometric reconstruction. For the other sensors included in table 4, it was on the same level, requiring the same number of GCPs.

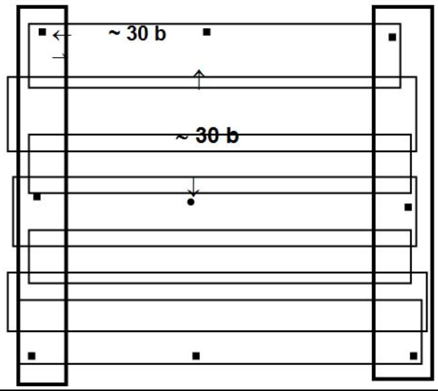
Sensor, test area	level type	GSD	SX/SY	SX / SY [GSD]
ASTER, Zonguldak	A	15 m	10.8 m	0.7
KOMPSAT-1, Zonguldak	A	6.6 m	8.5 m	1.3
SPOT, Hannover	A	10 m	4.6 m	0.5
SPOT 5, Zonguldak	A	5 m	5.1 m	1.0
SPOT 5, Zonguldak	B	5 m	5.1 m	1.0
SPOT HRS, Bavaria	A	5m x 10m	6.1 m	0.7 / 1.1
IRS-1C, Hannover	A	5.7 m	5.1 m	0.9
Resourcesat, Hannover	B	5.9 m	5.3 m	0.9
Cartosat-1, Warsaw	B	2.5 m	1.4 m	0.6
OrbView-3, Zonguldak	A	1m (2m pixel)	1.3 m	1.3 *
IKONOS, Zonguldak	B	1.0 m	0.7 m	0.7
QuickBird, Zonguldak	B	0.61m	0.5 m	0.8
WorldView-1, Istanbul	B	0.50 m	0.45 m	0.9
GeoEye-1, Riyadh	B	0.50 m	0.45 m	0.9

Table 4: root mean square discrepancies at independent check points determined by scene orientation
* OrbView-3 1m GSD, 2m projected pixel size; level type A = Basic imagery, B = projected to plane with constant height

Table 4 demonstrates that the georeferencing can be done for all sensors with pixel- or even sub-pixel-accuracy. The exception of KOMPSAT-1 was just caused by limited accuracy of the GCPs and OrbView-3 by not optimal radiometric image quality. The internal scene accuracy is even better as one GSD, limited by the identification and definition of control points in the images. The listed results are based on orientation by geometric reconstruction and bias corrected sensor oriented RPCs.

The orientation of the aerial cameras usually is computed by bundle block adjustment – a common orientation adjustment of a block of images. The bundle block adjustment can be supported by coordinates of the projection center coordinates determined by relative kinematic GPS-positioning and also attitude information by inertial measurement units (IMU) based on a combination of gyros and accelerometer. For satisfying accuracy the GPS-positioning has to be based on GPS carrier phase. The kinematic carrier phase solution has the disadvantage of the ambiguity solution – the number of waves has to be determined - and this can fail, causing the so called ambiguity errors which are mainly constant errors of the positions. During the turn around from one flight line to the next, the connection to some GPS-satellites can be lost and in the next strip different ambiguity errors may happen – this problem is named cycle slip, causing a change of the mainly constant shifts of the GPS-positions. By theory with IMU the full image orientation – projection center coordinates and attitudes – is given with a higher frequency in the range of 100 Hz, but the IMU has only good short time accuracy and in longer time systematic drifts, so it must be supported by GPS-positioning, delivering a good absolute accuracy but with lower frequency and the problem of cycle slips. In the combined use IMU is supporting the GPS-positioning and the GPS-positioning is supporting the IMU-data. So positions without cycle slips and attitude information without drift can be generated.

The direct sensor orientation by the combination of GPS and IMU must be based on the so called boresight misalignment, the relation of the IMU to the camera axis and the shift of the projection center against the IMU and the GPS-antenna. Depending upon the mechanical stability of the relation IMU to camera, the boresight misalignment has to be calibrated from time to time via a small test area containing few control points. Nevertheless it is recommended to use the direct sensor orientation together with a bundle block adjustment in a so called integrated block adjustment. The integrated block adjustment has the advantage, that the relative orientation of neighbored images is supported by tie points, avoiding y-parallaxes. In addition few GCPs may be used to improve vertical shifts, which may be caused by thermal effects to the focal length or not respected scale changes of the national coordinate system having a different scale at the reference meridian as far away from the reference meridian.



Black circle = vertical control point
Black square = X, Y, Z-control point

Figure 5: control point distribution for blocks with GPS-projection centre coordinates and crossing flight lines

Combined bundle block adjustments using GPS-projection center coordinates should be supported by crossing flight lines as shown in figure 5 to be able to determine constant shifts of the GPS-data which may be different from flight line to flight line.

