MAPPING FROM SPACE - A COOPERATION OF ZONGULDAK KARAELMAS UNIVERSITY AND UNIVERSITY OF HANNOVER

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ABSTRACT

With financial support of TUBITAK and the Jülich Research Centre, in 2002 up to 2005 the topic “Geometric & Semantik Analysis of Space Imagery for Topographic Mapping” has been investigated in a cooperation of the Zonguldak Karaelmas University and the University of Hannover. The cooperation continues up to today. In the area of Zonguldak a close to complete selection of the civilian available high resolution space images has been achieved. Together with available reference data and control points, measured by GPS, an intensive analysis was possible.

With the series of high resolution space images the different types of scene orientation has been tested. With sufficient accurate control points, a sub-pixel accuracy can be reached with all images using a correct mathematical model. Approximations like 3D-affine transformation and DLT for CCD-line scan images do have their limitations and cannot be used for sensors using a permanent change of the view direction during imaging.

With stereo scenes, digital surface models (DSM), showing the visible surface of the earth including vegetation and buildings, can be generated by automatic image matching. If the images have not been taken from the same orbit, problems of matching have to be expected especially caused by the changed sun elevation. The DSMs are more accurate in the open areas like in the forest and the accuracy is depending upon the terrain inclination. With a smaller height to base relation the matching may be more difficult. Especially in build up areas the height should be at least 3 times as much as the base. The SRTM height points can be more precise like the height models generated by matching, but in the rough area of Zonguldak, the point spacing of the SRTM C-band DSMs is causing a reduced morphologic information while the spacing of only one arcsec of the X-band DSMs shows more details.

The rule of thumb of 0.1mm ground sampling distance (GSD) in the map scale, as limit for the possible map scale, has been confirmed, but the individual conditions of imaging are also important. With an IKONOS scene taken under low sun elevation, the mapping is quite more difficult like in the case of short shadows belonging to a high sun elevation. Independent from this, some sensors do have a lower image quality like others taken under similar conditions.

1. INTRODUCTION

The cooperation between the Zonguldak Karaelmas University and the University of Hannover started with a 3 month visit of the second author in Hannover in 1999 and continued with a visit of the first author in Zonguldak in 2001. With financial support of TÜBITAK and the Jülich Research Centre from 2002 up to 2005 the cooperation has been intensified. During the period from 2002 up to 2005 with 10 visits in the partner universities by in total 7 research persons the continuing investigations in the field of mapping from space have been supported. In 2005 the achieved results have been used for an educational course “Mapping from Space” in Zonguldak with wide participation of the group interested in it from whole Turkey and some other countries. The cooperation was leading also into a common organisation of the ISPRS working group I/5 "Geometric Models of Satellite Sensors and DEM Generation" by both authors. This working group organised together with the ISPRS WG I/6 "Small Satellites" in February 2006 in Ankara the Workshop "Topographic Mapping from Space – with special emphasis on Small Satellites" with a good international participation. Currently a student from Zonguldak is writing his master thesis in Hannover.

The field of mapping from space has growing importance with the raising number of available high and very high resolution optical satellites and the acceptance by a large user community. In total 26 common papers about this topic have been publishes by the group of the Zonguldak Karaelmas University and the University of Hannover.

In the Zonguldak area a test field has been build up with precise control points and reference height models for the investigation of a wide range of civilian available space images.

