COMBINATION OF SATELLITE-DERIVED RASTER AND VECTOR DATA FOR 3D CITY MODELLING

Dennis Devriendt[1], Rudi Goossens[2] and Tharwat Ghabour[3]

1. Ghent University, Department of Geography, Ghent, Belgium; dennis.devriendt@ugent.be
2. Ghent University, Department of Geography, Ghent, Belgium; rudi.goossens@ugent.be
3. National Research Centre, Soils & Water use Department, Cairo, Egypt; thghabour@lycos.com

ABSTRACT

Since the launch of satellites (IKONOS, QuickBird, the future Pleiades) that deliver images with a spatial resolution of more than one meter, the modeling of an urban scene became a new possibility of remote sensing. The high level of spatial detail allows identifying specific urban objects, by which an urban environment can be measured in its three spatial dimensions (X, Y and Z). The possibility of very high resolution sensors to capture a stereo pair of images in one orbital pass gives high quality stereo models that allow the generation of a digital surface model (DSM).

The strategy followed in the proposed research project is to combine 3D raster and 3D vector data in order to obtain a more reliable digital surface model of an urban environment. Vector data structures are very well suited to represent entity data models, in the case of this proposal that will be buildings. Accurate automatic vector extraction from satellite images has improved a lot over the last years but still has not reached the level of the human operator. For this reason, the vector extraction from a satellite stereo pair will be done interactively in the stereo model. Stereo measurement of an object, depicted in a stereo pair, is only visible if this object is clearly visible in both the images of the stereo pair. This means that for most buildings no stereo measurement is possible near to it at the ground level. Normally only points at rooftop level or at the level of the cornice can be measured. As a consequence, building volume cannot be directly derived from the 3D-measurement of the building outlines. Therefore we propose in this project to use a digital surface model (DSM) of the non-built area will be used to retrieve the ground level height value.

In this paper we demonstrate the use of the C-NAV 2050G Differential GPS (DGPS) to measure ground control points (GCP) for an IKONOS stereo scene over Cairo. The 2050G sensor consists of a 22-channel precision GPS sensor with two additional channels for receiving Satellite Based Augmentation System (SBAS) signals and an L-Band demodulator for reception of C-Nav StarFire Network correction service, for decimeter-level position accuracy.

The construction of the hybrid 3D city model is described. Processing the IKONOS stereo pair in epipolar projection brings us immediately to the step of absolute and relative orientation. The buildings are measured interactively in the stereo model. A digital surface model is derived through automatic image matching. The occluded areas that are due to the measured buildings are removed and interpolated from the surface model. Finally the 3D features (polygons) are the converted to a solid geometry, which allows calculating the volume of the buildings.

INTRODUCTION

Advancements in imaging sensors are reducing the time and therefore the cost of producing image and elevation data layers. These data layers are rapidly becoming the base layers in for GIS. The increased use of these data and their improved quality is aiding the ability to automate some feature extraction tasks such as 3D scene reconstruction. The variety of users of feature data and the avail-ability of more complex levels of feature data continues to increase. This includes the increased collection and maintenance of accuracy and temporal information for vectors and manipulation of raster height information within GIS databases.

The URMO3D research project presented in this paper is part of the Support Programme for the use of Optical and Radar Federated Earth Observation data (ORFEO) from the Belgian Federal Science Policy Office. The ORFEO Support Programme has been set up to prepare for, support and promote the exploitation of the images from the Orfeo sensors. Orfeo is a dual system with meter resolution. URMO3D is situated in the methodological section, in which the focus is on defining and developing the tools needed for the operational exploitation of the future sub-metric optical and radar images.

This project aims the integration of a raster surface model, with its area covering character, and 3D vector information of the built-up area; a hybrid 3D city model can be generated from one data source, being a VHR stereo pair. As archives of VHR images will grow larger in time, the necessity will grow to use those archives in multitemporal analysis, also in three dimensions. The possibility of new very high resolution satellite sensors to make a stereo pair in one orbital pass allows creating stereo models of VHR images. This capability together with the sub-meter resolution gives the opportunity to map cities in three dimensions. This project deals with automated raster DSM generation and interactive 3D vector mapping of an urban environment. The combination of those two 3D representations will be used to improve one another combining their strengths and advantages. The idea is to generate a maximum amount of 3D information from a VHR stereo couple, as well in spatial coverage as in terms of resolution.

