

Slope based Grid Creation using Interpolation of LIDAR Data Sets

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Abstract: This article proposes a new approach of DTM creation from irregular LIDAR data scan. It shows the new way how to utilize GIS results in the 3D modelling branch. LIDAR has a form of digital model of relief which does not include artificial objects on the surface. DEM is created on the basis of individual points and their elevation values and is further used for segmentation and classification of the terrain. Key attribute for this operation is computation of the slope in the area of interest. Resulting classes are used as vector outlines. These outlines are intended to divide the point cloud into groups. Each of them has specific requirements for resolution. Flat areas can be modelled with less detail whilst hilly regions with sharp elevation changes require higher resolution. LIDAR input is processed by chosen interpolation method, in this case IDW and Renka-Cline algorithm. Irregular structure of the point cloud is converted into regular grid of points. This process is semi-automatic. It is implemented in C++ library in the application Origin. Output is automatically saved in predefined variable resolution (set of grids) and prepared to be processed in 3D.

1 INTRODUCTION

Light detection and ranging (LIDAR) is technology that provides information about elevation of scanned objects and their position. This technology is utilized in this article. Goal of this study is based on the previous research of authors. In this case, authors were looking for a method that could eliminate the disadvantages of triangulated irregular networks (TINs) and that lowers the hardware requirements as much as possible (Axelsson, 2000).

Current applied utilization of LIDAR is very rich and intersects a wide range of scientific disciplines. Most frequent example is creation of Digital Terrain Model (DTM). Practical example of the DTM creation can be found in research from Mandlbürger et al. (2009) who studied hybrid terrain models in the river flow modelling. Next one is the Digital Elevation Model (DEM). It is frequently used to compute elevation based analyses. The Digital Height Canopy Model (DHCM) is used for reconstruction of forests and vegetation. This research was done by Klimanek (2006) who used LIDAR technology in the forestry.

Reconstructed model of terrain relief can be enriched by buildings in the form of the Digital Building Model (DBM) and can be used for example

for antennae signal prediction or navigation (Li et al. (2007). All of these parts can be merged together to form one complex model. Prerequisite for this operation is data processing described in this text.

2 IDENTIFIED ISSUES AND GOALS IN GRID CREATION

The main goal of this paper is to create slope based set of quadrilateral grids. This grid set can be made by chosen interpolation method which can compute unknown value at a specific grid from the known, measured values. It is usually represented with certain error. Interpolated outputs can be stored as a set of LIDAR XYZ files. These files can be further processed by 3D applications in parametrical and procedural way to form almost photo-realistic visualisation with maintaining the presence of GIS analyses.

Partial steps can be summarized as follows: (1) Batch operations are handled by basic scripting and programming (C++) (2) Resulting grids have a form of quadrilaterals and they are saved as XYZ files in the form that will be handled by any 3D scripting

language in next research. (3) This processed grid can be used further for visualization, simulation or it can be utilized in any other scientific field, previous steps are prerequisites for this operation (4) Demonstration in the large area in the form of terrain model by use of constant grid.

2.1 Inputs and Outputs of Individual Operations

Outline of all key operations to reach set goals can be expressed by a simplified scheme of inputs and outputs (Figure 1). This expression represents the chained pipeline. The first input (LIDAR irregular data set) is processed through the entire process while partial output files are generated and re-used in the next steps.

