DIGITAL SURFACE MODELS IN BUILD UP AREAS BASED ON VERY HIGH RESOLUTION SPACE IMAGES

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ABSTRACT

The geometric resolution of very high resolution optical space sensors like IKONOS, QuickBird and OrbView-3 allows the generation of detailed digital surface models also in build up areas. This may be used as base for a 3D-city model. As result of automatic image matching the height value of the building top show the form of the houses within the spacing of the height models well, but in most cases the neighboured points on the ground have some distance from the building caused by viewing shadows. The size of the used sub-matrix for image matching also will lead to some rounding of the edges caused by the fact that the pixels partially are located on top of the buildings and partially on the ground or even the wall.

IKONOS, QuickBird, OrbView-3 and Cartosat-1 stereo pairs have been used for the generation of digital surface models in city areas. By simple theory the height accuracy is linear depending upon the height-to-base-ratio. This is the case for open and flat areas as well as for manual measurement, but not for image matching in cities. With a small height-to-base-relation (close to 1:1) only a limited number of points can be determined on the ground, degrading the overall information contents. In city areas it has been shown that a smaller convergence angle has some advantages and is not linear influencing the vertical accuracy - for a small convergence angle of the space images the standard deviation of the x-parallaxes is still better. Of course the mentioned problems are not the same for the very time consuming manual 3D-measurements. But in some cases of very high buildings also problems of the stereo impression are caused by a large convergence angle of the used satellites. Also this is leading to relative better results for a limited height-to-base-relation.

INTRODUCTION

DEMs are a basic component of a Geo Information System (GIS); they are required for the geo-reference of single images like for the generation of orthoimages. DEMs based on aerial images are not available in all parts of the world and sometimes they are classified. For several applications SRTM height models lead to satisfying results, but with just 3 arcsec point spacing their resolution is far away from the details which can be reached with very high resolution space image pairs. In addition synthetic aperture radar (SAR) has imaging problems in build up areas, causing problems for interferometric SAR. Also the basic resolution of SRTM with approximately 1 arcsec spacing cannot lead to required details in build up areas.

Automatic image matching with very high resolution space images is more difficult like with images having a larger ground sampling distance (GSD). A larger GSD corresponds to a low pass filter, reducing the local image differences of vertical elements. Such vertical elements and the shadows, shown differently depending upon the view direction, are causing problems especially for stereo models with large convergence angles. In aerial applications, in city areas usually normal angle cameras are used, having a height to base relation of 3.2, because automatic image matching of wide angle images with a height to base relation of 1.6 or even manual measurements are difficult in city areas, not allowing a stereo view to the street surface. An additional problem is the combination of view directions to a stereo model. Usually the orbit is not directly above the imaging area, requiring a stereo view from the side, enlarging the nadir angle and area of occlusion. A detailed survey is possible by laser scanning (LIDAR), but laser scanning is expensive and laser scanners are mainly concentrated to Europe and North America, only very few instruments are in use in other continents.

INFLUENCE OF VIEW DIRECTION AND MATCHING PARAMETERS

For the generation of digital surface models (DSMs), containing the height of the visible surface, feature based matching may be used as start information. A height model covering the whole area finally has to be made by area based matching, able to deliver results also in areas with moderate contrast. The area based matching needs a sufficient sub-matrix size in the images for reliable results, causing a low pass effect to the DSM. In addition in city areas the stereoscopic visibility of the objects is depending upon the nadir angle combination of both images. The low pass effect of the matching can be estimated depending upon the viewing and matching parameters like also the influence of the view direction.

