New Developments in Digital Elevation Modelling

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Problem of automatic DEM generation

The data acquisition of Digital Elevation Models (DEM) by manual photogrammetric measurements has widely been replaced by automatic image matching, LIDAR and Interferometric Synthetic Aperture Radar (INSAR). All these techniques are generating digital surface models (DSM) with points located on top of buildings and dense vegetation and not on the ground, like mainly requested. Especially in urban areas and forests, a high percentage of points is not belonging to the solid ground. The manual editing of the DSM is very time consuming, limits the advantage of the new techniques and is a break within the chain of automation.
Programs have been developed which are analysing and reducing the DSM to a DEM without human interaction. Only artificial objects, which shall not be removed, like dams, have to be specified by a polygon in advance.

By Karsten Jacobsen

Digital Elevation Models are a basic requirement for several applications. A terrestrial measurement is not economic, by this reason since several years photogrammetric methods are in use. The classical determination by direct contouring has been replaced by a determination of a grid of points. A photogrammetric operator can place the floating mark to the requested location – even if the point will be on top of a building, he can set it down to the height of the ground, based on the area around the building – this is not possible by the automatic functions which are widely in use now by economic reasons.

Generation of Digital Surface Model

By automatic image matching, points located on top of the visible surface are generated. In addition mismatches cannot be avoided. The percentage of not correct points is depending upon the used method. The first classification can be made by the manner of getting approximate values, here we do have mainly the image pyramids, partially supported by interest operators, identifying image points with sufficient contrast for matching and the region growing, based on some known corresponding points. The final method goes from the simple cross correlation, partially as vertical line locus, fixing the position of X, Y in the object space, to the image matching by least squares. In addition several modifications are in use. The simple cross correlation based on image pyramids is a fast method, which may be very efficient for several applications, but it can cause a higher number of mismatched points especially in areas of low contrast or repeating structures like a ploughed field. In build up areas all methods do have problems with shadows.
LIDAR can penetrate not too dense forest, but even the last pulse will not in any case be located on the ground. With the exception of some problems with the scene orientation, direct errors of LIDAR measurements can be neglected. INSAR can, depending upon the wavelength, partially penetrate the vegetation. But all methods are generating points located on buildings. There are some programs in use, especially by LIDAR companies, which are not fully automatically and very often there is no information about the used technique available. Another problem is the computation time, because the more often used filtering by prediction (least squares interpolation) is very time consuming. For mass production not highly qualified staff

has to handle the programs for filtering of the DSM, that means, the required settings have to be generated automatically.

Reduction of DSM to DEM

The automatic reduction of a DSM to a DEM is based on the relation of the neighboured height values. Randomly distributed points have to be handled in a different manner like equal distributed points, because the neighbourhood relation of randomly distributed points is more difficult, it takes more time and it is not possible to analyse profiles. For randomly distributed points in addition to a minimal and maximal height value, a combination of tolerated height differences depending of the point distance, a moving plane, a moving polynomial surface and a prediction is used for example in the Hanover program DTMCOR.

Equal distributed height information (raster arrangement) is more often in use, by this reason it will be described more in detail. In the Hanover program RASCOR the following methods are combined: check for minimal and maximal height, height difference of a point in relation to the neighboured points in X- and Y-direction, linear or polynomial regression in X- and Y-direction, height difference against a moving rotated plane or polynomial surface and height difference against the surface of a prediction. The linear or polynomial regression and also the rotated plane or polynomial surface are combined with data snooping – it is necessary to use the redundancy numbers for isolated points. In addition, for the identification of buildings, especially with LIDAR-data, sudden changes of the heights and in the same profile back changes are used. This function has usually no effect for data from automatic image matching, because such data usually do not show the buildings with a sudden height change, usually they are shown like small hills shown in figure 1, upper part, left hand side. The buildings, included in the first example cannot be seen very clear in the 3D-view of the model (figure 1), but they can be identified in the grey value coded height model (figure 2).

