A MODIFIED METHODOLOGY FOR ANALYSING ALS OBSERVATIONS

Wioleta Błaszczak-Bąk, Artur Janowski, Waldemar Kamiński, Jacek Rapiński

Faculty of Geodesy and Land Management
University of Warmia and Mazury in Olsztyn

ABSTRACT

Airborne laser scanning survey results in a set of observation in the form of a point cloud. The point cloud is subjected to a process of further analysis, which consists of the preliminary data processing stage, the main processing stage and the visualisation stage. Such an analysis can lead, among others, to construction of a DTM. In order to improve the effectiveness of the ALS point cloud analysis for the purposes of DTM construction, certain modifications can be introduced at all of the mentioned stages.
The authors of the study propose an improvement to the standard methodology of analysing ALS observations by introducing an optimization algorithm at the preliminary processing stage. In order to smooth a digital terrain model, digital processing techniques and algorithms were also applied.

1. INTRODUCTION

The Airborne Laser Scanning method (ALS) is one of the new, dynamically developing technologies of surface area measurements, from the range of LiDAR measurements (Light Detection And Ranging). Due to their high density and accuracy, the data obtained can be used, among others, for construction of a DTM. Currently, ALS technology supports compilations based on traditional aerial photographs [Briese, Pfeifer 2001, Pfeifer, Mandlburger 2008]. The numerous advantages of ALS technology include, among others:

- **Rapid measurement data obtainment.**
- **Reduced measurement result analysis time.**

The capabilities of the scanning systems allow the recording of a huge amount of measurement data in a short time, obtaining a so-called “large data set”.
A standard methodology of analysing ALS observations (F) in order to generate a DTM consists of the following stages: obtaining the point cloud, preliminary processing (including a filtration process) and main filtration (including DTM construction) [Vosselman, Maas 2010]. The F methodology uses the original point cloud at each of the stages, without analysing whether the data set includes points which can be omitted in the compilation.

In Błaszczak-Bąk et al. 2010a, Błaszczak-Bąk et al. 2010b, the authors proposed a modification of the F methodology, which consisted in introducing the optimization algorithm (O) at the stage of preliminary data processing, thus reducing the size of the measurement data set [Błaszczak, Kamiński 2007]. The algorithm uses methods of cartographic generalization, e.g. the Douglas – Peucker method (D – P) [Douglas, Peucker 1973], the Visvalingam – Whyatt method (V – W) [Visvalingam, Whyatt 1992] and others and it can be applied before filtration (O – F) or after filtration (F – O). On the basis of the research conducted to date, it can be claimed that the O – F variant facilitates operation of the data filtration algorithm, shortens filtration time and contributes to the effective and faster preparation of data for DTM construction without losing information which is necessary for proper execution of the task. On the other hand, the F – O variant makes it possible to reduce the set that is directly used for construction of the DTM and to preserve the unchanged set of points reflecting the area coverage.

The aim of this study is to supplement the O – F analysis methodology with a smoothing algorithm in order to construct an optimal DTM. The smoothing algorithm uses one of the DSP (Digital Signal Processing) techniques, namely DFT (Discrete Fourier Transform).

2. A MODIFIED METHODOLOGY FOR ANALYSING THE ALS OBSERWATION

A modified methodology for analysing a measurement data set obtained by airborne laser scanning is presented in Błaszczak-Bąk, Janowski (2009) and Błaszczak-Bąk et al. (2010a). A modification of the standard methodology of the ALS point cloud analysis consists in applying an optimization algorithm at the stage of preliminary processing of the data set [Błaszczak, Kamiński (2007), Błaszczak-Bąk et al. (2010a)]. The optimization algorithm aims to reduce the number of points in the set originating from the airborne laser scanning (the D_{ALS} set).

A modification to the methodology of analysing the ALS point cloud can have two variants:

- **the O – F variant, which consists in carrying out first optimization and then filtration at the preliminary processing stage;**
- **the F – O variant, which proposes filtration first and optimization later.**

The application of the O – F variant allows reduction of the number of data in the D_{ALS} set used for filtration [Błaszczak-Bąk et al. (2010b)]. As a result of optimization, two data subsets are created: D^{O} – a subset of points after optimization, subject to further analysis, and D^{EDS} – a subset of eliminated data.

