DIGITAL SURFACE MODELS DERIVATION FROM AIRBORNE LASER SCANNING DATA

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Abstract: *Within a time frame of only two decades, LiDAR technology has become a very important surveying method, that provides reliable geo-spatial information, being used in many scientific domains of activity, like: production of digital surface and terrain models, forest management and monitoring, corridor mapping, cultural heritage.*

In contrast to the Digital Terrain Model, describing the elevation of the ground surface, the Digital Surface Model represents the surface which can be seen from an acquisition platform. Over time, there were developed many algorithms for Digital Surface Models derivation from airborne laser scanning (ALS) data. Some of them are based on DSM_{max}*, containing the highest points within a defined raster cell, that has some disadvantages: in case of low point densities, it can contain void pixels and, in case of inclined smooth surfaces, it can show an artificial roughness. In order to obtain an improved DSM, the disadvantages of the* DSM_{max}*, are reduced by using an interpolated grid,* DSM_{mpl}*, containing heights based on moving planes interpolation.*

For the present case study, the Digital Surface Model of “Neubacher Au” area, located in Lower Austria was derived, based on a combination of two products, previously determined: the DSM_{max} *and the interpolated grid* DSM_{mpl}*. This algorithm is implemented in the scientific software package OPALS (Orientation and Processing of Airborne Laser Scanning data). For this test site, ALS data with a point density of 57 echoes per* m^2 *are available. Compared to the traditional DSM of the study area, the derived combined DSM offers a better visualisation of the territory, being better used in forestry applications.*

Keywords: *LiDAR technology, Digital Surface Model,* DSM_{max}*,* DSM_{mpl}

1. Introduction

Airborne laser scanning is an important surveying technology used in a multitude of applications, in fields such as topographic, environmental, industrial and cultural heritage 3D data acquisition. One of the main advantages of ALS is the acquisition of three-dimensional (3D) data with a high precision, based on polar measurements (angles and distances).

Compared to other methods, airborne laser scanning provides topographic models with a higher quality and at lower costs. As a result, ALS has become the preferred technology for the acquisition of Digital Terrain Models and also Digital Surface Models.

Airborne laser scanners are non-contact measurement instruments, that can capture and record the geometry and the textural information of visible surfaces of objects and sites. The resulting point clouds from laser scanning surveys contain points both on the terrain and also above it, represented by vegetation, trees, buildings [1].

The most commonly used topographic models are the Digital Terrain Models and the Digital Surface Models. A Digital Terrain Model, also known with the term of Digital Elevation Model (DEM) is a mathematical representation of the bare earth terrain with uniformly distributed z-values. In order to make a better description of the true shape of the bare earth terrain, the DTM incorporates the elevation of significant topographic features on the land, but also break- lines, that are irregularly spaced [2].

In contrast to the Digital Terrain Model, describing the elevation of the ground surface, the Digital Surface Model, also referred to as the Digital Canopy Model (DCM), describes the top surface that is visible from above, from an acquisition platform (e. g. aeroplane, helicopter). Therefore, a Digital Surface Model contains the elevations of the top reflective surfaces of trees, buildings and other features elevated above the bare earth. In open areas like streets, agricultural fields without vegetation, grassland with short vegetation or areas with bare soil, these two digital models are equivalent, but in contrast to the Digital Terrain Model, the Digital Surface Model describes the vegetation cover and manmade objects (buildings) as well. Also, the Digital Surface Models can include cars or other objects that are present in the area, during the data acquisition.

In present, there are numerous mathematical methods used in creating DSM models, from irregular X-Y-Z points. All these methods are based on the interpolation of the Z values, at regular X- Z intervals from the source data. Generally, the resulted surfaces are less accurate than the measured point data. The most common interpolation methods are described in [3], and they are: Bilinear interpolation, Moving Average, Moving planes, Inverse Distance Weighted (IDW) interpolation, Natural Neighbours, Trend interpolation, Spline interpolation, Kriging interpolation, Delaunay triangulation.

2. Presentation of the Study Area, Materials and Equipment

2.1. Presentation of the Study Area

The study area of the present research is located in Lower Austria (48° 12'50" N, 15° 22'30" E, WGS 84), at about 100 km west of Vienna. This territory is called Neubacher Au and includes a meandering region of the Pielach River, a pre-alpine river, right side tributary of the Danube.

