D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

Investigation into the automatic generation of heights of different Danish landscape types

Marianne Wind
Aalborg University
Fibigerstræde 11
9220 Aalborg East
Denmark

ABSTRACT

This article describes an investigation using automatic generation of heights over a typical Danish landscape. For this investigation the program Match-T has been used. The investigation is carried out over a test area of 3.5 x 4.0 km. The area represents more than 80 % of what could usually be termed typical Danish landscape. The test area is divided into five different landscape types. Over this area an experienced operator has measured points as a reference and each landscape type is registered by a code. Different parameters have varying influences on the accuracy. In this investigation a closer look into the influence of the accuracy of different flying heights, resolution of the images and grid sizes has been done. The accuracy obtained from the different parameters compared against the five landscape types will be studied. The goal of this investigation is to find the best combination between landscape types, flying heights, image resolutions and grid sizes.

1 INTRODUCTION

There are new possibilities within modern computer technology, which has increased the demand for digital elevation models (DEM). These models have traditionally been used for orthophoto production but also, e.g. landscape draping, calculation models of water flows and Civil Engineering contracts etc. For the whole area of Denmark a digital terrain model exists which is used for these purposes. The accuracy of an elevation model required by Civil Engineering contractors and water flow calculations is in the region of centimetres and therefore the accuracy of the existing digital elevation model is not accurate enough.

The existing DEM was produced by digitising the five metre contour lines on topographic maps in the scale of 1:50.000. The height information, which formed the basis of the five metre contours, was measured during the latter part of the 19^{th} and the beginning of the 20^{th} centuries. At that time, measurements were in the imperial units of ‘feet and inches’. Over the years these nearly 100 year old measurements have been converted, first from ‘feet’ to 2 metre contours, then to 2.5 and finally to the 5 metre contours. All these conversions were done manually. Finally the 5 metre contours are digitised by hand. The accuracy must therefore be assumed to be low [Balstrøm et. al, 1994]! The requirement of the accuracy for the digital elevation model was to be better than 2 m. Two analyses have been done to investigate the DEM accuracy. These show that the accuracy of the test areas varies between 0.75 and 1.3 m [Frederiksen, P., 1987]. Therefore it is assumed that the digital elevation model is better than the required 2 m. It should also be noted, that throughout the intervening years, different uses of the elevation model have shown that there are areas with errors greater than 2 m and it is not exactly clear where these errors are located.

There is therefore great interest for a newer and better digital elevation model of Denmark, which should have an accuracy better than the present 1.5 – 2 m. The general question is, can a digital elevation model with a better accuracy than the current model be produced more quickly and cheap for Denmark? The answer from people in the field of photogrammetry is; - ”use the methods being developed for the automatic generation of elevation models”!

Different systems to deal with fully automatic generation of heights have for many years been available and in many places these methods are an integrated part of the production by most photogrammetric companies. Different investigations with the automatic generation of elevation models have been done. These investigations have shown that the areas with vegetation cover and those which are built-up usually give bad results. In order to obtain better results it is normal for the problem regions to be edited. [Zeiss, 1992].

A closer look will be taken into the different types of Danish landscape and their influence on the accuracy of automatically generated heights depending upon the image scale (flying heights), image resolution and grid size of the elevation model. It is anticipated that an optimum combination will be found between these aforementioned parameters.

The program package Match-T, developed by INPHO of Stuttgart, is used and the examinations will be carried out by using the standards Match-T has set as being normally accepted as typical Danish landscapes.

2 DATA MATERIAL

A test area measuring approximately 3.5 x 4 km of a part of Denmark has been selected, this comprises flat area, village, gravel pit, undulating terrain and forest. It represents more than 80 % of a typical Danish landscape.

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

To compare image scale and accuracy over this test area, aerial photos were taken at three different heights, which yields images in scales of; - 1:5.000, 1:15.000 and 1:25.000. It is unrealistic to use aerial images in a scale of 1:5.000 over the whole of Denmark, because it would create large amounts of data and henceforth more processing work. The scale 1:5.000 is only included to produce the reference points. The traditional image scale for aerial images in Denmark is 1:25.000 but aerial images in 1:15.000 can be realistic if it can be shown that it is possible to obtain a significant improvement in their accuracy. For each image scale there are two sets of models included in this study.

