ADVANTAGES AND DISADVANTAGES OF THE HOUGH TRANSFORMATION IN THE FRAME OF AUTOMATED BUILDING EXTRACTION

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ABSTRACT:

This paper investigates the outcome of building extraction techniques from optical aerial and spaceborne high resolution data when applying Hough Transformation procedures. The proposed workflow consists of 4 major steps, namely the pre-processing of the data, nDSM (normalized Digital Surface Model) creation, building localization and building extraction. The advantages and disadvantages of this approach are discussed. The general conclusion is that the Hough Transformation is a very powerful tool for increasing the degree of automation during building extraction, while it is very robust against noisy data. Additionally the level of detail of the extracted buildings can easily be adjusted, but dark shadows in the images can make the algorithm produce erroneous results.

1. INTRODUCTION

Automated building extraction from high resolution image data (either airborne or spaceborne) is becoming more and more mature. Each day new techniques are investigated and the results are getting more and more reliable, while the degree of automation increases. Each of the building extraction methods is of course connected to certain pros and cons. The use of the Hough Transformation has proven to be very promising tool in the frame of the automated creation of Digital City Models, by extracting building properties from optical data.

This paper investigates the Hough-Transformation-approach in detail and points out its advantages and disadvantages. Furthermore, it concludes for which kind of data sets and accuracy pretensions this approach is recommendable. Moreover, the reachable degree of automation is also examined, in order to see how reliable results are that were produced without human interaction.

Altogether, five different datasets, coming from airborne and spaceborne sensors, were examined. These datasets depict urban regions with varying building densities.

2. WORKFLOW

The proposed workflow for automated building extraction from image data by employing the Hough Transformation has been thoroughly described in Vozikis (2004). Figure 1 shows the major steps of the process.

All steps in this workflow are highly automated and human interaction is reduced to a minimum.

In the following the 4 major steps are briefly described:

2.1 Pre-Processing

This step comprises the procedures from orientation of the input data up to the DSM (Digital Surface Model) creation. For VHR

satellite imagery the orientation approach is based on the RFM (Rational Function Model) (Vozikis et al., 2003). When dealing with aerial imagery it is made use of GPS/INS information in order perform direct georeferencing, and thus automated image triangulation (Scholten and Gwinner, 2003). The DSM extraction is performed by automated correlation procedures, which nowadays are very mature and produce very good results.
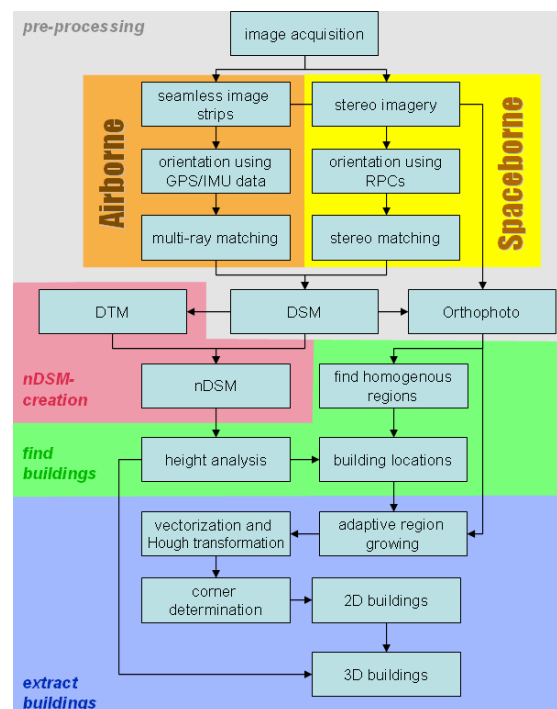

Figure 1: Proposed workflow for automated building extraction from image data

2.2 nDSM Creation

The goal is to derive the DTM (Digital Terrain Model) from the DSM and subtract it from the DSM in order to produce the so-

