RECENT DEVELOPMENTS OF DIGITAL CAMERAS AND SPACE IMAGERY

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Abstract

Digital aerial cameras have replaced analog film cameras. An information contents corresponding to aerial photos up to 2010 was only possible with digital system cameras as Vexcel Ultracam and Z/I Imaging DMC or line scanning cameras as Leica Geosystems ADS80 or Jena Optronic JAS-150. Now with very large size CCDs the panchromatic band of the DMC II has between 140 and 256 Mega pixels from one CCD and this with excellent image geometry. With large size digital camera images more precise results as with analog photos can be reached. A strong development came for mid-format digital cameras having now up to 60 Megapixels. Some of them are also used in configurations of 2 up to 5 cameras, leading to a similar imaging capacity as the large format digital cameras, but not with the same geometric quality. Usually such cameras have to be supported at least by relative kinematic GPS-positioning or even inertial measurement units. Standard mid-format cameras have only one CCD-array, where 3 color bands can be generated by Bayer pattern, while system cameras usually have 4 color bands. Unmanned aerial vehicles (UAV) are becoming popular; partially they are equipped with tiny digital cameras with just 1.8µm pixel size, but still satisfying potential.

With available 0.5m ground sampling distance (GSD) very high resolution optical satellites are competing with aerial cameras. Usually their image quality is on the same level. The absolute geo-reference in the range of 3m without use of ground control points (GCP) for GeoEye and Worldview images is satisfying for several applications. So for example a comparison of digital surface models (DSM) generated with IKONOS and with GeoEye stereo pairs was leading without GCP to discrepancies in X and Y below 10m and in the height below 1m. 0.5m up to 1.0m GSD allows the generation of 3D city models with satellite images. With semi global matching (SGM) sharp building contours can be generated.

In near future even 0.3m GSD will be possible with GeoEye-2 and Cartosat-3. Just now there is still a limitation of the USA to distribute space images having below 0.5m GSD, but caused by the Indian competition this may change.

Keywords: digital aerial cameras, geometric potential, optical space imagery, use of space imagery

DIGITAL AERIAL CAMERAS

Digital aerial cameras have changed photogrammetric aerial imaging faster as expected. Together with this change and supported by the flexibility of digital photogrammetric workstations, there is no more standardization of the cameras as it was the case with film cameras, having the same film format and usually only the variation of the focal length between 153mm and 305mm. Digital aerial cameras can be grouped into frame cameras, based on a CCD-array or a system of CCD-arrays and line scan cameras using CCD-lines with different view direction. Another grouping can be made with large, medium and small format, corresponding to the CCD-size and the number of pixels, but this grouping is not fixed because of the permanent growing capacity of CCD-arrays.

The information contents – what information is included – of digital images should be compared with the information contents of scanned analog photos. It is the question, how many pixels are required for the information contents included in a 230 mm x 230 mm film. The first simple estimations were based on the operational resolution of 40 line pairs per mm and that one line pair should be presented by 2 pixels, leading to 18 400² pixels. Very fast it was recognized that this was not the correct manner for the comparison of the information contents because of the quite better contrast and lower noise of digital images. A comparison of details which can be extracted for topographic mapping from DMC, UltraCAM and ADS40 images as well as scanned aerial photos having similar ground sampling distance (GSD), was leading to the result, that just 8520² pixels are required for the information contents of scanned aerial photos in relation to original digital images not degraded by lower effective resolution (Jacobsen 2008b). All the large format digital cameras have more pixels, so they are including more information in an image as a corresponding scanned photo.

Table 1. Large format digital cameras

camera	Panchromatic pixels	pixel size	f [mm]	frame rate	Pan / MS
DMC	7680 x 13824	12µm	120	2 sec	4.6:1
UltraCamD	7500 x 11500	9.0µm	100	1 sec	2.9:1
UltraCamX	9420 x 11310	7.2µm	100	1.6 sec	2.9:1
UltraCamXp	14430 x 17310	6.0µm	100	2 sec	3.0:1
UltraCamXpW	14430 x 17310	6.0µm	70	2 sec	3.0:1
ADS80 line scanner	12000	6.5µm	62	~1000 lines/sec	1:1
JAS 150S line scanner	12000	6.5µm	150	800 lines/sec	1:1
DMC II 140	11200 x 12096	7.2µm	92	2 sec	2.0:1
DMC II 230	14400 x 15104	5.6µm	92	1.7 sec	2.5:1
DMC II 250	14656 x 17216	5.6µm	110	1.7 sec	3.2:1

Leica Geosystems ADS40, the predecessor of the ADS80, was the first large format camera on the market, nevertheless today more digital frame as line scan cameras are in operation. One reason for the slower progress of line scan cameras was the required change of the whole photogrammetric software for handling line scanner images with geometry different to perspective images.

