ASPECTS OF RASTER DEM DATA DERIVED FROM LASER MEASUREMENTS

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ABSTRACT:

The „normal“ product of a TopoSys DEM is a raster based DSM / DTM. A TopoSys DSM / DTM is not a standard product. It is processed for the application of the customer. Because of the high data rate of the TopoSys laserscanner the process of the selection of the measured points to set the elevation values to the defined raster cell is very different. This is not visible to the customer. The possibility to select between first and last pulse data and the kind of sorting into raster cells gives the ability to preselect between hidden or shown objects on the earth / the delivered objects in the DSM. This paper should visualize views of the DSM production and should give a better understanding about raster based laser DEM's.

1. INTRODUCTION

TopoSys laser data consists of measurements of the first echo (FE), last echo (LE) and the intensity of an echo (EI). In a raster based DSM the data of FE and LE are merged together to get a good impression of the natural world on the one hand and of the application of the customer on the other side. The intensity measurements needs an own processing sequence and is stored into a second channel fitting geometrically to the DSM data. During different steps the merging of the data implies a filtering and a validation process. In many cases the result is a 1m raster grid tiled into 2x2km². The experience shows that a raster cell of 1m x 1m gives a good representation of the earth. The amount of data of a 2x2km² tile is easy to handle by the cus−tomer. But the raster model is not a real 3D − model, because there is only one representation value for a raster cell. During the processing a selection of points have to take place. A raster model is only a 2.5D − model and is determined and calculated for the application of a customer to get good results for his task afterwards.

2. SENSOR

First of all lets take a view to the sensor system and the special properties.

The TopoSys FALCON sensor consists of the sensor rack (laser / rgbi scanner, IMU), the computer rack (data storage, pre−processing) , operators console (c+c) and the gps − antenna and the cabling. The sensor is designed to an easy handling and fit−ting into the most common survey aeroplanes and helicopters. The minimizing of shadowing effects over cities and forests should gain a high penetration rate and a realistic processing of a DSM and DTM in such areas.

2.1 Parameters of the sensor

Table 1. shows the significant parameters of the TopoSys FALCON laser system:

field of view:	**~ 14.3°**
across track resolution	**1.96 mrad**
pixel per scan:	**128**
frequence:	**~83 kHz**
scan / sec:	**~650**
peak power :	**10 kw**
puls duration:	**5nsec**
range resolution:	**~0.02 m**
beam divergence:	**1mrad**
wavelength:	**1,56 µm**
max range:	**1600 m**

Table 1: Parameters of TopoSys Falcon

The parameters are tested and optimized during the years 1995 and 2000 with a prototype system. The improvements to the prototype system was the increasing peak power, therefore the enlargement of the range to 1600m and therefore a larger foot−print, and a better range resolution.

2.2 Scanpattern

Due to the high data rate of the laser and the fix optical system the amount of measurements in flight direction is more dense than the cross flight direction. Assume that an aeroplane has a velocity of ~70m/s, you will have every 0.11m a new scan measurement. The distance between the fibres depends on the flight altitude. Between an altitude of 800 − 1000m above the ground, the most common flight altitude, there is a distance of 1.5 up to 2m between the measurements of two fibres on the ground. The radius of the spot of one measurement depends directly on the beam divergence, which results in a diameter of ~1m on the ground at a distance of 1000m. The centres of up to 9 following measurements lie within such a spot. A comparison of the measurements before and after a scan is a first good vali−dation of the measurement of a scan.

Fig.1 gives an impression of the scanpattern on the ground.

A disadvantage of the scan pattern is recognized. If there are any objects between the spots of two fibres, these objects are not detecteded by the laser measurements. Objects touching the footprint of a fibre are well detected with the FE and / or LE measurement.