The use of a linear regression in the X- and Y-direction and a rotated plane is based on a general classification of the area as smooth. In the case of a classification as undulated or very undulated, polynomial functions are used. The required parameters for the filtering are identified by the program. The model analysis has to be done step by step. At first the height distribution is analysed if the area has not been identified as not homogeneous. A not homogeneous area is shown in figure 4 – the dominating flat area includes also a dump, which shall not be erased. After the elimination of the points located outside the tolerated Z-interval, the height differences of neighboured points are analysed. Based on the histogram a limit for the accepted height difference of neighboured points will be determined by the program and the data set will be reduced, based on this specification. In this way the program continues also for the next criteria. For the linear or polynomial regression and also the moving rotated plane or polynomial surface and the prediction, in addition the number of respected points in the neighbourhood have to be determined automatically.

If contour lines shall be generated, the DEM should be filtered more strong. This can be reached by a second iteration – after finishing the sequence of filtering, the program starts again from the beginning. In the second iteration the tolerance limits determined by the program will be smaller caused by the effect of the first filtering and so the final result will be a more smooth model. This has been done with the first data set, shown in figure 1 and 2 for getting more sufficient contour lines. Figure 3 shows on the left hand side the contour lines based on the original data set from image matching, it includes the buildings and is influenced by the vegetation and small errors of matching. The contour lines the right hand side of figure 3 are generated after filtering with 2 iterations without any manual editing.

Limitation of Automatic Filtering

In the area of the first example, on the left hand side of figure 1, just beside the buildings which are shown as steep hills, two roads on a small dam are visible. These dams are partially erased by the filtering. Such an effect cannot be avoided, because if the parameters are tuned for such dams, other elements, which shall be deleted, are accepted. This will be also the case for the second example based on LIDAR-data, shown in figure 4. This area includes a forest which could not be penetrated in any case by LIDAR and also the dam of a highway and two railroad lines. The point spacing of 10m is not totally sufficient for imaging the small railroad dams. In addition this area includes also a dump of a coal mine. That means it is a very difficult area for the automatic filtering. If the dams are not excluded from the main filtering, especially the lower dam parts are erased. By this reason, polygons around the dams have been used to exclude these objects from the filtering. Within the polygons, only the height difference between neighboured points are checked, to eliminate trees located on the dams or even cars, included in LIDAR-data. This not time consuming technique has been shown as very efficient.

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    19896 INPUT POINTS   (100 %)   SPACING:  10.00  10.00

     1535 POINTS SPECIAL (  7.72 %) BECAUSE OF AREA OF EXCLUSION
DEFAULT VALUES FOR NOT HOMOGENUOUS AREA
ANALYSIS FOR UNDULATED AREA
      FACTOR FOR LOWER POINTS:  3.00

    0 POINTS (   .00 %) NOT USED BECAUSE <   37.25
    0 POINTS (   .00 %) NOT USED BECAUSE >   95.14
  120 POINTS (   .60 %) REMOVED - Z DIFF. NEIGHBORED POINTS IN X >   5.248
  783 POINTS (  3.94 %) REMOVED - Z DIFF. NEIGHBORED POINTS IN Y >   5.248
    0 POINTS (   .00 %) REMOVED -  CHANGE OF Z-LEVEL UP/DOWN   X
    0 POINTS (   .00 %) REMOVED -  CHANGE OF Z-LEVEL UP/DOWN   Y
   32 POINTS (   .16 %) REMOVED - Z DIFF. NEIGHB. PTS. AREA EXCLUSION >  10.000
  735 POINTS (  3.69 %) REMOVED - Z DIFF. AGAINST POLY. FITTING 1:   7  2.029
  392 POINTS (  1.97 %) REMOVED - Z DIFF. AGAINST POLY. FITTING 2:  11  2.536
   65 POINTS (   .33 %) REMOVED - Z DIFF. AGAINST POLY. SURF.   12 >   2.536
  190 POINTS (   .95 %) REMOVED - Z DIFF. AGAINST PREDICTION PLANE >   1.268

    17611 OUTPUT POINTS   ( 88.52 %)  INCLUDING SPECIAL POINTS
     2285 POINTS NOT USED ( 11.48 %)
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table 1: statistics about point elimination corresponding to figure 4

Conclusions

The number of eliminated points is depending upon the area and the type of data acquisition. In the case of automatic image matching in difficult areas, up to 50% are excluded. The automatic data reduction has been shown as very efficient and much less time consuming than manual or partial manual improvement of a DSM to a DEM. In general no problems are existing with buildings, also in more dense build up areas. For the refined DEM the same accuracy like in open areas has been reached.