CCD-arrays available in the beginning were too small to compete with analog photos, so system cameras as the Intergraph ZI/Imaging DMC and the Microsoft Vexcel Imaging UltraCam were develloped using 4 respectively 9 CCD-arrays for the panchromatic channel. In addition the color information was captured with 4 separate sub-cameras with lower resolution. For the UltraCam the CCD-size was fixed, but for improving the information contents the pixel size was reduced from 9µm over 7.2µm to 6µm. Of course this increases the information contents, but the increase is not linear to the number of pixels because of reduced image quality. An edge analysis showed that the effective improvement was linear approximately only half of the nominal (Jacobsen 2008b). Z/I Imaging did not like to reduce the pixel size for the DMC; they mentioned that for a correct imaging this requires a different optical system.

Sub-images of the system cameras have to be stitched together to a uniform virtual perspective image. For the DMC this was not a problem caused by the slightly overlapping convergent arrangement of 4 sub-cameras which can be merged three-dimensional. With the 9 sub-images from 4 sub-cameras of the UltraCam the stitching is quite more complicate and caused some geometric limitation. Now by so called "monolithic stitching" the 9 panchromatic sub-images are stitched to the homogenous geometry of the lower resolution green channel, solving some existing problems (Ladstädter et al 2010). Even if improved and more reliable, the stitching to a lower resolution reference image is not the optimal solution and is contradict to the syntopic mode because of the offset of the optics of the green channel across the flight direction. With syntopic mode the time delayed exposure of the UltraCam is named for having the same projection center position for the 4 panchromatic sub-cameras, which are aligned in flight direction. But in reality the offset of the projection centers from the synthetic projection center has only a negligible, more theoretical influence. Reverse it happened with the syntopic mode that under rough flight conditions the stitching failed and a re-flight was required.

The GSD of frame images is limited by the frame rate, the flight speed, the end lap and the field of view for a pixel. With a slow, but still stable flight speed of 60m/sec and 60% end lap, the smallest GSD for the DMC is 39mm, for the UltraCamX 25mm, for the UltraCamXp 21mm, for the DMC II 140 27mm and for the DMC II

250 17mm, still improved by the new cameras. For the line scan cameras it is depending upon the line sampling rate and the flight speed. The line sampling rate of the ADS80 is improved against the ADS40 from 800 lines/sec to approximately 1000 lines/sec. With 60m/sec flight speed the ADS80 can reach 60mm GSD and the JAS 150S 75mm.

When the first large format digital cameras have been introduced, the dream of photogrammetrist was to replace the aerial film with one large CCD-array. This was not possible at those time, requiring system cameras. This changed now; with the new large format CCD-arrays from DALSA 140 and 252 Mega pixels are available. The problems of slow frame rate and price/performance ratio have been solved. With the introduction of the DMC II 140 and DMC II 230 in 2010 the real monolithic geometry is now available for the high resolution panchromatic channel. The DMC II 140 is using the DALSA 140 Megapixel CCD and the DMC II 230 the DALSA 252 Megapixel CCD. The DMC II 230, it is named 230 because the existing optics of the DMC II cannot use the full size of the CCD, and so a new optics is under development at Carl Zeiss and shall be available in spring 2011 for the DMC II 250.

