Modification of Lidar Point Cloud Processing Methodology

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Key words: optimisation, initial processing, large data set

SUMMARY

Airborne Laser Scanning (ALS), often called LiDAR (Light Detection And Raging), delivers a point cloud as a survey result. This point cloud consist of topographic surface data and coating elements (e.g. vegetation, buildings) is used to build a Digital Surface Model (DSM). The point cloud processing can be represented in following steps: OBTAINING DATA → PRE-PROCESSING → MAIN PROCESSING → VISUALISATION.

Existing methods of LiDAR point cloud processing, that leads to generation of Digital Terrain Model, are based on filtration algorithms designed especially for this purpose. The main task of these algorithms is to separate data from topographic surfaces and coating elements. This paper presents a modification of LiDAR point cloud processing with implementation of data set reduction (optimisation) algorithm in the PRE-PROCESSING stage [*Błaszczak 2006, Błaszczak, Kamiński 2007*].

The main goal of the research was to investigate the reliability and the efficiency of LiDAR point cloud processing methodology with implemented optimisation algorithm. The results confirm that, proposed modification improves the filtration algorithm by minimising the time needed for processing. It provides an effective way to generate DTM without loosing important data.

SUMMARY

Lotniczy skaning laserowy ALS (Airborne Laser Scanning) bardzo często nazywany LiDAR (LiDAR - Light Detection And Ranging) dostarcza rezultatów obserwacji w postaci chmury punktów. Chmura punktów zawierająca informacje o powierzchni topograficznej badanego terenu, o elementach pokrycia terenu, wykorzystywana jest do budowy modelu DTM (Digital Terrain Model) i DSM (Digital Surface *Model*). Opracowanie chmury punktów można podzielić na następujące etapy: POZYSKANIE DANYCH → PRZETWARZANIE WSTĘPNE → PRZETWARZANIE GŁÓWNE → WIZUALIZACJA.

Istniejące metodologie opracowania danych LiDAR prowadzące do uzyskania DTM opierają się na specjalnie skonstruowanych do tego celu algorytmach filtracji. W pracy autorzy zaproponowali modyfikację procesu przetwarzania chmury punktów LiDAR. Modyfikacja polega na poprzedzeniu procesu filtracji realizowanego w ETAPIE PRZETWARZANIA WSTĘPNEGO, algorytmem optymalizacji [*Błaszczak 2006, Błaszczak, Kamiński 2007*].

Głównym celem badań była kontrola wiarygodności i efektywności metodologii opracowania chmury punktów z wykorzystaniem algorytmu optymalizacji. Wyniki badań potwierdziły, że wprowadzona modyfikacja usprawnia działanie algorytmu filtracji danych, skraca czas filtracji, wpływa na efektywne i szybsze przygotowania danych do budowy DTM, bez utraty informacji niezbędnych do prawidłowej realizacji zadania.

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1. INTRODUCTION

Airborne laser scanning is a method of gathering information about the terrain. Collected point cloud is so called large data set $\boldsymbol{\Omega}_{Lidar}\{Pi(xi,yi,zi),npi\}$, where $i=1, 2, \ldots,k$; k - the number of points in original data set; *xi,yi,zi* - point coordinates; *npi* – Intensity (a measure of the return strength of the laser pulse, that generated the point). To generate a DTM from LiDAR point cloud a filtration (classification) of the gathered points must be performed. Filtration is the procedure that removes points that are "outliers" from DTM [*Kraus, Pfeifer 2001, Marmol U., Jachimski 2004*].
There are a variety of methods used to filter a point cloud. Among them one can distinguish:

a) Digital image analysis algorithms:
- Morphology filters [*Zhang et. al. 2002, Vosselman, 2001*]
- Gradient methods [*Hyyppä et. al. 2002, Wack, Wimmer 2002*]
- Active shape model [*Elmqvist 2002*]

b) Interpolation algorithms:
- Linear prediction [*Pfeifer et. al. 2001*]
- Interpolation with split functions [*Brovelli et. al. 2002*]
- Active TIN (Triangular Irregular Network) model method [*Axelsson 2000*]

Existing methods have some limitation due to faulty filtration in places with complicated relief. That is why research on new methods and filtration algorithms is still conducted.