DESCRIPTION OF THE PROJECT

Objectives of the project

The general objective of the proposed research project is to define a method to optimally represent and visualize an urban scene in its three spatial dimensions, using only data that is directly derived from a very high resolution stereo pair. In this project work will be done on IKONOS stereo pairs, but the developed method will be applicable to the Pleiades data. The goal is to obtain a hybrid 3D representation for urban areas, for which the geometric base is laid in as well raster as vector data. The surface continuity of the raster DSM will be combined with the object oriented approach of the 3D vector surface model. The goals of this project are:

Optimizing and assessing the accuracy of raster DSM generation and 3D vector extraction of VHR stereo couples and detecting the degree of automation that is feasible.

Integrating the three basic photogram metric product types (DSM, 3D features, orthoimage) to reach a hybrid 3D city model.

Testing the analytical possibilities of the developed city model on a rapidly changing urban environment.

The general structure of the project is so that a method for retrieving an urban surface model from VHR satellite images is obtained, and that the possibilities of this model will be tested in different ways. The method delivers a 3D city model which is first of all useful for visualization of an urban scene. This implies indirectly that it can be used to orthorectify satellite images in the sense of “true-ortho”, i.e. an orthoimage which is compensated for sensor orientation and image displacements caused by relief and buildings.

The raster DSM that is produced gives elevation points over a contiguous areas, but has errors in the occlusion areas. The 3D vectors that are retrieved interactively from the stereo model give the absolute height of buildings against a certain datum, but do not contain information about the building height with reference to the ground level. The combination of those height information layers should lead to the 3D hybrid city model that is the goal. The 3D vectors will be used to detect and remove occlusion areas from the raster surface model. The raster in its turn will be used to convert the 3D vector information about the buildings into a solid structure with a polyhedral structure instead of the former polygonal structure of the building.

Methodology

The general idea is to use VHR stereo couples to make a 3D representation of an urban study area. A digital surface model will be created in raster format for the whole study area; a 3D vector data-base will be made containing all the buildings in the study area. Those two sources of height information are then integrated into one 3D city model, of which the visualization and analytical powers are tested. Two 3D models will be created from separate stereo pairs of the same area, but from a different moment, in order to detect urban changes. The study areas are located in the cities of Ghent (Belgium) and Cairo (Egypt). The Ghent study area is used to develop and test the methodology, while the testing areas in Cairo are used to test the operational aspects of the workflow. For the two cities an IKONOS stereo pair is available. In both cities test zones were selected with a varying urban morphology (dense neighbourhoods with high buildings, residential, rural).

Figure 1: The Ghent study area with the test zones indicate, is located at the southern edge of the city close to the intersection of E17 and E40 highway. (North is at the right-hand side of the image) 2003-09-18 11:07 GMT, Azimuth1: 210.4809 degrees, Elevation1: 68.83065 degrees, Azimuth2: 346.8062 degrees, Elevation2: 78.86692 degrees

