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EXPERIMENTAL STUDIES INTO AUTOMATED DTM GENERATION ON THE DPW770

Uwe Bacher
Universitaet der Bundeswehr Muenchen

ABSTRACT

In this paper the accuracy of automatic DTM computation on the digital photogrammetric workstation DPW770 of Leica-Helava will be discussed. The software component of the photogrammetric System is the Softcopy Exploitation Tool (SOCET SET) by Helava, with module "Terrain". Basis for the investigation was a test data set (image scale 1:13000) of the Institute for Photogrammetrie of Stuttgart University, originally provided for an OEEPE test " Experimental Investigation into Automatic DTM-Generation". The two different possibilities for automatic DTM generation with SOCET SET, the non-adaptive method and the adaptive method, will be explored and compared. Investigated was the accuracy in a stereo model with rough topography and most different land use. In order to be able to determine the accuracy of automatically calculated elevations, a data set consisting of some 2700 check points was made available. The check points are distributed in a symmetric raster with 25 m grid distance and, for a more detailed analysis, are additionally furnished with attributes such as land use, terrain roughness, and texture. In order to be able to make a statement about the optimal scanner resolution, test data sets with resolution of 15 µm, 30 µm and 60 µm were also made available.

1 INTRODUCTION

Presently photogrammetry undertakes a rapid change from analytical to digital. Analytical plotters are replaced more and more by digital photogrammetric workstations, and there are already tasks that can be performed more efficiently with digital devices. In particular, the production of digital orthophotos [Reiss, 1997] and the digital aerotriangulationis must be mentioned.

One of the principal fields of photogrammetry, viz. the generation of digital terrain models, can meanwhile be carried out automatically with several programs offered on the market [Krzystek, 1991]. The evaluation of contour lines on the stereo-screen, unpleasant for the human operator, is replaced by the measurement of regular point grids. The density of the grid and therefore the detail reproduction in the computed DTMs can be chosen as desired. However, the automatic generation of DTMs becomes more and more difficult in the case that the area for the evaluation has to be interpreted or complex features have to be represented. To be mentioned above all is the generation of DTMs in built-up areas. Here satisfactory results without additional information cannot not be achieved [Gabet, 1996].

The following work is a contribution to the OEEPE test "Experimental Investigations into Automatic DTM-Generation". The achievable accuracy, quality and the achievement potential depending on different parameters will be explored. The parameters are, e.g., grid size, scan resolution or terrain type. Also, problems caused by vegetation, built-up areas or rough terrain ought to be investigated. Different possibilities and procedures for DTM-generation should be studied.

The digital photogrammetric workstation DPW770 from Leica/Helava was employed for the test.

1.1 Hardware

The main computer is a Sun Ultra 1 with 128 MB RAM and 16 GB hard disk capacity. A second monitor with a polarised mask from NuVision is provided for stereo vision. In this way, a stereo scopic view is possible with passive eyeglasses. Furthermore, the workstation has handwheels, footdisk and foot switches, common to analytical devices, for stereo compilation.

1.2 Software

The workstation runs under the operating system Solaris 2.5.1. The software package SOCET SET (softcopy exploitation tools) of HELAVA serves as photogrammetric software component.

2 UTILIZED DATA

2.1 Test data and test area

The images for this test were taken in July 1995 with a Zeiss RMK TOP Kamera. The image scale is about 1: 13000. The digitalization of the pictures was carried out at the PS1-Scanner of the Institute for Photogrammetry of Stuttgart University. The images were scanned with resolutions 7,5 µm, 15 µm, 30 µm and 60 µm.

The test area Vaihingen/Enz is about 30 kms West of Stuttgart. A small river (Enz) winds itself through the test area. A small town (Rosswang) as well as a quarry is right in the test area. The test area mainly consists of agriculture areas, open fields, vineyards, orchards as well as some small forests.

The topography of the area is mainly determinated by the river valley of the Enz. South of the river, the ground increases smoothly whereas the northern side is embossed by an undercut slope increasing in steepness. Relatively smooth ground follows farther in the North [Fig. 1]. The examined field has a North-South extension of about 2.7 km and an East-West extension of 1.8 km.