(a) **(b)** **(c)**

Fig. 1. The study area, Neubacher Au, Lower Austria; (a) Overview map of Austria; (b) location of the study area; (c) Study area Neubacher Au

2.2. Materials and Equipment

The Airborne Laser Scanning data used in this study was provided by the Department of Geodesy and Geoinformation, from the Vienna University of Technology.

The airborne data was acquired with a Riegl LMS Q1560 LiDAR sensor, characteriszed by a high laser pulse repetition rate up to 800 kHz and uses a laser wavelength of 1064 nm, in near infrared.

The entire system, equipped with an integrated IMU/GNSS, was mounted on a light aircraft flying at 600 m above ground level. The flight mission held on 26th of February 2015, in winter season, under leaf-off conditions. The resulted point cloud has a corresponding point density of 57 echoes per m^2.

2.3. Data processing

The main principle of LiDAR technology is to emit a laser pulse in a known, controlled direction and measure the time from emission until receiving of its echo, scattered back from surfaces within the instantaneous field of view [4]. Direct georeferencing provides the position and orientation of the measurement platform. Together, this is used for 3-dimensional location of the echoes, thus providing a georeferenced 3D point cloud [5].

The first processing steps of the resulted Airborne Laser Scanning point clouds (direct georeferencing, strip adjustment) were performed with the Riegl ALS software suite RiProcess. This is an especial package, designed for managing, processing, analyzing and visualizing data acquired with airborne laser scanning systems [6].

In the following steps, for the digital surface models derivation, the OPALS laser scanning software (Orientation and Processing of Airborne Laser Scanning data) developed by the Institute of Photogrammetry and Remote Sensing (I.P.F.) from Technical University of Vienna, was used [7]. The principal aim of OPALS is to provide a complete workflow for processing large ALS projects. It includes more modules, organized in an hierarchical structure, each of them having a well-defined area of activity. The main tasks covered by the software are: processing of raw sensor data, quality control, georeferencing, ALS point clouds filtering, Digital Terrain Model interpolation.

The comparison of the derived Digital Surface Models was made in “CloudCompare”, an open source software, that allows point cloud editing and processing algorithms, like: registration, segmentation, Hausdorff distance calculations.

3. Results and discussion

3.1. Applied method for DSM derivation

A topographic Digital Surface Model (DSM), as the name implies, is a representation of how the ground looks from above: "topo – graphic", and this is the digital model that most users are familiar with [8].

Usually, the modeling process of land surfaces is challenging in areas of natural rivers. The study area of Neubacher Au from Lower Austria, part of the Natura2000 conservation project, is a riparian area characterized by a complex morphology, a meandered region of the Pielach river, by alluvial forest with complex understory and open grassland.

The following figure represents an illustration for the Digital Surface Model derivation, corresponding to a tree, to an open area and a watercourse profile, principal elements met in the present study area.

There are represented both Digital Surface Model calculations: with dark red color is the DSM based on the highest points within a defined raster cell (DSM_{max}) and in blue color is the DSM derived using moving planes interpolation (DSM_{mpl}).