2. ANALYSED SPACE IMAGES

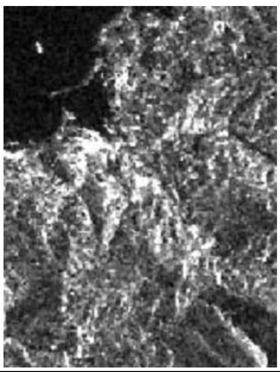


Fig. 1: JERS SAR L-band 18m GSD

Fig. 2: Landsat 7 TM 30m GSD

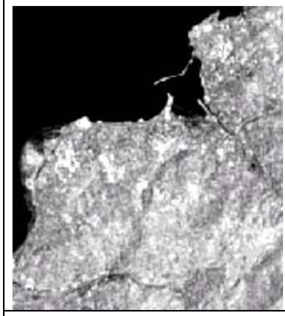


Fig. 3: Landsat 7 panchromatic, 15m GSD

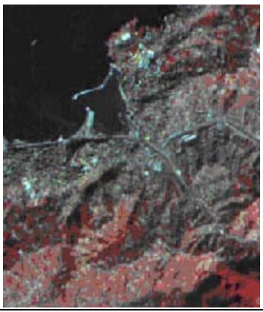


Fig. 4: ASTER 15m GSD

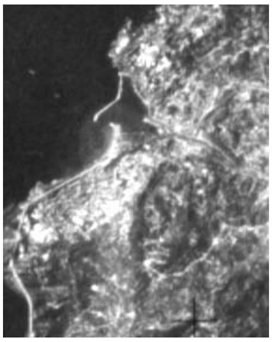


Fig. 5: TK350 photo 10m GSD

Fig. 6: IRS-1C 5.7m GSD

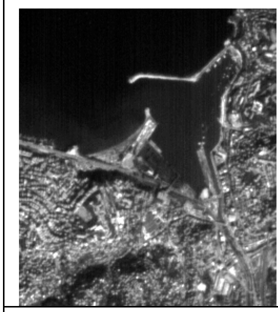


Fig. 7: KOMPSAT-1 6.6m GSD

Fig. 8: SPOT 5 5m GSD

Fig. 7: KVR 1000 photo 1.6m GSD

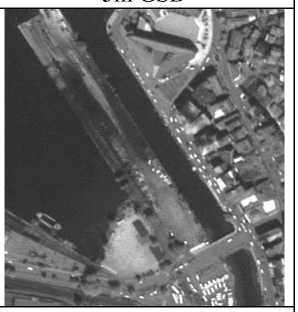


Fig. 8: OrbView-3 1m GSD

Fig. 9: IKONOS pan 1m GSD

Fig. 10: QuickBird pan 0.6m GSD

An overview of the space images used in the Zonguldak test area is given in figures 1 up to 10, showing the Zonguldak city area. It is still a pity that it was not possible to get BILSAT images of the test field or other areas.

During the start of the project also the Russian space photos TK350 and KVR1000 have been used, but the not optimal experience with the disturbing film grain and several scratches caused a concentration to the digital images, starting with the lower resolution and with the existence of very high resolution also the higher resolution images have been used. Partially some images of the same sensor, taken under different conditions are available. Stereo combinations allowed also the generation of digital elevation models (DEMs).

3. IMAGE ORIENTATION

All geo-coded data acquisitions are based on a correct image orientation. Within the cooperation project the geometry of the available space images have been analysed in detail and the required programs for orientation have been developed or improved.

All today high and very high resolution space images are based on CCD-line scanner images. The new satellites are flexible and do allow a fast and precise change of the satellite orientation. This leads to new possibilities of imaging – also during imaging the orientation can be changed, so a scan parallel to the object coordinate system is possible – also a scan against the orbit or in east-west direction. The mathematical model has to respect this.

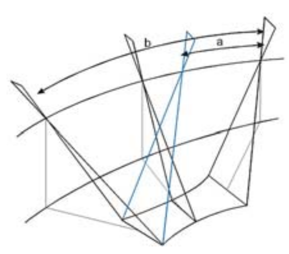


Fig. 11: change of view direction during imaging for reduction of image motion – slow down mode

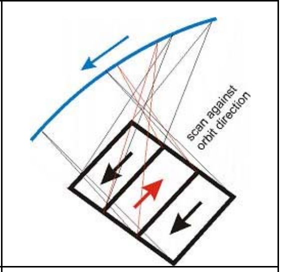


Fig. 12: scan in different directions by IKONOS and OrbView-3

The satellites are equipped with a positional system like GPS or DORIS, gyros and star sensors. Based on this information the scene orientation is known on a high accuracy level. So can IKONOS, QuickBird and OrbView-3 determine the sensor orientation without control points with accuracy in the range of 10m on the ground. This orientation information is available in form of rational polynomial coefficients (RPCs) - the relation of 3rd order polynomials describing the relation between the ground and the image coordinate system. Usually the RPCs are improved by means of control points, named bias corrected RPCs.

Just based on the available view direction from the scene centre or start of scene to the satellite, the general satellite orbit and the relation the orbit to the ground distance (slow down mode – see figure 11), the scene orientation can be reconstructed for any CCD-line. This reconstruction of the image geometry can be made also without control points like with the RPCs.