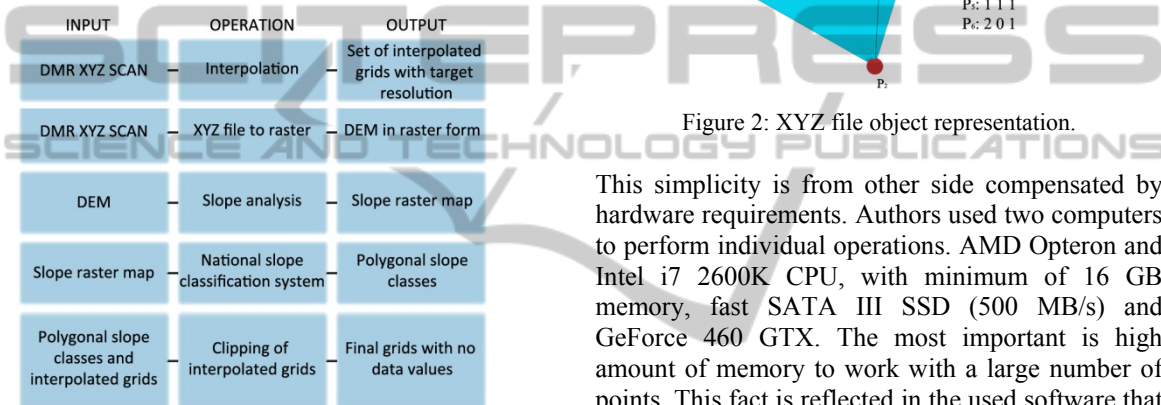


Figure 1: Processing scheme.

2.2 Used Data and Software

This chapter describes the used data and software that was needed to finish set goals. Authors had mainly one available input to finish them. LIDAR scan for area size 10x20 km. Source of data is from the Military Office for Geography and Hydrometeorology of Army of the Czech Republic. Data set is scanned by aircraft Turbolet L-410 FG. Scanning parameters are set to, fly height = 1200 m, plane speed = 250 km/h, beam frequency = 80-120 kHz, scan angle = 60°, scan direction = East-West, width and length of scanned stripe = 0,8 - 25/60 km and sides are overlapped by 50 %. Outputs resulted in two types of LIDAR models. First, the Digital Surface Model 1st generation (DSM 1G) which included all objects on the surface (terrain + vegetation, buildings,...). Second, the Digital Model of Relief 5th generation (DMR 5G). For this purpose is the DMR sufficient because authors solved only problems directly connected with terrain (Belka,

2012).

Scanned data are stored as XYZ text files. Each scanned point is represented by separate line with information about X/Y coordinate (WGS 1984) and Z elevation attribute (meters above sea level). Area is scanned and saved separately into 50 files that formed a rectangular matrix. These individual files are merged together and formed 800 MB big file that consisted 21 000 000 records (points). XYZ object representation is plain and can be demonstrated by basic object primitives (Figure 2).

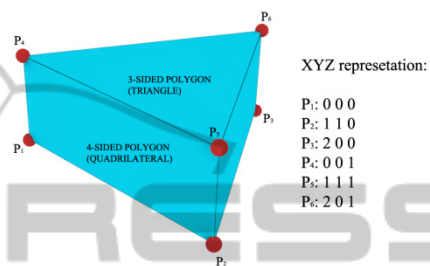


Figure 2: XYZ file object representation.

This simplicity is from other side compensated by hardware requirements. Authors used two computers to perform individual operations. AMD Opteron and Intel i7 2600K CPU, with minimum of 16 GB memory, fast SATA III SSD (500 MB/s) and GeForce 460 GTX. The most important is high amount of memory to work with a large number of points. This fact is reflected in the used software that is mainly used as 64 bit versions to fully utilize RAM capacity. The first one is ArcGIS 10 from ESRI - this application fully sufficed in all interpolation tasks based on local IDW algorithm and also prepared the LIDAR data set. Batch tasks in ArcGIS are made with the help of scripting language Python. The second suitable application is OriginLab. This application supports scripting, utilizes national algorithm library (NAG) and connects all the features within C++.

3 SIMPLIFYING LIDAR DATA SET BY INTERPOLATION

This chapter characterizes the basic principle of interpolation in case of simplifying irregular LIDAR scan to regular grid structure.

3.1 LIDAR Interpolation

Interpolation is the estimation of attribute (in this case elevation-Z) at unmeasured-unknown points

from measured points (known points). Weather forecast is a typical example of interpolation used in real life. Temperatures are measured at meteorological stations (known values) and interpolated throughout the whole area of interest. Points outside of it can be extrapolated. DEM is often created from contour lines. To create continuous raster surface, attributes (Z) from the contour polyline must be interpolated into the required grid with predefined unit resolution.

This is called the 2D interpolation because the values are interpolated on the surface that is defined by X and Y coordinates. It must be taken on mind that even contour lines are frequently already based on interpolation. In addition to these core applications there are other input data types that can be chosen for interpolation (points, lines, areas). Interpolation process can be divided in two main groups. Global interpolation considers all known points and computes the unknown values at specified location. Local interpolation method usually sets the distance radius (variable or fixed) around the known point and searches within it throughout the limited number of neighbourhood points for the computed value at specified position. The difference between them is the sensitivity to an outlier values.