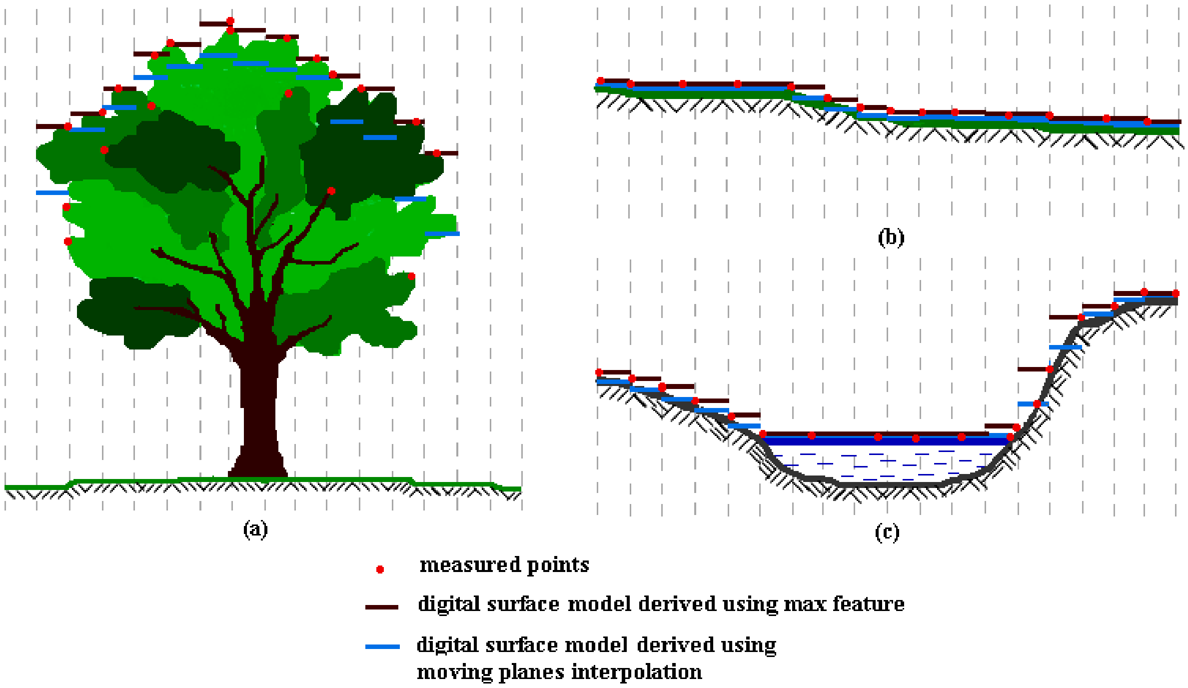


Fig. 2. Illustration of the Digital Surface Model derivation
(a) corresponding to a tree (b) to open areas, and (c) to watercourse profile

It can be easily seen that, for trees, the DSM_{mpl} is located under the real position of the tree highest points, so it can be said that the DSM_{mpl} underestimates the heights of the tree tops, causing big differences between real points positions and the approximated model. In contrast to DSM_{mpl}, that is not recommended for forested areas, the DSM_{max}, leads to a good approximation of the real surface.

On the other hand, for smooth surfaces and for inclined surfaces, the DSM_{max}, using the highest points within a cell, approximates the entire raster cell with the corresponding value, so it overestimates the surfaces, introducing an artificial roughness. In this case, for smooth inclined surfaces, the use of DSM_{mpl} is recommended, leading to better results.

In order to achieve better results and to derive an improved Digital Surface Model for the study area, an approach based on a combination of the DSM_{max} and DSM_{mpl} was used.

3.2. Processing steps

The Fig. 3 shows a short overview of the processing steps, applied in order to derive the Digital Surface Model of the study area of Neubacher Au.

In the pre-processing steps, the original ALS point clouds are co-registered and direct georeferenced and as a first step for the Digital Surface Model derivation, a data analysis was performed.

In order to obtain the two DSMs, namely DSM_{max} and DSM_{mpl}, two interpolation methods were used: based on highest points and moving planes.

In order to identify the different land cover types of the terrain, the surface roughness factor σ_z was determined and a corresponding raster was derived. Based on this input: the roughness parameter and the DSMs in raster format, the pseudo-code implementation within OPALS software was realized, leading to the improved combined Digital Surface Model of the "Neubacher Au" study area.