As listed in table 3, different digital cameras or camera systems can be used for image flights. Today mid-format cameras are reaching the same horizontal accuracy level as large format cameras, but the automatic block adjustment and handling of the smaller mid-format cameras is more time consuming and should be supported at least by GPS-projection center coordinates to avoid the requirement of a high number of GCPs. In addition the image geometry of the mid-format cameras has to be determined by self calibration with additional parameters because of the larger size of systematic image errors. For the precise determination of the systematic image errors special additional parameters for fitting corner effects of not satisfying flat CCD-chips should be included (Jacobsen et al 2010). The systematic image errors of the 4 sub-cameras of the IGI Quattro-DigiCAM are shown in figure 8. Its size exceeds the pixel size of 6.8µm and cannot be neglected. Larger values have been determined for the Trimble AIC-x1, dominated by radial symmetric effects, but also without radial symmetric components the systematic image errors are reaching a size of 2 pixels. Of course a bundle block adjustment with self-calibration can determine and respect it, but by model handling with a software package, which cannot respect the systematic image errors, model deformations especially in Z-direction cannot be avoided. A similar problem has been seen also with UltraCamX-images with systematic image errors in the size of a pixel, but it seems, the new Vexcel-software has reduced this problem.

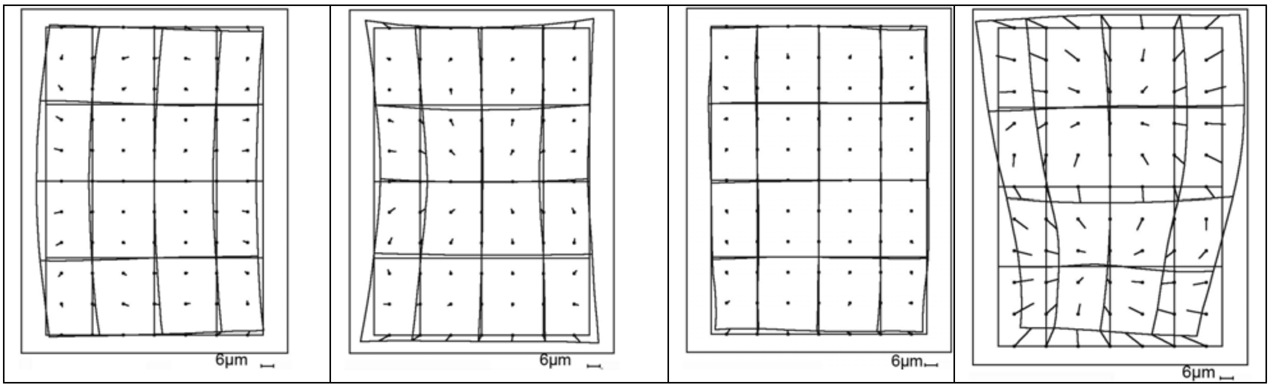


Figure 8: systematic image errors of the 4 sub-cameras of the IGI Quattro-DigiCAM

The test of the German Society of Photogrammetry, Remote Sensing and Geoinformation (Jacobsen et al 2010) with the cameras listed in table 1 and 2 was leading to standard deviations SX and SY below 1 GSD. With the large format digital cameras DMC, UltracamX, ADS80 and JAS-150 even for the vertical component the standard deviation did not exceed 1 GSD. For the mid format cameras mainly because of the height-to-base-ratio the vertical component was not as precise.

MAPPING

Mapping with digital cameras has advantages against mapping based on film cameras because of the better image quality and well defined spectral information including 4 spectral bands for the large format digital cameras including the line scan cameras. In addition the time consuming film scanning is not required and in long terms digital cameras are more economic because of not existing cost for film and film development. The infrared band, very important for vegetation mapping is quite difficult to be handled with analog cameras. If all 4 color bands are required, 2 analog cameras, one with true color film and one with false color infrared film have to be used in parallel. This is also the case for the mid-format digital cameras based on Bayer pattern.

As a rule of thumb 0.05 up to 0.1mm GSD in the map scale is required for satisfying identification of details, corresponding to 50cm to 1m GSD for a map 1:10 000 or 1.25cm up to 2.5m GSD for a map scale 1:25000. If the vertical component is important, the use of the systematic image errors during model handling is recommended, what cannot be done with any software package. Nevertheless a model deformation influences mainly the absolute accuracy and not so much the relative accuracy of closely neighbored points.

The mapping of synthetic aperture radar (SAR) images is difficult and needs special training. In an intensive comparison of mapping with optical and with SAR-images, having the same GSD, clearly more details have been identified in optical images (Lohmann et al 2004). Depending upon the object and experience of the operator only 20% to 90% of the objects, typically 60% to 80% of the contents identified in optical images could be identified in SAR-images.

CONCLUSION

The required ground resolution for mapping depends upon the map scale. Traditional manual mapping usually is based on color images – for mapping of vegetation structures false color infrared has advantages because of quite more clear object separation. For automatic classification a lower geometric and a higher spectral resolution has advantages. Classification with high resolution images has to be supported by the structure information because of too many variations of the similar objects is available. For high resolution images with 1m and smaller GSD an overlap between satellite and aerial images exist and the decision for use is just based on economic aspects.

Aerial images today should be taken by digital cameras. It does not matter, if line scan or large format frame cameras are used, but the handling of line scan cameras requires the complete chain of software programs. Mid-format aerial cameras today have their share, but usually they are restricted to 3 color bands, taken by Bayer pattern. Their handling in most cases is a little more time consuming as the handling of large format camera images, in addition larger systematic image errors have to be expected. Nevertheless their use may be economic for smaller projects. Finally the use of very high resolution space images or aerial images just depends upon the economic situation and not on technical aspects.

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