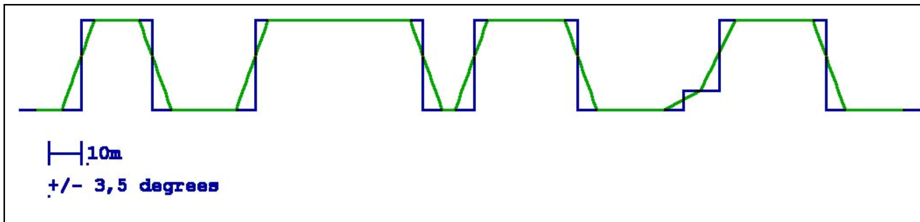
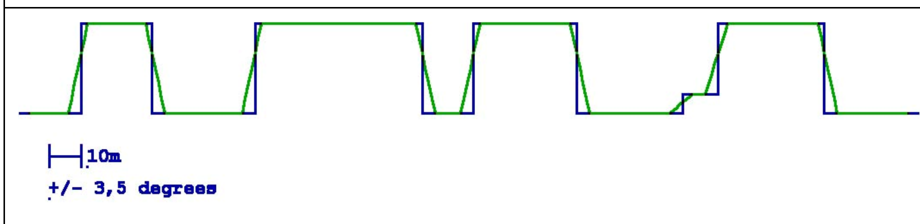
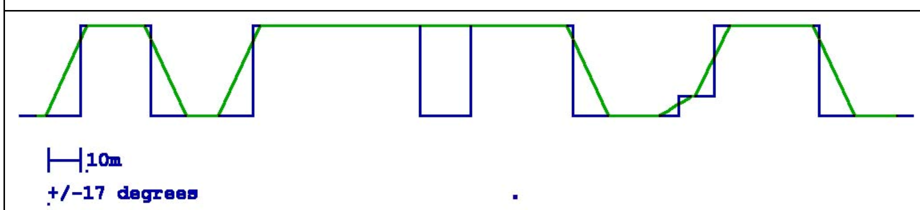
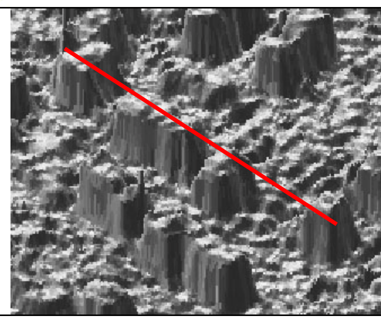
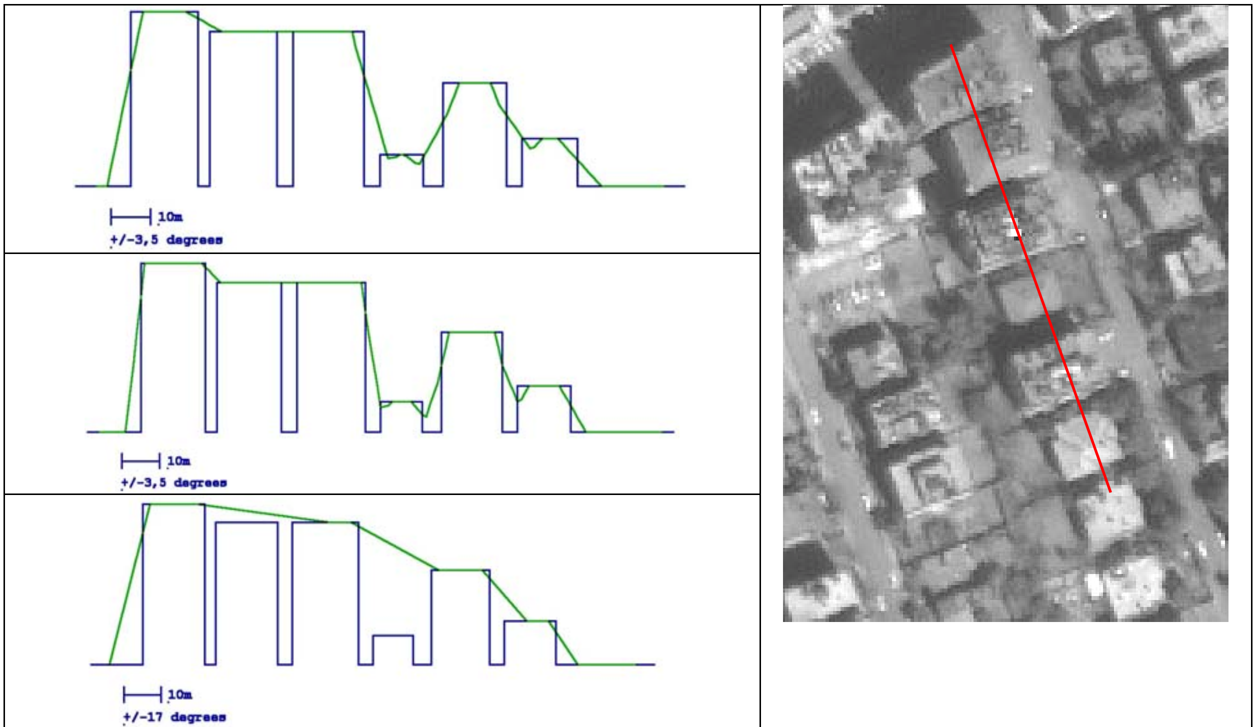
	profile of buildings (blue) and simulated DSM (green) for: sub matrix of matching 10x10 pixels, correlation limit 0.6, nadir angles +/- 3.5°
	profile of buildings (blue) and simulated DSM (green) for: sub matrix of matching 6x6 pixels, correlation limit 0.5, nadir angles +/- 3.5°
	profile of buildings (blue) and simulated DSM (green) for: sub matrix of matching 10x10 pixels, correlation limit 0.6, nadir angles +/-17°
 	sub-area of IKONOS image with investigated building profile and matching results 7.5° convergence angle, sub matrix of matching 10x10 pixels, correlation limit 0.6

