IMPROVING A DEM BY INTEGRATING DATA

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Commission II, Working Group 3

KEY WORDS: Digital Elevation Models, Data integration, Consistency

ABSTRACT

During the late 1980's a national Digital Elevation Model was established in Denmark. The elevation model was generated from digitised contour lines (5 metre interval) and have an accuracy of about 1.5 to 2 metres. Since the DEM was established the use of elevation models has spread out to a large number of applications which demand a higher accuracy. This paper describes the production of the second generation DEM based on contour lines (2,5 metre interval) supplemented with 3D objects from the national digital vector map.
The input contours are brought from raster format to tree dimensional vectors in a partly automised process where the mounting of elevations to the contours are assisted by the existing DEM.
The objects from the digital vector map are prepared for the DEM by an extraction of objects from the map database followed by an automatic correction of hydrographic objects.
The contour lines and the objects from the vector map are from two independent products. Before they are integrated in the new DEM the consistency of the two data sets is tested. This test is also used to estimate the achieved accuracy of the resulting DEM.
Using this procedure it is possible to generate a DEM with an accuracy of about 1 to 1.5 metres. The model is suitable for visualisation of the landscape in 3D. By including objects from the vector map in the basis data of the DEM it is assured that height information in the DEM corresponds to height information in the vector map. For instance it is possible to generate contours from the DEM that fits the hydrographic theme of the vector map.
In the last part of the paper further improvements to the DEM are investigated. An example of getting towards a 3D topographic model of the landscape is shown.

INTRODUCTION

This paper describes how a new DEM covering Denmark is established by integration of existing data. The work flow of the production is described and the resulting model is presented. An example of further improvements to the DEM is given.

BACKGROUND

The elevations of Denmark varies from -5 to 173 m asl. and the slopes are gentle and do not exaggerate 15% in the central parts of the country.

In 1985 the first DEM for Denmark was presented originally ordered by a national broadcasting organisation to assist in pointing out the best locations for a set of transmitters to serve a new national mobile phone system. This DEM had a spatial resolution of 50 metres produced from an interpolation of 5 metre contours digitized either by hand or vectorized from scanned map sheets in scale 1:50.000. A few years later a new interpolation procedure was used on the same data set by the National Danish Survey and Cadastre to form a DEM called D50 to be sold as the first national DEM (Frederiksen P. 1986).

Since 1993 a new vector based digital map called TOP10DK (described later) has been produced in Denmark. The intention from the beginning of the production was that this new vector map was to be delivered with the existing DEM from the 1980's. The reaction from the first customers was that the DEM and the vector map were in conflict at several locations. Examples of lakes from the map lying uphill (according to the DEM) were seen. Examples of streams from the map crossing small ridges in the DEM were also seen.

Recently the National Danish Survey and Cadastre decided to provide a second generation DEM for Denmark produced from digitized 2.5 m contours gathered from vectorisations of scanned map sheets of scale 1:25.000 and a set of additional topographical elements from TOP10DK.

THE AIMS OF THE NEW DEM

Fit TOP10DK

Since TOP10DK is to be delivered with a DEM these two products must fit together well. The height information in the DEM must not conflict with the height information from the objects in TOP10DK.

If for instance a hydrologist compute streams from the information in the DEM the computed streams must be at or very near by the measured streams i TOP10DK.

Suitable for visualisation

Today several of the common GIS products can visualise the terrain in 3D in some kind of perspective viewing. The development of the existing products will continue and new visualisation tools will arrive. The new DEM must therefore give a good and reliable visual impression of the landscape.

Water shed modelling

For some purposes environmental researchers need to model the water flow and the transportation of sediments in the landscape. It would therefore be convenient if the new DEM could form the basis of these computations.

Improve accuracy compared to the existing DEM

A general improvement of the accuracy of the national DEM is wanted both by the National Survey and Cadastre and the users. An accuracy of one metre on the z-coordinates in the national DEM is the long term goal. With this accuracy the DEM will fit the accuracy of the vector map TOP10DK.

