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3D-Building Height Extraction from Stereo IKONOS Data

Quantitative and Qualitative Validation of Digital Surface Models
Derivation of Building Height and Building Outlines

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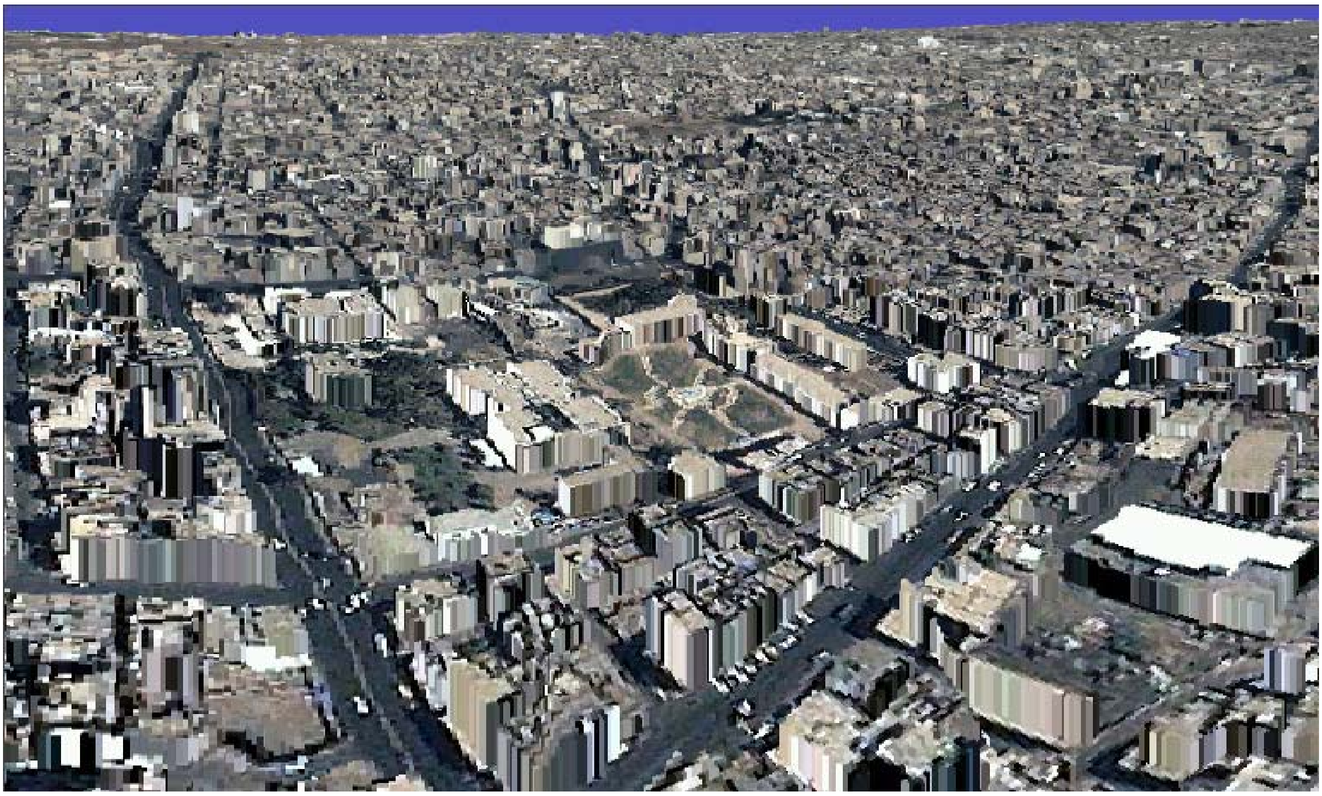

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Cover: 3D visualization of Sana'a. IKONOS rgb composite draped over the final DSM.

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Abstract:

This report is dealing with the digital surface model generation from VHR stereo satellite data with the focus on building height and shape extraction. The report provides a theoretical insight into orthorectification methods based on either empirical or rigorous, physical models and the theoretical aspects of digital surface model extraction. Orthorectification of stereo satellite data highly influences the accuracy of a digital surface model besides the selected matching methodology applied during the surface model extraction process. The requirement and ideal distribution of ground control points is discussed. In the final part of the report the results of four software packages, ENVI, PCI Geomatica, RSG and Leica Photogrammetric Suite, tested for urban DSM generation, are presented and described.

The orthorectification accuracy analyses were done using QuickBird and IKONOS data. For the digital surface model accuracy analyses stereo IKONOS data were mainly used. The data is commercially purchasable and is the satellite data with the highest geometric resolution that can easily be acquired as stereo datasets. Two datasets were used to perform the tests. One study area is situated in Nairobi where a variety of building types are present, from high-rise buildings to small illegal shacks. The second study area is in Graz, which was mainly chosen because a very detailed reference surface model was available.