called nDSM (normalized Digital Surface Model). This way all extruding objects in the data set (including buildings) stand on elevation height 0 (Figure 2).
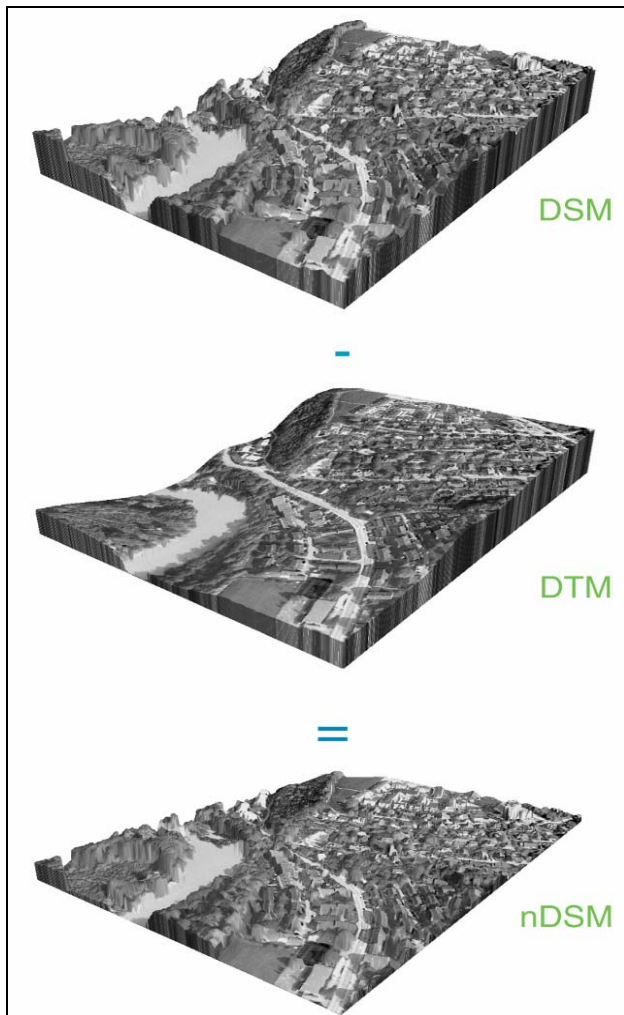

Figure 2: DSM, DTM and nDSM.

2.3 Building Detection

This crucial step deals with the identification of potential building candidates in the data sets (=determination of seed points inside buildings). It is proposed to perform 2 statistical analyses. First, perform a thresholding in the nDSM and filter out all objects that are not taller than a certain height, and second, perform texture analysis in the image data to keep only roof-similar regions in the data set (Vozikis, 2004).
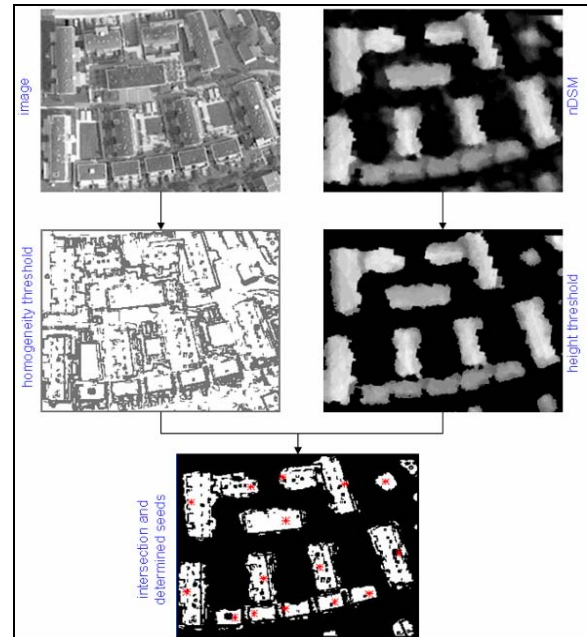

Figure 3: Computation of seed points (red asterisks) inside potential building candidates by height-thresholding and texture filtering.

2.4 Building Extraction

By applying the Hough Transformation the geometric properties of the buildings (building edges and corners) are extracted. Our approach is based on a stepwise, iterative Hough Transformation in combination with an adaptive region growing algorithm (Vozikis, 2004). The general idea is to transform the information in the image (feature space) into a parameter space and apply there an analysis. It is a technique for isolating features that share common characteristics. The classical Hough transformation is used to detect lines, circles, ellipses etc., whereas the generalized form can be used to detect features that cannot easily be described in an analytical way.

The mathematical analysis of the Hough Transformation is described in detail in Vozikis (2004) and Gonzalez and Woods (1992).Briefly it can be described as follows:

$$\rho = x\cos(\theta) - y\sin(\theta) \tag{1}$$

where ρ is the perpendicular distance of a line from the origin and θ the angle (in the range 0 to π) as illustrated in Figure 4.