In addition to these rigorous orientation methods also some approximations are in use, neglecting the known scene orientations. These are the 3D-affine transformation, the direct linear transformation (DLT) and the object oriented RPCs which is computing the most important polynomial coefficients of the preceding described RPCs based on control points. The 3D-affine transformation is using the mathematical model of parallel projection, neglecting the small field of view of the satellite sensors; the 8 unknowns require at least 4 three-dimensional well distributed control points. The 11 unknowns of the DLT try to determine the inner and the exterior orientation of perspective geometry, neglecting the individual projection centres for each CCD-line. In addition the determination of the inner orientation for the very small field of view of the satellite images is nearly not possible, leading to extreme correlations of the unknowns. The same correlation problem exists for the object oriented RPCs. This method shows always very small discrepancies at the used control points, but the commercial programs using it do not indicate any problem in the object space. With not optimal control point configurations IKONOS images showed sub-pixel discrepancies at the control points, but in the object space, even not in an extrapolation area, errors exceeding 50m occurred. This method is not serious and should never be used even if it is available in some commercial program packages.

The different orientation methods have been compared for the very high resolution sensors IKONOS, QuickBird and OrbView-3 in the Zonguldak test area with different numbers of control points.

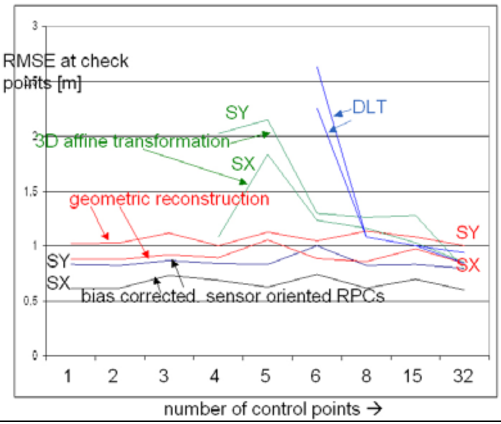


Fig. 13: Results at independent check points for the different orientation methods as a function of the number of control points for IKONOS

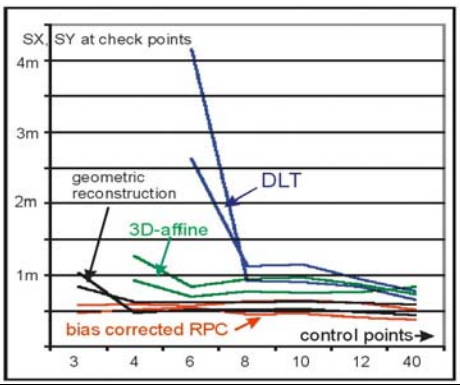


Fig. 14: Results at independent check points for the different orientation methods as a function of the number of control points for QuickBird

The both rigorous methods of sensor oriented RPCs and geometric reconstruction are correcting at first the influence of the different terrain elevation, after this a transformation to the control points will be made. The internal accuracy of the IKONOS scenes is very good, so a simple shift to the control points is sufficient leading to a sub-pixel accuracy starting with one control point. For the smaller ground sampling distance (GSD) of QuickBird at least a 2D-affine transformation is required. By this reason at least 3 control points have to be used for sub-pixel accuracy. The approximations 3D-affine transformation and DLT do need at least 2 control points more than required by the number of unknowns, the three-dimensional distribution must be very good and quite more control points have to be used for reaching a sub-pixel accuracy with IKONOS. For QuickBird the approximate solutions also with a higher number of control points are reaching only up to 1.3 GSD accuracy.

The orientation of OrbView-3 images is more difficult like for the 2 other mentioned very high resolution satellites. With the 3D-affine transformation only a standard deviation of 13m for the ground coordinates has been reached and with DLT 8.4m. Even an extension of the 3D-affine model by 6 more unknowns respecting the changing view direction was leading only to 2.8m accuracy. But also the bias corrected RPCs are limited to only 1.6m RMSE at independent check points. This is still a sufficient accuracy for mapping purposes, but it is limiting the accuracy of the generation of digital elevation models. The reason for the limited accuracy may be caused by the required slow down mode (figure 11) and the not so good internal scene accuracy.