DATA SETS INCLUDED IN THE DEM

During 1997 different data sets were tested to find the best present basis of a new elevation model. The result is that contour lines from maps at scale 1:25.000 are the most accurate of the existing data. The accuracy has been tested in 4 different parts of the country. The tests show that the height accuracy is in the interval 1 - 1.5 metres (Root Mean Square, RMS) with a few outliers of up to 2.3 metres.

To improve the level of detail in the model and to improve the accuracy of the resulting DEM, selected objects from the national digital map are added to the model as breaklines.

Contourlines from map 1:25.000

Lineage: The contourlines for the Danish topographic maps were registrated in the beginning of this century. They were collected by field work, and their advantage is that they are measured at terrain surface in all types of terrain. Also in dense forests. The unit used was feet. The original lines have been converted to contour lines with 2,5 metre interval. This convertion was done graphically by hand.

The contour lines have only been updated partly since the establishing. They are updated if major changes to the landscape take place for instance if a gravel pit is restored after end of production.

TOP10DK

Product describtion: TOP10DK means TOPographic map scale 1:10.000 covering DenmarK.

The production of TOP10DK was initiated in 1993 and the whole country will be covered by the end of June 2002. The map will be updated in a 5 year cycle.

TOP10DK consists of 21 object types (building, forrest, build-up area ect.). It is a vector based map established by photogrammetric measurement in arial photos scale 1:25.000. All objects in the map are registrated with tree coordinates. For well defined points the accuracy are demanded to be better than:
x-coordinate 0.75 metre (RMSE)
y-coordinate 0.75 metre (RMSE)
z-coordinate 1.00 metre (RMSE)
The accuracy of the registrated objects are measured in spot tests based on remeasurement of houses and roads in aerial photos scale 1:5.000.

The topology of the map is well described and the registrated data is passed trough a check for their topological structure. All roads form a 3D topological network, so does all hydrographic objects (reference: the KMS-homepage or TOP10DK specification).

Relevance for DEM: TOP10DK objects measured at the terrain surface can be used as input to the DEM. (Larsen, J. N. 1996)

Roads are separated in the following four classes "Non-transit roads" covering most roads in city areas and gravel roads in the rural areas, "roads 3 to 6 metre wide", "roads more than 6 metre wide" and "highways".

"Non-transit roads" and "Roads 3 - 6 metre wide" are constructed at (or very close to) the terrain surface and can give a reliable terrain break line.

Hydrography: The objects "lake", "ditch", "stream" and "coast line" can also contribute to the level of detail and the accuracy of the DEM.

The acheived results so far

The acheived results from combining contour lines and break lines from topgraphic maps have been tested i four areas by comparing generated DEM's with a DEM measured from aerial photos. The results from two significant areas are listed in table 1 and 2.

In table 1 are the results from a test area around the city of Ribe. This area is located close to the North Sea and is characterised by gentle slopes. In this area the accuracy of the DEM could be improved by about 25% compared to the existing model.

Test area	DEM-data	RMSE of DEM
Ribe	Contours 5 metre interval	1,5 metre
Ribe	Contours 5 metre interval Roads	1,4 metre
Ribe	Contours 5 metre interval Roads Hydrography	1,2 metre
Ribe	Contours 2,5 metre interval	1,1 metre

Table 1. Presentation of achieved results from investigations of DEMs based on 5 m contours, 2.5 m contours and additional data compared to a DEM created from aerial photographs. (Larsen, J. N. 1996)

In table 2 are the results from a test area around the city of Holbæk. In this area the landscape is more hilly. It is seen that in this area roads and hydrographic object do not improve the overall accuracy. But contour lines with interval 2,5 metre improves the accuracy of the DEM with about 25%.