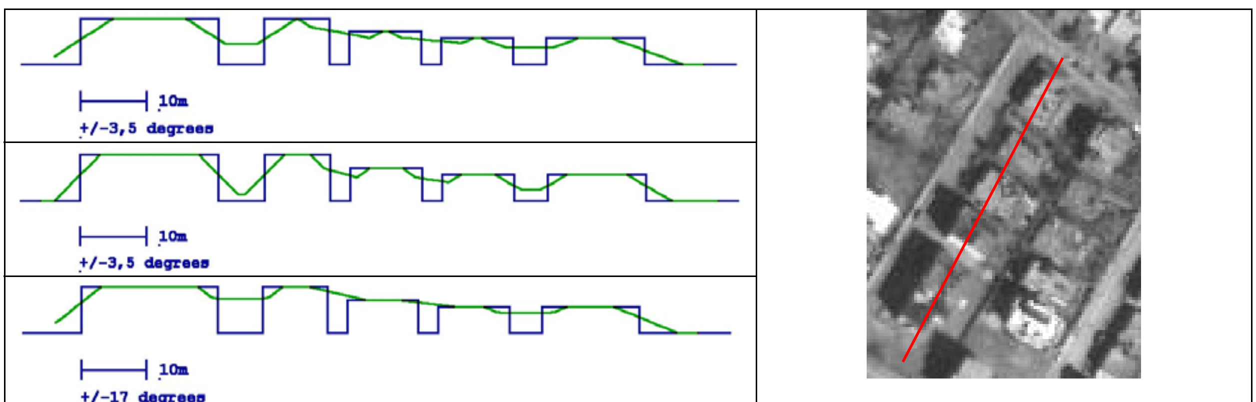
Figure 1. simulation of effect of area based matching for different sub matrix size and view directions based on real IKONOS stereo scene profile with large buildings with space and comparison with real data

The area based matching will not lead to a DSM with vertical facades of the buildings in the DSM. The size of the sub matrix for matching plays an important role and also the occlusion areas caused by the nadir angles of the views has a strong influence like shown in figure 1. If the spacing between the buildings is not large enough, especially larger nadir angles may lead to missing ground points, causing a merging of closely neighbored buildings (figure 1, 3rd profile, center) by interpolation of the height model. The simulated data in figure 1 are based on symmetric view directions with the same size of the nadir angles. In reality this usually is not as optimal – in most cases the imaged area is not located directly below the orbit, requiring also inclined view directions from the side.



above: matching 10x10 pixels, correlation 0.6, nadir angles +/-3.5° centre: matching 6x6 pixels, correlation 0.5, nadir angles +/-3.5° below: matching 10x10 pixels, correlation 0.6, nadir angles +/-17°	sub-area of IKONOS image with investigated building profile, city area

Figure 2. simulation of effect of area based matching for different sub matrix size and view directions – IKONOS, city area



above: matching 10x10 pixels, correlation 0.6, nadir angles +/-3.5° centre: matching 6x6 pixels, correlation 0.5, nadir angles +/-3.5° below: matching 10x10 pixels, correlation 0.6, nadir angles +/-17°	sub-area of IKONOS image with investigated building profile, periphery of city

Figure 3. simulation of effect of area based matching for different sub matrix size and view directions – IKONOS, periphery of city

The height profiles with the simulated matching profiles in figures 1 up to 3 demonstrate the problems of the area based image matching in build up areas. Smaller gaps between buildings disappear with larger sub-matrix for matching size and increasing nadir angle. Even smaller buildings in a row of larger buildings will not get matching points and will disappear by interpolation of the gaps. Smaller buildings with corresponding smaller gaps between the buildings (figure 3) will show the building structures, but more like a hilly area. The achieved real results correspond very well with the simulated data (see also figure 1).