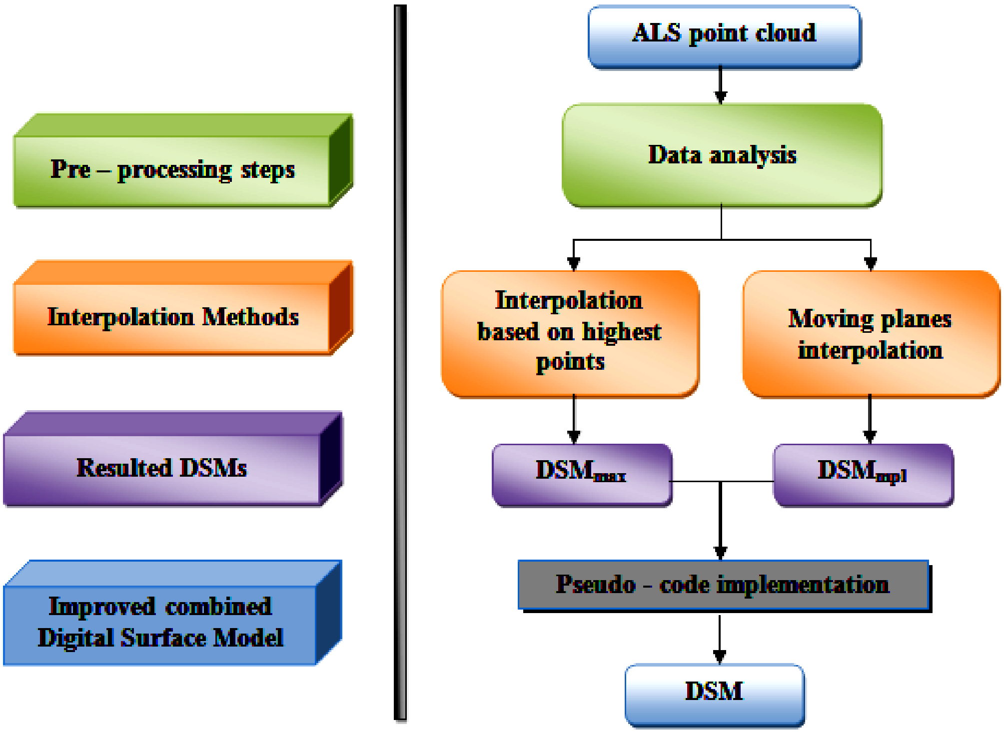


Fig. 3. Overview of the processing steps

3.3 Mathematical model

Principally, the mathematical model was represented by the pseudo code implementation within OPALS software:

$$\mathbf{Z[DSM] = z[\sigma_z]<0.5 \text{ or not } z[DSM_{max}] \ ? \ z[DSM_{mpl}] : z[DSM_{max}]}$$

The pseudo code implementation can be explained in a few words in the following way: the value of z (heights) for the final Digital Surface Model equals to the corresponding z value from DSM_{max}, if this one exists (is not None) and has a roughness value bigger than 0.5. This part corresponds to the vegetated areas. On the other hand, if these conditions are not accomplished for the rest of the image, the z value of the DSM will be taken from the DSM_{mpl}, having a roughness smaller than 0.5, corresponding to the open smooth areas. The entire algorithm was implemented in the scientific software package OPALS (Orientation and Processing of Airborne Laser Scanning data). The principal modules used in this study were: opalsCell, opalsGrid and opalsAlgebra.

3.4 DSM_{max} and DSM_{mpl} raster derivation

In a first step, using the OpalsCell module and a raster based analysis tool of OPALS software, the Digital Surface Model DSM_{max} of the study area was derived. The model contains the highest points within a defined raster cell of 0.50 meters and introduces an artificial roughness for the open vegetated areas and also for the inclined banks of the Pielach river. The shaded view of the DSM_{max} is shown in Fig. 4 (a).

In order to obtain an improved DSM, the disadvantages of the DSM_{max}, are reduced by using an interpolated grid, DSM_{mpl}, containing heights based on moving planes interpolation. For this purpose, the OpalsGrid module was used, that produced the digital surface model in a regular grid structure and additionally the σ_z roughness indicator was determined, feature that will be use in further processing steps. For each grid cell, a number of 8 neighbours was queried and the best fitting tilted plane that minimizes the vertical distances, was estimated. The height of the resulting plane at the grid point position, defined by the (x, y) coordinates, was mapped to the grid cell. The tilted plane interpolator allows the derivation of slope measures (slope, exposition) for each grid point [9]. The shaded view of the DSM_{mpl} is shown in Fig. 4 (b).