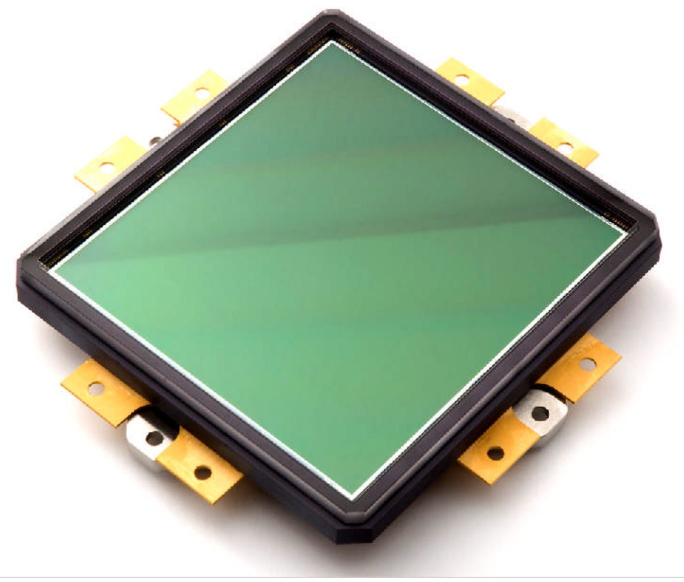


Fig. 1. DALSA 252 Megapixel CCD-array with 17216 x 14656 pixels (96.4mm x 82.1mm)

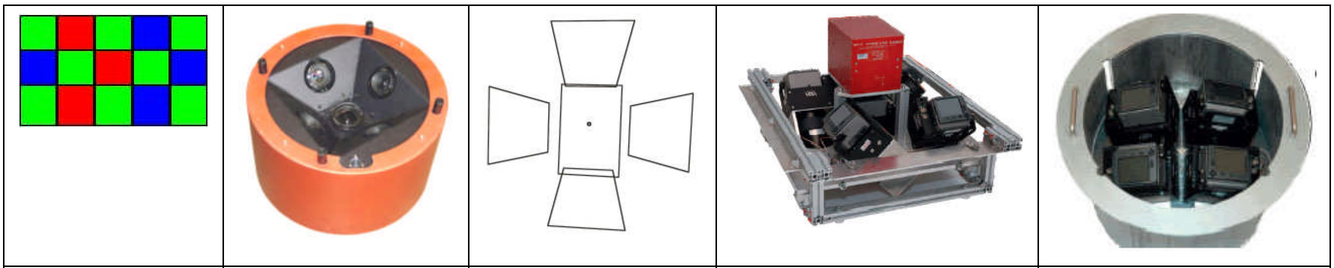
Own investigations of the DMC II 140 showed an astonishing good image geometry with systematic image errors in the root mean square below 1 micron. This is quite below systematic image errors of cameras used before. In an investigation of the Gerrman Society of Photogrammetry, Remote Sensing and Geoinformation beside other topics the geometry of the DMC, UltraCam X, ADS40, JAS 150S and the mid-format camera Rolleimetric AIC-x1 as well as the combination of four mid-format cameras, the IGI Quattro-DigiCAM have been analysed. Based on test data sets of 8cm and 20cm GSD with the line scan cameras ADS40 and Jena Optronik JAS 150S very good results have been achieved; the DMC was on a similar accuracy level and the UltraCam X slightly below. In the average this was clearly better as with the also used analog RMK TOP 15. With the IGI Quattro-DigiCAM also satisfying results have been achieved if it was supported at least by relative kinematic GPS-positioning. The image flight for the AIC-x1 was influenced by upcomming clouds, so no crossing flight lines are available, leading to a high number of required ground control points (GCP). In general the systematic image errors of the mid-format cameras was quite larger as for the other cameras (Jacobsen et al 2010).

Several types of mid-format cameras cameras are in use. Table 2 shows only some examples. As with the large format cameras there is a clear tendency to a higher number of pixels. In 2010 the capacity of the used CCDs was extended to 60 Megapixel from 40 Megapixels before by reducing the pixel size. For photogrammetric applications fix-focus cameras have to be used. Z/I Imaging RMKD and Vexcel Imaging UltraCamL are exceptions, they are system cameras similar to the large format cameras, but the RMK D has only one panchromatic sub-camera and the same resolution for the four multispectral cameras. The RMK D can be upgraded to a DMC II 140. All other mid-format cameras have only one CCD-array, generating multspectral information based on a Bayer pattern, having individual colour filters for any pixel (fig. 1 left hand side). By complex calculation RGB-images with the full number of pixels of the whole CCD are delivered. The effective resolution of such RGB-images is only 5% up to 10% below the nominal resolution of the full CCD-matrix. As disadvantage against the system cameras with separate color-sub-cameras the near infrared channel is missing, but it is also possible to use the Bayer pattern for green, red and near infrared. Usually systematic image errors – the difference between real image geometry and perspective geometry – are larger for mid-format cameras, with some special problems of the image corners requiring special additional parameters (Jacobsen et al 2010). Caused by the smaller field of view and the image geometry the determination of object heights has a limited accuracy and more flight lines are required for covereing the project area as with large format cameras. By these reasons mid-format cameras are used for smaller projects and cases where the accuracy is not so important.