Test area	DEM-data	RMSE of DEM
Holbæk	Contours 5 metre interval	2,0 metre
Holbæk	Contours 5 metre interval Roads	1,9 metre
Holbæk	Contours 5 metre interval Roads Hydrography	1,9 metre
Holbæk	Contours 2,5 metre interval	1,5 metre

Table 2. Presentation of achieved results from investigations of DEMs based on 5 m contours, 2.5 m contours and additional data compared to a DEM created from aerial photographs. (Larsen, J. N. 1996)

WORK FLOW OF THE PRODUCTION

In the following paragraphs a breef desciption of the work flow is given. The headlines are.

The contourlines are brought from digital raster format to vector contours with the elevation of the contours as the z-coordinate of each x-, y-coordinate on the contour.

The preparation of TOP10DK is a selection of relevant object from the map followed by an automatic correction of the hydrographic objects.

The consistency of the two data sets is tested by comparison of their height information.

Finally the two data sets are integrated in a TIN-model.

PREPROCESSING OF DATA

Establishing 3D contour lines

The analog contours are prepared by the following steps.

Scanning of sheets with contourlines as the sole theme. This has already been done in order to fit a digital production line for topographic raster maps.

Vectorisation of the scanned contourlines. The vector output is separated in tree line types:
dotted lines (elevation 2,5 m; 7,5 m; 12,5 m ect.),
thin full lines (elevation 5 m, 10 m, 15 m ect.) and
wide full lines (elevation 25 m, 50 m, 75 m ect.).
This is done semi automatic.

Automatic mounting of elevations to contour lines. Where about 85 - 90 % of the contour lines are given the correct elevation. The mounted elevation for each contour line is based on the existing DEM and objects from TOP10DK.

Manual control of the mounted elevations. The 3D contour lines are imported in a CAD-system with the original raster map as background. The height information on the raster map is used to verify the mounted elevation of the contour lines. Contour lines needed to be verified are marked in the automatic mounting of elevation. About 20 to 25% of the contours are marked.

The production of the first parts of the country shows that contours from 1 mapsheet covering 160 km^2 can be checked manually in 5 hours (in average).

Preparing TOP10DK

The relevant objects from TOP10DK are roads up to 6 metre width, lakes, ditches, streams and coast line.

The roads can be used as break lines in the DEM without any treatment. The preparing of the roads is therefore simply a selection of the objects "Non-transit roads" and "Roads 3 to 6 metre wide".

The hydrographic objects form a topological network in three dimensions but they are not measured hydrologically correct. As an example the z-coordinate of a lake can vary 2 - 3 metres from one side of the lake to the other. A lake is measured either at the water surface or at the banks and this can result in the differences of the z-coordinate. A similar situation can be found regarding ditches and streams. Sometimes the levels are measured at the banks and sometimes they are measured along the water surface.

To establish a more hydrologically correct water network ditches, streams, lakes and coast line are preprocessed. Lakes and coast line are made horizontal. Ditches and streams are corrected to give them an unambiguous slope. When this is done the objects are reconnected so that they once again form a 3D topological network. In this water network the relative accuracies are very high since the slopes of each object in the network are verified.

VERIFYING CONSISTENCY OF THE DATA SETS

Consistency

The data sets involved in producing the DEM are from two different productions. The contour lines from the maps at scale 1:25.000 are up to 100 years old and have only been updated partly since then. The objects from the digital map TOP10DK are measured photogrammetrically. TOP10DK data is up to 6 years old by now but will be updated in a 5 year cycle. Thus, the two data sets are totally independent. The demand to the accuracy of the objects in TOP10DK is that the accuracy of the z-coordinate must be better than 1 metre (absolute accuracy).

The accuracy of the contour lines has not (until now) been tested systematically. To get an estimate of the accuracy of the contour lines the objects from TOP10DK are used as control points. This means that before the objects from TOP10DK are included in the DEM they are used to verify that the two data sets fit together well.