The orthorectification accuracy results for both test areas show that the rigorous physical model performed best with an accuracy below pixel size with RMSE of 0.31m (x-direction) and 0.45m (y-direction) for the Nairobi QuickBird dataset. The empirical rational function based orthorectification achieved RMSE larger than the pixel size of 0.60m. A 1-order polynomial adjustment resulted in slightly better accuracies than a 0-order polynomial adjustment.

The orthorectification for the Graz IKONOS dataset resulted in similar accuracies: with the rigorous model RMSEs of 0.56m (x-direction) and 1.06m (y-direction) were achieved. The rational function based orthorectification with 1-order polynomial adjustment resulted in RMSEs of 0.97m and 0.63m. However, large RMSE of more than 10m for one of the used ground control points indicates that the model is not stable for the entire test area.

The physical models proved to be stable for both IKONOS and QuickBird data using few GPCs, eight for Nairobi, or a large number of GCPs, 26 for Graz. Consequently it is recommended to use the rigorous physical model for orthorectification of VHR satellite data if GCPs are available and a high geometric accuracy of the data is necessary. The RF model is still a viable alternative when high accuracy GCPs are very limited or not available. If the topography is rather flat in a dataset a 0-order polynomial adjustment with RF model orthorectification might be sufficient but a 1-order polynomial adjustment should be preferred if the terrain is rugged.

In the Nairobi test area mainly qualitative analyses and pointwise quantitative analyses were performed due to lack of reference data e.g. building heights and/or building outlines or a high-resolution digital surface model. The generated DSMs were evaluated by comparing them with reference height data taken from the internet, the GPS ground elevation data collected in the field, and data calculated by an alternative height extraction methodology. Additionally, two qualitative tests were conducted to come to a conclusion in terms of DSM quality relating to building height and shape extraction.

The five evaluation tests have shown that all tested software packages created DSMs that performed well in at least one of the tests. They all have advantages and disadvantages. Height accuracy as well as clear building shape extraction is of great importance for the use of DSMs in information extraction for settlement analysis and mapping. The highlighted tests are representing these criteria best. Judging them it can be concluded that overall the PCI and RSG software performed best. They should be favoured for DSM extraction. However, a big disadvantage of RSG is the computation time. Still, both software packages, PCI and RSG are recommended

for urban DSM extraction.

The quantitative accuracy assessment for the test area of Graz has shown that the best vertical estimation results were achieved with the software packages of LPS and PCI followed by RSG. The vertical MAE for built-up and impervious areas was 2.20m for PCI, 2.28m for LPS and 2.55m for RSG respectively. The RMSE was 3.05m, 2.96m and 3.25m respectively. Besides the vertical also the horizontal error should be considered depending on the different orthorectification methodologies applied (rigorous physical or RF based models). The shift compared with the reference DSM was between 3.06m and 3.27m. However, the qualitative, visual DSM evaluation has not confirmed the quantitative results. LPS with the best quantitative accuracy created fuzzy building outlines and contains low details in areas with smaller objects. PCI and RSG both produced DSMs with clear building outlines. They both are able to extract high details in areas with small buildings. Besides achieving the largest error in the quantitative analysis due to an erroneous mountain in the North of the test area ENVI also had problems in extracting correct multi-storey buildings outlines in the denser city area. It achieved good visual results with high details for rather small buildings.

Summarizing it can be said that the recommendations made for the Nairobi test area were confirmed by the quantitative and qualitative accuracy assessment done in the Graz test area. Both, PCI and RSG performed well or achieved at least acceptable results in both the quantitative and qualitative analysis. They both are recommended for digital surface model generation over built-up areas and settlements. Although LPS achieved the best quantitative accuracy it failed in creating DSMs with high details and clear building outlines. This is essential for building height extraction if the building outlines have to be still extracted from the data itself and are not available from cadastral offices as vector data layer. At last, ENVI showed a weak performance in creating large erroneous elevations in the test areas. It failed in achieving good quantitative results for both buildings and ground elevations. However, it should be mentioned that it successfully extracted fine structures of very small buildings in the Nairobi test area.

Two problems have to be addressed to extract building heights from stereo satellite data. First, the object height information has to be derived from the generated DSM. Two methodologies were presented to derive the object height layer: an indirect and a direct methodology. Second, the building outlines have to be delineated and extracted. A possible approach was proposed based on watershed segmentation.

The first results of the two tested methodologies are promising. A mean absolute error of 4.53m and 5.97m respectively was achieved when comparing them with reference building heights. Medium-height buildings were estimated well with an approximate error of one floor. Tall buildings are estimated with larger errors of two or more floors. These discrepancies have to be further analyzed. In case they are constant or linear the addition of an offset could be integrated into the current extraction methodologies.

Additionally, a building outline extraction approach based on watershed segmentation and preliminary results were presented. The methodology successfully detected most buildings. However, problems occur where buildings have complicated outlines. The extracted shapes of most building outlines are approximated and not representing the generally rectangular shapes of buildings. The next working steps will focus on the improvement of these approaches.

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