To apply this function on the whole image, Equation 1 can be extended as shown in Equation 2 (IDL, 2004).

$$H(\theta,\rho) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} F(x,y)\delta(\rho - x\cos(\theta) - y\sin(\theta))dxdy \tag{2}$$

where δ is the Dirac delta-function. Each point (x,y) in the original image F(x,y) is transformed into a sinusoid $\rho = x\cos(\theta) - y\sin(\theta)$.
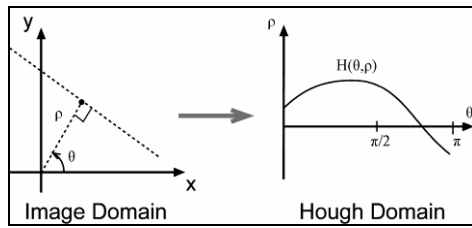
Figure 4: Hough transformation.

Points that lie on the same line in the image (feature space) will produce sinusoids that all intersect at a single point in the Hough domain (parameter space). For the inverse transform, or back-projection, each intersection point in the Hough domain is transformed into a straight line in the image (Figure 5).
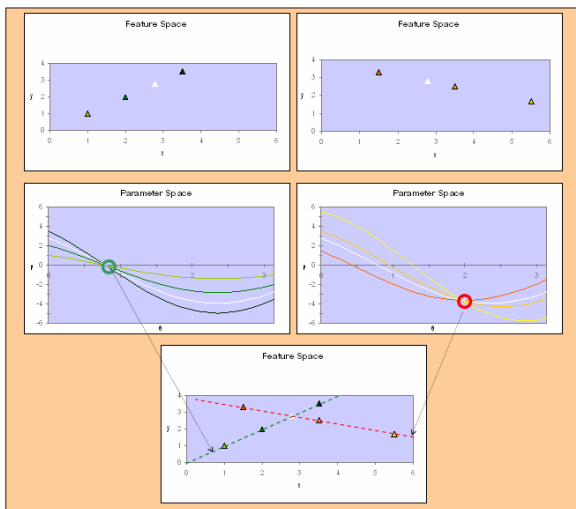

Figure 5: Example: Hough transformation.

3.   STRENGTHS OF THE HOUGH TRANSFORMATION

3.1 Noisy Data

The Hough transformation is a very powerful tool, especially when it comes to working with data sets that are noisy (IDL, 2004). Figure 6 illustrates an example, where the original image consists of points lying on three lines. The second input image is identical but additionally salt-and-pepper (random) noise was added. In this image it is rather difficult for the human interpreter to recognize the original three lines. The next step is a transformation into Hough domain. For each point one sinusoidal curve is drawn. The intersections of the sinusoids characterize points lying on a common edge (in image space). The higher the amount of such common points on one line is, the more sinusoids intersect at the corresponding location in Hough domain. Then, the local maxima (of sinusoid intersections) are automatically detected by setting a threshold of 20. This means that it is searched for lines (in image space), on which at least 20 points lie. The found local maxima are then back transformed and the final outcome is in both cases identical. The noise was completely disregarded.
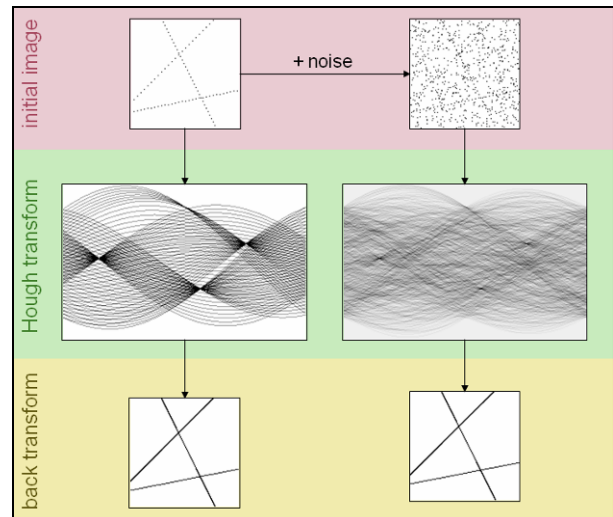

Figure 6: Example with noisy data of Hough and back transform.