To be able to assess the quality of the automatically generated heights it is necessary to have extremely accurate reference information (points). An experienced operator on an analytical plotter measures the reference points in the aforementioned 1:5.000 images. These points would therefore be expected to have an accuracy of ~ 4-5 cm. This signifies that now the automatically generated heights in images of 1:25.000 can be compared against reference points which are extremely accurate and where the accuracy is expected to be in the region of 0.5 m.

The reference points are determined at regular intervals within a 25 x 25 m grid. To be able to analyse terrain which is very undulating i.e. the landscape type gravel pit, the reference points are measured with a grid size of 5 x 5 m. In forested areas, a grid was chosen in some cases as close as possible to the regular grid.

As mentioned previously, the reference points represent five landscape types; - flat area, villages, gravel pit, undulated terrain and forest. Each of these landscape types have been given object codes, which makes it possible to analyse which landscape type produces the greatest errors and which types do not cause problems.

In order to take a closer look into the accuracy compared to the resolution, the images have been scanned in; - 15 µm, 30 µm and 60 µm by using a PS1-scanner from Zeiss/Intergraph.

3 MATCH-T

The Match-T system operates with pairs of digital or scanned aerial images. The process in Match-T can be divided into groups. First the image data has to be digitally orientated. The calculation part can be divided into pre-processing and then DEM-generation. The pre-calculation contains the normalising of the image pair in order to have the benefit of epipolar geometry. Thereafter follows the set up of image and feature pyramids by using the Förstner interest operator. The DEM-generation is carried out stepwise by going through the pyramidal data structure (image pyramid and feature pyramid over 8-9 levels) in order to be fast and practically independent of pre-knowledge about the terrain. The processes on each pyramid level can be divided into the matching of homologous image points, a 3-D intersection into object space and a robust DEM modelling with bilinear finite elements. This is done for each pyramid level. The matching is geometrically restricted by a parallax bound and the epipolar line [Krzystek, P et. al, 1992].

4 ACCURACY

Several investigations have been done into the automatic generation of heights including the Match-T program packages. The accuracy which can be attained, according to Match-T is of the order 0.1 $^0/_{00}$ of the flying height or better [Krzystek et al., 1992], [Ackermann et al., 1992]. Other investigations show that the accuracy can on occasion be worse. For a scale of 1:10.000 it should be possible to obtain an accuracy of around 0.15 m, but an investigation in Potsdam with images of 1:10.000 shows, that 78 % of the results are better than 2 m, 11 % are between 2-3 m and the remaining 11 % are worse than 3 m. [Seyfert, 1995].

5 HEIGHT DIFFERENCE

To be able to compare the automatically generated heights with the reference points, a height has to be interpolated for each (x, y)-position and for each reference point. A program for this purpose has been developed. This interpolation is accomplished by using the bilinear interpolation method. The height is interpolated from the four nearest neighbours in the grid, by the formula; -

$$z(x,y) = ax + by + cxy + d$$

The interpolated height will thereafter be compared with the height of the reference point in the same position by this simple formula; -

Diff = ‘z’int – ‘z’ref

The ‘z’int is the interpolated height, ‘z’ref is the height of the reference point and diff is the difference between ‘z’interpolated and ‘z’reference. Furthermore the standard deviation for every landscape type has been determined.

6 THE INVESTIGATION

In this investigation no editing has been done at all on the areas where errors could occur for instance regions which are built-up and covered with vegetation etc. The height generation is done for the whole model. In the standards information from Match-T the Danish landscape (terrain) is stated as being flat and a high smoothing degree has been selected. For each model (with the three different resolutions) a digital elevation model (DEM) has been generated with respect to the three grid sizes 5 m, 10 m and 25 m. To be able to reduce the calculation time the result from the orientation and the pre-calculation has been reused in all the following DEM-calculations with the three grid sizes. For the rest of the parameters the standard information suggested by Match-T has been used.

First the resolutions and the image scales are compared. This is done to investigate what accuracy can be obtained when they are generated over areas without any prior knowledge as to what landscape types the area represents. The standard deviation is calculated for the image scale 1:15.000 and 1:25.000 with respect to the three resolutions. There is no consideration taken of the grid sizes. The result, which can be seen in table 1, is calculated over the whole area without any editing. The accuracy for Match-T is given as 0.1 $^0/_{00}$ of the flying height and the result will be compared with this information.

