INVESTIGATION OF THE POTENTIAL OF MULTISCOPIC VHR SATELLITE IMAGERY FOR THE PRODUCTION OF 3D MODELS OF COMPLEX URBAN AREAS

Frederik Tack[1], Rudi Goossens[2], Dennis Devriendt[3], Gürcan Büyüksalih[4]

1. Ghent University, Department of Geography, Gent, Belgium; f.tack@ugent.be
2. Ghent University, Department of Geography, Gent, Belgium; rudi.goossens@ugent.be
3. Ghent University, Department of Geography, Gent, Belgium; dennis.devriendt@ugent.be
4. Bimtas, Istanbul, Turkey; gbuyuksalih@yahoo.com

ABSTRACT

Improved radiometric quality and geometric accuracy of high resolution sensors like Ikonos and Quickbird allow a more detailed mapping of urban areas. Due to this new generation of sensors the potential for producing 3D models of such complex areas has substantially increased.

The objectives of the MAMUD research project is to investigate how earth observation can contribute to a better monitoring, modeling and understanding of urban dynamics, and its impact on the urban and suburban environment. The outcome of the research can lead to the development of a useful tool for urban planning approaches based on sustainable development.

While most remote sensing based studies on urban dynamics only consider two-dimensional structure, in this research also stereoscopic and multi scopic imagery will be used to derive the third dimension, which is obviously important in describing urban morphology. The fast growing urban area of Istanbul is chosen as the study area of our research.

The subject of this treatise mainly deals with the potential of multi-angle image acquisition for improving the accuracy of the stereo model and reducing the impact of shadow and occluded areas. For the VHR multi scopic study an area extending from the centre of Istanbul to the urban fringe is chosen.

As Ikonos triplets might not be available, a triplet might be constructed from multi-orbit images. A configuration consistent of one Ikonos stereo pair combined with a nearly vertical Ikonos image from more or less the same orbit will be used. The Ikonos stereo pair is captured in March 2002. The images of the stereo pair have an elevation angle of respectively 67.59° and 75.59°. The collection azimuth is respectively 1.6° and 214.1°. The third image, captured in May 2005, has an elevation angle of 80.93° and a collection azimuth of 23.5°.

Research will concentrate, in first phase on the development of methods to optimize the extraction of 3D models and orthophotos from the bundled Ikonos triplet. Optimal methods need to be found to improve the preprocessing of the imagery, to improve the semi-automatically derivation of photogrammetric products and to improve the postprocessing of the products. What concerns the postprocessing, we can point at the load of manual editing that is necessary to get an acceptable quality for automatically derived 3D models from VHR satellite imagery of a dense urban area. Secondly we will also investigate the possibilities of creating stereo models out of images from the same sensor taken on a different date, e.g. one image of the stereo pair combined with the third image. Finally the photogrammetric products derived from the Ikonos stereo pair as well as the products created out of the triplet and the constructed stereo models will be investigated by comparison with a 3D reference. This evaluation should show the increase of accuracy when multi-imagery is used instead of stereo pairs.

INTRODUCTION TO THE MAMUD PROJECT

The subject of this treatise is one of the experiments conducted within the framework of the MAMUD project (Measuring And Modelling of Urban Dynamics) funded by the STEREO (Support to The Exploitation and Research of Earth Observation data) program of Belgian Science Policy.

Urban change processes are affecting the human and natural environment in a not unimportant way. This enlarges the need for more effective urban management approaches based on sustainable development. A sustainable urban management needs sufficiently detailed and reliable base information on the urban environment and its dynamics. The objectives of the MAMUD research project is to investigate the possibilities of earth observation for a better monitoring, modelling and understanding of urban dynamics. Five research teams, each with its own background and know-how, join their strengths to accomplish the objectives. The Ghent university team has the following main objectives:

- City surface model time-series generation from across track, multi temporal imagery: creation of stereo models out of two images of the same sensor (e.g. SPOT) taken of the same area but at a different date. (multi temporal approach)
- City DEM generation from multi-sensor images: investigation of the possibilities of DEM generation from non stereo VHR images from two different sensors (e.g. Ikonos and Quickbird). (multi sensor approach)
- City DEM generation from image triplets: investigation of the advantages of an image triplet, compared with a stereo pair. An image triplet might be constructed from multi-orbit images (e.g. one stereo pair combined with another image from more or less the same orbit) (multi scopic approach)

Multi scopic, multi sensor imagery research is an interesting challenge and, if successful, will increase the potential of producing time series of 3D information from VHR archive data (Ikonos, Quickbird, SPOT), which may be very useful in the future for studying urban dynamics.