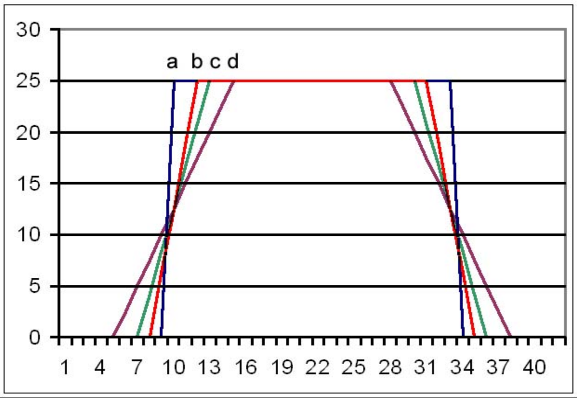


Figure 4. profile through a 25m high building
a: original building
b: sub-matrixes with 4 x 4 pixels
c: sub-matrixes with 6 x 6 pixels
d: sub-matrixes with 10 x 10 pixels

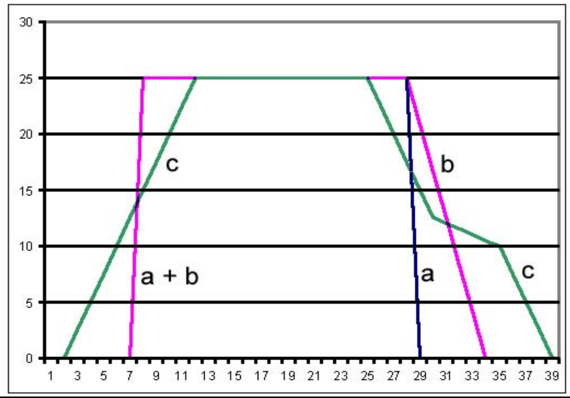


Figure 5. profile through a 25m high building
a: original building
b: shape with nadir 13° angle (view from left)
c: shape caused by nadir 13° angle + sub-matrixes 10 x 10 pixels

The influence of just the sub-matrix for matching and just the nadir angles to the profile of buildings can be seen in figures 4 and 5.

25m high building in OrbView-3 stereo model with height to base relation 1.4 (39° convergence angle), roof and ground marked

49m high building in IKONOS stereo model with height to base relation of 7.5 (7.6° convergence angle)

Figure 6. presentation of high buildings in conjugate images with different convergence angle

The strong effect of larger nadir angles to the presentation of buildings in the images is obvious in figure 6, left hand side, the tall building looks quite different in the corresponding images. A matching is possible on the roof and the ground shown in both images, but not in the area of the facades, leading to a hill structure in the DSM like shown by the simulations above. In images with smaller convergence angle (figure 6, right hand side), the building looks not so different in the corresponding scenes. This will lead to better matching with images having a smaller convergence angle or a larger height-to-base relation. On the other hand, with a larger convergence angle by simple theory better vertical accuracy can be achieved.

The height accuracy is linear depending upon the accuracy of the x-parallax and the height to base relation. For digital images and especially for images with unpublished inner orientation geometry the accuracy of the x-parallax should be expressed in units of GSD (formula 1). In this publication in general the standard deviation is used and not the LE90 or LE95. The standard deviation is based on 68% probability level – that means in the case of normal distributed discrepancies, 68% of the discrepancies are smaller than the standard deviation and 32% are larger. LE90 corresponds to 90% probability level and LE95 to 95%. The relation between LE90 and the standard deviation is 1.65 and for LE95 it is 1.96.

$SZ = h / b * Spx$ **Formula 1.** standard deviation of height (SZ) h = flying height above ground
b = base (= distance of projection centres)
Spx= standard deviation of x-parallax [GSD]

Corresponding to formula 1 the best vertical accuracy can be reached for a low height to base relation – that means a large base while the flying height is fixed for satellites; this corresponds to a large convergence angle. A small height to base relation or large convergence angle indeed leads to better height values of well defined points, but it is causing larger Spx-values by automatic image matching. It is important to find the optimal imaging geometry for the different object classes, because this usually is different for open areas than for build up areas.