2. PROPOSITION OF LIDAR POINT CLOUD PROCESSING METHODOLOGY MODIFICATION

As mentioned above, standard methods of LiDAR point cloud processing are based on filtering algorithms. In this paper we would like to present a modification of standard processing methods. This modification adds an optimisation of original data set stage before filtration. The modified optimisation of large data sets algorithm was used to reduce the number of points in point cloud [*Błaszczak 2006, Błaszczak, Kamiński 2007, Błaszczak-Bąk, Janowski 2009*]. The principle of this method is a use of cartographic generalisation methods to reduce the number of points in a point cloud without creating new entities – original points, with it's coordinates, are stored in a reduced data set. The generalisation is conducted in horizontal and vertical search belts p_p . These belts are parallel to OX and OY axes, and their size is user determined.
The LiDAR measurement is conducted along a survey line by given length, resulted from laser scanning angle and height of flight. During the algorithm execution there is no necessity to create the search belts. Generalization method can be applied in original belts, which were

created during LiDAR measurement. These areas are called now measuring belts. Survey point affiliation to a certain area is defined in a text file. This file is the result of the LiDAR measurement. The possibility of point elimination in original LiDAR measurement areas significantly simplifies the algorithm execution, what leads to following, stages:

Stage I - Reading of the dataset LiDAR (set $\boldsymbol{\Omega}_{Lidar}$ $\{P_i(x_i, y_i, z_i), np_i\}$).

Stage II - Selection of the method for generalization.

Stage III - Application of the method selected for reduction of points in all original measuring belts.

Stage IV – Completion of optimisation processing steps and writing the resulting dataset $\boldsymbol{\Omega}_R\{P_i(x_i, y_i, z_i), np_i\}$ (where $\boldsymbol{\Omega}_R$ is the dataset after optimization, $i = 1r, 2r, ..., m$, m – the number of points in reduced dataset) to the local software.

The outline of standard and modified methodology of LiDAR point cloud processing is presented on Fig.1.

3. FILTRATION OF LIDAR DATA

In general filtration can be done on raw survey data as well as on data processed with interpolation methods. In this paper filtration was performed on raw survey data set. Since the main goal of this paper is to present the modification of data processing and not investigation of filtration efficiency, only one method of filtration was used - moving polynomial method (moving surface) [*Elmqvist 2002, Jóżków 2007*]. Assume the following form of moving polynomial:

$$z(x, y) = \sum_{i,j}^{nl} a_{i,j} x^i y^j \qquad (1)$$

where: $i,j = 0, 1, 2, \ldots, n1$ (nl – order of polynomial); x,y,z – point coordinates; a_{ij} -estimated polynomial parameters. In this work polynomial of the first order was used. Residuals for each point can be denoted as follows:

$$\mathrm{v} = a_{0,0} + a_{1,0}x + a_{1,0}y - z^{obs} \qquad (2)$$

or using a matrix notation:

$$\mathbf{v} = \mathbf{A}\ \hat{\mathbf{X}} - \mathbf{z} \qquad (3)$$

where: $\mathbf{v}$ – residual vector;, $\mathbf{A}$ – coefficient matrix, $\hat{\mathbf{X}}$ – matrix containing parameters that are to be estimated, $\mathbf{z}=\left[z_1^{obs}, z_2^{obs}, ..., z_{k1}^{obs}\right]^T$ – vector of measured heights (kl- number of points in measuring set) . Using Least Squares method can be derived from:

$$\hat{\mathbf{X}} = (\mathbf{A}^T\mathbf{P}\mathbf{A})^{-1}\mathbf{A}^T\mathbf{P}\,\mathbf{z} \qquad (4)$$

where $\mathbf{P} = \mathrm{Diag}(p_1, p_2, \ldots, p_{k1})$ – weight matrix, matrix $\mathbf{A}$ has the following form:

$$\mathbf{A} = \begin{bmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ \vdots & \vdots & \vdots \\ 1 & x_{k1} & y_{k1} \end{bmatrix} \tag{5}$$