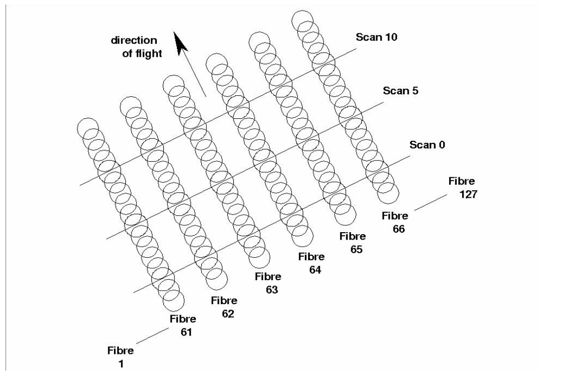

Fig 1: Scanpattern

2.3 FE / LE / INTENSITY

The registration of a sequence of pulses of one beam allows to determine the structure of the surface. The ’first echo’ (FE) registration allows to survey the top of objects, while ’last echo’ (LE) registration is used to survey the (forest) ground (fig 2).

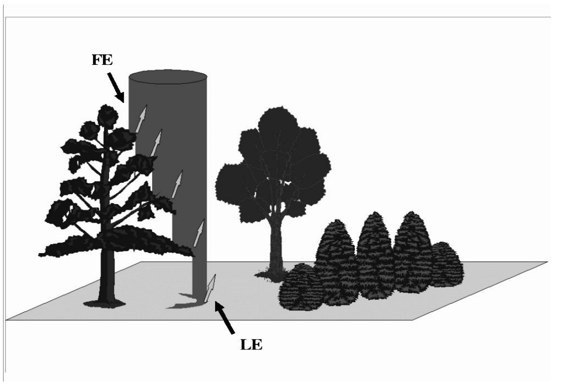

Fig 2: Principle of FE / LE

The echos between the first echo and the last echo are not stored after the whole measurement of one beam. But keep in mind that two successive echos must have a significant larger distance than the pulse duration of 5nsec or > 1.5m to detect the echo. Only in this case a separation of two successive echos is possible. This results that objects (ex.: bushes) lower than the pulse duration cannot be separated from the ground with one FE − LE measurement!

Additional to the last echo the intensity of the echo is measured. A common effect of the intensity is the variation of the intensity value of one measured object. This directly depends on the different viewing angles of the laser beam which hits the object and the structure of the surface of the object.

2.4 Accuracy

The accuracy of a laser measurement consists of three main error sources:

- GPS − positioning (< 0.05m PDOP 2.5)
- INS − roll, pitch, true heading angle measurement (0.17−0.35mrad)
- Laser −distance measurement (0.02m)

The resulting accuracy of a point in all three axis is expected to less than 0.15m at a flight altitude of 800m. The main parts of the errors consists of the GPS for the z − value and of the INS for the x,y accuracy. This accuracy is related to the centre of a spot.

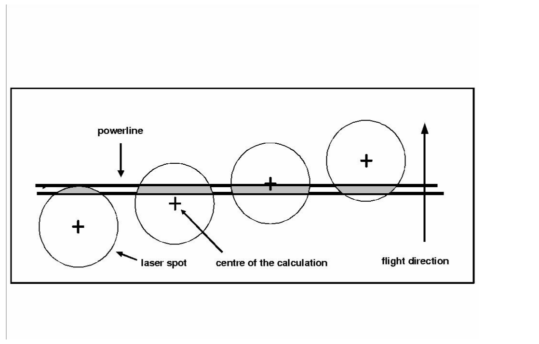

Fig 3: divergence and positioning

Fig. 3 shows a special effect at single objects with sizes less the diameter of a spot. They will not have the positioning accuracy mentioned above. All echos of the powerline are calculated center based (fig 3, crosses within the spot). The position of the powerline moves through the laser spot in the direction of the flight. This example shows again the difference and limits between the selected measurement of a single point measurement and the principle of laserscanning, the automatic measurement of areas of the surfaces. The point wise selection of the laser measurements is done afterwards during the processing.

