Accuracy of Automatically Collected Height Data over Denmark

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Abstract

Over the whole of Denmark several digital height models already exists. None of these height models fulfil the accuracy requirements, which are demanded by present day standards. The National Survey and Cadastre has therefore started an investigation into methods of how to obtain new height data. In this paper, the principle of interferometric SAR, Laserscanning, and their accuracy will be presented. A closer investigation will be done into the possibilities of digital photogrammetry. Here will be investigated the influence of the flying height and the size of the pixels. Lastly an evaluation of the three methods with respect to their accuracy.

1 Introduction

The new possibilities within computer technology have caused a growing demand for digital elevation models. They have traditionally been used for orthophoto production but now also for e.g. heights for landscape draping, calculating models for water currents, contractors business and in particular telecommunication companies.

One of these existing digital height models is managed and sold to the public by the National Survey and Cadastre. The height information which is the basis for this height model is ~100 years old. These 100 years old measurements have then been converted several times and at last digitised. It is known by the National Survey and Cadastre that this old height model does not have the accuracy which is demanded for height data at present. The National Survey and Cadastre has therefore started, in autumn 2000 the first step of a two step process towards obtaining a better height model. The first step of the process is to improve the existing height model with the existing data. This temporary first step has resulted in raising the accuracy up to 0.9 metre. The wish is to have an accuracy better than 0.5 metre, therefore it is necessary to consider other methods in step 2 of the process.

The next step is therefore to investigate other methods for providing a new and hopefully better height model over the whole of Denmark.

In this investigation the possibility of using interferometric SAR, laserscanning and automatically generated heights from digital photogrammetry will be presented. Traditionally, photogrammetry is used and therefore, the main part of this paper will concentrate on the possibilities of using digital photogrammetry to obtain the automatic generation of heights from digital images. The accuracy of all three methods mentioned are based on Danish terrain.

2.1 Interferometric SAR from satellites

The accuracy achieved by interferometric SAR from satellites is over 10 metres [Shiping, 2000; Morley et al., 2000]. This method can therefore not be used for this purpose because the desire is for an accuracy better than 0,5 metre.

2.2 Interferometric SAR from an aeroplane

When using interferometric SAR, a signal is sent from two radars on the aeroplane. These signals spread out towards the earth's surface (houses, trees etc.). This signal is reflected and returns to the antenna. In interferometric SAR the observations contain knowledge of the amplitude and the phase. By this method the differences of the phases between antenna R1 and R2 is determined, see figure 1. Knowing the aeroplanes height (determined by GPS and INS) and the phase differences between the two received signals the height of the object is obtained.

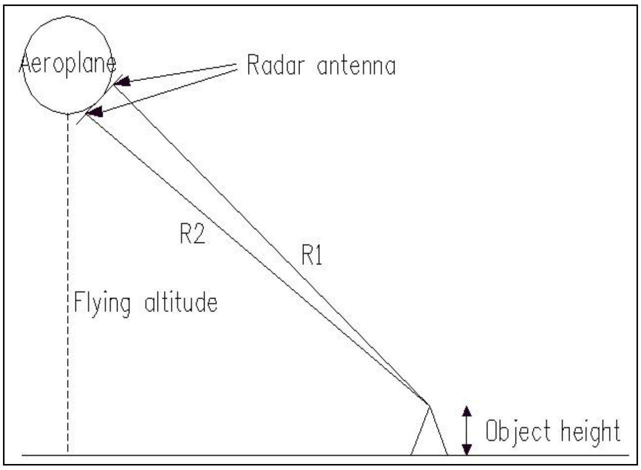

Figure1: The principle of interferometric SAR from an aeroplane.

2.3 Accuracy

According to [Skriver mv. 1999; Madsen mv.1999] the height can be determined with 1 metre accuracy.

