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Investigation of the potential of multiscopic VHR satellite imagery for the production of 3D models of complex urban areas

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ABSTRACT: In this treatise the discussion of a methodology and results of semi-automatic city DSM extraction from an Ikonos triplet, is introduced. Built-up areas are known as being complex for photogrammetric purposes, partly because of the steep changes in elevation caused by buildings and urban features. To make DSM extraction more robust and to cope with the specific problems of height displacement, concealed areas and shadow, a multi-image based approach is followed. For the VHR tri-stereoscopic study an area extending from the centre of Istanbul to the urban fringe is chosen. Research will concentrate, in first phase on the development of methods to optimize the extraction of photogrammetric products from the bundled Ikonos triplet. Optimal methods need to be found to improve the radiometry and geometry of the imagery, to improve the semi-automatically derivation of DSM's and to improve the postprocessing of the products. 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.

1 INTRODUCTION TO THE MAMUD PROJECT

The high level of detail and geometric accuracy of very high resolution satellite imagery as Ikonos, has made this kind of imagery suitable for DSM generation at feature level of urban environments. As urban areas are known as complex for photogrammetric purposes, a lot of research is done to cope with the specific problems of such areas during 3D modeling from standard stereopairs. As a multi-image based approach can make the 3D modeling more robust, in this treatise the discussion of a methodology and results of semi-automatic city DSM production from an Ikonos triplet, is introduced. Comparison of the benefits of a multi-image approach with DSM extraction from standard stereo couples will be highlighted. Only a few investigations have been published dealing with the concerning subject. Research published in (Baltsavias et al. 2006) and (Raggam 2006) can be referred.

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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 knowhow, 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 DSM 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 DSM 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 flexibility of producing 3D city models from VHR archive data (Ikonos, Quickbird, SPOT), which may be very useful in the future for studying urban dynamics.

2 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 concealed areas. Due to the convergent viewing angle of VHR sensors like Ikonos, terrain features with certain height above the surface are geometrically displaced in the imagery, leading to dissimilarities between the stereo images. 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 minimized. Methods need to be find to get a maximum accuracy for the digital surface model but with the lowest effort.

As discussed in (Buyuksalih & Jacobson 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, occlusion and noise (clouds, moving vehicles, etc.) in the image data can be reduced by getting the image information out of more then two images or by the so-called multi scopic record. As the stereo case is the minimum case for 3D mapping, the redundancy of an image triplet gives better constraints. The redundancy of the tri-stereoscopic approach will allow matching with a higher success rate as a correct match can be made if a point in object space is visible in at least two images. With the redundant information of a third image, the effect of occlusion and random noise as clouds and moving vehicles can be reduced. This approach strengthen also the geometric reconstruction because points in object space are calculated by the intersection or best fit of three image rays instead of two. This results in a more optimal image orientation and makes the model more reliable.

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

Image ID	Acquisition date	Elevation angle	Collection azimuth	Sun elevation angle	Projection & datum
A (Forward)	1/03/2002	67.59°	1.6°	39.1°	Epipolar – WGS84
B (Backward)	1/03/2002	75.59°	214.1°	39.1°	Epipolar – WGS84
C (Nadir)	16/05/2005	80.93°	23.5°	65.5°	UTM – WGS84

3 DATA SET AND STUDY AREA

The satellite Ikonos is able to rotate the CCD Linear Array 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. 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, stereo constellation, minimal time interval and optimal stereo constellation. Despite the big time interval, the 2005 Ikonos image was chosen to be the most optimal candidate.

The Ikonos STEREO product imagery, which comprises of a forward and backward image acquisition and the GEO Ortho Kit 2005 image are panchromatic, resampled to a spatial resolution of 1 m by the image provider and provided with the Rational Polynomial Coefficients (RPC) camera model file. Further characteristics of each image of the triplet can be found in Table 1.