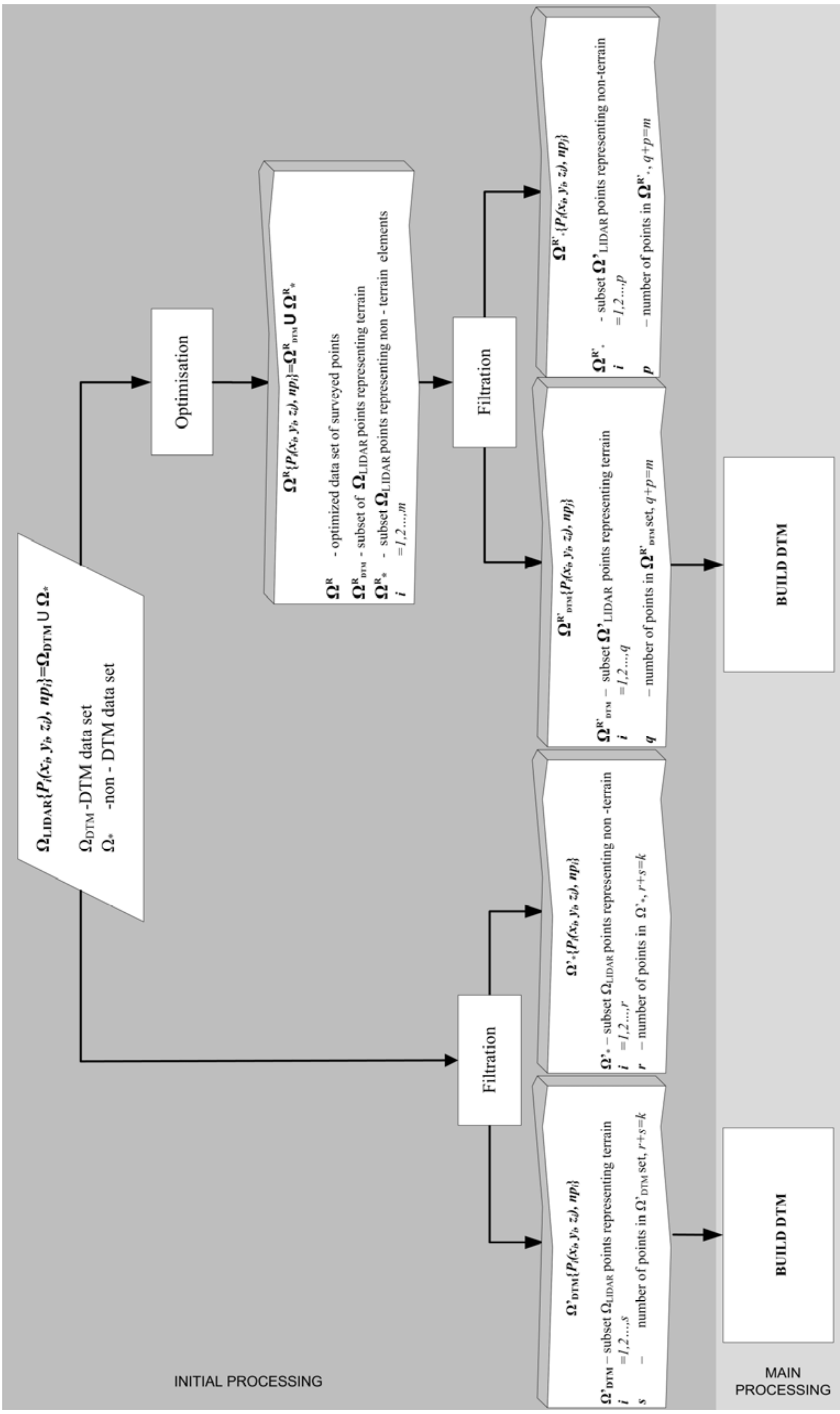

Fig. 1: Outline of standard and modified methodology of LiDAR point cloud processing

The parameters of the polynomial can be estimated using the methods based on robust estimation [*e.g.: Hampel 1973, Huber 1981, Kraus, Pfeifer 1998*]. In robust estimation, weights p_i ($i=1,2,\ldots k1$) of those of observations which residuals v_i are outside of certain range <-c; c> are attenuated by a clip function $w_i(v_i)$. The points that are not to be taken to create a DTM should be detected as outliers. In this paper Huber's clip function was used [*Huber 1981*]:

$$w_i(v_i) = \begin{cases} 1 & \text{dla } |v_i| \le c \\ \dfrac{c}{v_i}\,\mathrm{sgn}(v_i) & \text{dla } |v_i| > c \end{cases} \tag{6}$$