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Figure 1: The test area Vaihingen/Enz

2.2 Control data

As control data two data sets were available. On the one hand, 102 checkpoints in two areas measured with GPS (hilly and steep) and on the other hand photogrammetrically measured checkpoints in a regular grid of 25 m by 25 m. In addition, the checkpoints of the raster given attributes in order to allow for their precise analysis [Fig. 2].
The attributes are:

- land use
- vegetation height
- terrain roughness
- texture

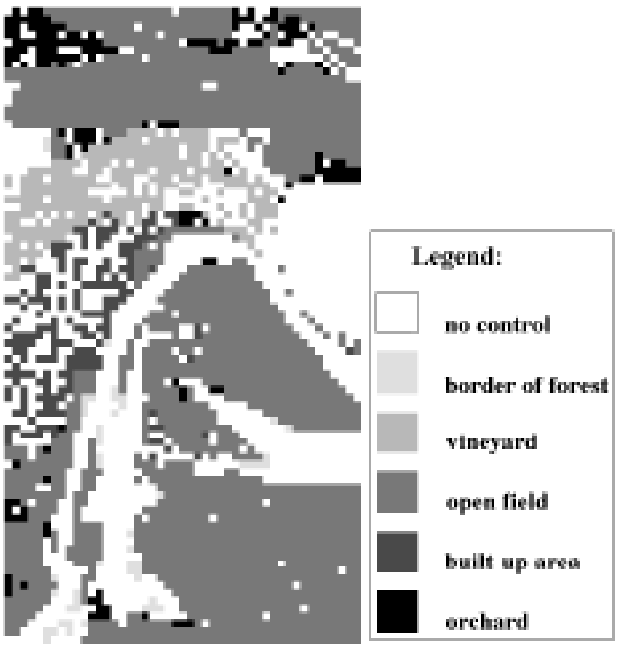

Figure 2: Representation of the terrain type for the test area

3 INITIAL WORK

Before one can begin with the generation of DTMs, the data must first be prepared. In the case of SOCET SET, these works are divided into 4 steps:

- creating a project
- import of the images
- interior Orientation
- triangulation

Creating a project
Here, information about the applied coordinate system, the used units, the project path etc. is requested. The information is necessary for the internal organization of the data.

Import of the images
The information of the camera calibration data is important here and if available, values for the camera location. The time requirement for the import of the images depends very much on the image size and the available storage medium. These tasks can be carried out as batch processes and thus require little interaction by of the operator.
During input of the image data, a minified image pyramid can be created. In this way, the images are used for faster zooming and automatic image matching.

Interior orientation
Under interior orientation one should understand here the connection between the scanned film and the digital image data. Interior orientation creates a transformation from film space to digitized image space. As solution types 4, 6 or 8 parameter transformations are offered. The determination of the interior orientation is performed semiautomatically. The first two fiducial marks must be coarsly measured manually. The exact measurement is then performed by the computer. The measurement can occur fully-automatic from the third fiducial mark. However, the approach breaks down if the fiducial marks such as in this test are not symmetrical or were scanned incompletely. In such a case, the fiducial marks must be measured interactively or manually.
The time required is less than one minute per image if symmetrical fiducial marks are available.

Triangulation
Here, the organization of the image block must first be carried out. By means of information on overlap, altitude and mean ground elevation approximate values for relative orientation are determined.
In a further step, tie-points are measured fully-automatic. Their is the possibility to measure interactively bad points or reject off arbitrary points. It proved to be more economical to measure more points automatically than necessary and delete bad or wrong measured points in a further step. As a result the relatively time-consuming interactive measurement process can be avoided [Kersten, 1997].

The measurement of the control points is performed interactively. A point is manually measured in the first image and measured automatically by the program in the remaining images in which it occurs.

Bundle block adjustment is performed in SOCET SET by the HATS Triangulation program. However, up to now GPS observations of the camera position can not be included in the adjustment.
The accuracies of the results for this test are shown in Tab. 1. The total time requirement for input, interior orientation and the triangulation of a stereo model is about 20 to 30 minutes.