3.2 Level of Detail

Another big advantage is the level of detail that can be 'defined' for the final back transformed building. It can easily be chosen how many edges (=intersections of sinusoids in parameter pace =local maxima) should be back-projected into image space and used for the building-edge extraction. In Figure 7 an example with 6 and 15 back-projected edges is shown.
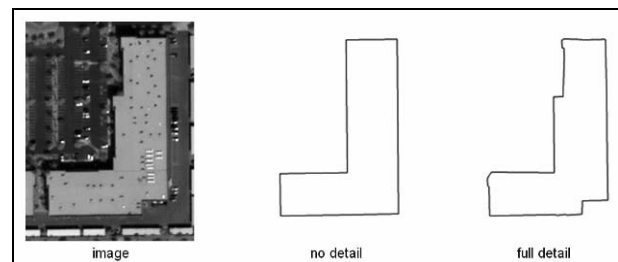

Figure 7: Level of detail during the Hough Transformation.

3.3 Forcing Angles

Quite often buildings are characterized by certain geometric properties. For example, two walls intersect at a certain angle. In the building extraction process it may happen that this geometric property is lost, due to inaccuracies of the input data, inappropriate algorithm strategies or other sources of error. Despite that, we want the extracted building, to obey to these characteristics, so it represents reality in the best way.

The implementation is quite easy, since the horizontal axis in parameter space represents angle θ. If the angle between two found edges has to be of a certain value, the horizontal distance between the corresponding local maxima in parameter space has to be equal to the wanted angle. Hence the deriving of the local maxima for the final back projection into image space is adjusted through the "angle" restriction (Figure 8).

Also a tolerance value that describes how big the maximum deviation from the requested angle can be introduced so that it is still forced into the right position.
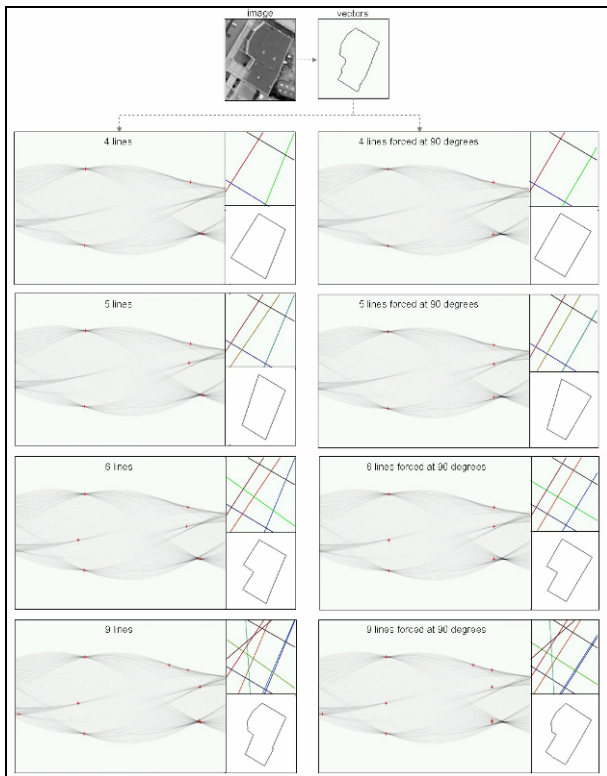
Figure 8: Left, example of Hough Transformation. Right, same example with 'Forced Angles'.

3.4 Bridging Gaps

The last advantage that is listed here focuses on handling missing/incomplete data. If the grey value differences inside a building are bigger than the differences between grey values inside and grey values outside the building, the adaptive region growing algorithm may fail to find all relevant pixels of a building. For example, in Figure 9 various steps of the region growing process are depicted. The seed point, that describes the found potential building candidate, is marked with a red cross in the image. In step 5 the grown region overflows the building edge and a big area is accumulated that does not belong to the investigated building. Hence the region growing process is terminated and the found region of step 4 is used for further processing.
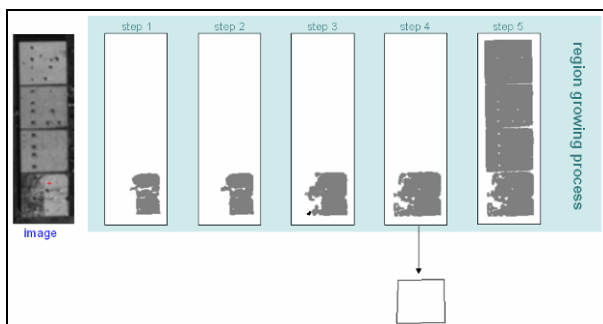

Figure 9: Example showing how the algorithm overcomes missing data.