This problem points to the fact that global method creates smooth surfaces and local method less smooth surfaces. Local method is not so sensitive to outliers but creates spikes. This issue must be considered before using available LIDAR data set which can be noisy and uncorrected from outlier values that were reflected from the unwanted objects (Figure 3).

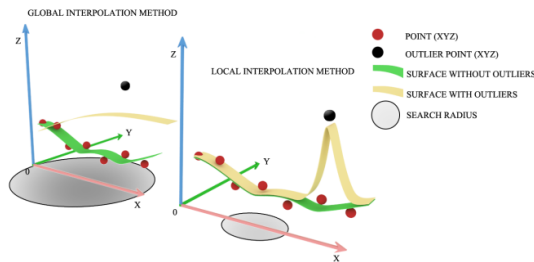


Figure 3: Global and Local interpolation methods.

Global interpolation can be represented by a surface which is calculated with a polynom of specified polynomial grade. For example linear (first grade), quadratic (second grade), cubic (third). Higher grade of polynom causes better curve/plane fitting through the points. But from another aspect it cases so called “Runge’s phenomenon” which computes wrong estimations of attributes for unknown points (peaks).

The most used local interpolator which is used also in this text is Inverse Distance Weighted Average (IDW). This method is based on the weighting the known attributes by an inverse power of distance between known and unknown point. The closer the unknown point is to a known point, the stronger the influence of the distance.

User can specify parameters which affect the output. p = exponent, 0 = no matter where the unknown point is, 1 = direct correlation with the distance, 2 = inverse power correlation with distance, 3 and more = higher influence of neighbourhood known points on the unknown points computation. Radius and number of known points used for computation - spatially affects the output. All these parameters must be carefully checked based on distribution of known data points (Figure 4) (Longley et al., 2011).

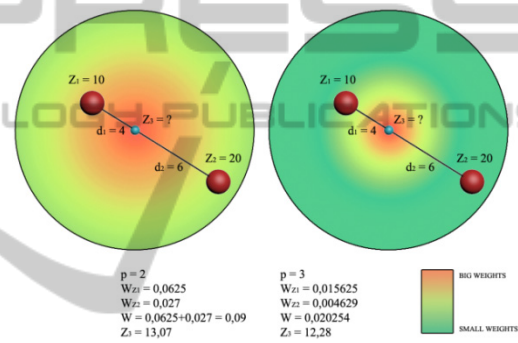


Figure 4: IDW power influence.

3.2 Batch Implementation

This text uses local interpolation of IDW and global version of Renka-Cline interpolation (Renka and Cline, 1984). IDW is computed in ArcGIS 10. Raw LIDAR data are loaded as 3D features. XY coordinates are additionally attached and the whole irregular structure is batch processed by a Python script. Script saves all interpolated grid outputs into specified folder. Each output is saved in different resolution defined by a target size of required polygon.

$$C_{X_i} = \frac{W}{P_i} \tag{1}$$

$$R_{Y_i} = \frac{H}{P_i} \tag{2}$$

Where, i = item in the array of resolutions, C_{X_i} = number of columns (X axis), R_{Y_i} = number of rows (Y axis), W = width of the area of interest, H = height of the area of interest, P_i = target size of the polygon.

The whole area of interest has a size of 10×20 km. Target size of polygons is set to array of {5 10 20 40 60 100} meters. Computation resulted in two input arrays, COLS {100,167,251,502,1005,2010}, ROWS {199,332,498,997,1995,3990}. Besides Python script in ArcGIS, authors use application OriginLab which combines scripting and programming steps to fully customize the computational process.