COMPLEXITY OF URBAN AREAS

A Digital Surface Model is a digital representation of the terrain and topographic object height in a grid structure. Interpolation of the discrete height values is needed to approximate the continuity of the ground surface. Urban environments are experienced as complex for 3D modelling purposes because of the steep changes in elevation and the discrepancy between the smoothness of the ground surface and abrupt discontinuities caused by buildings and other urban features. Without manual editing or filter techniques it's difficult to reconstruct vertical walls out of VHR satellite imagery. Kriging creates a smoothed surface and causes that individual buildings will have the shape of a bell instead of the rectangular geometry in an automatic derived surface model. A second consequence of steep changes in elevation is the occurrence of shadow and occlusion areas. Due to the convergent viewing angle of VHR sensors like Ikonos, crosswise to the direction of flight, terrain features with certain height above the surface are geometrically displaced in the imagery. By this distortion of their true position, parts of the ground surface can be hidden in the satellite image, the so called occlusion areas. Shadow areas, which have poor contrast, and occlusion areas lead to mismatches during the image matching algorithm and errors in the resulting surface model. Manual editing of these errors leads to a high accuracy and more detailed results but is not cost effective, so this process step must be minimised. Methods need to be find to get a maximum accuracy for the digital surface model but with the lowest effort.

As discussed in (Buyuksalih, 2007) the first problem can be approached by applying a median filter. The filter removes noise and enhances edges. Errors in the surface model caused by the presence of shadow and occlusion in satellite imagery can be reduced by getting the image information out of more then two images or by so-called multi scopic record. By the multi angle acquisition noise due to correlation errors (clouds, moving vehicles, etc.) can also be reduced. This approach leads also to redundancy in the geometric reconstruction, so that the model should have higher accuracy because points in object space are calculated by the intersection or best fit of three image rays instead of two.

VHR SATELLITE DATA AND TEST FIELD

The satellite Ikonos is able to rotate the sensor up to an angle of 26° off-nadir so the satellite can take images of the same location from two different view points on the same orbital track. Next to along track stereo pairs, it is also possible to create stereo couples out of images from the same area but taken from a different orbit at a different date. These are so called across track stereo pairs. This approach to form couples has some disadvantages as radiometric differences and changes of the ground surface due to the time gap between acquisition of the imagery. For this experiment a triplet is constructed out of an along track Ikonos stereo pair taken in March 2002 and a third image taken in May 2005. The third image can be considered as a nadir image. Selection criteria for the near vertical image were multiple: overlap with stereo couple, cloud-free acquisition, complementary elevation angle and collection azimuth and minimal time interval. Despite the big time interval, the 2005 Ikonos image was chosen to be the most optimal candidate.

The panchromatic Ikonos CARTERRA GEO-product images have a spatial resolution of 1 m. GEO product images are corrected for geometric distortions except for the relief and have the acquired level of detail to distinguish individual terrain objects. Further characteristics of each image of the triplet can be found in table 1.

Table 1: Characteristics of the three VHR satellite images acquired over the study field

Image ID	Acquisition date	Elevation angle	Collection azimuth	Sun angle elevation
A	1/03/2002	67.59°	1.6°	39.1°
B	1/03/2002	75.59°	214.1°	39.1°
C	16/05/2005	80.93°	23.5°	65.5°

Parts of Istanbul, Turkey are chosen as test field for the project, partly because it's a city characterized by an intense urban growth. The high resolution test area covers the overlapping area between the Ikonos 2002 stereo pair and the 2005 image and covers an area of approximately 60 km^2, containing Istanbul's historic peninsula. It concerns a densely built-up area with a height range of 220 m and geo-morphological characterized by a hilly landscape.