If the mixed data sets fit together well the consistency of the data sets are approved. The height information from the contourlines is testet with the height information from the TOP10DK-objects as reference, and the consistency of the data sets is described by normal statistics (mean deviation, RMSE, standard deviation ect.).

Estimation of accuracy of DEM

The direct outcome of the consistency test does not indicate anything about the absolute accuracy of the contour lines. Thus given the knowledge of the absolute accuray of the objects in TOP10DK it is possible to estimate the absolute accuracy of the contourlines from this equation (Shearer, J. W. 1990)

$$RMSE(x - y)^2 = RMSE(x)^2 + RMSE(y)^2 \qquad \text{Eq.1}$$

The value on the left of the equation is the outcome of the consistency test. The right side of the equation is a summation of the variation of the height of the TOP10DK-objects (known) and the variation of the height of the contourlines.

In this way it is possible to describe both the consistency of the data sets and to estimate the accuracy of the old contourlines.

Until now the tests have shown that the contour lines have a general accuracy in the interval 1 - 1.5 metres (RMSE). However, a few outliers with accuracies up to 2.3 metres (RMSE) have been found in the most hilly parts of the country.

The objects from TOP10DK affect the resulting DEM locally around the objects. However the basis of the model is the contour lines. The statistics calculated in the consistency test are therefore used to describe the accuracy of the resulting model. The resulting model will be more accurate than indicated by the statistics since additional data is added to the final DEM. But better safe than sorry.

INTEGRATION OF THE DATA SETS

Create TIN model

When the accuracy of the contour lines has been verified the different data sets are integrated. The contour lines are used as the basis of the resulting model, and roads, ditches, streams, lakes and the coastline from TOP10DK are included as breaklines in the model.

DERIVED DATA

Grid model

A group of users participated in a pilot project were the possibilities of establishing a new DEM were investigated. They all worked with grid models and it was therefore decided that the standard DEM to be sold is a grid model. The grid model is generated from the TIN model with 25 metre spacing.

Contour lines

Both for analog maps and for use in a GIS, contourlines are a very comprehensive way of describing the landscape. A set of new contours with 2,5 metre interval are therefore generated.

Contours generated from the TIN model were tested, and it was found that their cartographic presentation were poor. A TIN model is very honest - mismatches between input contours and input breaklines were seen as sharp angles in the generated contours. A subsequent generalisation of the contour lines led to intersecting contours and was not succesfull.

Instead contours are generated from the grid model. The grid is a generalised describtion of the landscape and it is easier to get a satisfactory result this way. From the basic TIN model a 25 metre grid model is generated. This grid model is smoothed with an 3X3 average filter with these parameter values:

$$\begin{vmatrix} 1 & 1 & 1 \\ 1 & 4 & 1 \\ 1 & 1 & 1 \end{vmatrix}$$

From this resulting smooth grid, contourlines with a satisfactory cartographic presentation can be generated.

FORTHCOMMING IMPROVEMENTS

Perspective viewing

There are interesting possibilities in perspective viewing of maps. Raster maps draped on a DEM give a very good impression of the landscape. This can be enhanced if you start working with 3 dimensional symbols on the map. Topographic objects with a vertical extent can be illustrated in the map/DEM. Buildings, forests, windmills and others are landmarks that ease the orientation in the map/DEM.

3D topographic model

If objects in the topographic map are measured with a reliable height, it is possible to establish a 3D topographic model of both the landscape and the objects on top of the landscape.

TOP10DK has been tested as input to this kind of 3D model.

The buildings in TOP10DK are measured at the roof gutter. This means that the height of the building according to mean sea level is known. From the DEM the height of the terrain surface according to mean sea level is known. From these two heights it is possible to construct the walls of the buildings in TOP10DK. Since the buildings are measured at the roof gutter the buildings in the 3D topographic model have flat roof.