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

Images with a scale of 1:15.000 are flown at a height of approximately 2250 m and images with a scale of 1:25.000 are flown at a height of approximately 3750 m. The standard deviation is in metres.

	15.000	25.000
0.1 $^0/_{00}$ of the flying height	0.225	0.375
15 µm	2,19	3,19
30 µm	2,07	2,91
60 µm	2,01	3,63

Table 1: The standard deviation of different flying heights with respect to the resolutions.

It can be seen from table 1 that the resolution has no immediate influence on the accuracy for the scale of 1:15.000. For the scale of 1:25.000 the resolution of 60 µm is significantly worse than the result for the resolutions of 15 µm and 30 µm. Furthermore it shows, that an accuracy of 1 $^0/_{00}$ of the flying height is more realistic than Match-T's suggested accuracy of 0.1 $^0/_{00}$ of the flying height, when no consideration is taken into what landscape type the area contains.

The interesting point now is, which landscape types contributed towards the largest errors? To be able to investigate this closer, a more detailed look at the chosen landscape types is necessary.

In the rest of the investigation the connection between the scales (1:15.000 and 1:25.000), the resolutions (15 µm, 30 µm and 60 µm) and the grid sizes (5 m, 10 m and 25 m) will be studied for the five landscape types. The purpose is to find if and where there are any significant height errors occurring whilst using the different resolutions and grid sizes.

6.1 Scale 1:15.000

The following three figures show the accuracy of the five types of landscape when comparing them against the resolutions 15 µm, 30 µm and 60 µm and the three grid sizes in the scale of 1:15.000.