3. PROCESSING

The calculation of the point clouds of the flight strips results in a big amount of data. A first impression of the needed storage capacity of the TopoSys FALCON system is shown in table 2:

data of a 1km strip:

=> ~9000 scans*127 fibres*2 (FE+LE) => ***~2.3 e6 points***

area of a standard tile 2*2km²:

=> ~14 strips * 4.6e6 points => ~ 64e6 points ~ ***750MB*** **(12byte/point (N, E, Z))**

Table 2: Overview ’point cloud’

To handle the stored data, all strips are pre−sorted for a quicker access to the points afterwards. A tile based processing supports the data handling. Tiles are build up within a high resolution raster to keep a high x,y−accuracy.

3.1 Principle

The high resolution raster supports the TopoSys way of a point based, validated processing of a DEM. TopoSys trusts the accuracy of the single measurements of the laser scanner. Because of the high density of the measurements an interpolation and comparison between the closest measurements is sufficient for validation. The principle is to validate and hold the true validated measurements as long as possible. An interpolation takes place only within the same determined high class, if more than one point exists. This point is assigned to the raster cell of the destination raster. Due to the high density of the measured points, there is the possibility to select a validated elevation out of many measured surrounding points to determine a raster cell value.

The advantage of the high resolution raster compared to a point cloud is the easier processing witin a regular raster and the pos−sibility of a quicker filtering with standard algorithms after−wards.

3.2 High resolution raster model

At TopoSys the processing of a high resolution raster (cell size 0.25 up to 2m) is possible with different modes. These modes depends on the application of the customer and sets preferences to the selection of the points from the point cloud. Within the new geocoded regular grid one elevation is assigned to each grid cell (not to the grid node). This elevation describes the best fit of the whole raster cell.

Because of the number of measurements per grid cell it is pos−sible to select the points depending of two basic modes / prefer−ences, the assigning to lower or higher values.

With this approach the points of FE and LE are handled sepa−rately. Four basic DEM models are able to process with extreme effects:

1. Assign FE highest values (FE high)
   results in a surface model in which all extreme values are retained (e.g. power lines, fences, thin walls, branches of a leafless tree etc.). Small breaks between buildings disap−pear.
2. Assign FE lowest values (FE low)
   results in a surface model in which narrow objects (e.g. power lines) disappear but breaks between buildings are mostly retained. Buildings become smaller than for the version 1.
3. Assign LE highest values (LE high)
   results in a surface model in which all high and small objects disappear (e.g. branches of a leafless tree). Build−ings have about the same size than for version 1. and small breaks between buildings are not represented. Small ditches are missing but small dams are visible.
4. Assign LE lowest values (LE low)
   results in a terrain model in which only extended objects (buildings, evergreen trees, etc.) are retained. Buildings are smaller than in reality, but small breaks between buildings are represented. Small ditches are represented while small dams will disappear.

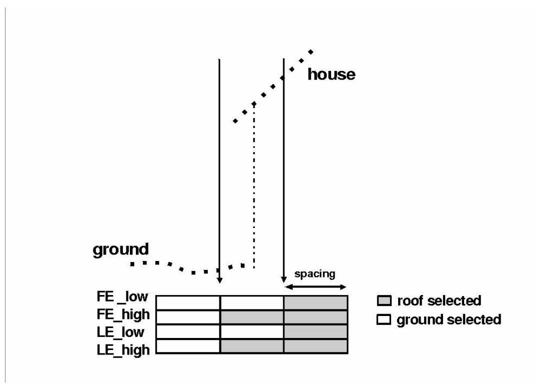

Fig 4: Raster selection

The different effects (above mentioned 1 − 4)) of the size of objects are viewed in fig 4. The result of the sorting into the four rasters are drawn in the graphic below, the shape of the ground and the house. The various selections of the raster cells are shown with grey coloured raster cells. There the edge of a house get smaller or larger in the raster based model depend on the preference of sorting. This effect happens to all objects (egdes) with a significant difference / step in the height.
This effect is shown in the examples section impressionable.