4. DIGITAL ELEVATION MODELS

DEMs are required for several purposes, they are a basic component of a geo information system (GIS), but they are not always available with the required accuracy and point spacing. At the start of the cooperation only a reference height model based on digitized contour lines of a topographic map 1 : 25 000 was available having a vertical accuracy of approximately 6 to 8m and a point spacing of 40m. At first a stereo models based on Russian space photos TK350, covering an area of 160km x 160km and a model from ASTER covering 60km x 60km with 15m GSD have been created.

The DEM generation based on the TK350 was disappointing – the film grain was disturbing the matching and especially in the forest area the contrast was poor. Even if matching errors of 150m and larger are excluded, in the open areas only a standard deviation of the heights SZ = 20.0m + 23.9m * tan α, with α = terrain inclination, has been reached. In the forest areas it was only SZ = 49.0m + 11.4m * tan α. The automatic image matching with ASTER images was quite better. Especially in the forest the near infrared band has quite better contrast. The analysis of the ASTER height model against the reference height model indicated a horizontal shift, so this was determined by adjustment with the Hannover program DEMSHIFT with 64m in X and -16m in Y. After the shift the root mean square differences have been SZ = 12.8m + 95m * tan α for the open areas and SZ = 15.6m + 73m * tan α for the forest areas – a quite sufficient result for the 15m GSD and the height to base relation of 2.0 of ASTER corresponding to 0.4 pixels standard deviation of the x-parallax.

With a SPOT5-model having a height to base relation of 1.86 and a GSD of 5m better conditions for a DEM generation do exist. The image matching was without problems. Against the reference height model form the topographic map a not so satisfying result of SZ = 11.7m + 2m * tan α has been reached; but this is still dominated by the accuracy of the reference DEM. In 2005 also a reference DEM based on a large scale photogrammetric mapping became available. Against this more detailed reference DEM having a spacing of 10m quite better results are reached with SZ = 4.0m + 14m * tan α for the open areas and SZ = 7.5m + 16.8m * tan α for the forest areas and against check points SZ = 3.5m + 0.9m*tan α. But at check points we do have a good object contrast and no disturbing neighboured elements, leading to too optimal results for the whole DEM. The accuracy of 4.0m for flat and open areas corresponds to a standard deviation of the x-parallax of 0.4 pixels for the SPOT scenes. This always good value is still influenced by the buildings in the open areas, so it must be better for open agriculture areas. The discrepancies in the forest areas do show a bias of 3.9m and an asymmetric frequency distribution of the height differences caused by the not too high trees in the Zonguldak area.

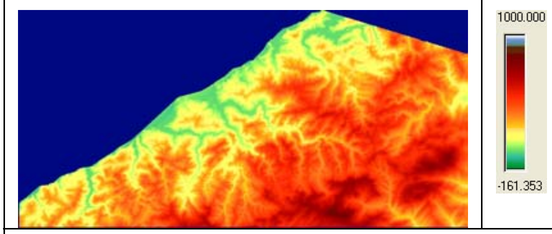


Fig. 15: colour coded SPOT5-DEM of Zonguldak area

With a KOMPSAT-1 model having a height to base relation of 2.1 SZ = 11.9m + 4.7m * tan α in the open areas and SZ = 13.4m + 8.8m * tan α in the forest areas has been reached. For open and flat areas this corresponds to a x-parallax of 0.8 pixels.

Three IKONOS images of the Zonguldak area, taken from different direction, but at different seasons are available. The matching of these images was not successful because of the quite different sun elevation causing quite different shadows. In the forest areas the matching failed nearly completely and also in the city area it could not be accepted. Also based on other results it can be stated that the stereo images should come from the same orbit or the difference in time should not exceed approximately 10 days.

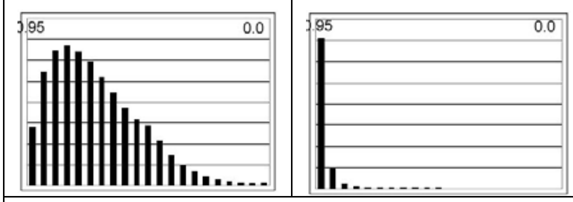


Fig. 16: frequency distribution of correlation coefficients of least square matching – left: Zonguldak, right: Maras

The first test of an OrbView-3 stereo model taken from the same orbit, with a height to base relation of 1.4 has been made. This model is available just since short time, so no final height accuracy analysis could be made. The height to base relation of 1.4 corresponds to a convergence angle of 39°. This is optimal for open areas, but difficult for the dense Zonguldak city area. By this reason the frequency distribution of the correlation coefficients in the city is not optimal (figure 16).