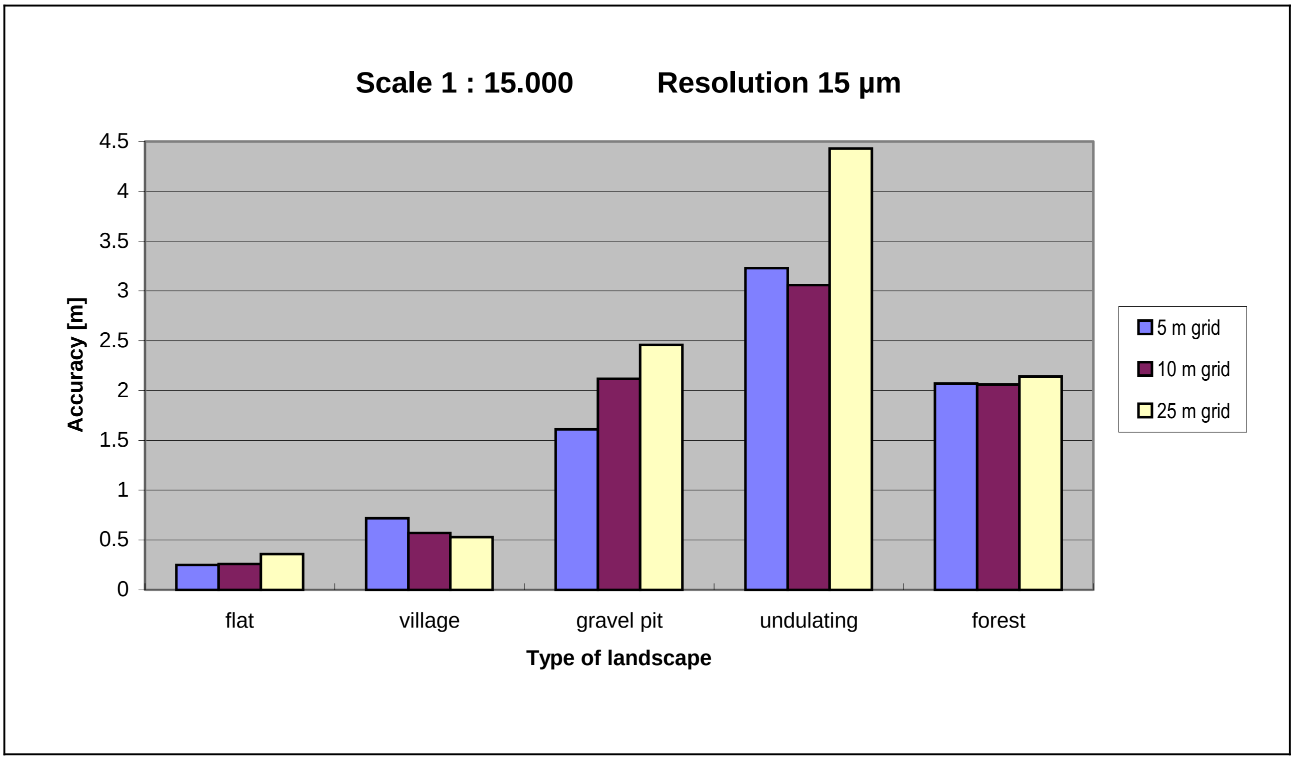

Figure1: The influence of the grid sizes upon the image scale 1:15.000 with a resolution of 15 µm.

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

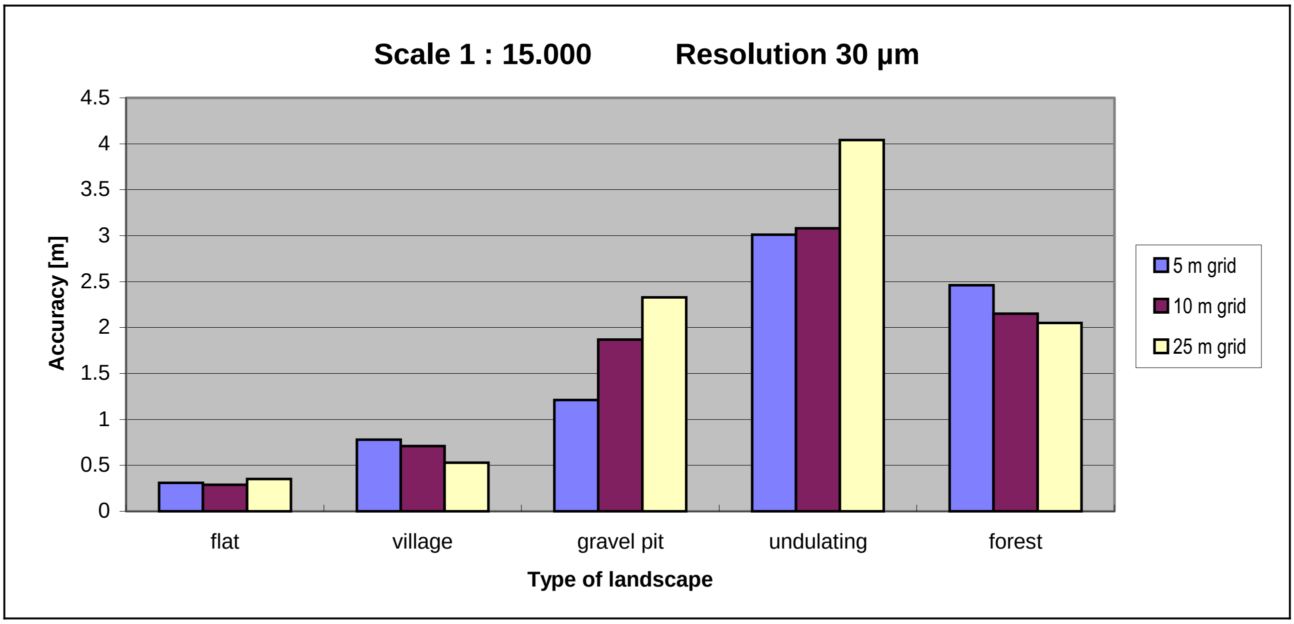

Figure 2: The influence of the grid sizes upon the image scale 1:15.000 with a resolution of 30 µm.