OriginLab uses C++ compiler and a NAG library (Numerical Algorithm Group) which contains approx. 1600 mathematical and statistical algorithms. Following C++ code shows the batch solution of performing Renka-Cline within an application OriginLab. Source code shows only basic procedure and script text output due to the limits of article size. User specifies the input file with LIDAR scan. In this case it is 800 MB big XYZ data set. Active layer is loaded into XYZFile object. XFBASE class provides an access to scripting functions, in this study xyz_renka from NAG library. After that, data are iteratively processed and saved separately. Timer shows the length of the computational process and saving operations. Saving a large xyz file can take a significant amount of time. In case of grid resolution = 2010×3990 (8 million of points) over 2 minutes and iteration generated 300 MB big grid file. Files are stored in created directory.

```
void renka()
{
Alg = "RENKA-CLIME";
open_file();
Worksheet XYZFile =
Project.ActiveLayer();
for (int i=0;i<max;i++)
{
timerStart = GetTickCount();
int_to_fixed_str(gridValuesX[i],3,bufX)
int_to_fixed_str(gridValuesY[i],3,bufY)
outRes = bufX + " " + bufY;
XFBASE xf("xyz_renka_nag");
data.Add(XYZFile, 0, "X");
data.Add(XYZFile, 1, "Y");
data.Add(XYZFile, 2, "Z");
xf.SetArg("iz",data);
xf.SetArg("rows",gridValuesX[i]);
xf.SetArg("cols",gridValuesY[i]);
xf.Evaluate();
timerEnd = GetTickCount();
line;
printf("Algorithm: Renka-Clime\n");
printf("Resolution:%d",gridValuesX[i],
" × ",gridValuesY[i]);
printf("\nValues:%d\n",gridValuesX[i]*g
ridValuesY[i]);
```

```
printf("Pure computation completed
in:%d ms\n",timerEnd-timerStart);
convertMatrix();
Export_ASCII();
timerEndSave = GetTickCount();
printf("Saving the output file took :
%d ms\n",timerEndSave-timerEnd);
printf("Total time: %d
ms\n",timerEndSave-timerStart);
line;
}
printf("\n");
}
*****
Algorithm: Renka-Clime
Resolution: 2010
Values: 8019900
Pure computation completed in : 11544
ms
Saving the output file took : 3370 ms
Total time: 14914 ms
*****
```

Following figure shows the data output of interpolation process. Set of grids are characterized by an ascending resolution (Figure 5).

Name	Size	Date (finished)
.I.	<DIR>	04.03.2013 17:47
export_resolution_100 199 xyz	747 802	04.03.2013 17:45
export_resolution_167 332 xyz	2 085 388	04.03.2013 17:45
export_resolution_251 498 xyz	4 700 820	04.03.2013 17:45
export_resolution_502 997 xyz	18 845 437	04.03.2013 17:45
export_resolution_1005 1995 xyz	75 494 242	04.03.2013 17:46
export_resolution_2010 3990 xyz	302 009 062	04.03.2013 17:49

Figure 5: Data output of interpolation process.

The same situation applies to IDW grid set which is created in ArcGIS. Grid can be stored either as a point feature or a raster image. Figure 6 shows three of six created grids in both forms, as raster and point features. The big sized image on the left is the whole area of interest. Black square outline magnifies the area to show the finest details in the grid resolution.

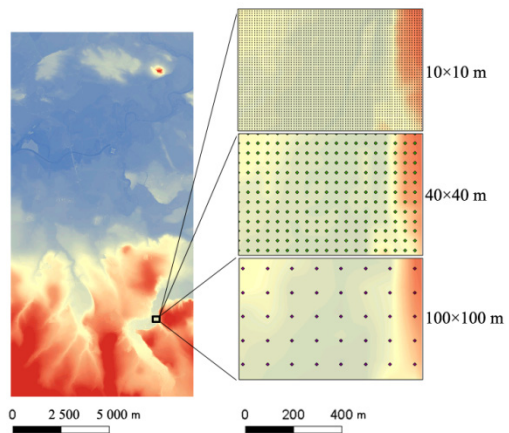


Figure 6: Interpolated grids as raster and point features.

4 GRID SEGMENTATION USING DEM SLOPE ANALYSIS

This part is focused on the creation of clip polygons in ArcGIS. These polygons will be used to clip the computed set of XYZ grids which resulted from the interpolation process. In this example authors used three types of grids. Grid 1 has cell size of 5 meters, suitable for hilly regions with sudden elevation changes. Then Grid 2 has the cell size of 20 meters, for highlands. The Grid 3 has the cell size of 60 meters, for flat lands. Reason for excluding other grids is based in grid comparison. This comparison is made by computing grid volumes and split sample validation. Detailed results of these tests go beyond of the subject of this article. They will be explained further in next research. This fragmentation provides the ability to process large territory. It would not be possible with constant grid of 5×5 meters because of hardware requirements.