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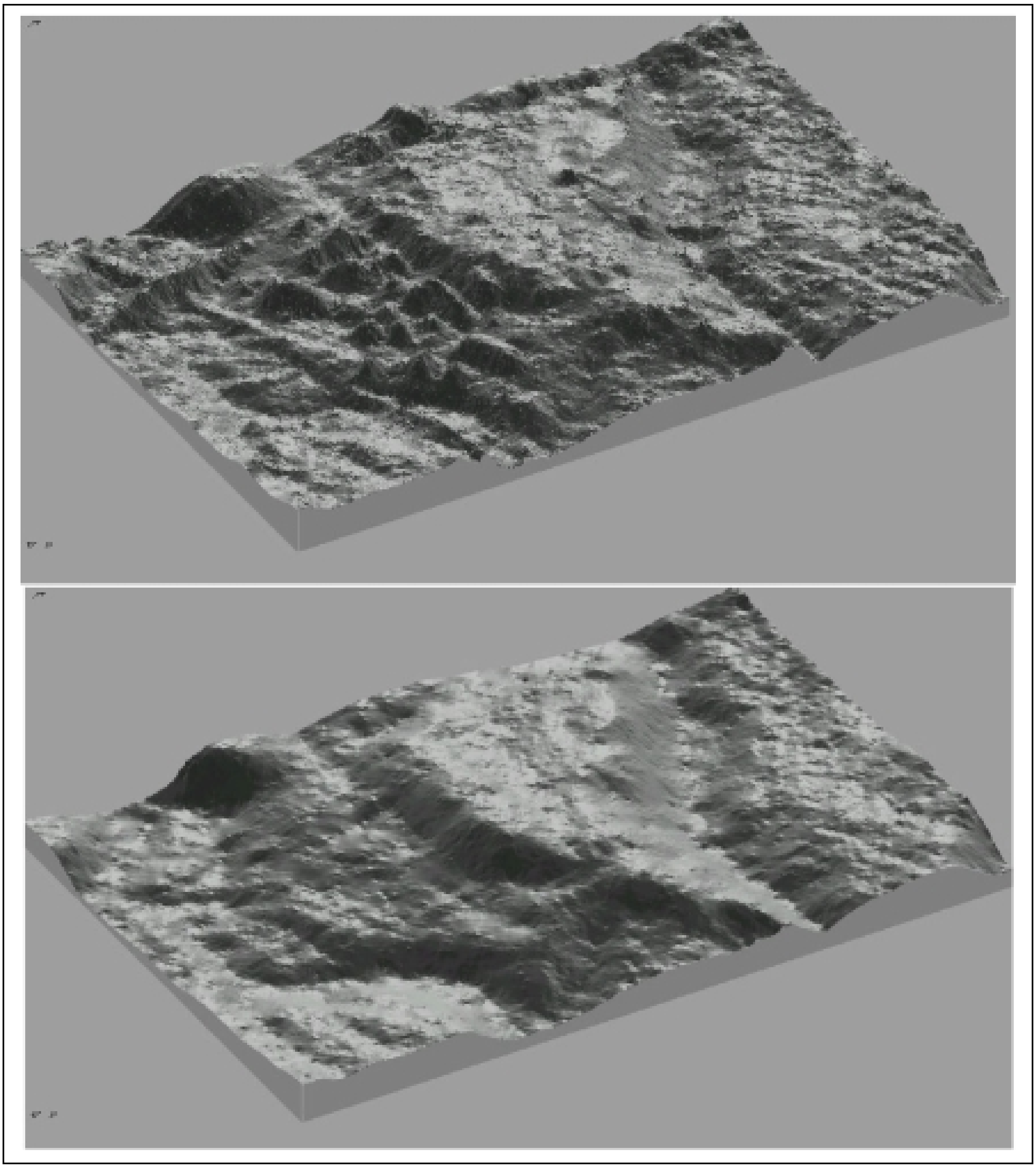

figure 1: data set determined by image matching, above: original DSM, below: reduced DEM