Afterwards, the D^{O} subset is subject to filtration. As a result of filtration, two subsets are created: $DTM^{O\text{-}F}$ – used for construction of a DTM and D^{R} – containing points that have not been qualified for DTM construction.

The F - O variant makes it possible to reduce the set which is directly used for DTM construction. The modification pursuant to the F – O variant consists in carrying out filtration of the original measurement set, D_{ALS}. The filtration of the D_{ALS} set results in obtaining two subsets: DTM^{F} – a subset of points, which will be used for DTM construction, and D^{R} – a subset of points not qualified for DTM construction. Afterwards, optimization is carried out only towards the DTM^{F} subset. As a result of the optimization, the following subsets are created: $DTM^{F\text{-}O}$ – an optimized subset of data for DTM construction and D^{EDS} – a subset of eliminated data.

As follows from the previous research, presented in Błaszczak-Bąk et al. (2010a) and Błaszczak-Bąk et al. (2010b), among others, it is more advantageous to use a modified

methodology of point cloud analysis in the O – F variant. Therefore, in the present study, the authors restricted themselves only to this variant, for practical purposes.
In the modified methodology of ALS point cloud analysis, the O – F variant applies all filtration methods known in the literature of the subject. The present study uses the robust method of moving surfaces, which is presented in a further part of the study.

3. OPTIMIZATION OF THE ALS DATA SET

While analysing the ALS point cloud, the effectiveness of the main processing stage can be influenced by the application of an algorithm reducing the number of observations in the D_{ALS} data set at the preliminary processing stage [Błaszczak, Kamiński 2007, Błaszczak-Bąk et al. 2010a].
The algorithm of the ALS point cloud optimization is carried out by means of reduction and it uses known methods of cartographic generalization. The starting point for executing the algorithm is to create the so-called "search strips" in the XOY plane. Detailed calculations are performed in the search strips. In the case of ALS, search strips most often overlap survey strips. The width of the survey strips results directly from the measurement and depends on the laser scanning angle and the flight altitude. The optimization algorithm consists of the following stages:

- **Establishing survey strips in the XOY plane.**
- **Choosing the method for cartographic generalization used for reducing the size of the measurement set (e.g. the D – P method).**
- **Application of selected generalization method in every strip (in the YOZ plane).**

4. FILTRATION

The main problem in the construction of the DTM model from the cloud of points obtained by means of ALS is to identify points representing the lay of land. The identification uses the methods of filtration which should (as far as possible) be carried out on real data [Borkowski 2004, Sithole, Vosselman 2004]. Filtration methods based on original survey data include, among others, the moving surface method [Elmqvist 2002, Jóźków 2007]. While executing the filtration by the moving surface method, one can use, e.g. polynomials. For the purposes of the present study, the polynomial of the first degree was used, in the following form:

$$z(x,y) = a + bx + cy \quad (1)$$

where: x,y,z – coordinates of points, a, b, c – estimated parameters of the polynomial. In the present study, the polynomial of the first degree was assumed for analysis purposes. Correction equations can therefore be written in the following form:

$$V_i = a + bx_i + cy_i - z_i \quad (2)$$

Relation (1) can be also noted as:

$$V = A\hat{X} - z \quad (3)$$

where: $V = [V_1, V_2, \dots, V_k]^T$ correction vector (k – number of observations in the analysed data set), $\hat{X} = [\hat{a}, \hat{b}, \hat{c}]^T$ – vector of estimated parameters of the model,