It is obvious that the top left corner is not identifiable at all in this region. Even more it is also rather difficult to imagine the

left vertical edge. Nevertheless, when applying the proposed building extraction algorithm this edge is found without difficulties. By intersecting it with the upper horizontal edge, the top left corner point of the building (which is not visible at all in the grown region) is reconstructed without effort. This problem is very common, since many times parts of buildings are covered by shadows or vegetation, and hence some of the corner points are not visible.

4. DISADVANTAGES OF THE PROPOSED APPROACH

4.1 Heterogeneous Roofs

Heterogeneity in the imagery can lead to misinterpretations and may mainly affect the steps of seed point determination and adaptive region growing, in the proposed workflow.
One of the basic assumptions made for finding seed points inside buildings was the homogeneity of roof colour and roof texture. In practice, there are cases with roofs of a rather heterogeneous, unsymmetrical behaviour. This is not a problem as long as the radiometric variations inside the building are less than the difference between the interior and exterior of the building.

Furthermore, also the behaviour of the adaptive region growing algorithm becomes unpredictable as it is unable to decide where to stop the growing process. In these cases additional constraints must be taken into consideration, like e.g. approximate region shape and size, in order to support the region growing algorithm.
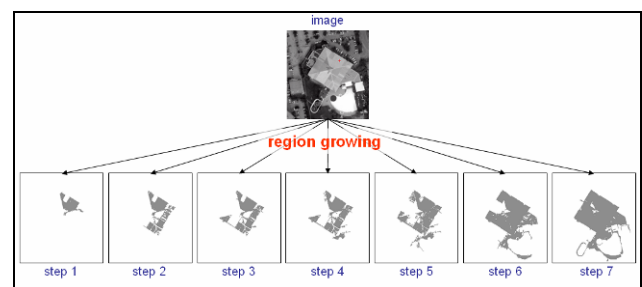

Figure 10: Example illustrating the region growing problem when dealing with heterogeneous roofs.

Such a problematic case is shown in Figure 10. When looking at the region growing steps, one can see that the accumulated area first flows over the border (from step 4 onwards) and not before step 7 the whole building is covered by the grown region. Even if the algorithm were able to automatically recognize when the whole building is filled, the subsequent processes (i.e. edge and corner extraction) would fail to compute a correct solution.

4.2 Shadow Effects

Since the proposed approach is based on intensive image processing, effects leading to alterations in the grey value distribution can influence the result negatively.

Illumination problems or shadow effects can affect the image radiometry so that the exploitation techniques fail or produce erroneous results. Especially in highly urban areas with high-rise buildings and skyscrapers smaller buildings may be totally

or partially covered with cast shadows (Figure 11). If the grey value difference over the building is very high, the algorithm cannot extract the building information correctly.

Figure 11: Highly urban area with big shadow effects.

4.3 Complex Buildings

In paragraph 3.2 we proved the capability to extract a rather high amount of detail of buildings if and only if there is a clear distinction between the regions belonging to the building and not belonging to it.

In cases, were the building is very complex (Figure 12), the building outline becomes more and more difficult to be identified. In this example even human interpretation is difficult and it is hard to decide where the outer boundary of the building really is.

Figure 13 shows an example demonstrating the capability and limitations of the discussed approach. The grown region does not include the upper terrace and thus it is not included in the extracted vectors. The building is incomplete!

Figure 12: Complex building.

The problem is caused by the unclear arrangement of "outer" walls. Additional constraints and restrictions during the region growing process might help to overcome this insufficiency.
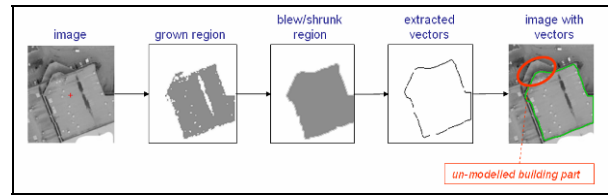

Figure 13: Example of incomplete building extraction.