The influence of the sub matrix size for matching is as well important. Like shown above, by theory the figure of the buildings will be more close to the real shape. On the other side the matching requires a sufficient size of the sub matrix to bridge discontinuities and areas with low contrast and to reduce the noise.

EXPERIENCES

The number of stereo scenes taken with very high resolution satellites from the same orbit is limited. The stereo imaging from the same orbit limits the possibility to take other scenes within between. The selling price for a stereo scene is below the sum of prices for scenes which can be taken without the rotation of the satellite for stereo configuration. So for the satellite companies it is not economic to generate stereo pairs. The conditions are different for the different satellites depending upon the satellite agillity. The time to slew the scene center 300km on the ground for IKONOS is 25sec, for QuickBird 62sec and for OrbView-3 32sec. This will be improved for Worldview-1 and -2 to 10sec, respectively 9sec (McGill 2005), improving also the conditions for stereo imaging. Today instead of using stereo scenes from the same orbit, also stereo configurations of images not from the same day are handled. This of course may be influenced by changes of the vegetation – this is limited in build up areas, but also by the effect of different sun elevation.

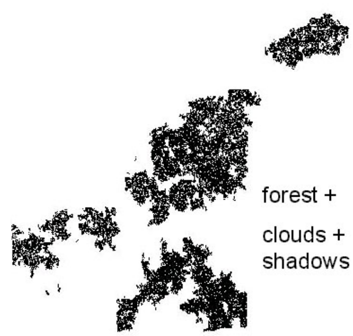
		
IKONOS sun elevation 41.5°	IKONOS sun elevation 67.2°	distribution of matched points

Figure 7. influence of sun elevation to images and image matching, mountainous city of Zonguldak, Turkey

From the city area of Zonguldak, Turkey, some IKONOS scenes have been used, taken at different time of the year. The image taken in July with 67.2° sun elevation looks quite different like the image taken in October under 41.5° sun elevation (figure 7). In city and forest areas the change of the sun elevation makes the automatic matching of such image combination hopeless as it can be seen also at the distribution of the matched points in the IKONOS image combination taken in July and October (figure 7, right hand side). Just 33% of the possible points have been matched with a correlation coefficient above the tolerance limit of 0.5.

Optimal matching conditions have been found for an IKONOS stereo model with height to base relation of 7.5 (7.6° convergence angle). The negligible time interval of just 12sec and the small angle of convergence resulted in very similar images; in this model between 80% and 90% of the possible points have been matched by least squares with a correlation coefficient above 0.95.

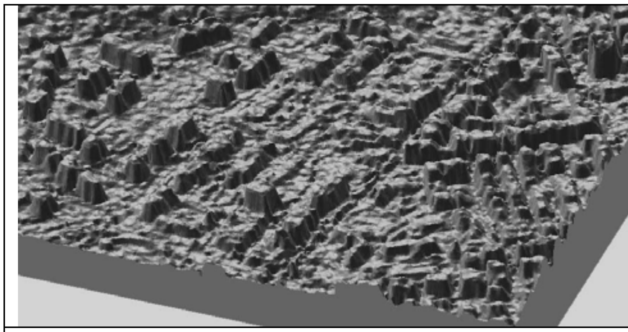


Figure 8a. 3D-view to IKONOS DSM (same area like figure 1), matching with sub-matrixes 10x10 pixels, point spacing 1, median filter 7x7

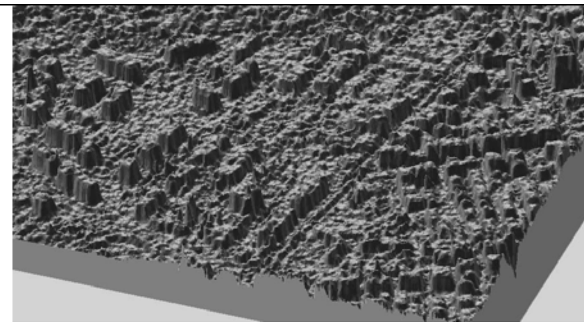


Figure 8b. 3D-view to IKONOS DSM (same area like figure 1), matching with sub-matrixes 6x6 pixels, point spacing 1, median filter 7x7

In this model a vertical accuracy of 1.7m has been reached for areas with good contrast, this corresponds to a standard deviation Spx = 0.22 GSD. It was confirmed by the root mean square y-parallax of the intersections of 0.25 GSD.. As rule of thumb the general accuracy of a DEM checked with a reference DEM has approximately the double standard deviation like identified at individual check points.