Table 1: Accuracy of triangulation

Resolution	Number of control points	Number of tie points	RMS- Image [µm]
15	9	23	1.65
30	9	26	2.4
60	9	31	4.8

4 POSSIBILITIES OF DTM GENERATION WITH SOCET SET

With SOCET SET, two different methods are available for computing elevation data: non-adaptive automatic terrain extraction as well as the adaptive automatic terrain extraction.
To find homologous points in corresponding images, image correlation is employed as Subpixel accuracy is achieved by interpolation.

The automatic terrain extraction works as an iterative process. It starts in a small pyramid level and large dot distance. The dot density is increased in each pyramid level until level 1:1 is achieved. The results of the previous stages serve as approximations in each case for further calculations.

Non-adaptive method

The non-adaptive method requires a user specified strategy. The algorithm has a large number of parameters. A given combination of these parameters is called a strategy. By tuning the parameters of the strategy file the quality of the DTM can be improved.
Table 2 shows the 12 strategy files offered by SOCET SET. Furthermore, it is possible to create a strategy file that is suited best to the actual terrain.
A strategy file will normally not fit to a complete stereo model. So the stereo model has to be subdivided into several subareas with the same terrain characteristics. The received DTMs have to be merged afterwards.

Table 2: Strategies for the DTM generation

Maximum Terrain Slope	High-Speed Extraction	High-Accuracy Extraction	High-Accuracy & Removes Artefacts such as Buildings and Trees	High-Accuracy & High-Speed for very dense DTM Grids
20 degrees	flat	flat_1	flat_plus	flat_dense
30 degrees	rolling	rolling_1	rolling_plus	rolling_dense
50 degrees	steep	steep_1	steep_plus	steep_dense

Adaptive method

The adaptive method uses a so-called inference engine to generate image correlation strategies adaptively according to terrain type (flat, hilly, steep) [Zhang, 1997]. If the terrain changes within the DTM covered area, adaptive automatic terrain extraction will use different strategies depending on the terrain. Therefore, it is not necessary that DTM-covered areas are from the same type. The adaptive method is not limited to only one stereo model but can accommodate as many images as desired for DTM-generation. Therefore, every available area in the block can be evaluated in one step. The method also offers the possibility to smooth the DTM or remove artefacts like trees or buildings during the computation of the DTM. Four smoothing levels (none to high) are available. For filtering of artefacts, a minimum height as well as a maximum width of the objects to be filtered may be set.
Verification and interactive terrain edit
For the interactive editing of the automatically produced DTMs, SOCET SET provides three different possibilities:

- post editor
- area editor
- geomorphological editor

Post editor
Individual posts can be reviewed and edited one after the other. The points are displayed on the stereo screen and can be adjusted if necessary. Further more the post editor shows information about the elevation of the point and the quality of the measurement. The quality is shown by using the correlation coefficient.
This possibility of editing is the most precise one offered by the system. However it is quite time consuming.

Area editor
The area editor can be used to edit DTM-posts within a polygon. Different filters are available for this purpose. Here, among other things, smoothing the DTMs is possible, trees and houses can be eliminated, the DTM can be lifted or lowered around a set factor within a field or can be brought to a fixed level.
The post-treatment with the field editor is easy to use and quite favorable in time consumption. However, the results are not always very satisfactory and a lot of experience is necessary for the different tools.

Geomorphological editor
With the geomorphological editor it is possible to insert edges into the DTM. Furthermore it is possible to adapt the DTM to linear features like mountain ridges or grooves. Different predefined shapes are available for this or generic shapes can be created.

5 INVESTIGATION PROCEDURE

On the basis of the test data and the diverse possibilities of the software an almost arbitrary number of test DTMs could be computed. A manageable number of test examples was selected from these possible combinations. From the examples, the test requests could be achieved satisfactorily. In order to compare the required time the DTMs were computed in each case for the same test area. The coordinates of this test area are:

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lower left corner: X = 3750 m, Y = 1000 m
upper right corner: X = 4900 m, Y = 3100 m

The test is divided into two main parts, the investigation of the non-adaptive method and of the adaptive method.