$z = [z_1, z_2, \dots, z_k]^T$

– vector of the altitude of points obtained from ALS, A – matrix of determined coefficients.
While looking for the answer to problem (3) using the method of least squares, one can obtain a vector of estimated parameters $\hat{X}^{LS}$ of the following form:

$$\hat{X}^{LS} = (A^T PA)^{-1} A^T Pz \tag{4}$$

where: $P = \mathrm{Diag}(p_1, \dots, p_k)$ is a diagonal weighting matrix, while $p_i = \frac{1}{D_{P_iP_0}}$, ($D_{P_iP_0}$ – is a distance between P_i points and the point of interpolated altitude P_0, i=1,…,k, k – is a number of points subjected to analysis. Estimated parameters can be also calculated with the application of robust estimation principles [Hampel 1973, Huber 1981]. In robust estimation, weights of p_i observations with standardized corrections $\bar{V}_i = \frac{V_i}{m_{V_i}}$ (where $m_{V_i} = \sqrt{P^{-1} - A(A^T PA)^{-1} A^T}$, is a mean error of the correction) falling outside the previously specified acceptable range <–g; g> are damped by the dumping function. The literature of the subject provides many forms of the dumping function, e.g. Hampel 1973, Huber 1981. The research presented in this study uses a one-sided form of the weight function applied in the Huber method (H). The function is written as follows:

$$w_i(\bar{V}_i) = \begin{cases} 1 & \text{when } \bar{V}_i \le g \\ \frac{g}{\bar{V}_i} & \text{when } \bar{V}_i > g \end{cases} \tag{5}$$

Calculations in robust estimation are executed in an iterative process, in which equivalent weights $\bar{P}_i$ are determined from the following relation:

$$\bar{p}_i = p_i w_i(V_i) \tag{6}$$

Polynomial parameters that are robust for outliers (objects belonging to the area coverage) can be obtained by executing the following iteration procedure:

$$\hat{X}^l = (A^T \bar{P}^{l-1} A)^{-1} A^T \bar{P}^{l-1} z \tag{7}$$

where: $\bar{P} = \mathrm{Diag}(\bar{p}_1^l, \bar{p}_2^l, \dots, \bar{p}_k^l)$) – is an equivalent weighing matrix, (l=1, 2.…, – is a number of iterations). The iteration process most frequently starts with the results obtained by the least squares method: $\hat{X}^0 = \hat{X}^{LS}$.

5. DTM SMOOTHING WITH APPLICATION OF DSP TECHNIQUES

Optimization and filtration lead to obtaining a cloud of points which create a data set for construction of a DTM. The model constructed with such data contains information about the macro- and microrelief. In many DTM applications (e.g. in compilation of certain thematic maps: soil, geological, environmental), the microrelief does not contribute any significant information about the relief, and in many cases, it makes the

DTM less clear. For these reasons, the authors decided to remove microrelief before creating a DTM. There are numerous methods which can be used for this purpose [Vosselman, Mass 2010] including the application of DSP algorithms (Digital Signal Processing) [Lyons 2000, Zielinski 2007].

In DSP, a discrete signal is sampled at constant intervals. For the needs of this study, the relief is treated as a discrete signal in the distance domain.

In order to check the distribution of frequencies in a given signal, one must go from the distance domain to the frequency domain. This can be achieved by applying the Discrete Fourier Transform – DFT, commonly used in signal analysis. An algorithm which greatly simplifies and shortens calculations which must be performed in order to find DFT is Fast Fourier Transform – FFT. The FFT method consists in matrix notation of the DFT transform, and then in uniform distribution of points approximating the signal graph [Kincaid, Cheney 2006]. The surface of the area can be presented by a certain finite number of sinusoidal functions of appropriate frequency, amplitude and phase. Representation of the relief can be therefore similar to the variability of the electric signal, while interference occurring in the course of the topographic surface can be considered equivalent to the noise appearing during signal transmission [Marmol, Jachimski 2004].

The algorithm of the FFT method applied in this study in order to remove the microrelief is executed in the following stages:

1. Preliminary processing of the ALS point cloud.
2. Construction of GRID in order to obtain an equally sampled signal in space. Dispersed points can be interpolated to GRID by various means [Kraus, Otepka 2005].
3. Arrangement of signal points in the following order: $p_{1.1}$, $p_{2.1}$, ..., $p_{i,1}$, $p_{i,2}$, $p_{i-1.2}$, $p_{i-2.2}$, ..., $p_{1.2}$, $p_{1.3}$, ...– where the indices stand, respectively, for a line and a column of the grid created.
4. DSP application.