ISBN 978-3-925143-79-3

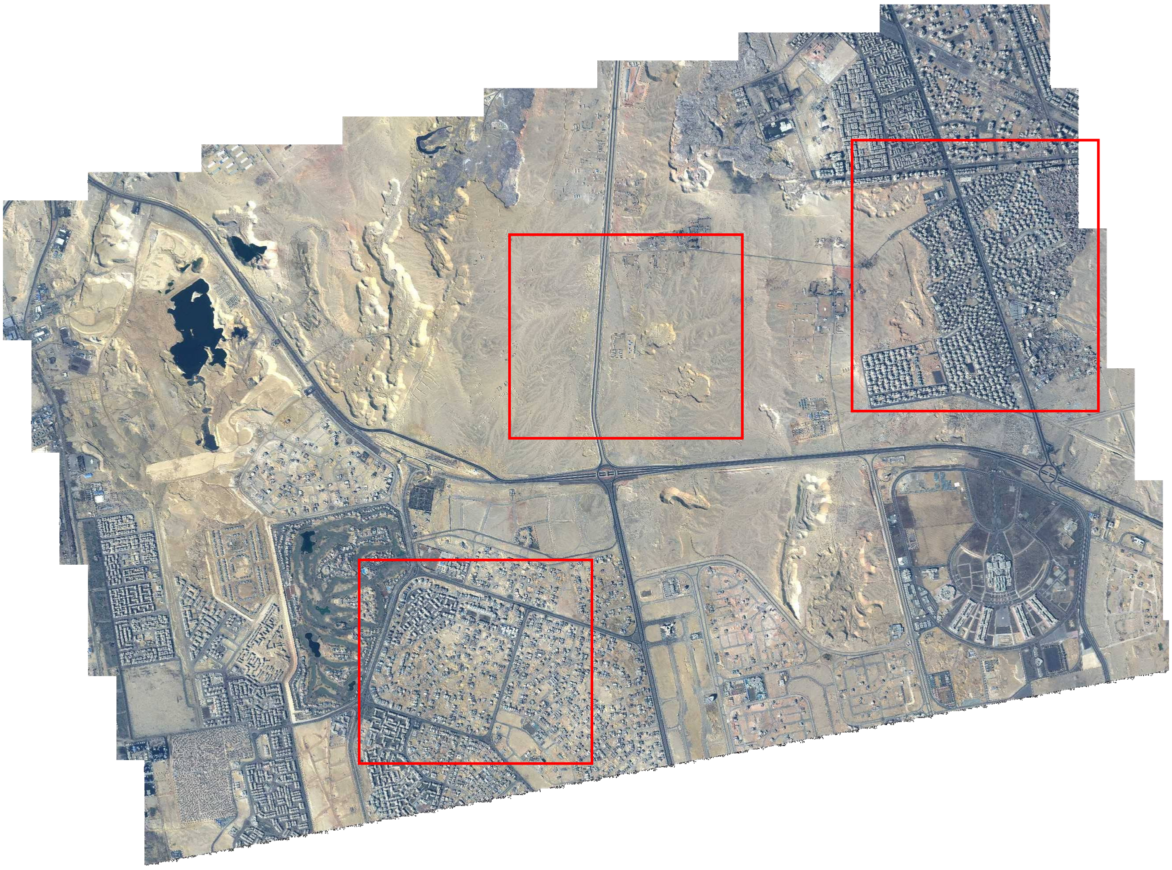

Figure 2: The Cairo study area with the test zones indicated, located east of Cairo close to Heliopolis airport. The test zones are on both sides of the ring road. 2005-01-20 08:43 GMT, Azimuth1: 155.8838 degrees, Elevation1: 66.94662 degrees, Azimuth2: 52.3463 degrees, Elevation2: 68.90756 degrees.

In the Ghent study area an extensive database of high precision ground control points (GCP) was available from recent projects. In October 2007 a set of 25 GCP in the Cairo area was measured with the C-NAV 2050G Differential GPS. This system uses the signal from a geostationary satellite as differential to obtain an accuracy that is comparable with the traditional DGPS measurements. The nominal accuracy is around 30 cm, which is enough to process the one meter resolution IKONOS stereo images.

Semi-automatic DSM generation: The 2 step method

The method that we have applied to generate digital surface models (DSM) from VHR stereo pairs of urban areas is briefly described in the following paragraph. Automatic DSM (Digital Surface Model) generation through image matching does not give satisfying results when treating VHR stereo pairs, due to the presence of occluded areas in the stereo model. Therefore a manual intervention during the automatic process is needed.

Step 1: adding break lines to the stereo model

In a first editing step, before the matching algorithm is applied, break lines are manually added to the stereo model. In general these break lines are roof boundaries. The absolute condition for a feature to be selected as break line is that it must be clearly visible in both images of the stereo model. These break lines act as a restriction for the matching algorithm.

Step 2: Contour fitting of the matching results

After the break lines and the automatic parallax calculations, the stereo model still needs to be edited. In this step we ensure that the heightcontourlines fit close to the buildings.

Hybrid method of DSM generation

The problem with the 2-step method is that it takes a lot of manual intervention in both steps. In dense urban areas, around 90% of the production time consists of operator interventions. In the URMO3D project it is investigated how the current 2-step method can be optimised for the extraction of raster DSMs and 3D vectors. Through the interaction of both types of datasets, the three basic photogrammetric products (raster DSM, 3D features, ortho image) will be combined to form a hybrid 3D city model. The workflow is explained in figure 3. The goal of the hybrid model is not only to reduce the amount of time that is necessary to produce a 3D city model, but also to obtain an optimal representation of an urban area. The raster surface model is used for ground elevation, whereas the 3D features represent buildings as true volumes. As such, the buildings will have volumetric properties, not only as an attribute value, but also from their geometric representation.