ISBN 978-3-925143-79-3

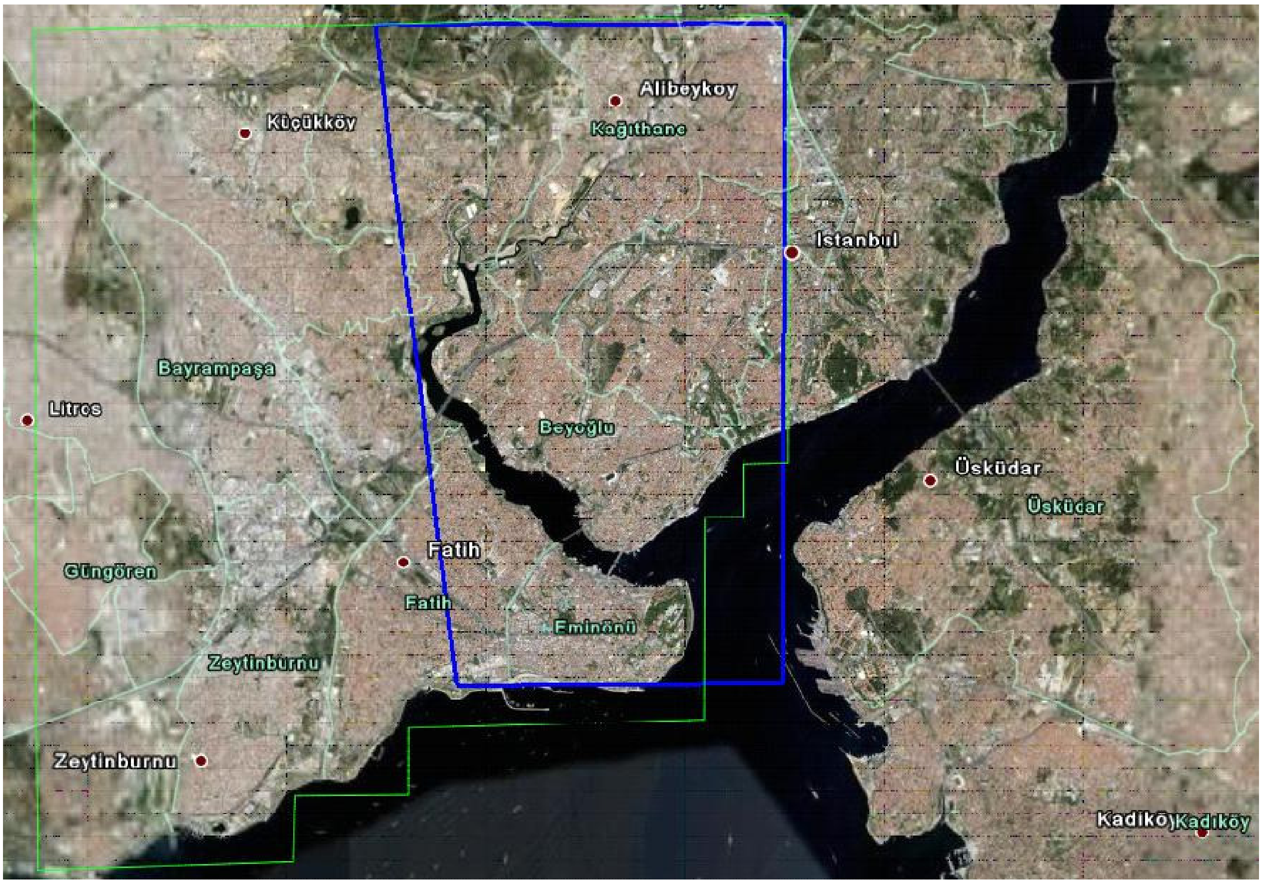

Figure 1: High resolution test field: the green area covers the Ikonos 2002 stereopair, the blue area covers the high resolution test area or overlap between the Ikonos 2002 stereopair and the 2005 image.

PREPROCESSING THE SATELLITE DATA

Before processing the VHR imagery a contrast enhancement is executed as this lead to a more reliable image matching. Especially between images of the same area but taken at different dates from different orbits large radiometric differences can occur, leading to poor matching results. A Wallis filter was applied for contrast enhancement and for the radiometric equalization of the three images. The 11 bit imagery had to be converted to 8 bit for processing with the photogrammetric workstation VirtuoZo.

DSM PRODUCTION

Most commercial digital photogrammetric workstations can only perform an image correlation matching algorithm on two images simultaneously. To process a digital surface model out of the triplet we have chosen for an approach that produces DSM's out of the different possible stereo combinations of the triplet and afterwards to filter out the final DSM by extensively comparing the three different individual DSM's pixel by pixel. One along track stereo couple will be constructed and two across track stereo pairs (different orbit; different date of acquisition). The big time gap between the images of an across track stereo pair results in radiometric variation and topographic changes which makes the matching more difficult. Possibilities, restrictions and advantages of creating photogrammetric products out of across track stereo couples are discussed in (Taillieu, 2004).