2.4 The advantages and disadvantages of interferometric SAR

The advantages of this method is that it can quickly and therefore cheaply aquire height data. Every flight path (the width of the mapping area) is 12 km, but can be increased to between 24 – 48 km. When the width of the flight path is increased, the point density will get smaller [Skriver et al, 1999]! This method can cover a larger area in a shorter time. Furthermore, it is not wholly dependant on weather conditions or the time of year as e.g. the method for digital photogrammetry. But, to avoid reflection from e.g. treetops it could be an advantage to fly in autumn or winter time. Interferometric SAR is also independent of light, therefore it is also possible to fly during night time. The disadvantage is that the accuracy is not good enough to attain the goal of 0.5 metre. Furthermore this method has a ´shadow´ problem, which occurs on steep slopes like mountains, houses etc. this problem is illustrated in figure 2.

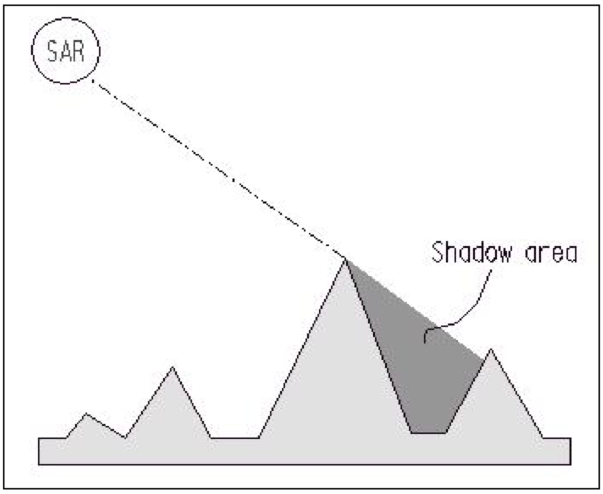

Figure **Fehler! Unbekanntes Schalterargument.**: The shadow problem when using interferometric SAR from aeroplanes

3 Laserscanning

When using laserscanning, the distance between the earth and aeroplane or helicopter is determined by measuring the time, which the laser signal takes to travel the distance from the antenna to the earth and back again. The distance between the aeroplane and the terrain is half the difference in time between the sent and the received signal which moves with the speed of the light.

To be able to transfer the measured distances to a terrain height the receiving position of the aeroplane or helicopter has to be known. This is done by GPS and INS.

The width of the area which is covered by laserscanning (the width of the flight path), is dependant on the laser beams angle and the flying height. Economically, it is more advantageous to have wider paths. This is immediately not advantageous because, it means that the angle of the scanning has to be increased. The increase in the angle equates to problems with the accuracy. The attack angle for the measured points gets lower the further out from the centreline the measurement is made. It has therefore to be valued between price and precision. In general the systems scan up to a width of 0.7 times the flying height. Some systems can scan up to a width of 1.12 times the flying height [Flatman mv. 2000]. Furthermore this method has also great problems with shadow areas, see figure 2.

3.1 Accuracy

The biggest contribution of errors in laserscanning comes from the determination of the position of the aeroplane. Especially in hilly terrain this can mean large errors. The accuracy of terrain heights obtained by laserscanning are from 0.1 m to 0.6 m with typical values between 0.15 – 0.20m [Flatman mv. 2000; Petzold 1999]. Deviations on plane co-ordinates are in the interval between 0.1m – 3m with typical values between 0.3m – 1m.

3.2 The advantages and disadvantages of laserscanning

Laserscanning has many advantages, because it does not rely on daylight conditions, this method can be used at night time. Furthermore it is suitable for measuring in wet areas, over ice and snow, through tracks etc. [Wever, 1999]. But, during weather conditions such as low clouds, fog and rain, the laserscanning can not take place [Wever, 1999].

4 Digital photogrammetry

Different systems to deal with the fully automatic generation of heights have for many years been available. Experience shows that different systems give different results. In this investigation, the programme package Match-T, developed by Inpho, Stuttgart is used. The Match-T system operates with pairs of digital or scanned aerial images. With newer versions of the programme more images can by indicated (a whole block), but the calculation will still be done between the image pairs. First, the image normalises, thereafter every image feature is extracted by using the Förstner interest operator. The DEM -generation is carried out stepwise by going through the pyramidal data structure. The matching is geometrically restricted by a parallax bound and the epipolar line [Krzysted et al.]