1) Separate retrieving of 3 dimensional data: in raster format for the terrain, and in vector format for the buildings (at rooftop or cornice level)

2) Removal of the occlusion zones in the raster model, by simulating the satellite viewing angles. This causes gaps in the raster surface model

3) These gaps are interpolated to obtain a homogenous and area covering surface model at terrain level.

4) The 3D vectors, combined with the raster information, allow buildings to be represented in the model as solids.

5) The final model with a raster DSM for the terrain, and 3D solids for the built-up area.

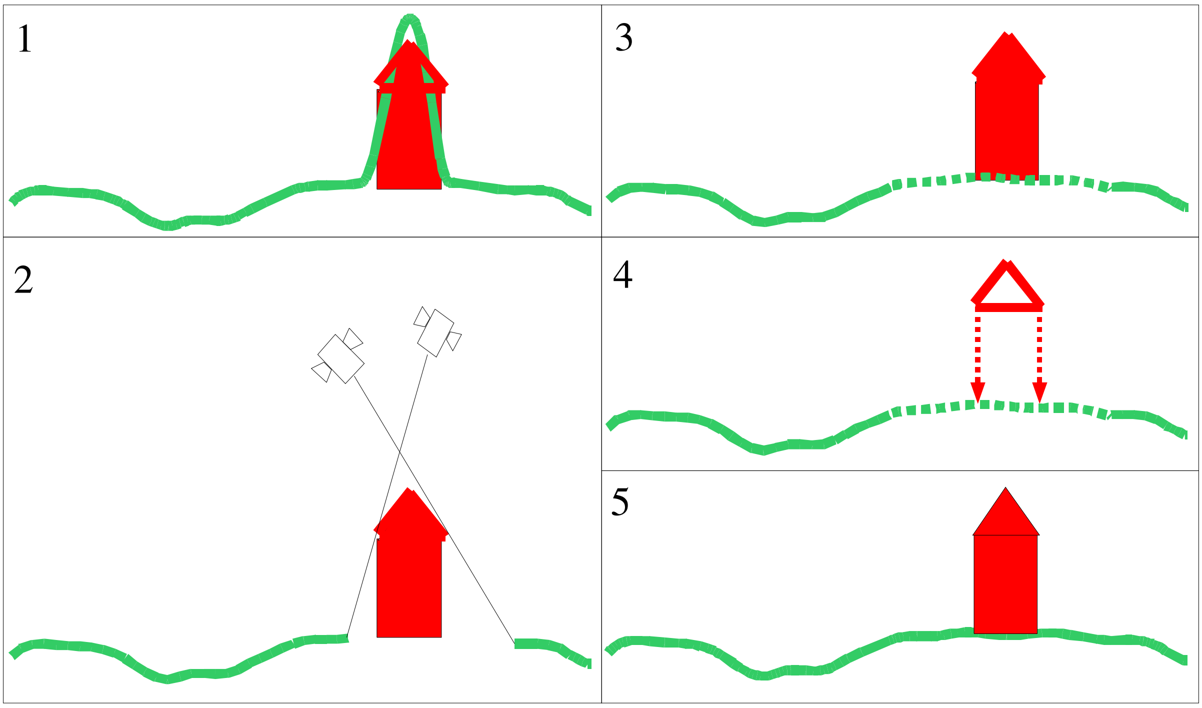

Figure 3: The red lines and areas represent the 3D vectors, the green lines represent the raster surface model.

Flowchart

The complete flow of information from data to hybrid city model is described in the following paragraphs. The flowchart is shown in Figure 4, and shows in colour code the status of the project with regard to the degree of automation or completeness of the blocks in the diagram. (green = fully investigated and operational, blue = needs additional work with regard to automation, magenta = operational, but still needs to be optimised).

ISBN 978-3-925143-79-3

Given a set of GCP (accuracy better than half the spatial resolution of the satellite images) and an stereo pair (in epipolar projection), the stereo model is easily determined. Once the relative and absolute orientation are finished, the model is ready for the extraction of 3D data.