For the non-adaptive method, only the stereo model with 30 µm resolution was considered. For this stereo model a DTM with 5 m grid-size was produced with all available strategies.

With the adaptive method DTMs from the image pairs with 15 µm, 30 µm and 60µm resolution were computed. In order to evaluate the influence of the grid-size on accuracy a DTM with 2.5 m, 5 m and 25 m gridding was computed for every model. For the 5 m and 25 m grid-size, DTM with and without filtering and smoothing (filtering of 2 m minimum height and 20 m maximum width of objects as well as medium smoothing) were generated.

For accuracy information a reference raster made by the Institute for Photogrammetry of Stuttgart University was employed. In this way it is possible to divide the results into different land uses and terrain types.

The times for the computations determined in the test should give only a coarse view of time requirement. It could not always be ascertained that no other applications would run on the computer during the DTM generation. In this way, one can explain some of the results that do not correspond to the conceptual ideas.

6 RESULTS

6.1 Non-adaptive method

The investigation result of the non-adaptive method clearly shows the weaknesses of the flat - strategies for larger areas with different terrain types. On the other hand it is possible to achieve good results with the steep and roll – strategies in larger areas with different terrain types [Fig. 3].

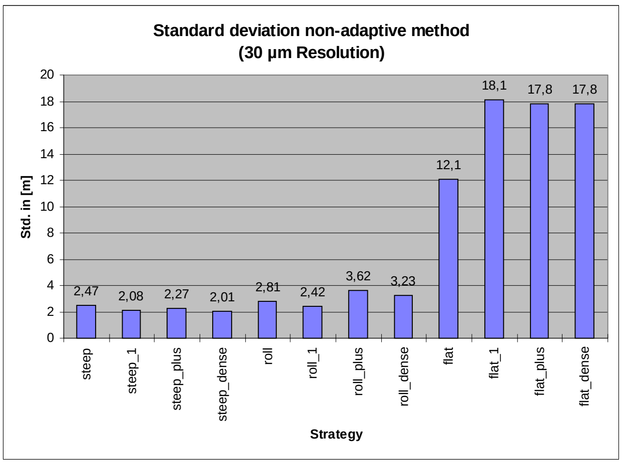

Figure 3: Standard deviations of the non-adaptive method - according to strategies

Table 3: Accuracy of the non-adaptive method

Strategy	av_diff [m]	RMS [m]	Std. [m]	Time [min]
steep	-0,748	2,58	2,47	04:29
steep_1	-0,655	2,18	2,08	05:50
steep_plus	-0,538	2,33	2,27	06:25
steep_dense	-0,557	2,08	2,01	04:20
Roll	-0,748	2,91	2,81	06:13
roll_1	-0,622	2,5	2,42	09:23
roll_plus	-0,202	3,62	3,62	08:30
roll_dense	-0,251	3,24	3,23	06:04
flat	1,45	12,2	12,1	02:10
flat_1	3,35	18,4	18,1	03:31
flat_plus	5,85	18,7	17,8	03:42
flat_dense	5,87	18,8	17,8	02:40

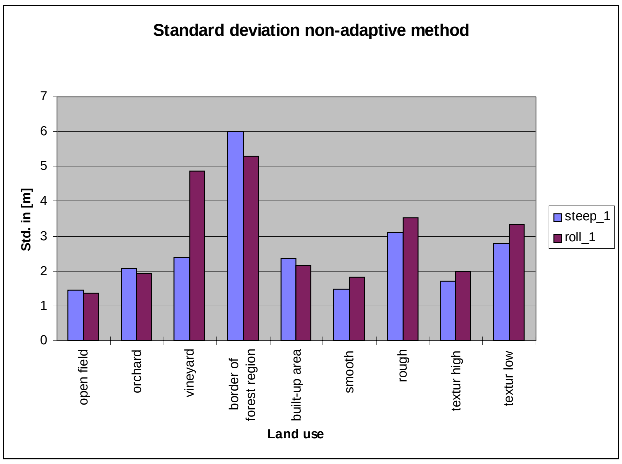

Figure 4: Standard deviations of the non-adaptive method - in terms of land use

The greatest differences between the steep and roll - strategy show itself in the fields of the vineyards. However, the reason for it is less due to the landuse but rather at the fact that the vineyards represent the steepest slopes in the investigation area. In the remaining areas the differences between the two strategies are not significant.