Noise and blunders in the different DSM's will not be identical. Because of the different viewing angles, the occluded surface will not be identical and because of the multitemporal differences between the 2002 stereo pair and the 2005 near vertical image the shadow pattern will be differently. Combining the three DSM's afterwards, each with its own characteristics and blunders must reduce the error in the final DSM.

Table 2: The H/B ratio, a half-measure for the theoretical altimetric precision, is respectively presented for the different stereopairs.

Stereopair	**Images**	**H/B ratio**
AB	forward - backward	1.56
BC	backward - nadir	2.38
AC	forward - nadir	3.70

DSM production is done by two different photogrammetric workstations: the softcopy photogrammetrical software VirtuoZo by Supresoft inc. and PCI Geomatics OrthoEngine. VirtuoZo has the restriction that the geometric reconstruction can be executed at only two images at the same time. PCI Geomatics OrthoEngine allows to execute the relative and absolute orientation at the three images simultaneously which makes the model more reliable. For the DEM creation stereo pairs need to be formed out of the triplet. To make the results of both approaches comparable same GCP's are used. We believe that it is an interesting research to compare the results as each workstation has its own characteristics, advantages and disadvantages

Figure 2: subimage of ikonos A: high buildings leading to huge image displacement, long shadows and occluded areas.

ISBN 978-3-925143-79-3

Figure 3: Part of drape (DSM overlaid with ortho image) created out of stereo couple AB. Due to big image displacement of the buildings shown in figure 2, mismatches lead to errors in the DSM.

Figure 4: Part of drape created out of stereo pair AB after manually editing the tall buildings. Even after manual editing, it's not possible to reconstruct the tall buildings without errors. Image information out of more then two images could reduce this error.

DSM production with VirtuoZo

During relative orientation homologue points are searched to relocate the two images of a stereopair relatively. In VirtuoZo this step is done in a fully automatic way according a feature based matching algorithm, but it needs a manual check for mismatched points, e.g. points on moving vehicles or vegetation. During the absolute orientation, the mathematical relationship between image coordinates and object coordinates is fixed by adding 17 ground control points. On both images of the stereo pair the points with known 3D coordinates are located manually. The GCP's have a homogeneous distribution over the test field.

The DSM is processed by measuring the parallax between corresponding pixels of stereo couples in epipolar format. Corresponding pixels are found according to an image correlation matching algorithm that is a mixture of an area-based and feature based approach. The three DSM's are calculated with a grid size of 3 meters. Ortho images, which can be draped over the DEM's are produced with a resolution of 1 meter. In a final phase the DSM's are manually edited for major blunders (water bodies, clouds, multi temporal differences, etc.) Out of the triplet, three DSM's are produced.