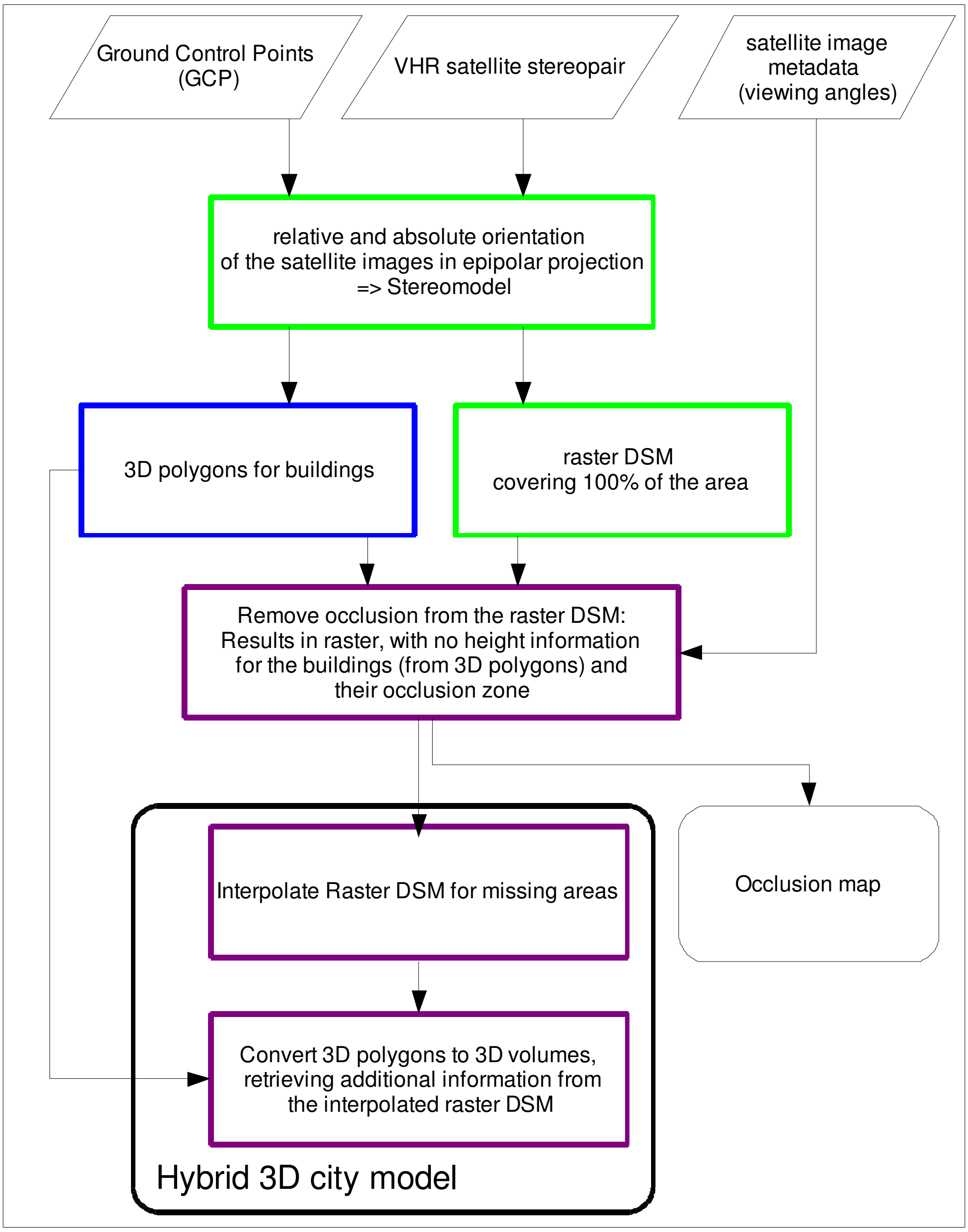

Figure 4: Flowchart showing the processing from stereopair to hybrid 3D city model.

Up till now we used manual measurement for the 3D vector extraction. Improvement through automation is certainly needed for this work. The extraction of the raster surface model on the other hand, goes fully without manual intervention. The matching algorithm from VirtuoZo (combination of area based and feature based matching) software was tested for a scope of matching window sizes, and window spacing. From the smallest possible matching window (5 by 5 pixels), up to a larger window (19 by 19 pixels) with a minimum spacing of 1 pixel in rows and columns, and a maximum spacing of n (n = size of the window), the matching algorithm was executed. For every combination, the ratio of successfully matched points was retrieved. This ratio gives an indication of how well the algorithm works, but does not say anything about the spatial distribution of the successfully matched points. It should also be noted that the 'unsuccessfully' matched windows, still receive a height value, but are less reliable. Because the resulting surface model is in-

ISBN 978-3-925143-79-3

terpolated as a regular grid between the matched image points, the unsuccessful matching only causes problems when it is aggregated. Areas where this occurs are usually well know : water bodies, occlusion areas, clouds, and in some case also shadow areas.