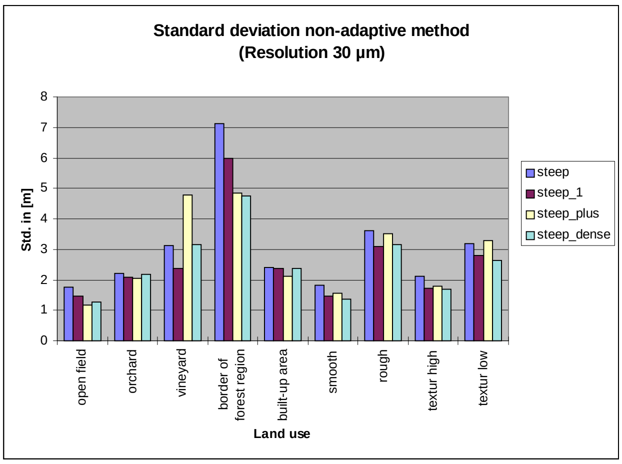

Figure 5: Standard deviations of the non-adaptive method - according to land use and strategies

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6.2 Adaptive method

With the development of the adaptive method for DTM generation, the developers of SOCET SET succeeded a step into the correct direction. The test showed the better quality of the results from the computations with the adaptive method impressively compared to the non-adaptive method.

However, it must be mentioned that better results could be achieved with the non-adaptive method by subdividing the evaluation area and generate DTMs for the subareas. These smaller DTMs can later be merged into one DTM. For this, however, a lot of experience is necessary in the selection of the strategies, and compared to the adaptive method the time-advantage is lost by extensive preparation work.

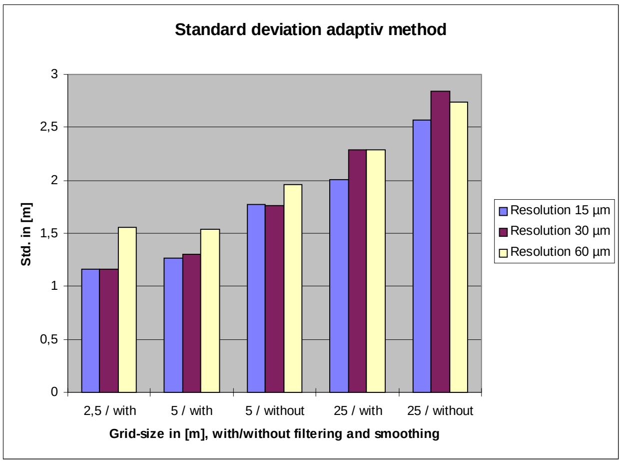

Figure 6: Standard deviations of the adaptive method - according to the scan resolution

The tests showed that the scanning resolutions of 25 µm to 30 µm mainly employed today in practice are completely sufficient. The accuracy differences to finer resolutions are small and without doubt do not justify the considerably bigger time requirement during computation as well as the considerably bigger memory requirement of the images. The coarsest resolution of 60 µm in this test shows by far worse results than the finer resolutions. However, it has its importance certainly for applications with lesser high accuracy requirements [Fig. 7].

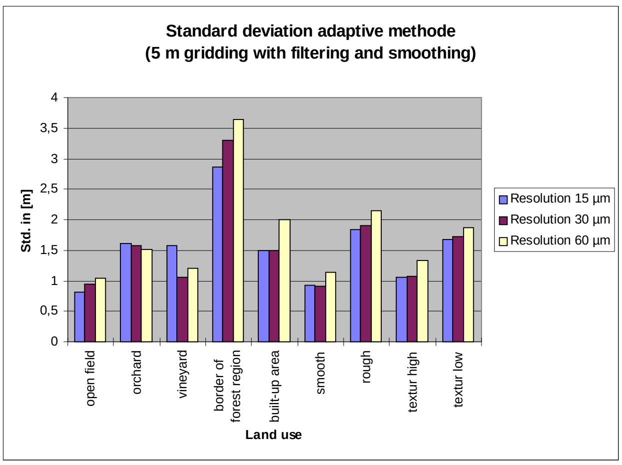

Figure 7: Standard deviations of the adaptive method - according to the scan resolution and land use

A DTM grid-size of 5 m appears useful, the accuracy compared with the 2.5 m grid is only slightly worse, however, the working time advantage is massive. The results with the 25 m grid are considerable worse, whereas the time advantage is quite large [Fig. 8].