Information from Inpho, is that the accuracy will be 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 be sometimes worse. For a scale in 1:10000 it should be possible to reach an accuracy of about 0.15 metre. An investigation in Potsdam with images in

1:10,000 shows, that 78 % of the results are better than 2 metre, 11 % are lying between 2-3 metre and the remaining 11 % are worse than 3 metre [Seyfert, 1995].

In this paper, a closer look will be taken at the accuracy which can be obtained over Danish terrain. Only two primary factors will be investigated;-flying height and resolution – not method, software etc.

4.1 Data material

A test area representing a typical Danish landscape has been chosen. In order to compare image scale and accuracy in this test area, aerial photos have been taken with a wide-angle camera in three different flying heights, which gives images in scales of;- 1:5,000, 1:15,000 and 1:25,000. These three flying heights have been chosen to see if there is a linear connection between the image scale and the accuracy. To be able to take a closer look into accuracy compared with the resolution, the images have been scanned in;- 15 μm, 30 μm, and 60 μm on a PS1-scanner from Zeiss/Intergraph. To be able to value the automatically generated heights, reference points are determined ~10,000 points in a 25m x 25m grid on an analytical plotter by an experienced operator. In the images 1:5,000, the reference points have an accuracy of ~ 4-5 cm.

4.2 Investigation

Firstly, an investigation is done without any editing being done at all. The height generation is done automatically in the same grid 25m x 25m as the reference points. The accuracy is determined for the images in scale;- 1:5000, 1:15000 and 1:25000 with respect to the three resolutions. The results are compared with the expected **$^0/_{00}$** of the flying height, see table 1.

	1:5,000 (Φ(1))	**1:15,000 (Φ(1))**	**1:25,000 (Φ(1))**
0.1 $^0/_{00}$ of the flying height (The expected accuracy)	0.075 m	2.225 m	0.375 m
15 μm	3.51 m	2.75 m	2.68 m
30 μm	3.18 m	2.51 m	2.68 m
60 μm	3.10 m	2.26 m	2.05 m

Table 1: Accuracy with respect to the resolution, image scale and expected accuracy.

As can be seen, the accuracy is a lot worse than the expected 0.1 $^0/_{00}$ of the flying height. The reason for this could be gross errors. Two things have to be in focus, the result which is shown in table 1 is influenced by gross errors and there is a possibility of an offset, because the heights are generated over the terrain. The gross errors have to be deleted and the result shifted with the offset so that the normal distribution will happen around 0. This is done by an iterative process. It is commonly known when a calculation is normal distributed, only 3 $^0/_{00}$ of the results are lying outside 3*Φ. Therefore all Φ(1) from the first calculation$_1$, see table 1, is taken and multiplied with 3. This value is used as a deleting level. All points which have a deviation higher than 3*Φ(1) are deleted. A new accuracy Φ(2) and offset(2) is determined and these values will be used for the next calculation$_3$ the results which are lying outside 3*Φ will be deleted. First, the accuracy from the first in the iteration where the deleting level is now put to

3*Φ(2) and so forth until the whole iteration stabilises. This iteration is done for all the images in 1:5000, 1:15,000 and 1:25,000 with respect to the images resolution 15µm, 30µm and 60µm. The result is shown in table 2, where the achieved accuracy is shown with respect to the scale and resolution of the images, the flying height and $^{0}/_{00}$ of the flying height and the offset.