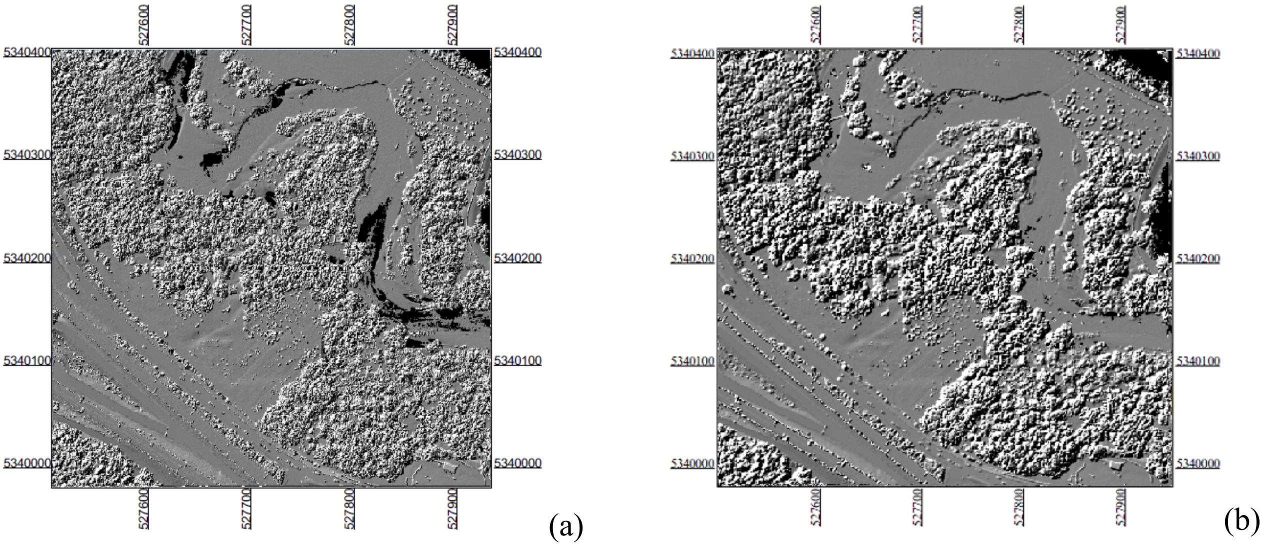


Fig. 4. (a) Shaded DSM_{max} and (b) Shaded DSM_{mpl} grid obtained by ”movingPlanes” interpolation method (8 neighbours; 1 m search radius) with a spatial resolution of 0.50 m.

The quality of the two DSMs is analyzed by substracting the DSM_{mpl} from the DSM_{max}, difference made with OpalsDiff module. As shown in Fig. 5, the difference heights are in the range of centimetres for open areas and 1 to 2.5 meters corresponding to the forested areas.

Also, for a better analysis, from the two DSMs, the corresponding point clouds were obtained, that were further imported into "CloudCompare v. 2.6.2" software. A triangular mesh using the Delaunay triangulation interpolation method was created for the DSM_{mpl} and in the next step, the Hausdorff distance was computed, using the *"Compute Cloud to mesh distance*" function of the software. The result was a digital raster model, containing the differences highlighted with a specific colour palette (Fig. 6).