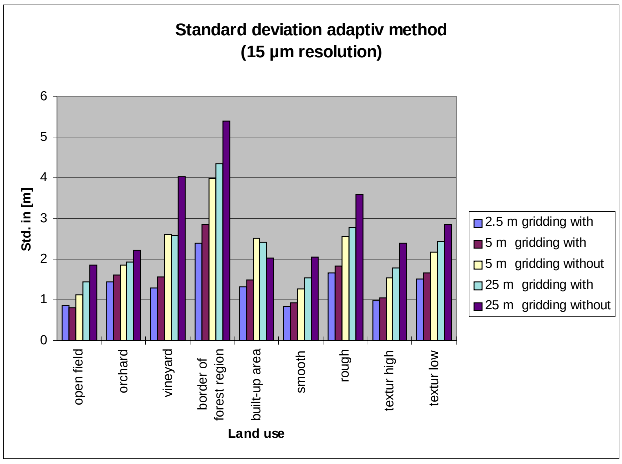

Figure 8: Standard deviations of the adaptive method - according to the grid-size and land use

Table 4: Accuracy of the adaptive method

Grid-ding, Filter-ing	Res. 15µm av_diff [m]	Std. [m]	Time [min]	Res. 30µm Av_diff [m]	Std. [m]	Time [min]	Res. 60 µm av_diff [m]	Std. [m]	Time [min]
2,5m, with	-0,481	1,16	51:17	-0,529	1,16	25:00	-0,472	1,56	23:09
5m, with	-0,46	1,27	28:30	-0,562	1,3	12:15	-0,513	1,54	9:27
5m, with-out	-0,578	1,77	27:40	-0,626	1,76	11:35	-0,568	1,96	9:00
25m, with	-0,693	2,01	5:05	-0,871	2,29	3:02	-0,87	2,29	1:26
25m, with-out	-0,769	2,57	4:50	-0,818	2,84	2:55	-1,01	2,74	1:20

In order to generate a DTM of the ground surface without possible coverage of houses or trees, it appears reasonable to perform a filtering of artefacts and a smoothing. It must be decided, however, on an individual basis about the best parameters for the filtering and the way of smoothing [Fig. 8]. Further experiments are still necessary for this.

Best results were achieved as expected in the open field whereas built-up areas and forest boundaries exhibit bad results. The bad results of the vineyards are due to the vegetation coverage that causes a more or less constant offset, also due to the fact that the vineyards represent areas with largest terrain inclination [Fig. 7].

Areas with a smooth terrain surface achieve an approximately twice as high accuracy as regions with a rough surface. As expected, the automatic procedures for DTM generation have greater difficulties at areas with low texture than in such ones with much texture what is also clearly reflected in the accuracies of the results.

7 PROBLEM AREAS

Problems during automatic computation of DTMs occur mainly in built-up areas, areas with strong vegetation coverage as well as on very steep terrain.
In built-up areas, the problems depend on the density of housing. Separate houses can be extracted from the DTM with relatively small effort. On the other hand, the results become unreliable in built-up areas especially in case of very dense housing [Fig. 11 &. 12]. The results can indeed also be corrected by a filtering, however, one hardly gets out of a manual post-treatment in these areas.

In areas with vegetation coverage one must distinguish very strongly according to the density of the vegetation coverage. In forests, the ground can only be recognized in the rarest cases and therefore, it is plausible that the tree top surface comes into the DTM. If the forest is of homogeneous height it is possible to reduce the height by a shift to the actual height and thus represents approximately the actual ground. Small vegetation areas like hedges or individual trees can be filtered from the DTM similar to houses and represent no great problem. On the other hand, a change from open field to forests causes great problems. As Fig. 10 shows, a ridge is deceived here where no one is. During a manual post-treatment it is quite difficult to correct these mistakes, because it is hard to find the exact border of the forest area. For a visual estimation of the problem areas the height representation with contour lines is very useful.