Scale_resolution	Flying height [m]	Achieved accuracy [m]	Accuracy as $^{0}/_{00}$ of the flying height	Offset [m]
1:5,000_15µm	750	0.19	0.25	0.01
1:5,000_30µm		0.21	0.28	-0.03
1:5,000_60µm		0.28	0.37	0.09
1:15,000_15µm	2250	0.32	0.14	0.75
1:15,000_30µm		0.47	0.21	0.76
1:15,000_60µm		0.59	0.26	0.81
1:25,000_15µm	3750	0.50	0.13	1.64
1:25,000_30µm		0.62	0.17	1.63
1:25,000_60µm		0.86	0.23	1.05

Table 2: Accuracy achieved by the different image scale and image resolution with respect to the flying height

It can be seen in table 2 that the accuracy for images in 1:5000 lies between 0.19 – 0.28 metre. For images in 1:15,000 the accuracy is between 0.32 –0.59 metre and images in 1:25,000 the accuracy is between 0.50 –0.86 metre. The accuracy is still not down to 0.1 $^{0}/_{00}$ of the flying height as mentioned by [Krzystek et al. 1992; Ackermann et al. 1992]. The accuracy is higher when the image scale is higher, but if the accuracy is taken into consideration as $^{0}/_{00}$ of the flying height, it seems that the lower the image scale, the better accuracy.

4.3 Accuracy, image scale and resolution

Based on the accuracy previously determined it will be interesting to see if the image scale is linearly proportionate with the accuracy. The optimum will be if the accuracy is proportionate with the image scale. This means, that the accuracy is getting better when using images with a higher scale.

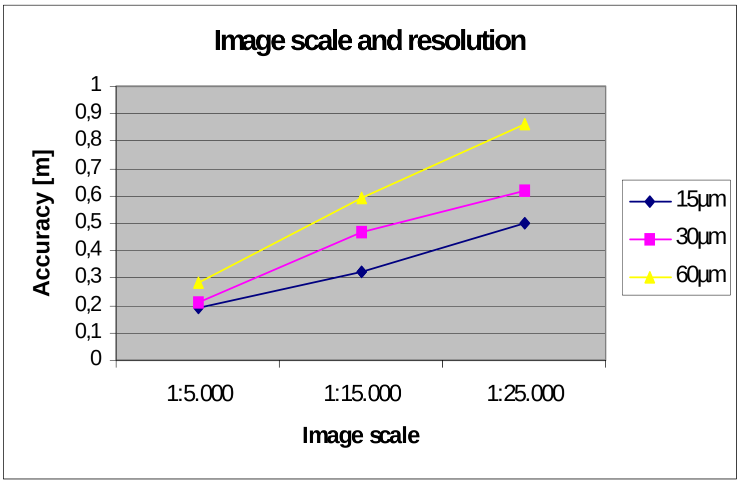

Figure 3: The influence on the accuracy by image scale and resolution.

In figure 3 the accuracy is nearly linearly proportional with respect to the image scale irrespective of the resolution. Furthermore it can be seen that there is a connection between the image scale and accuracy, where, the accuracy gets lower, when the image scale is lower. However, it should be noted that the accuracy does not get worse with the same factor as the image getting smaller, e.g. from 1:5,000 to 1:15,000 there is a factor of 3, where the accuracy gets worse with a factor ~2 and from 1:5000 to 1:25,000 there is a factor of 5 but the accuracy gets worse with a factor ~3.

4.4 Accuracy

With the automatic generation method, accuracy better than 1 metre can be achieved no matter the scale or resolution. For the goal of 0.5m, this can be achieved for all images in 1:5000 no matter the resolution. For images in 1:15,000, resolution 15µm and 30µm also gives accuracy's better than 0.5 metre. The results for images in 1:25,000 are not good enough.

It will now be interesting to see how many points in percents had to be deleted to achieve the result which can be seen in table 2.

In figure 4 the iteration process for images in 1:5,000 had to be repeated more than 10 times before the iteration stabilised. Furthermore it can be seen from figure 4, to achieve the accuracy's for images in 1:5000 of 0.19m – 0.28m it was necessary to delete ~29 % for images with the resolution of 60µm, and up to ~32.5 % for images with the resolution of 15µm, which is a considerable amount of points being deleted..