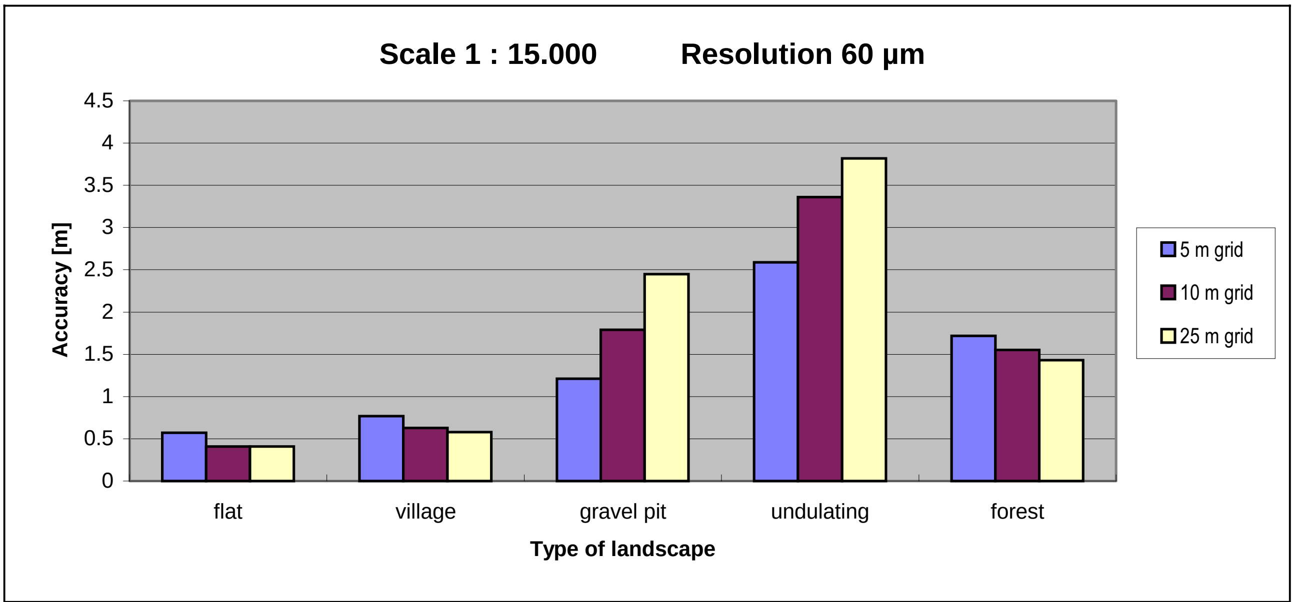

Figure3: The influence of the grid sizes upon the image scale 1:15.000 with a resolution of 60 µm.

It is easy to see that the best results are obtained from the landscape types flat area and village. The areas where the greatest problems arise are; - gravel pit, undulating terrain and forest. In the landscape types gravel pit and undulating terrain it is plain to see that the grid sizes do have an influence. A field study indicated that the undulated area can best be described as an area with large hillocks and not large rolling hills. The area can therefore be described as being very hilly. The logical conclusion would be that when there are very hilly areas, a small grid size should be used to obtain the best result. In the forest areas a small grid size should be used to avoid interpolation errors between the grid points.

It is clear that scanning the images with a higher resolution does not mean that the result will be better, therefore there is no reason to create more work for little or no better end results.

Only for the landscape type ‘flat area’ can Match-T’s suggested accuracy of 0.1 $^{0}/_{00}$ of the flying height be attained.

6.2 Scale 1:25.000

The same analysis’s can be done with the images in the scale of 1:25.000.