Such a series of matching procedures was carried out for the study areas of Ghent and Cairo, both in urban and rural context. For both study areas it became clear the occlusion due to buildings and satellite viewing angle, had a large impact on the matching result.

The next step is to remove the occlusion zones from the raster surface model. This is done by projecting the occlusion areas of the 3D features on the raster DSM to obtain an occlusion map. Such a map is calculated for both satellite images, through hillshading of an integrated DSM (the 3D features are rasterized and then overlaid on the raster model). The 0-class in the hillshading map is considered to represent the occluded areas. We are still investigating a more direct method to retrieve occlusion maps, by actual projection of the 3D features on the raster model.

We can then remove the buildings and their occlusion areas from the raster surface model, after which the surface model is interpolated to fill up any missing areas. This forms the first part of our hybrid 3D city model, namely a raster surface model for the ground level. To convert the 3D features to solids, a new set of vectors is derived. For every polygon in the original dataset, a new polygon is derived, with the height information from the raster surface model. The final step is then to combine both 3D vector datasets and obtain a volume property for each building.

CONCLUSIONS

From the 2 step method for DSM generation over urban areas the hybrid method was developed. Up till now the method still requires a large part of manual intervention of the human operator. The current benefits however, are found in the different output of the method. Where the 2 step method delivers a single dataset representing the terrain and all the objects on it, the hybrid method gives us two separate and very different types of 3D models. One part describes the terrain, the other part consist of 3D vectors for the built up area. The combination of those two brings us to the key-benefit of the hybrid method, namely that both datasets do not suffer from any errors that are due to the time between their respective data sources, since both results are derived from one and the same satellite stereo pair.

The automated procedures of image matching were optimised in terms of algorithm performance. We will test the accuracy of the resulting surface models for the Ghent study area to check whether the optimised procedures give an actual better surface model. The current occlusion maps still suffer from the influence of vegetation. The interpolation of the missing areas in the raster part of the hybrid model results in an overestimation of the terrain height. Alternative interpolation techniques will be tested, but also the possibility of surface models with a coarser spatial resolution will be tested.

ACKNOWLEDGEMENTS

The authors would like to thank the team from Belgian Federal Science Policy (http://www.belspo.be) and CNES for providing the funds for this research. The comments from the URMO3D steering committee were highly appreciated.

REFERENCES

i Arnold, Jr., C.L., D.L. Civco, M.P. Prisloe, J.D. Hurd, and J.W. Stocker, 2000, Remote-sensing-enhanced outreach education as a decision support system for local land-use officials, Photogrammetric Engineering and Remote Sensing, 66 (10), 1251-1260.

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

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, High Resolution Mapping from Space 2003.

iv Devriendt, D., Goossens, R., De Wulf, A., Binard, M., 2005, Improving spatial information extraction for local and regional authorities using Very-High-Resolution data - geometrical aspects, In: Proceedings of the 24th EARSeL symposium: New Strategies for European Remote Sensing, May 2004, Dubrovnik, Croatia, pp 421-428

v Devriendt, D., Binard, M., Cornet, Y., Goossens, R., Accuracy assessment of an IKONOS derived DSM over urban and suburban area, In : Proceedings of the 2005 workshop EARSeL Special Interest Group "3D Remote Sensing" - use of the third dimension for remote sensing purposes

vi Jacobsen, K. , 2005, Analysis of Digital Elevation Models based on space information, New Strategies for European Remote Sensing, Rotterdam : Millpress, pp 439-451

vii Jacobsen, K. 2003, Orthoimages and DEMs by QuickBird and IKONOS, Remote Sensing in Transition, Rotterdam, Millpress, 273-279

viii Taillieu, K; Goossens, R., Devriendt, D., Dewulf, A., Van Coillie, S., Willems, T., 2005, Generation of DEMs and orthoimages based on non-stereoscopical IKONOS images, New Strategies for European Remote Sensing, Rotterdam : Millpress, pp 453-460

ix Vandevoorde, T., Binard, M., Canters, F., De Genst, W., Stephenne, N., Wolff, E. 2003 Extraction of land use / land cover - related information from very high resolution data in urban and suburban areas, Remote Sensing in Transition, Rotterdam : Millpress, pp 237-245

x Zhou, G., and R. Li, 2000, Accuracy evaluation of ground points from IKONOS high-resolution satellite imagery, Photogrammetric Engineering and Remote Sensing, 66 (9), 1103-1112.