With a Bayer pattern up to now no TDI, the electronic forward motion compensation, can be used as it is the case for the cameras from Z/I Imaging and Vexcel Imaging. This reduces the sensitivity of the cameras. Only DIMAC uses a mechanical forward motion compensation.

Table 2. examples of mid format digital cameras

camera	pixels	pixel size	f [mm]	frame rate	Pan / MS
RMK D	5800 x 6500	6µm	45	1sec	1:1
UltraCamL	9735 x 6588	7.2µm	70	2.5sec	1.8:1
DigiCam	8964 x 6714	6.0µm	35 / 50 / 80	1.6sec	Bayer pattern
Trimble Aerial C.	8924 x 6732	6.0µm	35 / 47 60 / 72	2.0sec	Bayer pattern
DIMAC	7216 x 5412	6.8µm	50 - 210	1.9sec	Bayer pattern



Bayer pattern

Track'Air MIDAS camera system

Footprints of MIDAS camera system

IGI Penta DigiCam

IGI Quattro DigiCam

Fig. 2. details of mid-format cameras and camera systems

A possibility to overcome some limitations of the mid-format cameras is the use of a combination of mid-format cameras. DIMAC is using a combination of 2 cameras with excentric principal point. Other companies as for example IGI is using a combination of slightly convergent cameras, they are offering a combination of 2, 3, 4 and 5 cameras. For covering a larger area, IGI Quattro DigiCam can be used, but if no virtual images of the camera combination are generated, the system cameras should be supported at least by relative kinematic GPS to avoid the requirement of a high number of GCPs.

The system cameras as Track'Air MIDAS and IGI Penta DigiCam have another function as it is obvious with the footpronts (fig. 2 center). As with the camera from Pictometry with such systems the building facades in cities shall be imaged.

The use of unmanned aerial vehicles (UAV) extends fast, caused by improved cost benefit relation and navigation support. In several countries weight limits for UAV requiring small systems. So company BLOM build a UAV with a weight of just 0.5kg, equipped with a tiny camera having 3072 x 2304 pixels with 1.7 microns pixel size and 5.9mm focal length. With 1.7µm pixel size the nominal resolution is not the same as the effective resolution determined by edge analysis, it corresponds to 3.5µm pixel size, but nevertheless the images are useful for several applications. Of course the navigation of such UAVs is difficult under windy conditions, but blocks even with higher overlap can be flown, giving a good overview over the project area.

OPTICAL SPACE IMAGERY

The number of earth observation satellites is growing permanently. Military earth observation was the first operational application of satellites in the 1960th, but today earth observation is open for civil use. Following only optical satellites with images available for civil application are mentioned. With ground sampling distance (GSD) – the distance of neighbored pixel centers projected to the gound – of up to 0.5m a competition between space and aerial imagery exist. So the decision between use of aerial and space images is just based on economic situation and availability of images. The problem with restrictions for aerial images in some countries has been bypassed by space imagery.