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

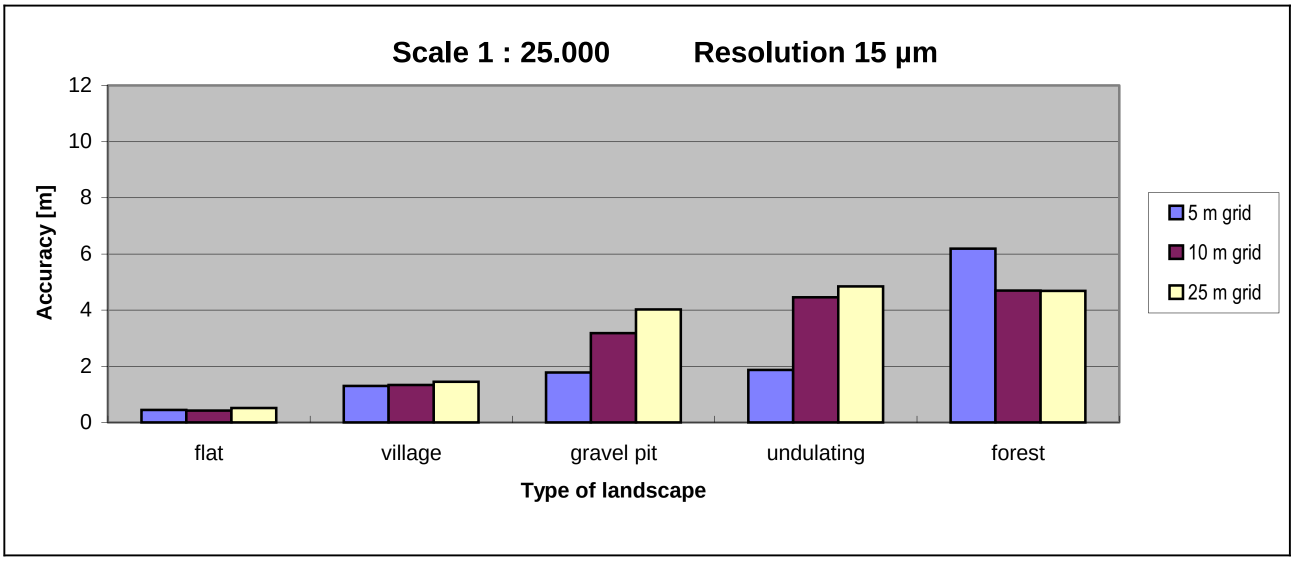

Figure 4: The influence of the grid sizes upon the image scale 1:25.000 with a resolution of 15 µm.

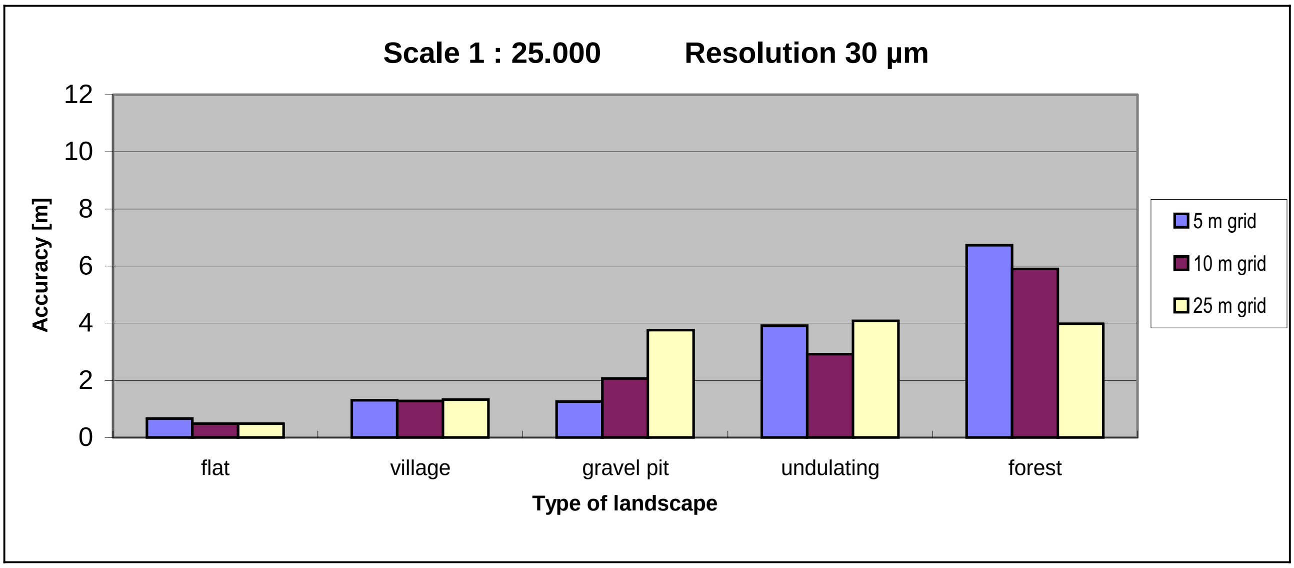

Figure 5: The influence of the grid sizes upon the image scale 1:25.000 with a resolution of 30 µm.