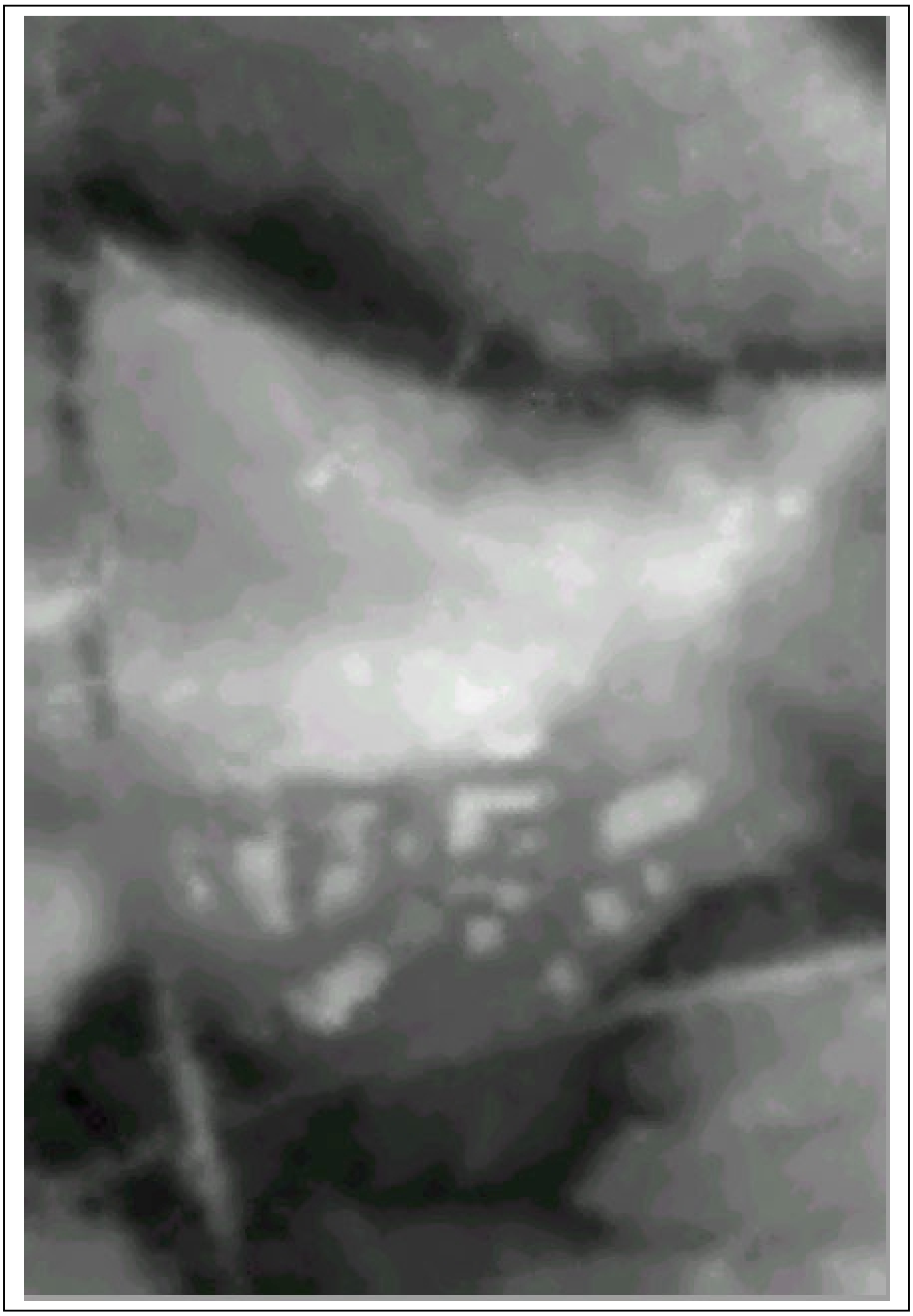

figure 2: grey value coded DSM corresponding to upper part of figure 1

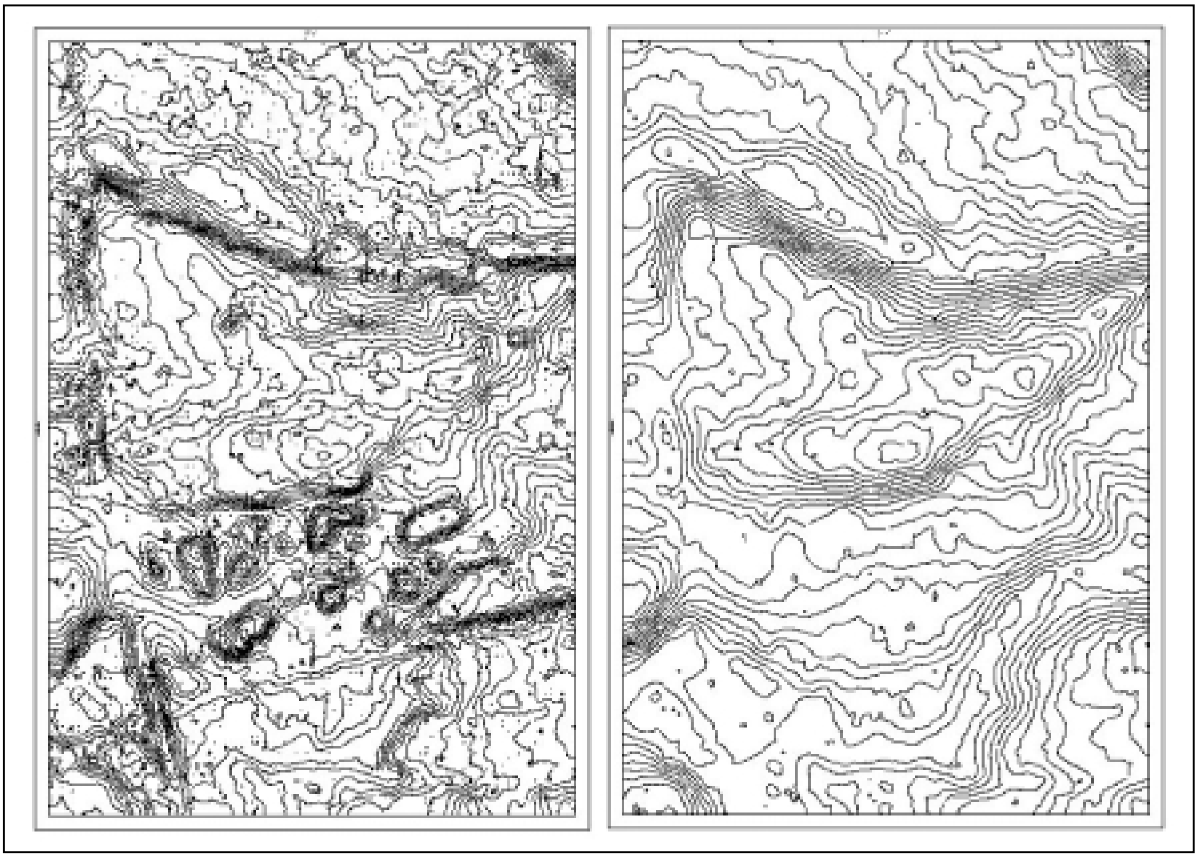

figure 3: contour lines corresponding to figure 1, contour interval: 4 ft
left: original data set from image matching, right: after filtering