Beside the four basic DEM models two standard modes are cal−culated to process a natural sized view of an area with an auto−matic mode:

1. FE − auto: weigthed setting of the raster cell
   results in a surface model with nearly normal sized build−ings, vegetation is shown in an emphasized size of the form
2. LE − auto: weigthed setting of the raster sell
   results in a surface model with the same dimensions for buildings as in FE −auto, but the surface in vegetation areas is shown clearly, vegetation is strongly reduced.

3.3 EXAMPLES

The following examples (fig. 5 − 10) show a processed DEM of a project in Belgium with the different modes of the processing mentioned above. The shown pictures are shadow relief images calculated with a standard emboss filter to get a better possibil−ity of interpretation.

Data of the flight:
flight area: Belgium, Wallonien area, project zone 4
date: 14.12.2001
area: 400 x 400m
altitude: ~ 900m => strip width: ~ 230m

The pictures on the left side (fig. 5 − 7) show the processing results of the LE data and the pictures on the right side the same parameters set to the FE measurements. Whereas the FE meas−urement data purely consists of real FE data, the LE measure−ment are only present at edges of hard surface objects (roofs) or in forest areas (branches). So the LE − data consists of LE measurements and, when no LE measurement is available (ex.: open meadows), the LE signal is identical to FE.

Within the high − mode processing all objects are emphasised. This results in an enlargement of artificial objects like houses (upper left area in the images fig. 5, 8) and happens to natural objects like lower bushes and trees. In fig. 5 (LE −high) this effect to natural objects is not as strong as in fig. 8, because of the LE measurements at the edges of objects and within forest areas. A better penetration in forest areas is obvious in the lower left and upper right corners of the shadowed DEM. The ground model is much better in the LE model. Open expanse terrain like the meadows are not afflicted.

The opposite effect is shown in fig. 6 (LE − low) and fig. 9 (FE − low). The houses in the upper left part and the bridge in the midd get very small dimensions, the natural vegetation is reduced to rests of bushes in fig. 6 in the lower left part. This model is a pre−step of a DTM. More objects are retained in the fig. 9 of the FE measurement.

These four models (fig.5,6,8,9) are quite different − from over−sized DSM in the upper right (fig. 8) to a raw DTM in the midd left (fig. 6), but the input data are nearly the same. The differ−ence (effect) is only the kind of sorting or weighting during the processing.

A standard DEM is processed at TopoSys with a kind of “nor−mal” automatic mode without a given preference to the top or to the ground. The results are displayed in fig. 7 and 10. The arti−ficial objects get real sizes and the expansion of the natural objects are within limits. The quality of these two models are situated between the low and high sorting models of the FE (fig. 8/9) and LE (fig. 5/6).

But these six models have the pretension of a special use in a dedicated application. The FE high and FE −auto models are