In the area of Maras an IKONOS model with a height of base relation of 7, corresponding to a convergence angle of 8° was leading to very good matching results because the matched images are very similar. The convergence angle of 39° in Zonguldak causes a view to buildings from the left and the right side, showing different facades – based on this the matching is not optimal. For city areas a smaller convergence angle is required.

With the Shuttle Radar Topography Mission (SRTM) a nearly world wide height model has been generated and the US C-band results are available free of charge in the internet with a spacing of 3 arcsec, corresponding to 92m at the equator. For the Zonguldak area also the German X-band height model with a point spacing of 1 arcsec has been used. It is the question if the generation of height models based on space images is justified if SRTM DEMs can be used. The SRTM height models have been compared against the precise reference DEM leading to the results shown in table 1.

X-band open area	SZ = 4.6m + 10.6m * tan α
X-band forest	SZ = 5.7m + 13.0m * tan α
C-band open area	SZ = 5.9m + 5.7m * tan α
C-band forest	SZ = 6.3m + 6.5m * tan α

table 1: accuracy of SRTM height model in Zonguldak

There is no very clear difference between the accuracy of the X-band and the C-band height model at the given points. By theory the X-band data should be more precise, but the C-band data represents in the mean results from 2 to 3 orbits while the X-band data are usually only based on one orbit. The accuracy of height models based on interferometric SAR is depending upon the aspects (direction and size of terrain inclination).

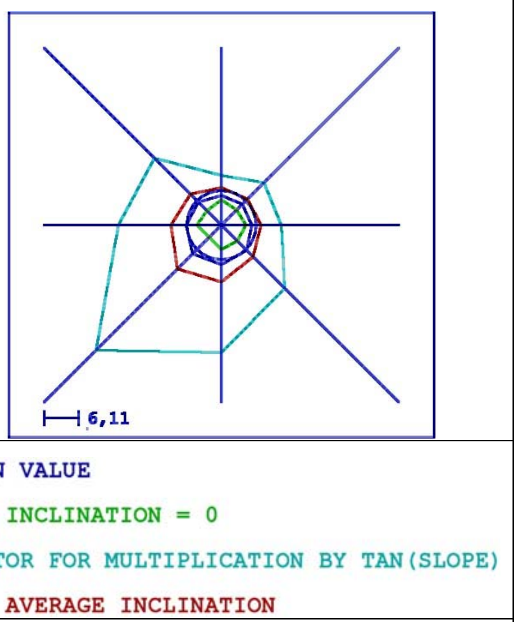
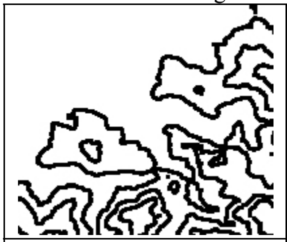
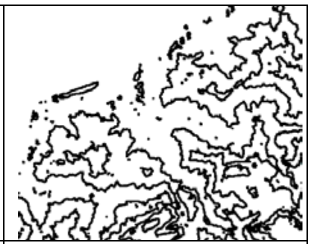


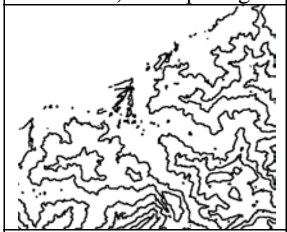
Fig. 17: accuracy of SRTM X-band DEM in open areas as function of aspects

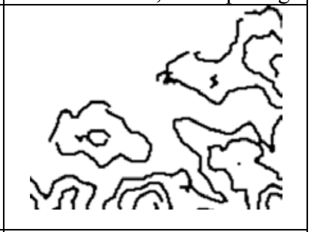
Figure 17 shows the clear dependency of the SRTM X-band height accuracy depending upon the aspects. The direction of the largest values does correspond very well to the direction perpendicular to the orbit. For the C-band the dependency upon the aspects is not so clear caused by the average between the results based on ascending and descending orbit.

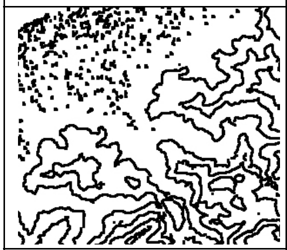
The accuracy of the height model generated by SPOT is in the accuracy range of the SRTM X-band DEM, so it is the question of also the free available SRTM C-band height model can be used instead of the SPOT-data. This also depends upon the morphologic contents which can be seen at details of generated contour lines.