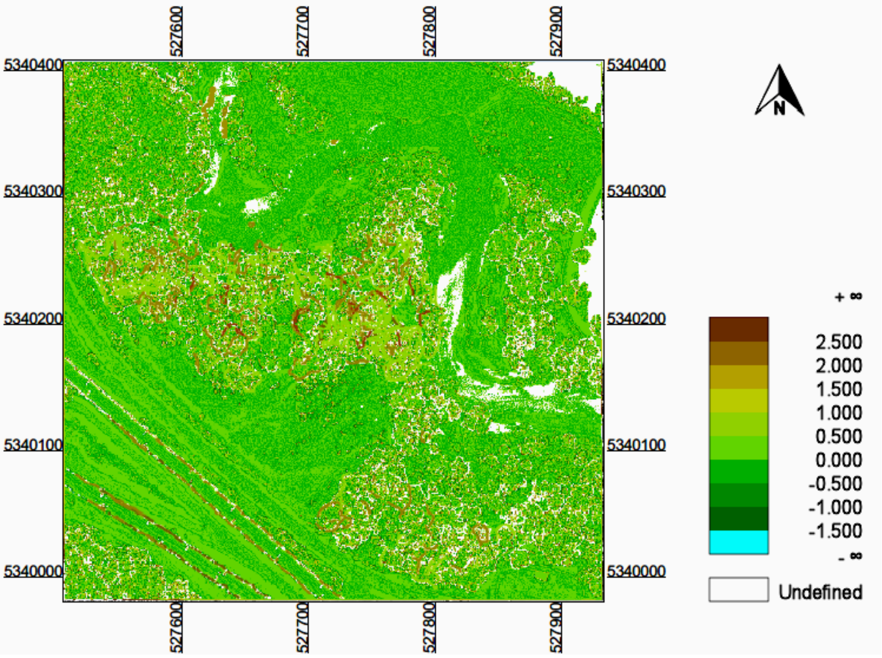
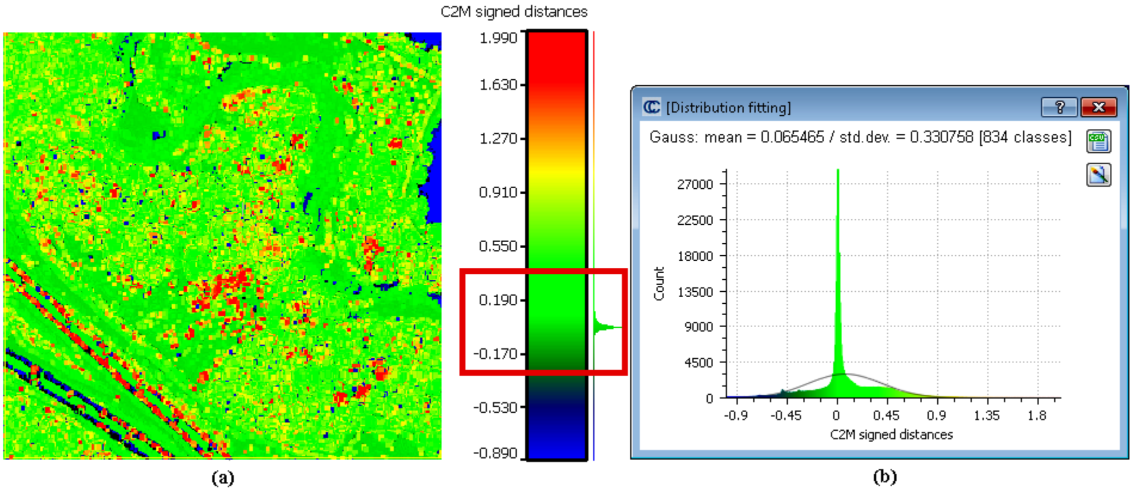


Fig. 5. Difference between the DSM rasters ($DSM_{max} – DSM_{mpl}$) derived with OPALS

Furthermore, an analysis over the computed differences can be made: in areas with high vegetation, it can be seen that the DSM_{mpl} underestimates tree heights the differences having positive values. For open areas, the differences are ranging from 0.25 m to 0.5 m, in the range of centimetres, demonstrating that in these areas, the two Digital Surface Models are quite the same. The resulting histogram shows a value for the mean differences of 6 cm and a standard deviation of 0.33 m.



Gauss: mean = 0.065465 / std.dev. = 0.330758 [834 classes]

(a) (b)

Fig. 6. (a) The differences between the Digital Surface Models with the corresponding colour scale and (b) The distribution histogram

Table 1 shows the minimum and the maximum differences between the Digital Surface Model obtained by using moving planes interpolation (DSM_{mpl}) and the corresponding point cloud of the Digital Surface Model derived using the highest values (DSM_{max}).

Table 1. Differences between Digital Surface Models DSM_{mpl} and DSM_{max}

Differences	$\mathbf{DSM_{max} - DSM_{mpl}}$
Positive values	1.99 m
Negative values	-0.89 m
Mean value	0.06 m
Standard deviation σ	0.33

3.5 Surface roughness raster image derivation

A very important parameter used in further computations is the σ_z value, defined as the surface roughness. This parameter was obtained as an additional feature per grid post, corresponding to the DSM_{mpl}. The σ_z value indicates the standard error of the estimated grid post elevation.

This parameter plays a significant role in the mathematical model implementation, because it is used to identify buildings roofs, streets and open areas on one hand, and fully vegetated areas on the other hand [10].

Therefore, depending on the surface roughness values, either the DSM_{max} or the DSM_{mpl} was used for the final Digital Surface Model heights computations. Figure 6 represents the resulted σ_z image, corresponding to the present study area, that shows a good classification of smooth and rough surfaces.