The main steps can be summarized as following. Irregular LIDAR data set is converted to raster form (DEM). This conversion is targeted to adequate cell size and based on chosen method (e. g. most frequent, mean.). Precision in the preservation of real-measured values decreases but it is sufficient for finding the outlines for all grids. In the next step the slope analysis is performed. Quality of analysis is based on the DEM cell size. Slope tool calculates the maximum rate of change between each cell in the raster and its eight neighbours.

These steps are shown magnified to recognize cell size, on the Figure 7.

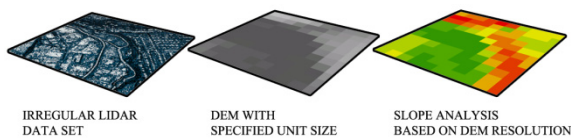


Figure 7: Slope analysis based on DEM.

To simplify the situation, ranges are aggregated into 3 groups (the same number of used grids). Flat, semi-steep and steep regions (Table).

Table 1: Aggregated ranges.

Slope class	Gradient [%]
Flat region	0-20
Semi-steep region	21-35
Steep region	>36

Decimal values of the raster are converted to integers. This operation is prerequisite for raster to polygon conversion. This conversion is made in high

precision to match individual outlines without blank spaces. The process can be adjusted according to the terrain type. Mainly by slope requirements, norms or by DEM cell sizes (Figure 8).

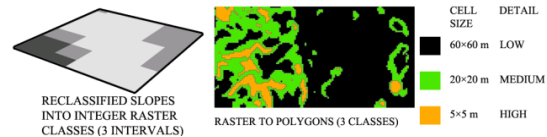


Figure 8: Polygons used to clip interpolated grids.

Minor buffer can be also applied to each polygon class to extend the boundary. This boundary will provide an easier intersection of reconstructed surfaces.

The final step in data preparation is to clip each selected grid with associated polygon - 5×5 m grid with orange coloured polygon, 20×20 m grid with green polygon and 60×60 m with black polygon. Some overlaps are apparent along the outlines of each class. These overlaps will work like intersection areas in the future research which will utilize these data files for 3D scripting (Figure 9).

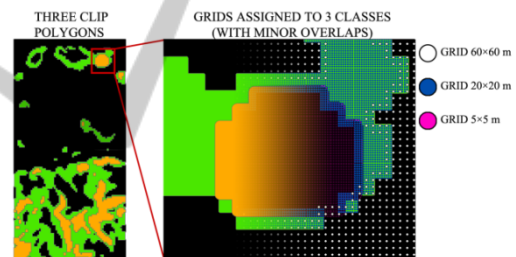


Figure 9: Assigned grids based on the slope analysis.

5 DISCUSSION AND CONCLUSIONS

This section summarizes the results and outlines possible ways forward in the future research.

5.1 Discussion

Authors performed a hybrid method of DTM creation. This method is based on the classification and segmentation of interpolated grids by chosen method (IDW and Renka-Cline). This method should lower hardware requirements by lowering the resolution in certain areas and increasing the resolution in high slope locations. Adaptive slope adjustment of the interpolated grid resolution in certain topographic locations can increase reconstructed DTM dimensions significantly. This

study is based on the previous research where authors explained parametric and procedural visualisation which is built on the single grid with constant resolution. Output from the previous research with constant grid can be demonstrated by following figure and will be very similar even in this study but in much larger area (Figure 10).



Figure 10: Constant grid used in 3D visualisation in previous research (Processed in 3D Studio Max).

The future work will be directed to area of 3D scripting (Maxscript). Set of XYZ files - interpolated grids will be processed in 3D environment (3D Studio Max). Each of chosen grids will form quadrilateral polygonal surface. By help of parametric, procedural and set operations, the DTM will be fitted by a set of models to form digitized photo realistic 3D polygonal version of terrain model. Real-world attributes (height, density, coordinates and sizes) will be maintained along with possibility to combine all features with analyses.

5.2 Conclusions

The main goal and partial steps are completed successfully. Solution of these steps, however, resulted in other issues which will be further explained in following research. These issues are mentioned in the discussion. Results can be used for example for simplifying computational tasks related to LIDAR car control by means of substitution of point cloud by DTM which provides faster results.

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