Parts of the megacity Istanbul, Turkey are chosen as test field for the project, partly because it's a city characterized by an intense urban growth. Despite the enormous size, it's a very compact city concentrated along the Bosphorus strait. 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 and going up to the north to the urban fringe. It concerns a densely built-up area with a height range of 220 m with the lowest point at sea level and geo-morphologically characterized by a hilly landscape.

4 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 due to different illumination and atmospheric conditions, leading to poor matching results. To enhance the contrast for each image individually and to equalize the radiometric differences between the imagery, a Wallis filter was applied (Wallis 1976). The Wallis filter performs a non-linear, locally adaptive contrast enhancement. Actually a large kernel divides the image in different sections and within each section the local contrast is optimized. Applying a Wallis filter on the original images does not only result in a good local contrast and equal overall contrast but normalizes also the radiometry between the images of the across-track stereopairs.

Next to the radiometric enhancement a method for geometric normalization was devised. The Ikonos 2002 stereo couple is epipolar projected by the image vendor and suitable for stereo applications. As the 2005 image is taken from a different orbit, the images are displaced to each other and the internal geometry will be slightly different because of the different scan direction.

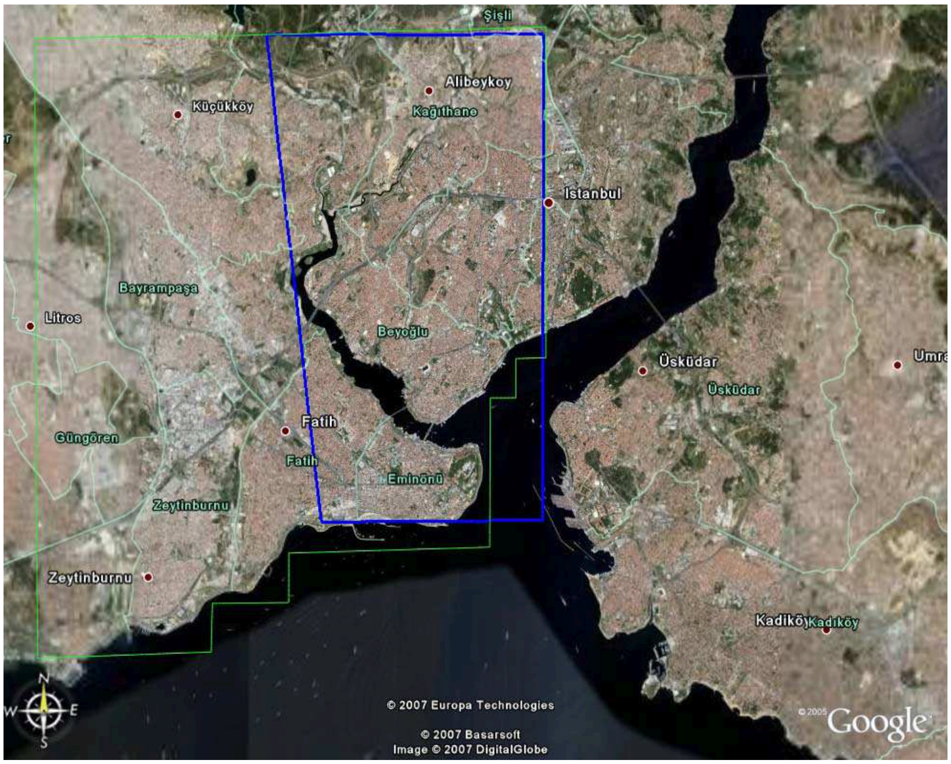

Figure 1. High resolution study area: the green polygon covers the Ikonos 2002 stereopair, the blue polygon covers the extent of the high resolution test field or overlap between the Ikonos 2002 stereopair and the 2005 image. (Source: Google earth)

Geometric normalization of the 2005 image with the 2002 imagery is done by image coregistration in ENVI. A first-order polynomial transformation is performed to geometrically align the multitemporal imagery. A first-order polynomial transformation corrects for rotation, translation, scaling and shearing.