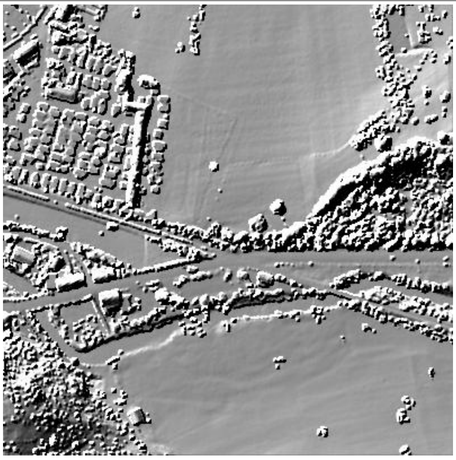

Fig 5: LE − high

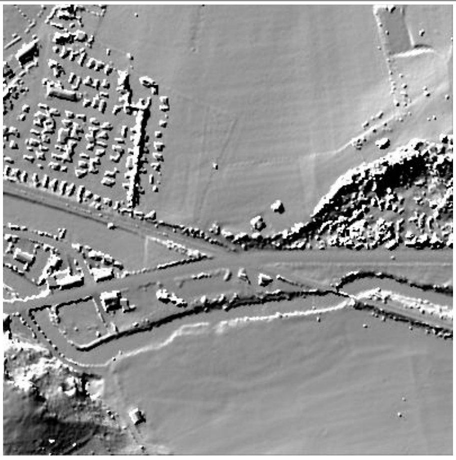

Fig 6: LE − low

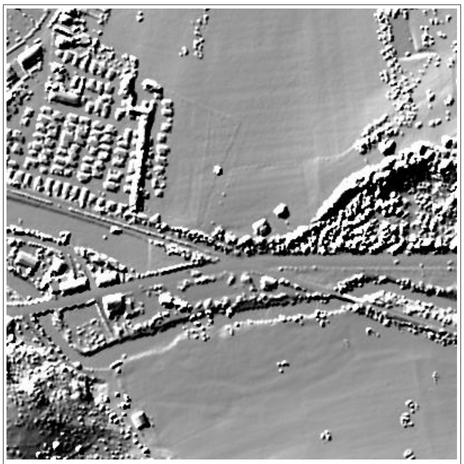

Fig 7: LE − auto

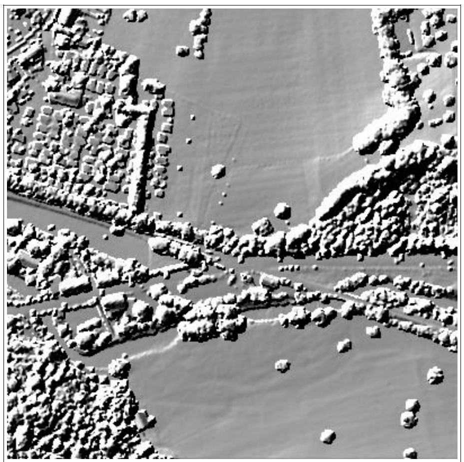

Fig 8: FE − high

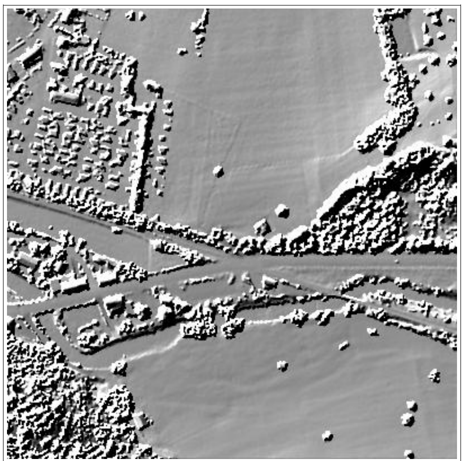

Fig 9: FE − low

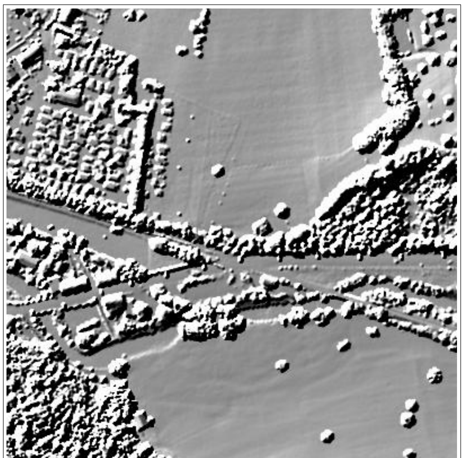

Fig 10: FE − auto

used in 3D visualisation and object reconstruction packages, to get a good emphasised impression of the situation (trees and objects are retained).

The LE − low and the LE − high model is the basis to build up and process the DTM for hydraulic applications depend on the ground water application or the flood water simulation application. A ground water application needs brooks and ditches, but dams are not interesting. The flood modelling needs dams and objects upon the surface, because of the roughness of the surface, but brooks and ditches are not the interesting one. The automatic DSM models are the basis for the processing of the ortho−rgbi images. The natural size of objects are essential to get the correct ortho − rectification of the measured objects. For example: An emphasised big single tree near a street in the DSM would result in a visual displacement of the street infor−mation in the calculated rgbi − image.