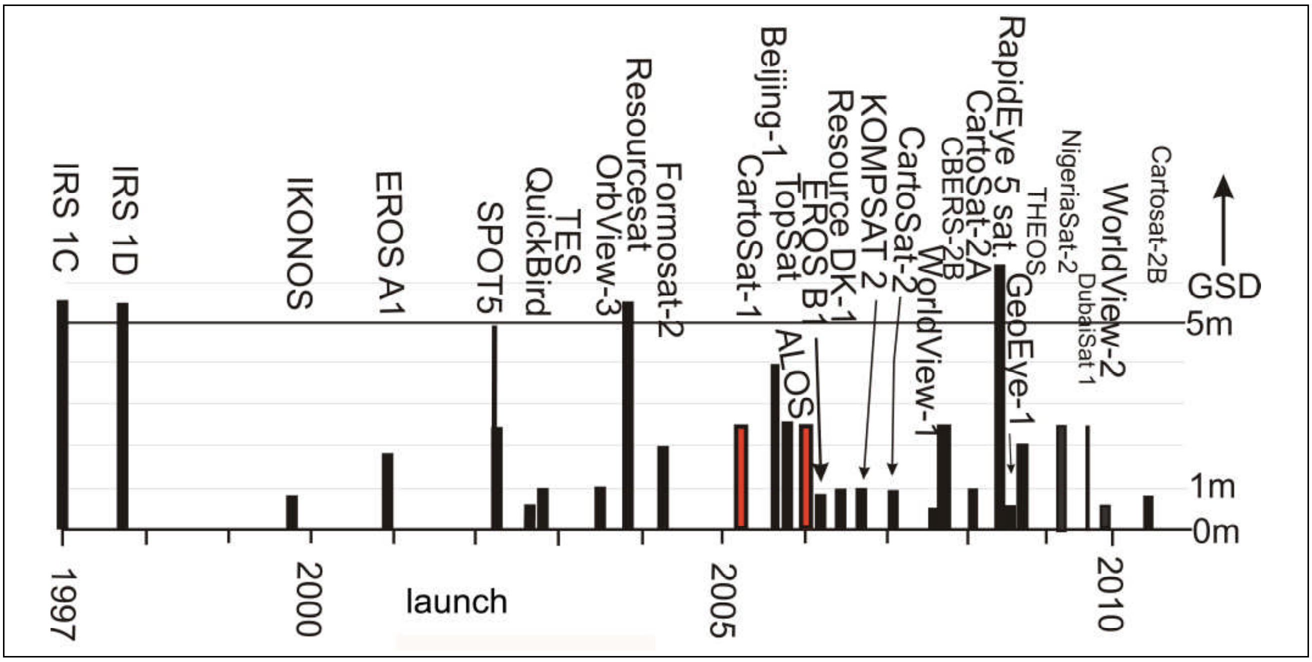


Fig. 3. high and very high resolution optical satellites in sequence of launch with GSD of panchromatic band

Not only the existing optical satellites are important, also the access to the images, which is difficult for some of them, the imaging capacity and the possibility of programming – the order of a special scene for taking in a specified time periode – plays a role. As it can be seen in table 3, the theoretical imaging capacity of the new satellites has strongly be enlarged against more old systems.

Table 3. Theoretical imaging capacity of some very high resolution optical satellites

satellite	Collection rate	Approximate theoretical collection capacity / day
IKONOS	2365 km²/min	150 000 km²/day
QuickBird	2666 km²/min	135 000 km²/day
OrbView-3	*1483 km²/min*	*80 000 km²/day*
WorldView-1	4512 km²/min	750 000 km²/day
GeoEye-1	2842 km²/min	pan: 700 000 km²/day; pan+ms: 350 000 km²/day
WorldView-2	4686 km²/min	975 000 km²/day
Rapid Eye	5 satellites	4 000 000 km²/day

The launched optical satellites (fig. 3) have to be supplimented by announced systems (table 4). Of course quite more optical systems are announced and also in space, but especially images taken by small satellites are often limited just to the owning country. With GeoEye-2, planned for 2012, and Cartosat-3, planned for 2014, the GSD even will be improved. For the satellites operated from the USA up to now a restriction to the GSD of 0.5m exists, why images from GeoEye-1 having 0.41m GSD for nadir view and WorldView-1 with 0.45m GSD and WorldView-2 with 0.46m GSD are only delivered with 0.5m GSD. But this may change by the competition of Cartosat-3. Sentinel-2 is included in table 4 even if the GSD is limited to 10m, but Sentinel-2 may become more important because the images shall be available free of charge.