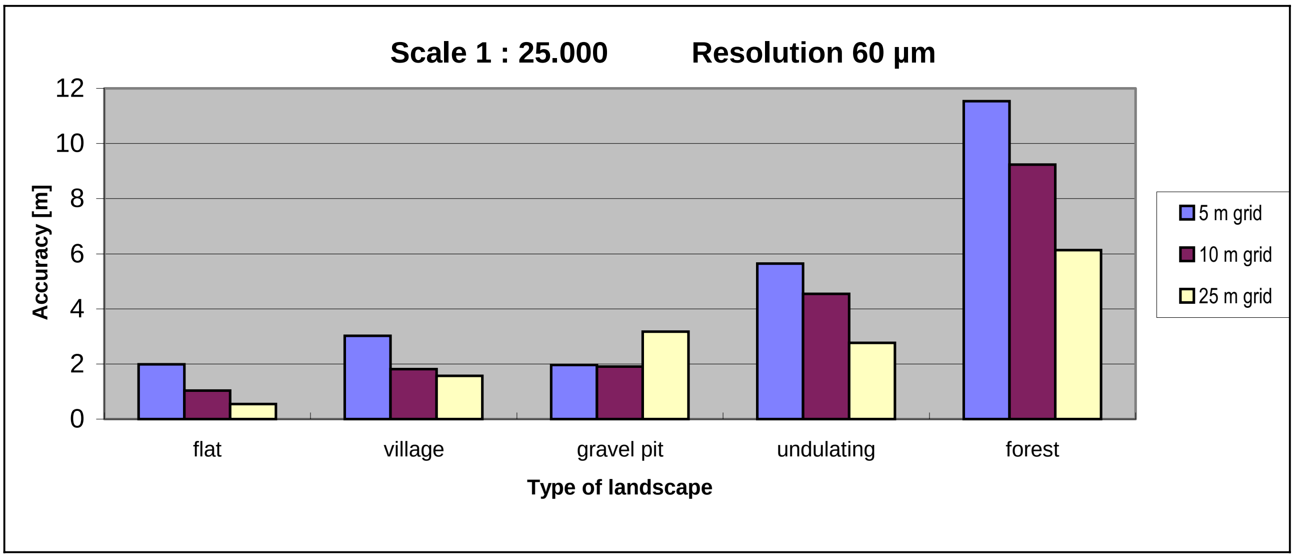

Figure 6: The influence of the grid sizes upon the image scale 1:25.000 with a resolution of 60 µm.

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

Also here it is evident that Match-T can best handle the landscape types of ‘flat area’ and ‘villages’ and only for these landscape types the accuracy of 0.1 $^{0}/_{00}$ of the flying height can be attained.

It can be seen from figures 4 and 5 that small grid sizes usually lead to the best results being obtained from all types of undulating terrain. In figure 6 it can be seen that small grid sizes should not be used for images with a small scale such as 1:25.000 and coarse resolutions such as 60 µm.

7 CONCLUSION

For an image scale of 1:15.000 the resolution has very little influence. With the image scale of 1:25.000 it can be seen that changing the resolution reduces the accuracy. Therefore the image scale with a resolution of 60 µm should not be used, a higher resolution is recommended. Furthermore the analysis shows that knowledge of the landscape where the automatic generation has to be done is necessary. This knowledge is required in order to be able to select the correct grid size for the different landscape types. This would allow the optimum accuracy to be achieved.

If a minimum of data coupled with a maximum of accuracy for the images in a scale of 1:15.000 is an objective, then these should be scanned with a resolution of 60 µm. The grid size 5 x 5 m should be used for the undulating terrain and a 25 x 25 m grid size for the remainder. The new accuracy achieved by using this information regarding the correct grid size for the different landscape types would be 1.54 m. This is an improvement of approximately 0.5 m compared to the results in table 1. This improvement is obtained prior to the final editing.

The same consideration should be given for images in the scale of 1:25.000 with a resolution of 30 µm and 5 x 5 m for the undulated areas and 25 x 25 m for the remainder. This would produce a total accuracy of 2.53 m, which also is an improvement of approximately 0.5 m without any form of editing.