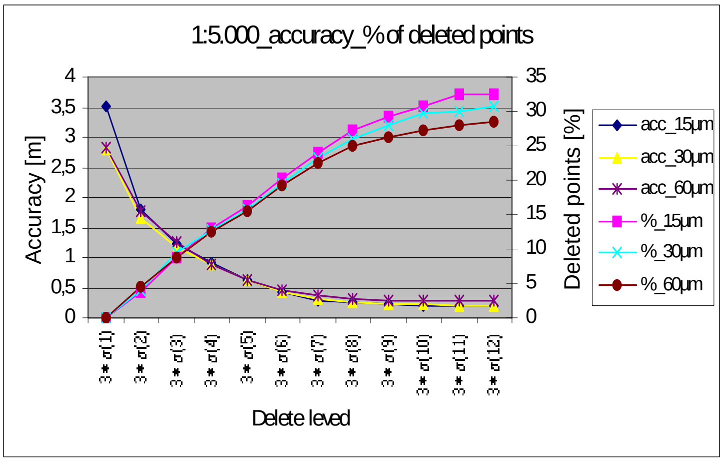

Figure 4: Accuracy for images in scale 1:5.000 obtain by deleting gross errors shown in percents.

In figure 5 the iteration process for images in 1:15,000 had to be done approximately 10 times before the iteration stabilised. Furthermore, more points had to be deleted for the images with the resolution of 15µm (over 25 %) before that iteration stabilised compared with the two other resolutions. For images with the resolution of 30µm and 60µm ~ 20 % of the points had to be deleted.The achieved

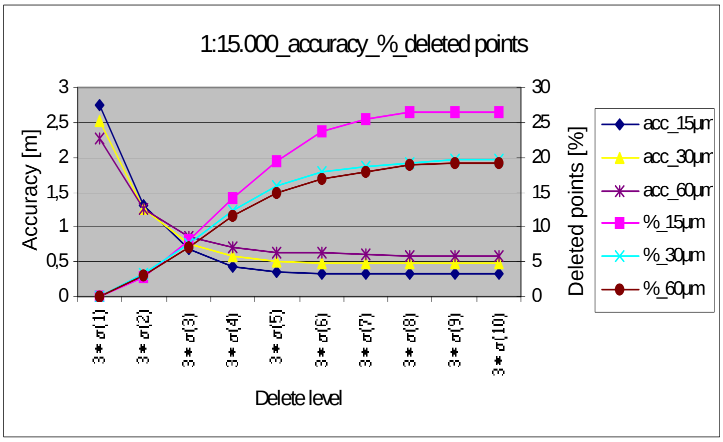

Figure 5: Accuracy for images in scale 1:15,000 obtain by deleting gross errors shown in percents.

accuracy lied between 0.32m – 0..59m.

For the images in 1:25,000 there has been a large difference in the percentage of points, which had to be deleted before the iteration stabilised, see figure 6. For the image with the resolution 15µm over 40% had to be deleted before the process had stabilised and the accuracy of 0.5m was achieved. Only ~12 % had to be deleted for the image with the resolution of 60µm. For image with the resolution of 30µm ~30% had to be deleted.

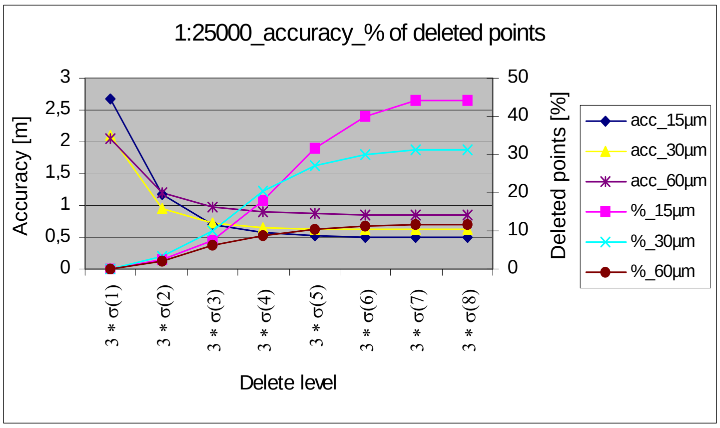

Figure 6: Accuracy for images in scale 1:25.000 obtained by deleting gross errors shown in percents.