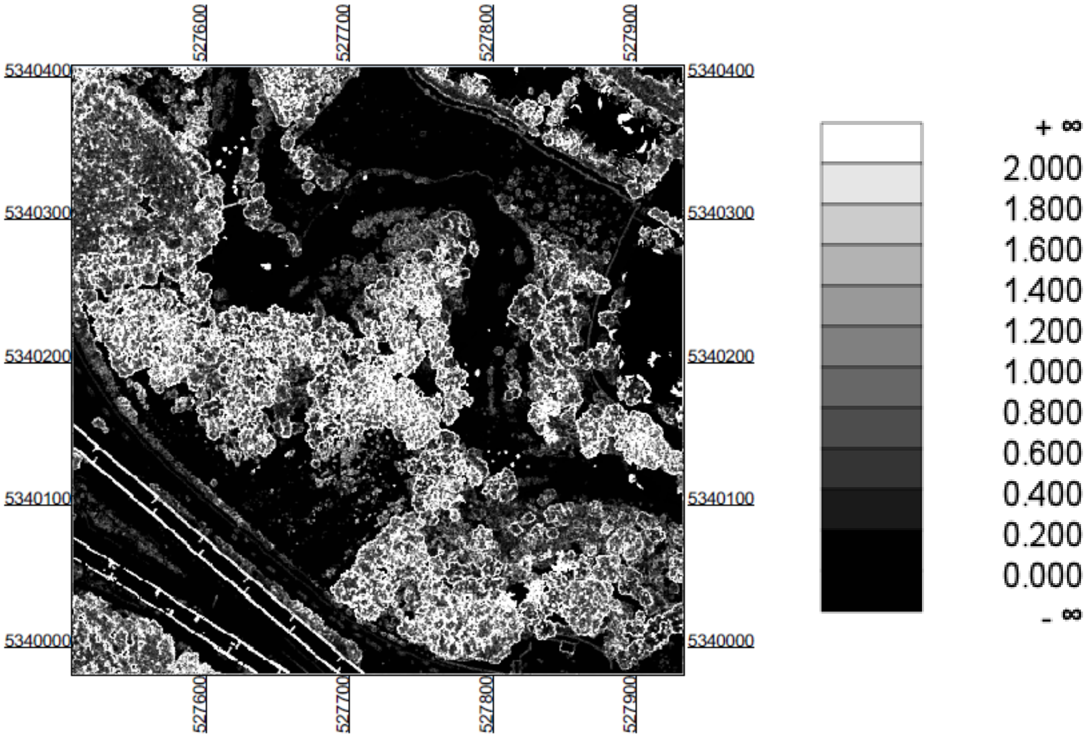
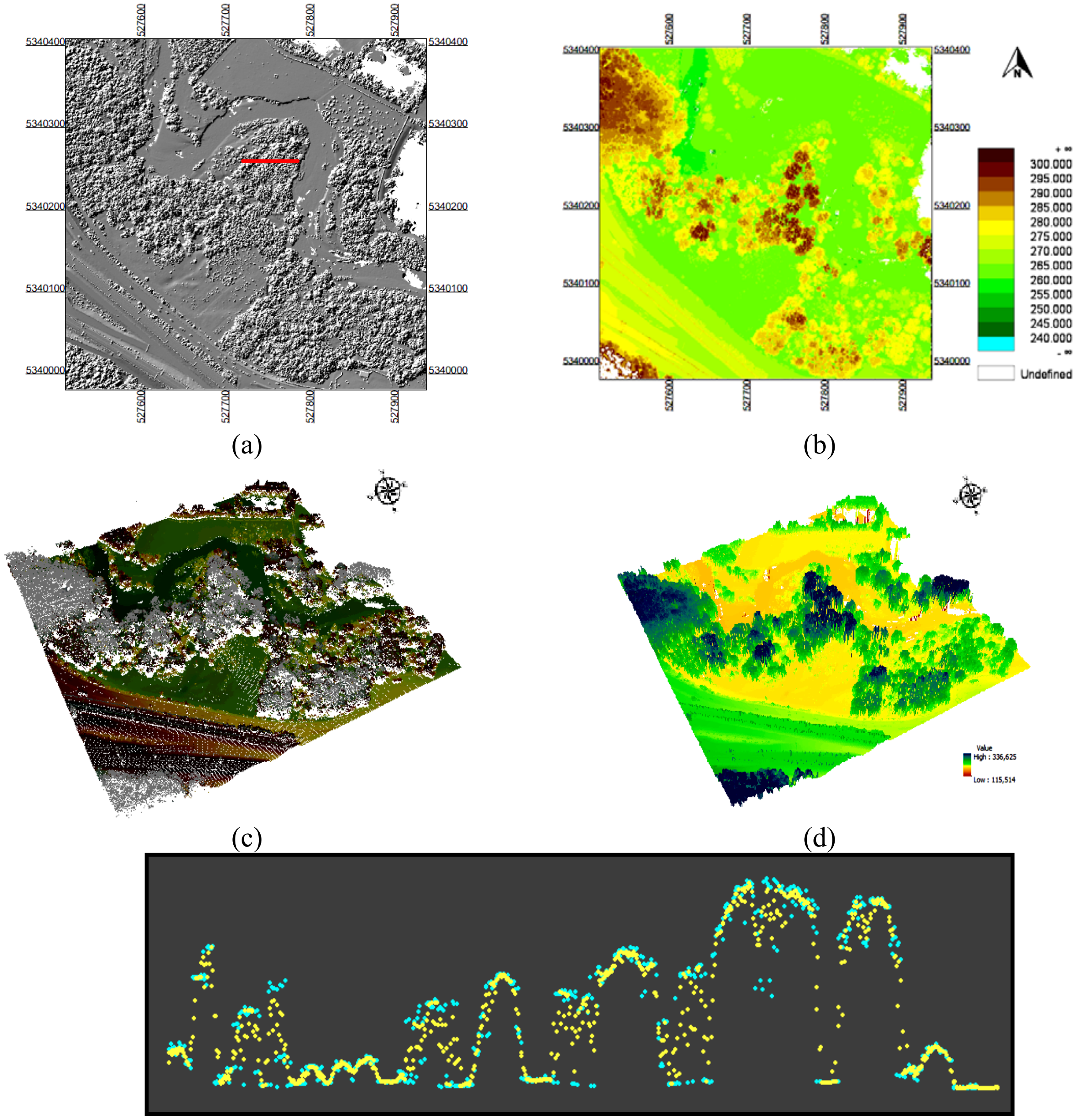