The forests are measured with a z-coordinate either at ground level or at the top of the trees. Due to this fact it is not possible to calculate the heights of the forests. In stead all forests are given a height of 10 metres. Thus the forests are illustrated as 3D symbols.

In figure 1 and 2 examples of this 3D topographical model are shown.

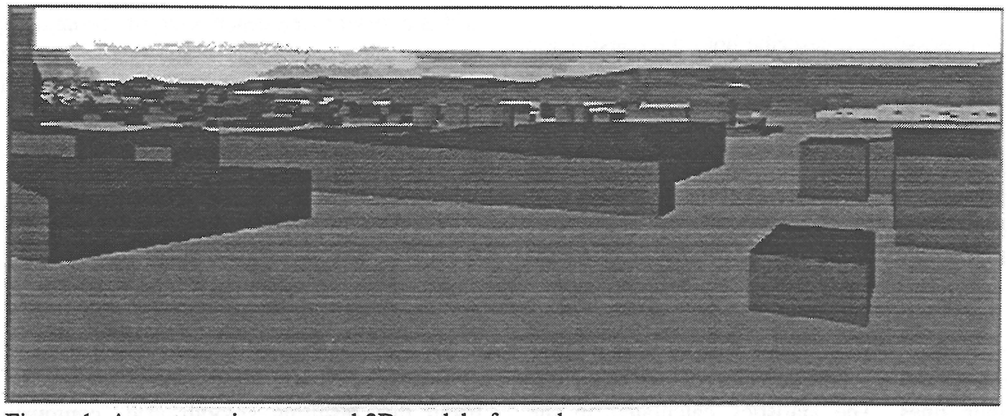

Figure 1: An automatic generated 3D model of an urban area

Figure 2: An automatic generated 3D model of a rural area

The model does not give a photo realistic or cartographic presentation of the landscape. But for some technical investigations this model can be applicable. The model can also be used for presentation of the landscape - especially if you do not zoom in to close.

DOES THE NEW DEM FULFILL THE AIMS?

In the beginning of the paper, four demands to the new DEM were listed. Here are the conclusions reached so far in the evaluation of the DEM.

The general accuracy of the DEM is monitored by the test of consistency between input contour lines and break lines from TOP10DK. It is found that the accuracy of the new DEM is improved by 25 to 50 % compared to the old one. It is a step in the right direction. But still improvements have to be made.

The visual impression of the model is good. It has been used by environmental researchers in draping of ortophotos and perspective presentations of the landscape. They have found the model useful for this purpose.

Water shed modelling puts up strong demands for the accuracy of a DEM. To model the right slopes and aspects of a very flat landscape like the Danish is a difficult task. The only test of the DEM as basis for water shed modelling shows that further improvements of the model are needed in order to satisfy the demands from environmental researchers. Still they are better off with the new DEM than the old one.

Since objects from TOP10DK are included in the basis of the DEM, conflicts between height information in the DEM and height information in TOP10DK are avoided.

THE GENERAL OUTCOME

As long as map data and basis elevation data are produced from independent productions there will be mismatches or even conflicts when the data sets are combined. If the described work flow is regarded as an example - a case - it is possible to extract some general ideas.

In this case basis elevation data are contour lines. To improve the resulting DEM, basis data could be produced from SAR, digital photogrammetry or another method that appears to be convenient.

Test of consistency

If the basis elevation data is changed it will still be necessary to verify and describe the consistency of the two data sets. In the described case the accuracy of the height information in the map data could be regarded as superior to the height information of the basis elevation data. But even if basis elevation data and map data have a comparable accuracy of their height information there will be mismatches. These mismatches must be described before an integration can take place.

Creating consistency

The integration of data in the resulting DEM is also necessary if mismatches between the data sets are to be removed. What the users recognise when they are working with maps and DEM's in combination are the mismatches of the two data sets. If the two data sets are integrated the mismatches are removed by definition. The task of assuring the reliability of the product belongs to the producers/data owners.

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