4.4 DSM Inaccuracies

In paragraph 2.3 it has been shown how nDSM information is handled in order to determine seed points. One can imagine that finding seed points might become difficult if the nDSM is not accurate or if it is coarse compared to the building sizes.
Figure 14 is an extreme example to demonstrate the problem in case of a too coarse nDSM. It also makes not much difference if the height threshold or kernel size (for homogeneity calculation) were chosen differently. A greater height threshold would cause the exclusion of buildings for subsequent steps, and a greater kernel size would cause regions over small buildings not to be considered as building candidates and hence neglected further on. Though exaggerated, this example clearly shows the possible impact of too coarse DSMs on the quality building extraction.

4.5 Adjacent Buildings

Adjacent buildings can produce two kinds of problems. The first one is shown in Figure 15 where the extracted buildings do not share a common border anymore. This misinterpretation is due to the fact that building outlines appear as prominent and rather thick ribbon-like features in the image. Hence the region growing algorithm stops too early and includes only the inner edge of these border ribbons. These errors can be removed by growing the found regions over their edges until the adjacent building has been reached. Of course, a-priori knowledge is necessary as one has to know in advance which building blocks are compound houses and where borders to adjacent buildings are located.
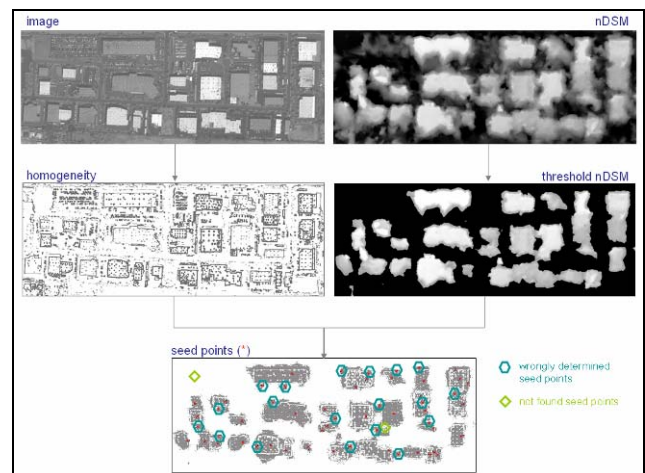

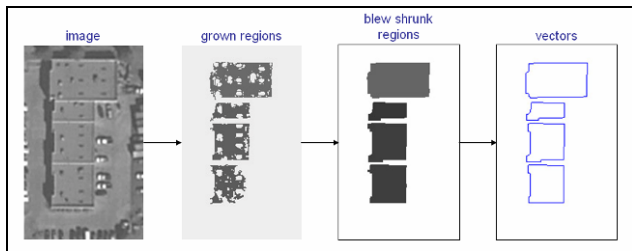Figure 14: Wrong seed points due to nDSM inaccuracies.

Figure 15: Buildings do not have a common border anymore.

5. CONCLUSION

The research shows that by using the Hough Transformation for building extraction we have many advantages, such as the good handling of noisy data, the easy adjustment of level of detail of the output data, the ability to force certain geometric properties into the extracted buildings and the possibility to bridge gaps, meaning that building corners that might not be visible in the imagery can be determined accurately. The proposed methodology proves to have certain weaknesses when dealing with radiometrically heterogeneous roofs, when big shadows partly cover roofs of the buildings to be extracted, when the building geometry becomes very complex, or when the input data set comprises many compound building.

Summing it up, one can conclude that the Hough Transformation is a very powerful tool for automated building extraction and creation of digital city models, but the degree of automation is still highly correlated to the quality of the input data.

REFERENCES

Gonzalez, R.C., and Woods, R.E., 1992. *Digital Image Processing*. Reading, MA: Addison Wesley.

IDL (2004): Image Processing in IDL, Reference Manual. Research Systems Inc., Ver. 6.1, 560 pages.

Kraus, K., 2000. *Photogrammetrie Band3. Topographische Informationssysteme.* 1st ed., Duemmler Verlag, Koeln.

Scholten, F. and Gwinner, K., 2003. *Band 12 "Publikationen der Deutschen Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation",* Bochum, pp. 419-426.

Vozikis, G., 2004: Automatic Generation and Updating of Digital City Models using High-Resolution Line-Scanning Systems. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 34, Part XXX.

Vozikis, G., Jansa, J. and Fraser, C., 2003. Alternative Sensor Orientation Models for High-Resolution Satellite Imagery. *Band 12 "Publikationen der Deutschen Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation",* Bochum , pp. 179- 186.