8 CONCLUSION

The accuracy of automatic DTM computation on the digital photogrammetric workstation DPW770 of Leica-Helava was explored. Investigated was the accuracy in one stereo model with rough topography and most different land use. A data set consisting of some 2700 check points was made available. The check points are distributed in a symmetric raster with a gridding of 25 m, and, for a more detailed analysis, additionally furnished with attributes such as land use, terrain roughness, and texture. In order to be able to make a statement about an optimal scanner resolution, test data sets with different resolutions of 15 µm, 30 µm and 60 µm were also made available.

In order to be able to make a comprehensive statement on achievable accuracies, several representative examples were chosen from the many possible test combinations, and the corresponding accuracy situation was determined. The results attained show that the adaptive method is superior to the non-adaptive method as far as reachable accuracy and user friendliness are concerned. As has been expected, automatic methods yield best results in flat and open, well textured terrain. In this case, elevation accuracies better than one meter could be achieved with the adaptive method. The results deteriorate as soon as the areas have little texture or the terrain is very steep. The results turned out to be practically unusable at edges of forest regions, along tree lanes or in built-up areas, unless additional filtering methods for 'eliminating' 3D objects like trees or buildings are employed.

REFERENCES

Gabet, L., G. Giraudon, L. Renourd, (1997): Automatic generation of high resolution urban zone digital elevation models. ISPRS Journal of Photogrammetry and Remote Sensing, 52, pp. 33 - 47.

Kersten, Thomas, Silvio Häring, (1997): Effiziente digitale Aerotriangulation in der Praxis. ZPF 4/1997, 118-128.

Krzystek, P., (1991): Fully automatic measurement of digital elevation models with MATCH-T. Proceedings of 43rd Photogrammetric Week, University Stuttgart, 1991, pp. 203-214.

Reiss, Peter, (1997): Production of Digital Orthophotos and Orthophotomaps at the Bavarian Land Survey Office. Proceedings of 46st Photogrammetric Week, University Stuttgart, 1997, pp. 293 – 302.

Zhang, Bingcai, Scott Miller, (1997): Adaptive Automatic Terrain Extraction. Proceedings SPIE, Volume 2xxx, xxx.

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Figure 9: Contour lines derived from DTM without filtering and smoothing

Figure 10: Contour lines derived from DTM after filtering and smoothing

Figure 11: Contour lines derived from DTM without filtering and smoothing (built-up area)

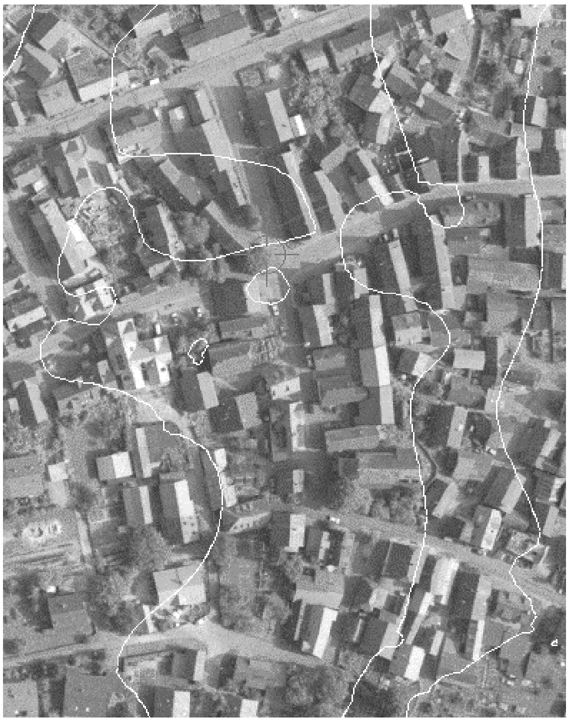

Figure 12: Contour lines derived from DTM after filtering and smoothing (built-up area)