5 DSM PRODUCTION

Digital surface model extraction from high resolution satellite imagery requires the availability of a database of ground control points. During two field trips to Istanbul the necessary GCP's for photogrammetric processing of the DSM's were collected in close collaboration with Dr. Gurcan Buyuksalih from the Istanbul Metropolitan Planning Centre (IMP-Bimtas). Because accurate large-scale maps were available for the study area and because of the difficulties of GPS measurements in the narrow streets of the densely built-up area, there is chosen for an approach to derive the GCP from maps. 37 GCP were derived from 1:5000 scale topographic maps, even distributed over the high resolution study area.

5.1 *Standard stereoscopy*

DSM results from stereopair and triplet need to be compared with each other to get an idea of the possible improvements of the tri-stereoscopic approach. In first place, the along track stereopair is processed. DSM extraction from the Ikonos stereopair was performed with the photogrammetric

Figure 2. Part of DSM generated from Ikonos stereopair with ortho-image draped over it for 3D photorealistic visualization.

workstation VirtuoZo by Supresoft inc. After importing the imagery and GCP, the image orientation can be performed. During relative orientation conjugate points are searched to relocate position and orientation of the images of a stereopair relatively. In VirtuoZo this step is done in a fully automatic way according to 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 stereopair 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 disparity between corresponding pixels of the images of the stereocouple in epipolar format. For each pixel to be matched in the first image, the matching algorithm searches for the conjugate pixel in the second image that correlates the most by shifting a kernel of certain size along the epipolar line. The image correlation matching algorithm is a mixture of an area-based and feature-based approach. The DSM is calculated at a grid size of 3 meters. The RMS for the GCP residuals were for X, Y and Z respectively 0.57, 0.72 and 1.92 m. A true ortho-image, which can be draped over the wire-frame for visualization purposes, is produced with a resolution of 1 meter. In a final phase the DSM is manually edited for major blunders (water bodies, clouds, multi-temporal differences, etc.).

5.2 *Tri-stereoscopy*

From a theoretical point of view the redundancy of a third image should lead to a more reliable photogrammetric processing. First of all a more optimal image orientation is possible because of the redundancy in the geometric reconstruction. Points in object space can be calculated by spatial intersection or best fit of three convergent image rays instead of two. Secondly, image matching can be performed with a higher success rate because a successful match can be made if an object point is clearly identifiable in at least two images. With the information of a third image, the effect of occlusion and random noise as clouds and moving vehicles could be reduced.

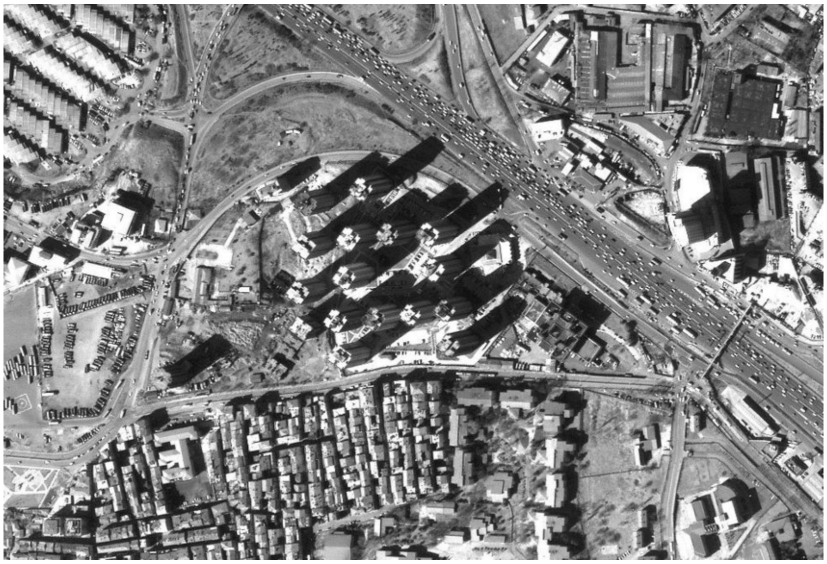

Figure 3. Subimage of ikonos A: high buildings leading to huge image displacement, long shadows and occluded areas.