An important step in point 4 is the choice of the filter which is to be used for smoothing the signal. There are four types of filters [Temes, Mitra 1978]: a low-pass filter, a high-pass filter, a band-pass filter and a band-rejection filter.

For the purposes of the present study, the use of a low-pass filter is recommended. Out of all known low-pass filters, the Butterworth filter was selected. This filter, as compared to other filters, has the most flat amplitude-frequency characteristics in the passband. This takes place at the cost of a slope of the characteristics at the end of the passband. The characteristics should start maximally flat for zero frequency and incline only near the f_g cutoff frequency (f_g is usually the frequency of 3dB.

An important point while applying the Butterworth filter is to establish the so-called cutoff frequency. The cutoff frequency determines the signal graph after application of the filter.

In case of applying the Butterworth filter to remove the microrelief, the choice of the cutoff frequency will determine the degree of DTM "smoothing".

6. AN EXAMPLE OF PRACTICAL APPLICATION

In practical analyses, a set of survey results in the form of a point cloud obtained from Idaho Geospatial Data Clearinghouse, University of Idaho Library (Internet access at http://inside.uidaho.edu/geodata/LiDAR/) was used. This set contains about 19,100,000 points. For the purposes of this study, a sub-set containing about 24000 points was used, as presented in Fig. 1.

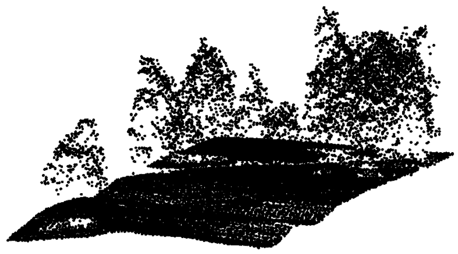

Fig. 1. The original ALS point cloud subset.

The presented D_{ALS} subset was subject to further optimization and afterwards, filtration. After applying the O – F variant, the DTM^{O-F} subset was used, which is presented in Fig. 2.

Fig. 2. The ALS point cloud subset after application of the O - F variant.

Next, on the basis of the DTM^{O-F} subset, the GRID was constructed with the application of the Kriging method, assuming a mesh of 30 cm (the mean distance between adjacent points in the cloud).
At the subsequent stage, the grid points were arranged in appropriate order to facilitate the DSP application.
Since microrelief should appear in the signal as high frequency constituents, a low-pass filter was used for filtration purposes (according to the assumption presented above). Fig. 3 presents the signal for one selected strip.
In order to establish the cutoff frequency, the FFT of the signal was created. The FFT of the signal is presented in Fig. 4.

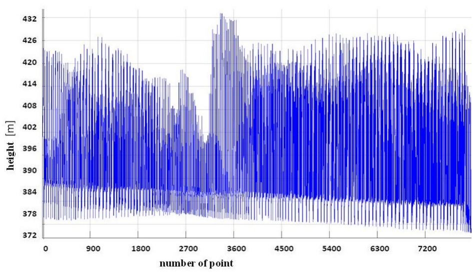

Fig. 3. Signal for one strip.

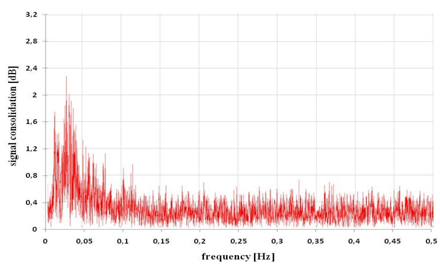

Fig. 4. FFT of the signal.