4.5 The advantages and disadvantages of digital photogrammetry

With the digital photogrammetry method, accuracy better than 0.5m can be achieved for images in 1:5,000 and 1:15,000. Disadvantages are that there are many gross errors and these have to be detected before the higher accuracy can be achieved. Without reference points it is not easy to find the gross errors.

5 The advantages and disadvantages of the three methods

The best accuracy is achieved by laserscanning. The second best accuracy is achieved by automatically generated heights by digital photogrammetry. The lowest accuracy is achieved when using interferomic SAR. The disadvantage of laserscanning is the small area, which is covered, which means lots of flying time and data. When taking these reasons into account, the interferometric SAR is the best solution, but the interferometric SAR gives the lowest accuracy. The method by generating heights automatically from digital images lies between laserscanning and interferometric SAR with respect to accuracy and the amount of data. Furthermore the greatest advantage of digital photogrammetry is that, at the same time have automatically generated heights from images for e.g. mapping. It is not necessary to fly twice.

6 Conclusion

The investigations into using interferometric SAR from an aeroplane over Danish landscape produces an accuracy of ~1m, which is not good enough if, the goal is height data better than 0.5m. This method on the other hand gives a lot of height data quickly and therefore cheaply. The laserscanning method gives an accuracy of ~0,2 cm, which fulfils the requirements of the goal set by The National Survey and Cadastre, but the measurement is very long winded because there has to be many hours of flying which generates an extremely large amount of data to process. The photogrammetric method obtains an accuracy better than 0,5m which can be achieved for images in the scale 1:5000 and 1:15,000. It is not realistic to cover the whole of Denmark with images in scale 1:5000. It will also mean an extreme amount of data and it is not realistic to process. To cover the whole Denmark it will be more realistic to use images in the scale of 1:15,000. The accuracy achieved by automatically generated heights from digital images is 0.19m –0.86m and can only be achieved when one can find and delete the gross errors. If this is not the case, the accuracy's mentioned in table 1 (2.05m – 3.51m) have to be taken into account. This means that only the laserscanning method fulfils the goal of 0.5metre!

References

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

Flatman, A. C. and Rasmussen, J. K. (2000): Laserscanning - En kvalitetsvurdering, Afgangsprojekt 2000, L10L-1, Landinspektøruddannelsen, Aalborg Universitet.

Krzystek, P. and 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.

Madsen, S. N., Dall, J. and Skriver, H., (1999): SAR-Genererede højdemodeller og tematisk kortinformation, GIS i Danmark 2, Teknisk Forlag, ISBN 87-571-2272-5, pp. 27 - 38.

Morley, J. G., Walker, A. H., Muller J-P. A. L., Kitmitto, K., Mitchell, K. L., Chugani, K., Smith, A., Barnes, J., Cross, P. A. and Dowman, I. J. (2000): Landmap: Creating a DEM of the British isles by SAR interferometry, International Archives of Photogrammetry and Remote Sensing. Vol. XXXIII, Part B4. Amsterdam 2000, pp. 686 – 693.

Petzold, B. (1999): DTM Determination by Laserscanning, An Efficient Alternative, European organization for experimental Photogrammetric Research, Proceedings of the OEEPE-WORKSHOP on Automation in Digital Photogrammetric production, OEEPE, pp. 215- 223.

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

Skriver, H., Dall, J. and Madsen, N. S. (1999): Kortlægning med billeddannende radar, Landinspektøren Nr.2-99, Tidsskrift for kortlægning og arealforvaltning, 39. Bind, 108. Årgang, pp. 336 – 341.

Shiping, S. (2000): DEM generation using ERS-½ interferometric SAR data, International Archives of photogrammetry and Remote Sensing, Vol. XXXIII, Part B4. Amsterdam 2000, pp. 963 - 970.

Wever, C. (1999): Laserscannermessungen- ein Verfahren setzt sich durch, GIS – Geo-informationssysteme, Zeitschrift für raumbezogene Informationen und Entscheidungen, Journal for Spatial Information and Decision Making, ISSN 0935-1523, pp.12 –17.