The small angle of convergence allowed the use of sub matrixes for matching just having only 6 x 6 pixels, leading to more details about the object and to more vertical facades in the DSM (figure 8). Such small sub matrixes cannot be used for stereo configurations having some days difference in time or having larger angle of convergence. From the area of Phoenix, Arizona some QuickBird images have been used for the analysis of automatic matching in the city area. The combination of the used images has been taken with 10 days difference in time causing no problems with changed shadows. The build up area was matched successfully (figure 9). Difficult was the height determination in large parking places at shopping centres – the cars have moved and so the matching failed (figure 9).

Figure 9. overlay of matched points to QuickBird image

matched points = white
dark parts = matching failed

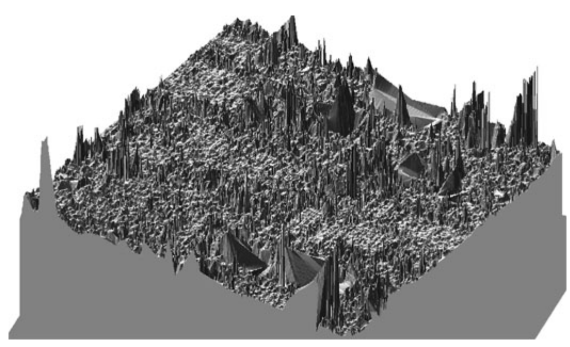
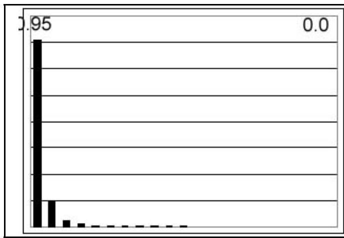


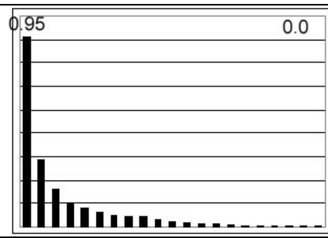
Figure 10. shaded DSM generated by QuickBird image matching

Dark image parts, moved cars and repeated elements, especially on roof tops, caused in some areas errors in matching (peaks in figure 10). The caused height errors have been eliminated automatically with the Hannover filter program RASCOR (Passini et al 2002). After this, the result was satisfying. The dominating small individual houses with trees and bushes around, did not lead to clear shapes of buildings. A comparison with a reference DEM was difficult - by filtering not the whole influence of the buildings and the vegetation could be removed. The reached mean square difference of 4m corresponds with the height to base relation of 11.6 to Spx = 0.6 GSD; under the difficult conditions of the comparison this is a satisfying result. The y-parallax of the intersection was in the same range, confirming it.

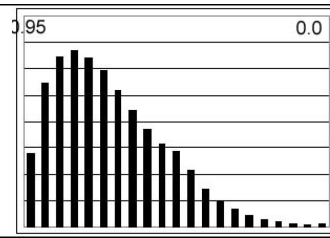
The area of Zonguldak has been imaged by OrbView-3 from the same orbit with a height to base relation of 1.4, corresponding to a convergence angle between both view directions of 39°. The city area of Zonguldak is build up densely with high buildings, partly in mountainous terrain. Also with wide angle aerial images having a standard height to base relation of 1.6, automatic image matching as well as manual measurements would be difficult, so problems in the city area have been expected from the beginning.



IKONOS, Maras



QuickBird, Phoenix



OrbView-3, Zonguldak

Figure 11. frequency distribution of correlation coefficients

The frequency distribution of the least squares matching correlation coefficients for the above mentioned areas is shown in figure 11. Under the optimal conditions for IKONOS in Maras the matching was optimal with very high correlation coefficients. The used QuickBird stereo with 10 days difference in time and also a small convergence angle of 5° even shows good matching results. Quite different results have been achieved with the OrbView-3 stereo model caused by the large convergence angle. Even with the reduced acceptance level 0.5 for the correlation coefficients, just 53% of the possible points have been matched successfully.