After creating the FFT of the signal, a low-pass Butterworth filter was applied to smooth the microrelief. Pursuant to Fig. 5, the following cutoff frequencies were assumed: 0.050 Hz, 0.033 Hz, 0.020 Hz.
Operation of a low-pass Butterworth filter at the cutoff frequency of 0.050 Hz is presented in Fig. 5a. Fig. 5b i Fig. 5c present the operation of this filter at cutoff frequencies of 0.033 Hz and 0.020 Hz.

c)

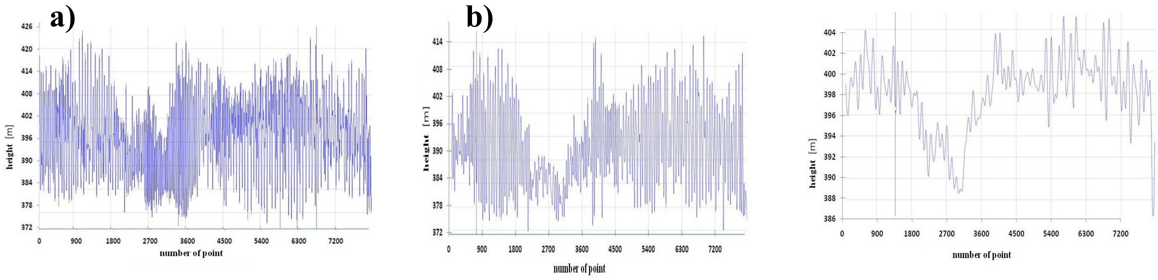

Fig. 5. a) The signal after filtering for cutoff frequency of 0.050 Hz; b) The signal after filtering for cutoff frequency of 033 Hz; c) The signal after filtering for cutoff frequency of 020 Hz.

7. DTM CONSTRUCTION

Application of the modified methodology of the ALS point cloud analysis made it possible to generate the DMT presented in Fig. 6.

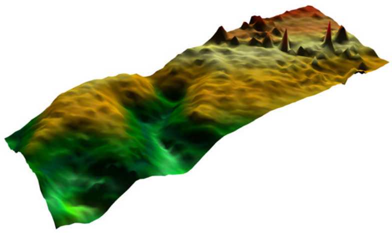

Fig. 6. The DTM generated pursuant to the O - F variant.

For comparison purposes, DTMs were generated, the construction of which was preceded by application of the DFT algorithm. The subsequent illustrations presents, respectively: Fig. 7 – DTM for cutoff frequency of 0.050 Hz, Fig. 8 – 0.033 Hz, Fig. 9 – 0.020 Hz.

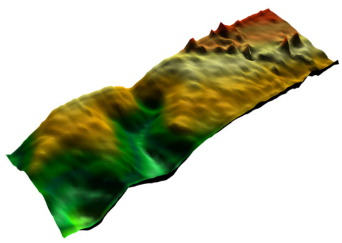

Fig. 7. DTM for cutoff frequency of 0.50 Hz.

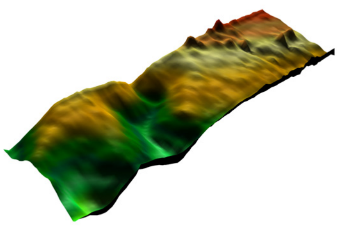

Fig. 8. DTM for cutoff frequency of 0.33 Hz.

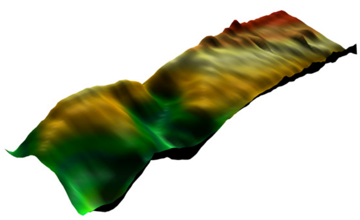

Fig. 9. DTM for cutoff frequency of 0.20 Hz.

While comparing the results obtained, one can observe that the most convenient DTM model (as regards minimization of the microrelief) was obtained for the cut-off frequency of 0.20 Hz.

8. CONCLUSION

This study proposes a method to be used while analysing the ALS point cloud in order to obtain a DTM.

In the opinion of the authors, the analysis carried out according to the schema of modified methodology of the ALS point cloud analysis with the application of DFT is optimal as regards the quality of the DTM constructed and the computational efficiency. This methodology obtains a DTM with the accuracy needed for a specified task. The optimization stage reduced the number of points in order to accelerate further stages, the filtration removed from the data set those points that did not belong to the DTM and DSP removed the microrelief, which is redundant in many compilations.

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