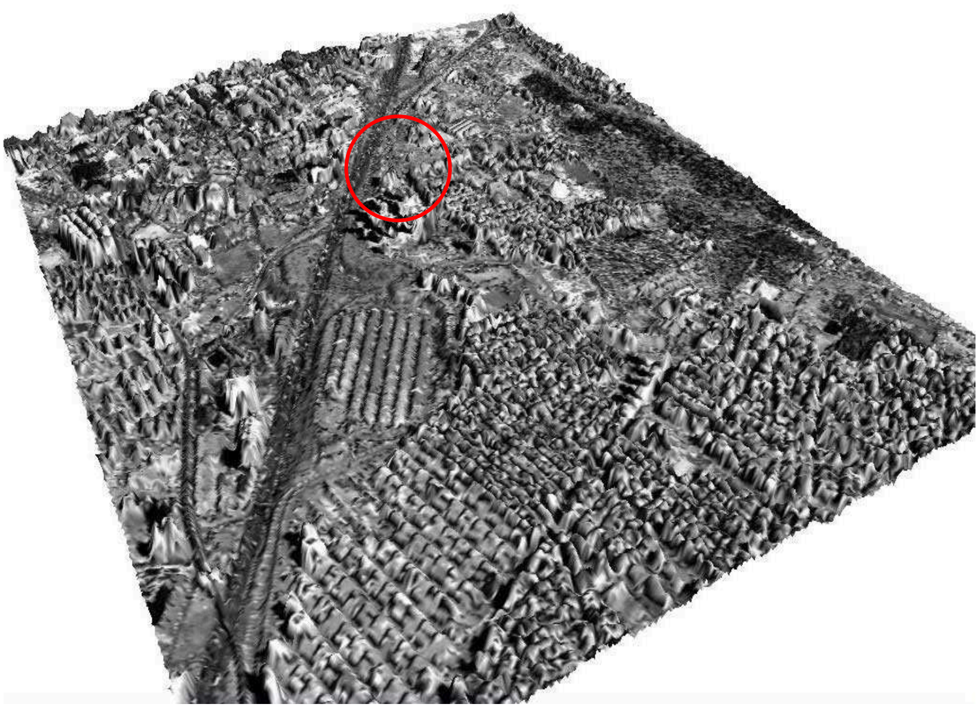

Figure 4. Part of drape created out of along-track stereopair. Due to big image displacement of the buildings shown in Fig. 2, mismatches lead to errors in the DSM. From a theoretical point of view, redundant information from a third image could reduce this error.

Processing of the Ikonos triplet will be performed with SAT-PP. SAT-PP, commercially released by ETH Zurich in April 2008, is able to perform image matching on more then two images simultaneously (Zhang & Gruen 2006). This is in contrast to most commercial photogrammetric software (also Virtuozo) which is able to match only two images at the same time. After processing the Ikonos triplet, DSM results can be compared with a DSM reference to describe the geometric accuracy and to quantify the possible improvements of the tri-stereoscopic approach.

6 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 treatise. The future work deals in first phase with the photogrammetric processing of the bundled Ikonos triplet with the newly acquired photogrammetric workstation SAT-PP, released by ETH Zurich in April 2008. After processing the Ikonos triplet, the resulting DSM from stereopair and triplet will be compared with a DSM reference to describe the geometric accuracy and to quantify the possible improvements of the tri-stereoscopic approach. A DSM reference was already derived from 1:5000 digital topographic maps at the Istanbul Metropolitan Planning centre.

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