This study shows that if the method of automatically generating heights is used to determine a new digital elevation model for Denmark and the desire is that the accuracy should be better than the already existing one, areas such as gravel pits and forests have to be edited out. If areas with hills are edited out also the amount of land remaining is so small that the automatic generation method is of no further use. The improvement in the accuracy by using the optimum grid sizes only has the effect that an elevation model generated automatically obtains the same accuracy as the already existing one.

When contemplating any aerial photography over Denmark consideration should be given to the knowledge gained regarding the relationships between image scale and resolutions. To cover the whole of Denmark with an image scale of 1:15.000 approximately 14000 images will be required (information from Kampsax-GeoPlan, Copenhagen). An image with a resolution of 60 µm uses up 15 Mbyte, the total amount of data generated for covering the whole of Denmark in this scale would amount to; - 14000 images x 15 Mbyte = 210 Gbyte.

If the image scale were to be changed to 1:25.000, then approximately 5000 images would be required for covering the whole of Denmark (again this information was obtained from Kampsax-GeoPlan, Copenhagen). An image with a 30 µm resolution uses ~ 60 Mbyte therefore 5000 x 60 Mbyte = 300 Gbyte would be necessary to cover Denmark.

The difference in the amount of data between image scales of 1:25.000 and 1:15.000 is that the amount increases by a factor of 4 from 15 Mbyte to 60 Mbyte while the number of images does not increase by a factor of 4. To consider whether the flying has to be done in a scale of 1:15.000 or 1:25.000 an estimate of manpower and data capacity must be taken into account. Of course the data processing will take a longer time when using the image scale of 1:15.000 than using images of 1:25.000.

8 DISCUSSION

If an accuracy higher than 1.5 m is required without having any prior knowledge of the landscape other information will have to be considered. In Denmark digital colour orthophoto could be included to locate those areas which contributed towards the errors. This could be i.e., by classifying the orthophotos to find regions such as forests. These areas can then be located and found in the images where the automatic generation is done and it should at this stage be possible to edit out this region. Areas such as very undulated land cannot be found by a classification method, so only some of the problems are solved. To be able to find areas such as gravel pits and undulated terrain it is still necessary to study the area either in stereo or to go on a field trip.

9 REFERENCES

Ackermann, F., Hahn, M., (1991): Image Pyramids for Digital Photogrammetry, Digital Photogrammetric Systems, Wichmann, Edner/Fritsch/Heipe.

Ackermann, F, Schneider, W., (1992): Experience with automatic DEM generation, Commission IV, ISPRS, Washington, D.C., pp. 986-989.

Balstrøm. T., Jacobi, O., Sørensen. E. M., (1994): GIS i Danmark, Teknisk Forlag, ISBN 87-571-177-6, pp. 113-122.

Frederiksen, P., (1987): A digital elevation model for radio communication, ISPRS, International Society for Photogrammtry and Remote Sensing, Working group lll/3 – Digital Terrain Models, Proceedings of the international colloquium. Progress in Terrain Modelling, Technical University of Denmark, pp. 127-132.

Hahn, M., Förstner, W., (1988): The Applicability of a Feature Based Matching and a Least Squares Matching Algorithm for DTM Acquisition. International Archives of Photogrammetry and Remote Sensing, Kyoto, Vol. 27, Part B9, pp. III 137-150.

Krzystek, P., Wild, D., (1992): Experimental accuracy analysis of automatically measured digital terrain models. Robust Computer Vision: Quality of vision Algorithms. Förstner, Ruwiedel (ed.). Wichman Verlag. Karlsruhe, pp. 372 - 390.

Krzystek, P., Ackermann, F. (1995): New investigations into the practical performance of automatic DEM genertion.

Larsen, J. N. (1996): Brugerkrav til en dansk højdemodel, Institut for Planlægning, Faggruppe Landmåling, Danmarks Tekniske Universitet.

Seufert, E., (1995): Erste Erfahrungen bei der automatischen Generierung von digitalen Höhenmodellen in Siedlangsgebieten, Photogrammetric Week '95, Fritsch/Hobbie, Wichmann Verlag, pp. 269 - 276.

Zeiss, Info, photogrammetric Department, (1992): TopoSURF, Auromatic Measurement of Digital Elevation Models.