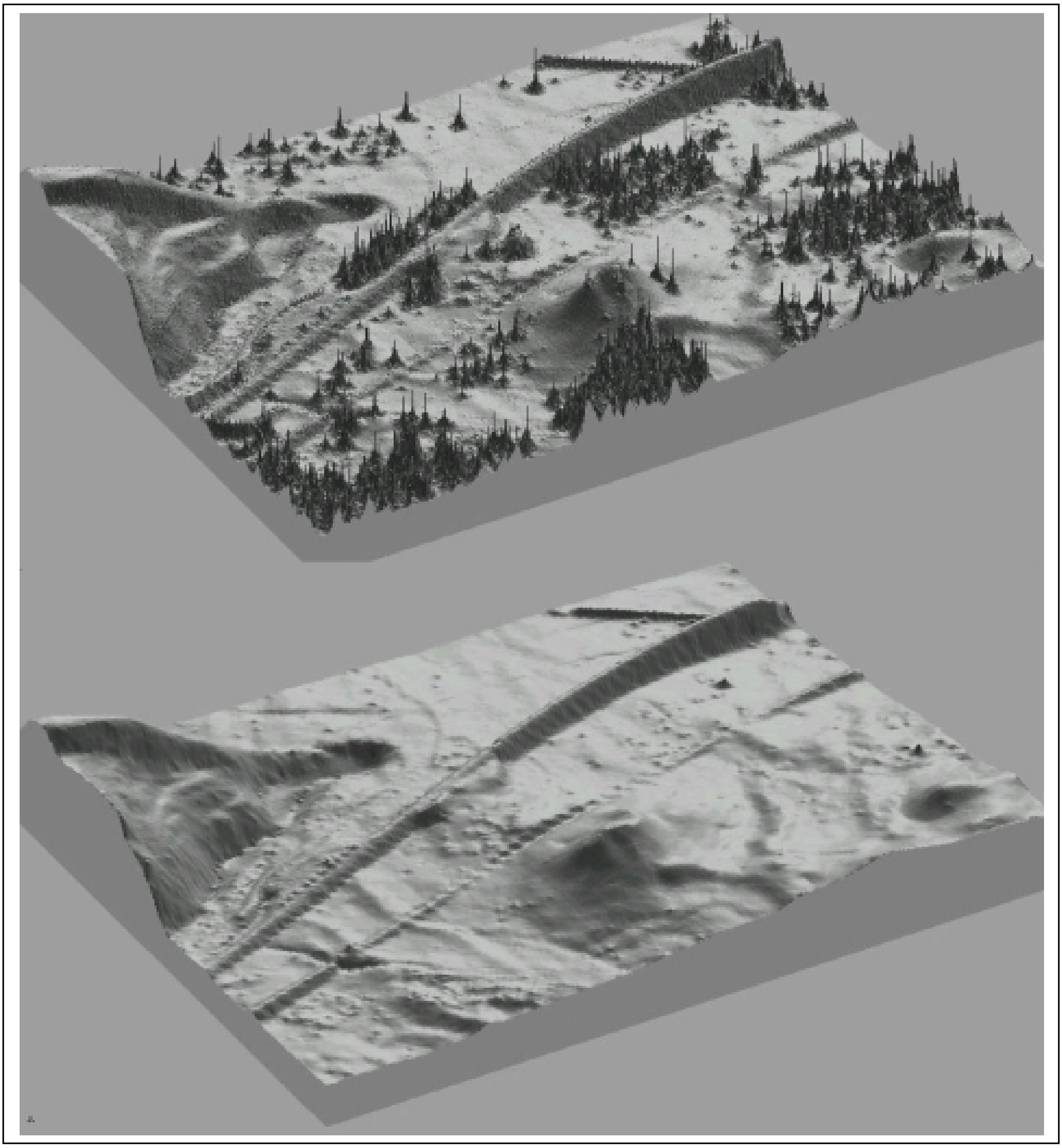

figure 4: data set from LIDAR – above: original data set, below: after automatic filtering