Fig. 7. The σ_z image of the Neubacher Au – study area with the corresponding colour legend

3.6. Digital Surface Model derivation

Finally, the two DSMs were combined, based on the σ_z values, using the "OpalsAlgebra" module of the software. The DSM_{max} was used for the rough parts of the study area, vegetated area ($\sigma_z > 0.5$ m) and the DSM_{mpl} for the remaining areas. The final DSM can be viewed in shaded mode, using "OpalsShade", in different colour pallets, using "OpalsZColor", or in 3D view, as shown in Fig. 8.



(a) (b)

(c) (d)

(e)

Fig. 8. Digital Surface Model of the study area in raster format (20 cm cellsize)
(a) Shaded raster view in Quantum GIS software with profile position
(b) Coloured view of the DSM with Standard Palette, 5m interval
(c) 3D visualisation of the DSM point cloud in FugroViewer, using "Earth Tones"
(d) 3D visualisation of the DSM in "ArcScene" software, using standard color ramp
(e) Profile of DSMs (blue dots - DSM_{max} and yellow dots - DSM_{mpl})

4. Conclusions

The presented method, used for Digital Surface Models derivation, is based on the roughness information within each raster cell, in order to make a reliable combination of the previously determined products, DSM_{max}, using the highest values and the DSM_{mpl}, resulted using moving planes interpolation.

The interpolation techniques are very well known, they are not new, but the focus is not on the applied interpolation method, but on the different algorithms used in Digital Surface Model derivation, algorithms, that take into account the aspect of the terrain, complexity and topography. Therefore, in a first step it was determined the roughness parameter and then, according to its values, it was chosen the interpolation methodology. This parameter was selected, because it has a significant role in identifying and defining the forested areas, low and high vegetated areas, areas close to watercourses.

In this way, by the presented methodology, there can be obtained an improved series of Digital Surface Models, with a higher accuracy, that take into account the terrain topography. These models are offering a better visualisation of the analyzed territories and can be further used in a variety of applications like forestry, engineering surveys, environmental management.

5. References

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