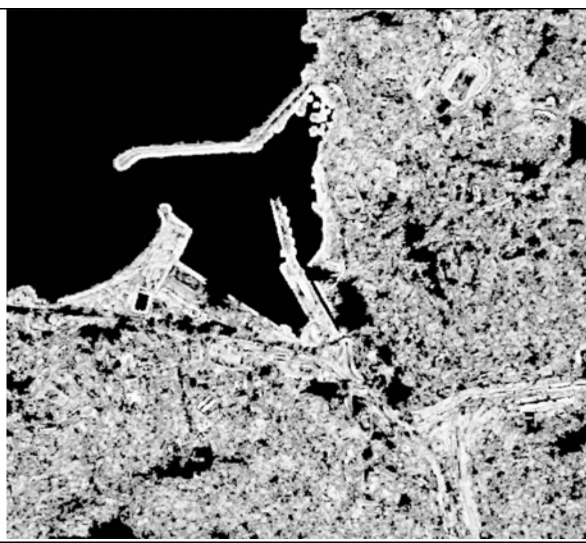


Figure 12. quality image of OrbView-3 matching
grey value 255 = correlation coefficient = 1.0
grey value 127 = correlation coefficient = 0.5
grey value 0 = correlation coefficient < 0.5

Figure 13. corresponding sub-area of OrbView-3 scene

The quality image of matching the city area (figure 12) shows the problems, the brighter parts – that means higher correlation values – are in the open and more flat areas while the matching in the densely build up and mountainous areas was poor or even failed.

The satellites SPOT-5 with the stereo sensor HRS, Cartosat-1 and ALOS/PRISM are always generating stereo combinations by 2, respectively 3 cameras. While the SPOT-5 HRS images are used only for the DEM generation by SPOT Image and the images are not distributed, the Cartosat-1 and the ALOS/PRISM images are available. Cartosat-1 and ALOS/PRISM have 2.5m GSD, making the matching easier than with the higher resolution images.

In the frame of the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP) three stereo models have been investigated (Jacobsen 2005). Only smaller cities with not so high buildings are included. The height to base relation of 1.6 (convergence angle 35°) together with 2.5m GSD did not cause any problem in the build up areas, no gaps are shown in the matched DSM. For 2.5m GSD the buildings are too close together to allow the isolation of individual buildings in the height model, only building rows can be seen. Nevertheless excellent standard deviations of the height in relation to reference height models have been reached with $SZ = 3.17 + 3.14*\tan\alpha$, $SZ = 3.22 + 1.97*\tan\alpha$ and $SZ = 2.39 + 8.80*\tan\alpha$ for the three areas, where α describes the terrain inclination. For well defined objects, like buildings, the accuracy usually is better by the factor 2 than for the average of all points in the DSM, including also areas with poor contras.

CONCLUSION

Automatic image matching with very high resolution space images is more difficult like with lower resolution. Similar problems like with aerial images appear in city areas. It is optimal to use stereo pairs taken from the same orbit just with a limited number of seconds time difference, but it is not a problem to combine images taken with 10 days difference in time. Nevertheless digital surface models can be generated in city areas with very high resolution space images. Of course a manual plotting of the buildings leads to the highest accuracy and detailed results, but this is very time consuming. In build up areas the matching of images with a small convergence angle (large value of height to base relation) has advantages against the matching with a large base, which is causing a loss of matched points by reason of differences in the images taken from different direction and is not leading to a good shape of the buildings because of the large view shadows. So the often used height to base relation of 1.6 or even 1.4 has advantages for the open areas, but for the central city areas a larger value (smaller convergence angle) should be preferred. By theory with a smaller size of the sub-matrixes used for matching, the building shape should be clearer, but together with the lower accuracy and the required filtering it has not a real advantage.

By simple theory the height accuracy is linear depending upon the height to base relation, but vertical elements viewed from different directions are presented quite different causing problems of matching and leading to larger standard deviations of the x-parallax. So the optimal height to base relation for city and also mountainous areas is more in the range of 3.0. Very good results have been reached also for very small convergence angles. The standard deviation of the x-parallax is in the range of up to 0.22 GSD for small convergence angles, but in any case it was below 1 GSD.

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