(for the numerical example c was 2.0).
Clip function modifies the weights p_i. As a result equivalent weights $\overline{p}_i$ are derived from

$$\overline{p}_i = p_i w(v_i) \tag{7}$$

Estimated parameters of polynomial are calculated using iterative procedure

$$\hat{\mathbf{X}}^l = (\mathbf{A}^T \overline{\mathbf{P}}^{l-1} \mathbf{A})^{-1} \mathbf{A}^T \overline{\mathbf{P}}^{l-1} \mathbf{z} \tag{8}$$

where: $\overline{\mathbf{P}}$ = Diag ($\overline{p}_1, \overline{p}_2, \ldots, \overline{p}_{k1}$) - matrix of equivalent weights, l=1, 2,…, - number of iterations..

The iterations can be ended when a desired accuracy of parameters is reached.

The results from the Least Squares (LS) method is taken as a start point for iteration procedure:

$$\hat{\mathbf{X}}^0 = \hat{\mathbf{X}}^{LS} \tag{9}$$

4. EXAMPLE OF PRACTICAL APPLICATION

Modified LiDAR data processing was applied to reduce the number of observations in a point cloud from survey of a section of a road in Bielsko-Biała. The tested large dataset comes from Visimind surveying system, which comprises of Riegl LMS-Q240 laser, GPS Topcon, IMU, and digital cameras. The laser scanning angle equaled 60 degrees, with resolution of 10 000 Hz. The scan was made during a helicopter flight at the speed of around 50 km/h and the height of around 70 m. The subset of LiDAR data used for digital tests contains 15 000 points. The $\boldsymbol{\Omega}_{Lidar}$ data set from thee survey in Bielsko-Biala was processed using standard methodology of LiDAR data processing. The point cloud was filtered using a moving surface method with Huber clip function. The calculations were made in six scenarios – with moving square of 1x1 meter (I), 3x3 meters (II), 5x5 meters (III), 7x7 meters (IV), 10x10 meters (V) and 15x15 meters (VI).

The same set of data was used to test modified method presented in this paper. At first the data set was optimized using Douglas – Peucker method [*Douglas, Peucker 1973*]. Then the above filtration was applied to a reduced data set.

5. TEST RESULTS

The results of the tests are presented in Table 1 and Table 2.

1	2	3	4	5	6	7	8	9	10
Scenario no.	Number of points in original data set.	Number of points removed during optimisation.	Number of points after optimisation.	Optimisation time [sec]	Size of moving window	Number of points removed during filtration.	Number of points after filtration (points for DTM)	Time of Huber processing [sec.]	Total operation time (5+9)
I	15 000	10 089	4911	5	1mx1m	4	4 907	1	6
II	15 000	10 089	4911	5	3mx3m	120	4 791	1	6
III	15 000	10 089	4911	5	5mx5m	267	4 644	5	10
IV	15 000	10 089	4911	5	7mx7m	293	4 618	17	22
V	15 000	10 089	4911	5	10mx10m	392	4 519	30	35
VI	15 000	10 089	4911	5	15mx15m	466	4 445	151	156

Table 1

Analyzing the above tables shows clearly that in both cases for each scenario the time consumption grows with the size of the moving square. Notwithstanding the time needed for both optimization and filtration is a couple of times shorter then filtration only. Optimisation takes about 5 seconds, which is not relevant in the whole processing time. The number of points to remove, change with the size of the moving square. The bigger moving square the more points are being removed from the data set.