Furthermore new results are obtained with a combination of the above images. Take a FE−high and a LE−low outcome and build the difference results in an image, which represents the shapes of the houses (edges) and all trees. Change detection with a cadastral map would show all new buildings for an update.

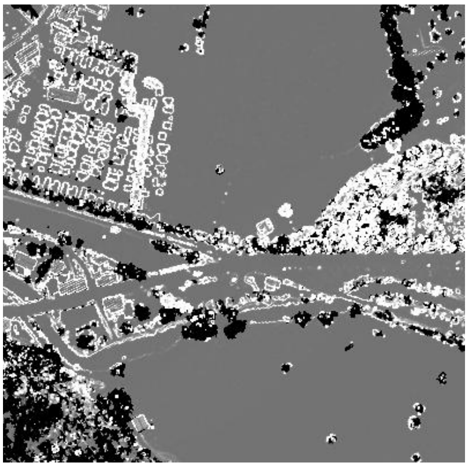

Fig 11: FE−low − LE−high

Fig 11 contains this information too, here the FE−low and the LE−high image was substracted. The black parts represents the better penetration of the LE signal. The shapes of the houses in the upper left part are very clear. The difference image of FE−high and LE−high (fig. 12) contains no buildings. This effect is predicted in fig. 4. Both echos contain the same information in the raster at hard surface egdes.

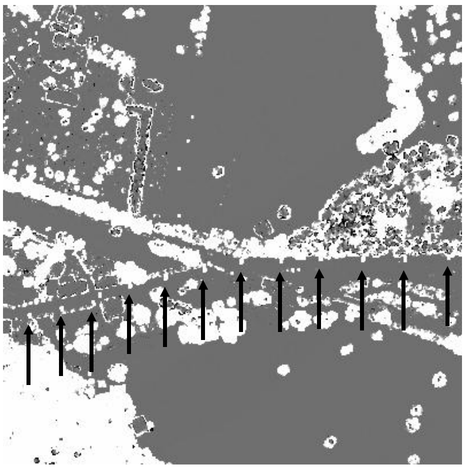

Fig 12: FE−high − LE−high

But this image shows impressively only the whole vegetation. This result should be very useful for forest applications. An other effect is seen along the street, the position of the street lighting. These objects are already visible in the figures 8 and 10.

The processing of other different models in this way is possible. These examples should show the various kinds of application based processing and possibilities to get the special data and the kind of information which is in the data.

On the other hand the question rises: What is the true DEM? The only true DEM is the nature itself. A better approach is the original 3D measured point cloud. If you try to reduce the point cloud into a special system, raster depend of an application, you have to decide what kind of data or points you want. Then the true DEM is no more existent, only a special description.

4. CONCLUSION / DISCUSSION

The basic aspects of laser scanning with the laser sensor from TopoSys (FALCON) and the TopoSys way of the processing of a raster model was presented. Depend on the user defined application the production of the raster based DEM represents only this one special model of the earth surface. Because of the elevation model is a 2.5−D model the calculated information represents not all available laser measurements. The raster model delivered to the end user contains only the information optimised for his special application.

On the other hand the full 3−D information (with all informa−tion) of a point cloud take pains, because of the high amount of data and the availability of special processing software on the side of the customer.

The aspects of the processing of raster DEMs was described, the TIN models (meshes) here was not mentioned. TIN’s are special models with a good reduction of the amount of point data. But for different applications the question is the same as for the raster model, how to select the correct point for the application of a user on the one side and on the other how to make an intelligent point selection / reduction within the point cloud and within the limits of the required accuracy.

The echo intensity is not considered in this paper. This addi−tional information is able to support the selection of measure−ments and point classification. The results of first tests will be presented in future reports.