Table 4. some announced high resolution satellites

satellite	launch	Organization, country	GSD panchromatic and multispectral
Pleiades 1 and 2	2011, 2012	SPOT Image, France	0.5m pan, 2m RGB IR
SPOT 6 and 7	2012, 2014	SPOT Image, France	1.5m pan, 6m RGB IR
Sentinel-2	2013	ESA, Europe	10m visible range with 13 bands
GeoEye-2	2012	GeoEye, USA	0.25m pan, 1,0m RGB IR
Cartosat-3	2014	ISRO/ANTRIX, India	0.33m pan, 1m multispectral

A bottle neck for mapping is the requirement of ground control points. With WorldView (WV) and GeoEye-1 the absolute geo-reference quality without use of GCPs is 4m respectively 6.5m CE90, satisfying for several purposes (table 5). This accuracy is related to a satisfying height model or three-dimensional object determination in a stereo scene. CE90 is the circular error with 90% probability; under the condition of standard deviation of object coordinates X (SX) identical to SY, there is following fixed relation: CE90 = SX ∗ 2.146 = SY∗2.146. The absolute geo-reference of WorldView and GeoEye-1 is improved more as three times against IKONOS and QuickBird. Of course not any optical satellite has such a geo-positioning as shown with Formosat-2 and Kompsat2 (table 5) and also the Indian satellites, but Cartosat 3 it is announced with 20m CE90. The geo-reference of Radar images only depends upon the satellite position and not the attitudes as for optical satellites. So with radar-images even a higher level of absolute geo-reference can be achieved if satisfying height models are available. For disaster mapping the German DLR partially uses the absolute geo-reference of radar-images as indirect control information for optical space images (Schneider et al 2010).

Table 5. absolut geo-positioning without ground control points

Satellite	IKONOS	QuickBird	WV-1	WV-2	GeoEye	SPOT5	Formosat2	Kompsat2	RapidEye
CE90	15m	23m	6.5m	6.5m	4m	<50m	230m	80m	10m
SX / SY	7m	11m	3m	3m	2m	<23m	107m	37m	5m

The generation of topographic maps with space images is limited by the information contents and not the accuracy. Intensive own studies showed that images with 0.1mm GSD in the map scale are required for the identification of the required object details. This corresponds to a map scale 1:10 000 for 1m GSD or 1:5000 for 0.5m GSD. With the announced 0.33m GSD of Cartosat-3 or 0.25m GSD of GeoEye-2 mapping even with larger scale will be possible in near future.

Height models generated by optical space images should be based on images taken nearly at the same time. With the exception of SPOT 5 the listed satellites have to rotate the whole satellite for changing the view direction, so they are equipped with reaction wheels – fast rotating giros. If they are accelerated or slowed down, a moment goes to the satellite causing a rotation. A fast and precise rotation is possible. WorldView 1 and 2 are equipped with control moment giros, keeping the giros stable in inertial space; this leads to a faster rotation, improving the possibilities of taking stereo pairs from the same orbit. For the slower rotating satellites the imaging capacity is reduced drastically by the rotation to the other view direction required for a stereo model, so only a limited number of stereo scenes taken by very high resolution sensors are in the archives, this may be improved by WorldView. With stereo satellites as Cartosat-1 and ALOS PRISM of course large areas are covered by stereo pairs, but the GSD is limited to 2.5m.

With new matching technologies as the semi global matching (SGM), initiated by computer vision, with 0.5m up to 1m GSD images high quality 3D-city models can be generated (Alobeid et al 2010). A comparison of 3D-city models based on IKONOS, GeoEye and aerial photo stereo pairs, gave satisfying results for IKONOS and GeoEye, while with scanned aerial photos having 70cm GSD the images had to be improved by an average filter 3x3 to reduce the influence of the film grain to give acceptable results. Of course this would be different with original digital aerial images not affected by film grain as scanned photos.

In a test for change detection of buildings, digital surface models (DSM) based on an IKONOS stereo pair from May 24th 2008 and a GeoEye-1 stereo pair from September 15th 2009 have been compared. As geo-reference oriented scanned aerial photos with 7cm GSD were available. The shift of the GeoEye-1 DSM generated without control points against the aerial images is for X: 0m, for Y: -1m, for Z: -2.5m and for IKONOS DSM against GeoEye DSM +8m, -9m, 0.6m. The filtered differential height model can be seen in figure 5. There are still some effects caused by viewing shadows and poor contrast on a road, but any building change has been detected, even a new building with a height of just 3.7m. The relative accuracy of the height models without effects by viewing shadows and poor contrast areas is in the range of 0.5m, an accuracy which required before large scale aerial images.