1	2	3	4	5	6
Scenario no.	Number of points in original data set.	Size of moving window	Number of points removed during filtration.	Number of points after filtration (points for DTM)	Time of Huber processing [sec.]
I	15 000	1mx1m	8	14 992	1
II	15 000	3mx3m	620	14 380	5
III	15 000	5mx5m	758	14 242	39
IV	15 000	7mx7m	801	14 199	136
V	15 000	10mx10m	925	14 075	491
VI	15 000	15mx15m	819	14 181	2415

Table 2

Figure 2a and 2b depicts the terrain before (original data set) and after optimization. Figures 3a,3b and 4a,4b presents respectively results tests for 10x10 meters (V) and 15x15 meters (VI) scenario. The points that were identified by the algorithms as outliers are marked red. The colour of the remaining points represent its height (green – lower, orange – higher).
The illustrations below show that in both methods of LiDAR data processing, the same points are removed (usually the elements of terrain coating). In optimized data set less points are removed due to smaller number of data set.

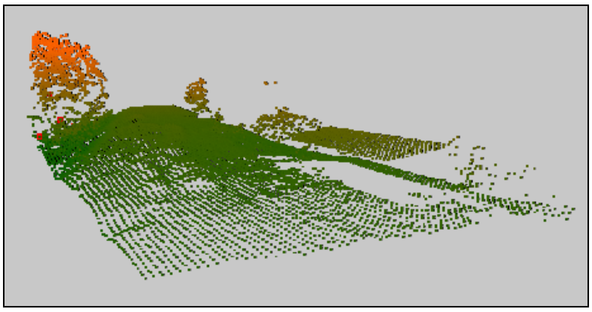

Fig. 2a.The original LiDAR point cloud

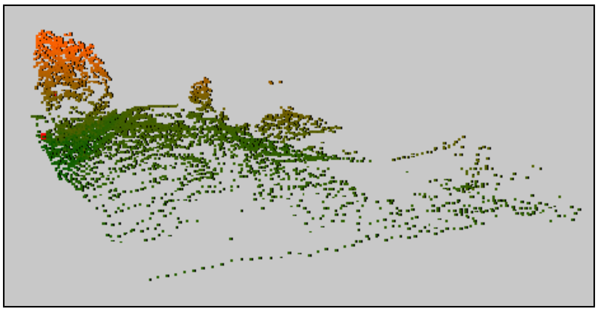

Fig. 2b. LiDAR point cloud after optimization

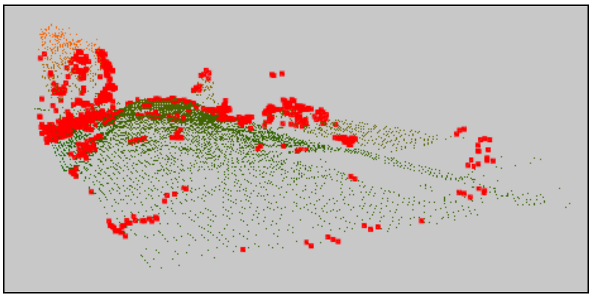

Fig. 3a. The original LiDAR point cloud after filtration using scenario V

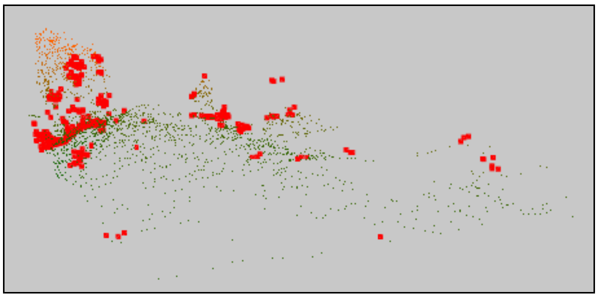

Fig. 3b. LiDAR point cloud after optimization and filtration using scenario V

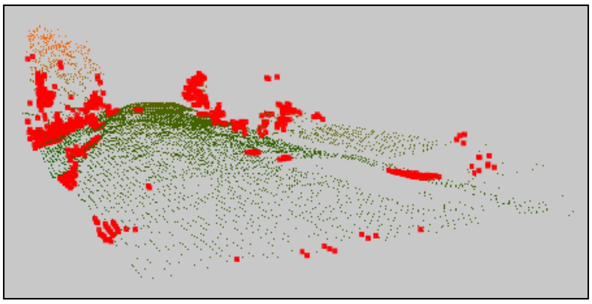

Fig. 4a. The original LiDAR point cloud after filtration using scenario VI

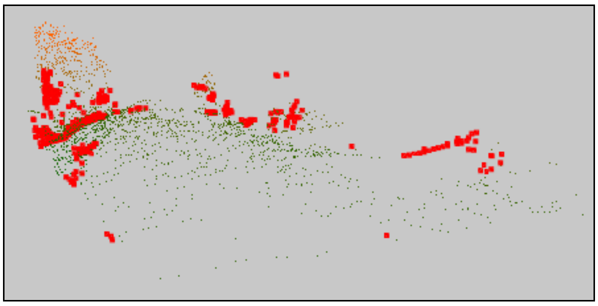

Fig. 4b. LiDAR point cloud after optimization and filtration using scenario VI

6. CONCLUSIONS

The result of study conducted in this paper, allows to state that LiDAR data filtration is definitely a prospective subject. The process of optimizing the dataset obtained through the airborne laser scanning, which can precede the filtration process, greatly facilitates data classification. This leads to a more effective and quicker preparation of data (to build a DTM) without the loss of information necessary to finalize the task correctly.
Modification of LiDAR processing methodology speeds up the filtration process (up to few times in presented example). In both cases the same points are removed from data set, which means that the terrain model should not be disturbed.
Anybody interested in this subject is welcome to cooperate with authors of this paper.

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REFERENCES

Axelsson P., 2000: DEM generation from laser scanner data using adaptive TIN models. International Archives of Photogrammetry and Remote Sensing Vol. XXXIII/4B, Amsterdam.