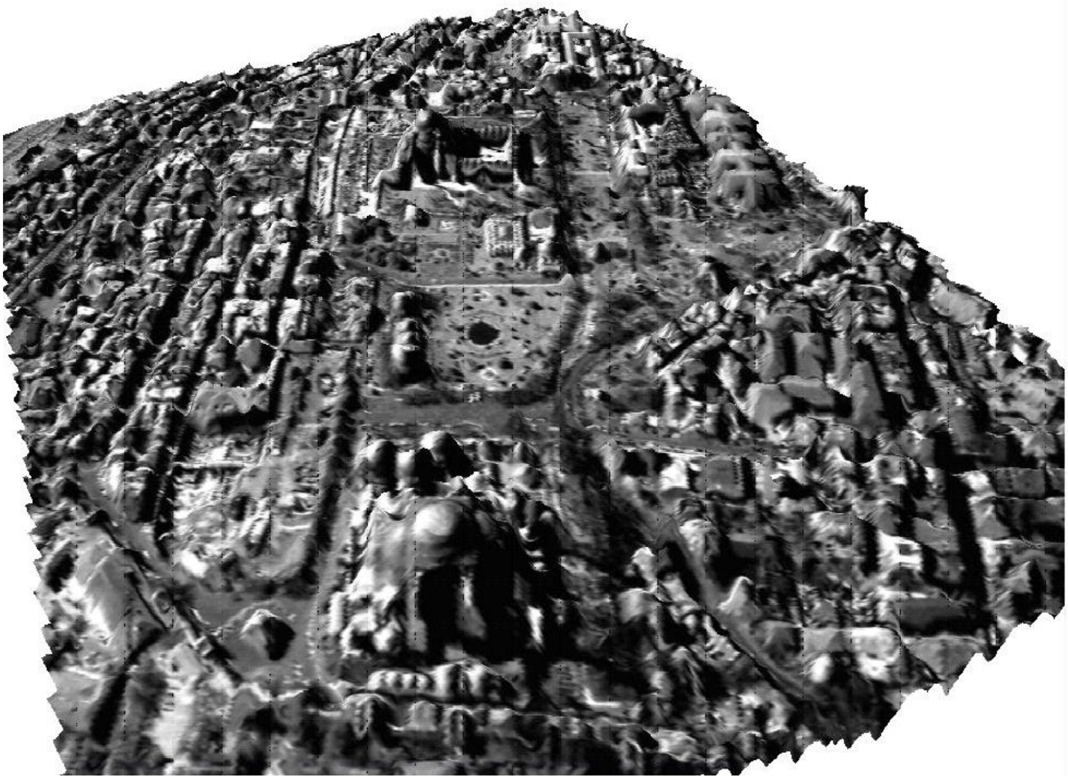

Figure 5: screenshot of part of the drape created out of the stereo couple AB with VirtuoZo workstation.

DSM production with PCI OrthoEngine

RPC's that are provided together with the Ikonos imagery by the image vendor in an ancillary text file were used to import in the rational function math model, that describes the relationship between image and object space. A first-order transformation, executing a translation and rotation, was chosen. Afterwards a block bundle adjustment is applied, after adding the 17 GCP's manually, to simultaneously compute the geometric models for the three images. This redundancy results in a more reliable model, as three-dimensional coordinates are calculated as an intersection or best fit between three viewing lines. After epipolar projection, parallaxes are extracted out of stereo couples by an area based image matching procedure according a hierarchical multi-scale strategy.

ISBN 978-3-925143-79-3

Three DSM were produced out of the same combination of stereo couples extracted from the Ikonos triplet.

FUTURE WORK

We introduced an approach to reduce noise and blunders in DSM by using the information from VHR images taken from different angles. However, only an initial step of our planned research is presented in this work. The future work deals in first phase with the comparison of all extracted DEM's with a reference. An accurate reference DSM with 30 cm GSD, that will be provided by Bimtas, Istanbul, will give us information on the geometric accuracy and quality of the produced DSM's. We will also be able to compare the results of the different used photogrammetric workstations. In the next phase the different DSM's extracted from combinations of stereo pairs will be compared pixel by pixel to filter out the most reliable height value to create the final DSM. There will be set a threshold for the height value to stipulate if height for a pixel between the DSM's is identical. In case of identical pixels, information will be extracted from the DSM created out of the along track stereopair. Their advantages is described in chapter three. In third phase an accuracy check of the final DSM will be done as well as the comparison with the stereopair DSM's.

ACKNOWLEDGEMENTS

The Belgian Science Policy Office is gratefully acknowledged for funding the work presented in this paper (SR/00/105). The authors also wish to thank the other teams of the MAMUD project.

More information about the MAMUD project can be found on www.mamud.be

REFERENCES

i Bethel, J.S., J.Ch. McGlone and E.M. Mikhail, 2001. Introduction to Modern Photogrammetry, John Wiley & Sons, Inc., New York, 477 p.

ii Buyuksalih G., Jacobson K., 2007. Digital surface models in build up areas based on very high resolution space images. In: ASPRS 2007 Annual Conference, Tampa, Florida, 7-11 May, 2007

iii Devriendt, D., Goossens R., Dewulf, A., Binard, M., 2003. Improving spatial information extraction for local and regional authorities using Very-High-Resolution data – geometric aspects. In: High Resolution Mapping from Space 2003

iv Jacobson, K., 2005. Analysis of Digital Elevation Models based on space information. In: New strategies for European Remote Sensing, Rotterdam : Millpress, pp. 439-451

v K. Taillieu, R. Goossens, D. Devriendt, A. De Wulf, S. Van Coillie & T. Willems, 2004. Generation of DEMs and orthoimages based on non-stereoscopical IKONOS images, pp. 453 – 460. In: Proceedings of the 24th symposium of the European association of remote sensing laboratories, Dubrovnik, Croatia, 25 – 27 May 2004

vi Li Zang an Armin Gruen, 2006. Multi-image matching for DSM generation from Ikonos imagery, In: ISPRS Journal of Photogrammetry and Remote Sensing 60 (3) (2006), pp.195-211