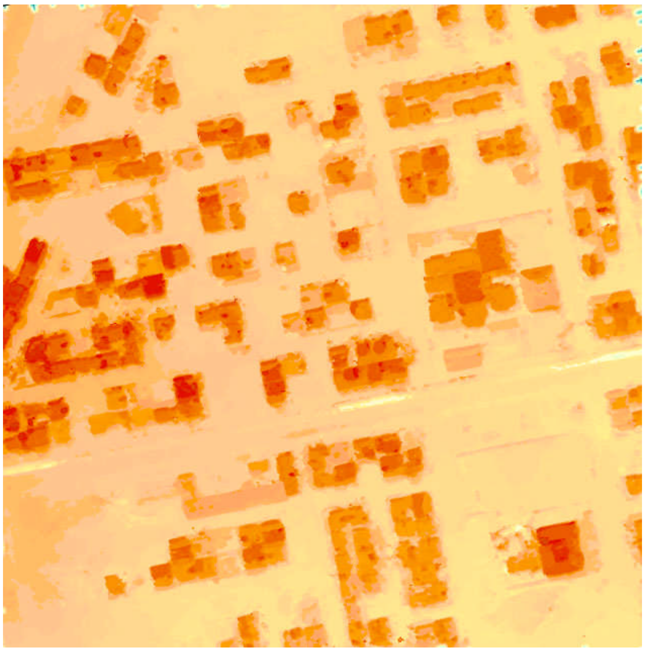


Fig. 4. color coded urban DSM generated by semi global matching with GeoEye-1 stereo pair

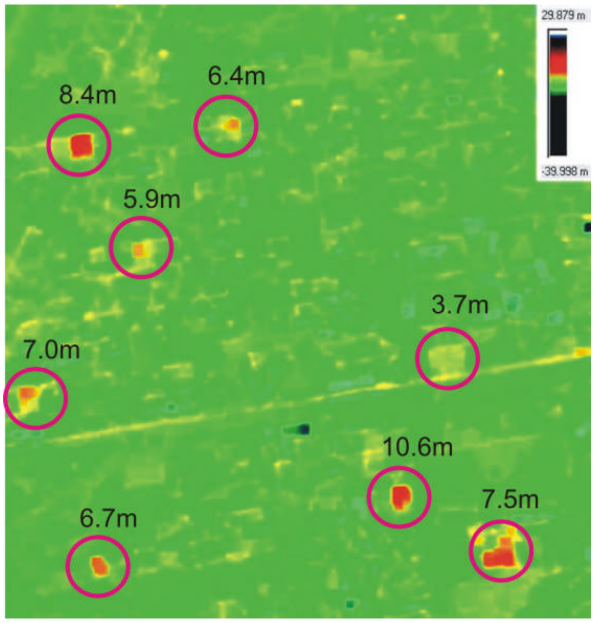


Fig. 5. filtered DSM height difference GeoEye from 2009-09-15 – IKONOS from 2008-05-24

CONCLUSION AND OUTLOOK

Digital aerial cameras now have an enlarged number of pixels, so new mid-format cameras have a capacity not far away from the first large format digital cameras. Nevertheless the geometry of mid-format cameras is not on the same level as for large format cameras. With the introduction of a CCD-array with 252 Megapixels having a frame rate of just 1.7 sec a significant step in the development of digital cameras has been made. Mid-format system cameras got also some fields of application. Even tiny cameras for UAVs became important for photogrammetry. The development of digital aerial cameras continuously goes on.

Optical satellites have improved the ground resolution and this still continues. With improved absolute geo-reference without use of ground control points for some application a satisfying accuracy level has been reached. For the announced Pleiades even a higher accuracy of 3m CE90 is proposed and by indirect control via radar satellite images also images of satellites with lower geo-reference quality can be oriented.

The former limitation of most often four color channels has been extended with eight color channels of WorldView-2. With faster rotation of WorldView the conditions for getting stereo pairs from the same orbit has been improved. Several optical satellites are announced with down to 0.25m GSD, but also with Pleiades the number of satellites with 0.5m GSD will be enlarged.

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