Błaszczak W., 2006: Optimisation of large measurement results sets for building data base of spacial information system. Dissertation. Olsztyn.

Błaszczak W., Kamiński W., 2007: Data number reduction in measurement results set using optimization algorithm. FIG Working Week 2007. Strategic Integration of Surveying Services. The Hong Kong Institute of Surveyors. Hong Kong. CD-ROM.

Błaszczak W., Kamiński W., 2007: Optimisation of large measurement results sets for building data base of spacial information system. Przegląd Geodezyjny No. 6/2007

Błaszczak W., Janowski A., 2009: Proposed Technology of LiDAR data processing to build DTM. Reports on Geodesy No. (2) 87, 2009. Research contributions in the field of engineering surveying within the period 2007-2008.

Brovelli M. A., Cannata M., Longoni U. M., 2002: Managing and processing LIDAR data within GRASS. Proccedings of the Open source GIS – GRASS user conference, Trento.

Douglas D. H., Peucker T. K., 1973: Algorithms for the Reduction of the Number of Points Required to Represent a Digitized Line or its Caricature. The Canadian Cartographer, 10(2).

Hampel F. R. ,1973: Robust estimation: A condensed partial survey. Z. Warsch. verw.Geb.27.

Huber P. J., 1981: Robust Statistics. John Wiley and Sons.

Hyyppä J., Pyssalo U., Hyyppä H., Samberg A., 2002: Elevation accuracy of laser scanning – derived digital terrain and target models in forest environment. International Archives of Photogrammetry and Remote Sensing, Vol. XXXIV/ 3A, Graz.

Jóźków G., 2007: Moving polynomial in filtering of airborne laser scanning data. Report of the 2nd ISPRS WG VI/5 and SC 2nd Summer School, Ljubljana, Slovenia July 1-7th

Kraus K., Pfeifer N., 1998: Determination of terrain models in wooded areas with airborne laser scanner ISPRS Journal of Photogrammetry and Remote Sensing, 53, 193-203.

Kraus K., Pfeifer N., 2001: Advanced DTM Generation from LiDAR DATA. International Archives of Photogrammetry and Remote Sensing, Vol. XXXIV-3/ W4, Annapolis, MD, 22-24 Oct.

Marmol U., Jachimski J., 2004: A FFT based method of filtering airborne laser scanner data. International Archives of Photogrammetry and Remote Sensing Vol. XXXIII/3, s. 1147-1152, Istanbul.

Vosselman G., 2001: Adjustment and filtering of raw laser altimetry data. OEEPE Workshop on Airborne Laserscanning and Interferometric SAR for Detailed Digital Elevation Models, Stockholm.

Wack R., Wimmer A., 2002: Digital terrain models from airborne laser scanner data – a grid based approach. International Archives of Photogrammetry and Remote Sensing, Vol. XXXIV / 3B, Graz.

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