ASTER, 45m spacing


KOMPSAT-1, 20m spacing


SPOT 5, 15m spacing


SRTM C-band, 80m spacing


SRTM X-band, 27m spacing

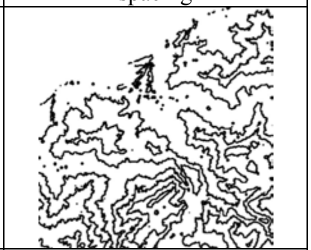

reference height model spacing 10m

Fig. 18: contour lines of generated DEMs, contour interval 100m

The SRTM X-band DEM with an average spacing of 27m shows details not far away from the reference DEM, but SPOT5 with 15m and KOMPSAT-1 with 20m spacing are still a little more detailed in spite of the equal or lower accuracy of the height points. The C-band DEM with a spacing of 80m in the average does not describe the details very well. Even the quite less accurate ASTER DEM having 45m spacing is showing more morphologic details. Of course this result from the mountainous area of Zonguldak cannot be transferred to a more smooth landscape – there the situation may be different, but in the area of Zonguldak the generation of height models based on space images still leads to more details like the SRTM C-band DEM and partially also the SRTM X-band DEM.

5. MAPPING

One of the main reasons for using space images is the generation of GIS-data. Today orthoimages are one of the most often used geoinformation products. Here we do have the simple rule, that the orthoimages should have at least 8 pixels/mm; corresponding to a publication scale of 1:5000 for QuickBird, 1:40 000 for SPOT5 and 1:120000 for ASTER. For vector maps the relation between GSD and the publication scale of a topographic map is more complex. We do have the rule of thumb of 0.1mm GSD in the publication scale for topographic maps, but this depends also upon the imaging conditions.

	GSD	largest publication scale
ASTER	15m	1 : 150 000
KOMPSAT-1	6.6m	1 : 66 000
IRS-1C	5.7m	1 : 57 000
SPOT5	5m	1 : 50 000
OrbView-3	1m	1 : 10 000
IKONOS	1m	1 : 10 000
QuickBird	0.62m	1 : 6 200

Table 2: possible publication scale of topographic maps corresponding the rule of thumb of 0.1mm GSD in map

The rule of thumb cannot be used so strict, so for example with KOMPSAT-1 and IRS-1C topographic maps 1 : 50 000 can also be generated like 1 : 5000 from QuickBird images. The bottle neck is not the accuracy; the mapping accuracy must not exceed 0.25mm in the publication scale. With all digital space images accuracy of 1 pixel for well identifiable objects can be reached and this corresponds to a publication scale 2.5 times as much as shown in table 2. The limiting factor is the identification of details required for the publication scale. Of course this is not totally fixed, it is depending upon the details shown by the maps of the different countries and it is depending upon the area – for the wide and regular roads and building structures in the USA a larger GSD can be accepted like for unplanned areas in other countries. In addition the imaging conditions cannot be neglected – especially the sun elevation is important.


sun elevation 67°


sun elevation 41°

Fig. 19: influence of sun elevation to IKONOS images

As it can be seen in figure 19, the identification of roads and road limits is very difficult in the shadows caused by a sun elevation of 41° in the narrow streets of Zonguldak.

In addition the general image quality is not the same for the different sensors. Panchromatic Landsat 7 scenes having the same GSD of 15m like ASTER do not allow the identification of the same details like ASTER. IRS-1C with 5.7m GSD but a limitation to 6bit grey values showed only an effective GSD of 6.9m, determined by edge analysis. So with KOMPSAT-1 images having 6.6m GSD more details could be identified like with IRS-1C.


Fig. 20:

pan-sharpened IKONOS, 41° sun elevation

QuickBird, IKONOS and SPOT5 can take colour information with a lower resolution in parallel to the panchromatic images. By pan-sharpening the colour and the panchromatic information can be joined to a high resolution colour image. The object identification is easier with pan-sharpened images like with panchromatic images (compare figure 20 with figure 19 right hand), but only few additional objects could be identified by means of the colour information.

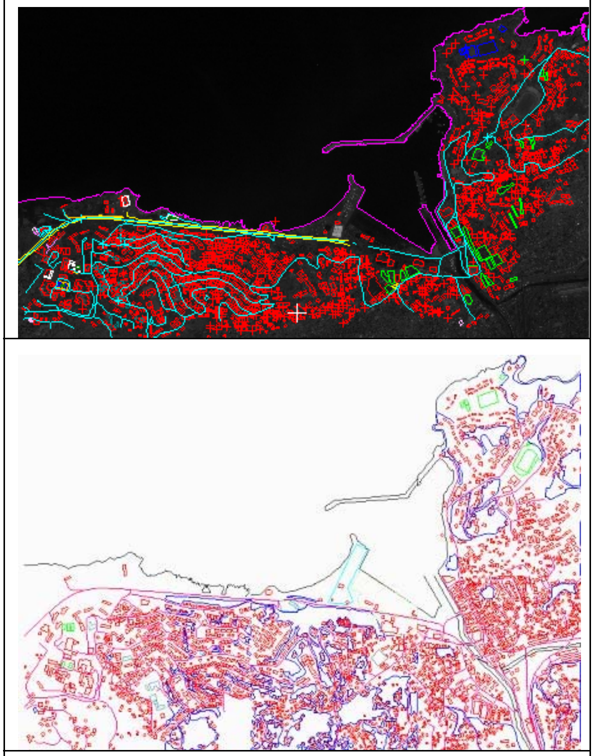


Fig. 21: above: map generated with OrbView-3 image, below: IKONOS; + = identified building, but vectors could not be plotted

In general the rule of thumb shown in table 2 has been confirmed. With OrbView-3 images some buildings could be recognized, but the plotting was not possible. OrbView-3 has a GSD of 1m, but this is only reached by over-sampling of neighboured pixels by 50% - the projected pixel size is 2m x 2m on the ground. This is the explanation of the a little lower mapping quality with OrbView-3 images.

6. CONCLUSION

An overview of the results based on the cooperation between Zonguldak Karaelmas University and the University of Hannover is given. More details can be seen in the high number of publications. With the common research an international recognized high standard has been reached. The permanently growing number of high resolution space images has caused the use of space images in competition to low and medium scale aerial images for more and more applications. Together with the growing number of sensors it was necessary to upgrade and complete the programs of the University of Hannover for image orientation, DEM and ortho-image generation.

ACKNOWLEGMENTS

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REDUCED NUMBER OF COMMON PUBLICATIONS

Büyüksalih, G., Jacobsen, K.: Determination and Improvement of Digital Elevation Models based on MOMS-2P Imagery, Turkish-German Geodetic Days, Berlin, 2001

Büyüksalih, G., Kocak, M.G., Oruc, M., Akcin, H., Jacobsen, K: DEM Generation by ASTER and TK350, Joint Workshop "High Resolution Mapping from Space 2003", Hannover 2003

Büyüksalih, G., Kocak, M.G., Oruc, M., Akcin, H., Jacobsen, K: Handling of IKONOS-images from Orientation up to DEM Generation, Joint Workshop "High Resolution Mapping from Space 2003", Hannover

Büyüksalih, G., Jacobsen, K.: Generation and Validation of High Resolution Space Image DEMs, ASPRS annual convention, Denver 2004

Büyüksalih, G., Oruc, M., Jacobsen, K. 2004: Precise Georeferencing of Rectified High Resolution Space Images, ISPRS Congress, Istanbul 2004

Kocak, G., Büyüksalih, G., Jacobsen, K., 2004: Analysis of Digital Elevation Models Determined by High Resolution Space Images, ISPRS Congress, Istanbul 2004

Topan, H., Büyüksalih, G., Jacobsen, K., 2004: Comparison of Information Contents of High Resolution Space Images, ISPRS Congress, Istanbul 2004

Büyüksalih, G., Kocak, M.G., Oruc, M., Akcin, H., Jacobsen, K., 2004: Accuracy Analysis, DEM Generation and Validation using Russian TK-350 Stereo-Images, The Photogrammetric Record, 19 (107), pp 200-218

Büyüksalih, G., Jacobsen, K., 2005: Optimized Geometric Handling of High Resolution Space Images, ASPRS annual convention Baltimore, 2005

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Most of the listed and not listed common publications are available in the WEB-page of the Institute for Photogrammetry and Geoinformation of the University of Hannover: http:/www.ipi.uni-hannover.de