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Research

JUSTIFICATION OF QUALITY ESTIMATION METHOD OF CREATION OF DIGITAL ELEVATION MODELS ACCORDING TO THE DATA OF AIRBORNE LASER SCANNING WHEN DESIGNING THE MOTOR WAYS

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ABSTRACT

The method of creation of digital elevation models according to the data of the airborne laser scanning was considered. The dependencies of the density of the laser points from the angles of relief slopes were determined, which represent the plain relief with the angles of slope up to 2°; hilly relief with the angles of slope up to 4°; high relief with the angles of slope up to 6°; mountain and piedmont relief with the angles of slope up to 6°. The minimal number of the laser points necessary for the creation of digital elevation models was revealed for a distinct specific relief. The relief modeling of geophysical well logging along the designed motor ways was performed in the work. The relief modeling was performed in two stages: the first stage of modeling is a creation of a digital model of relief that includes all points belonging to the ground surface. This digital elevation model was accepted conventionally as "ideal model". It was compared with the digital elevation models with the less density of cloud of laser points (CLP). The second stage of the modeling is a creation of a digital elevation model according to the points obtained taking into account the rated error of the laser scanner (m=0.1 m). The areas were determined for the estimation of the data quality of the airborne laser scanning: anthropogenic character of relief; the areas located on the relief of the biggest angles of scope such as hilly relief with the angles of slope up to 4° and high relief with the angles of slope up to 6°. The estimation of the quality of the digital elevation models built according to the data of the airborne laser scanning was performed.

INTRODUCTION

Designing of the motor ways was always a labour-intensive process. In the modern world, the motor ways are the main roads for transportation of people and cargo. The requirements to the motor ways are increased every year. They shall provide the high degree of traffic safety and be constructed in a shortest possible time. Regarding this, the creation of technologies aimed at the increase of designing quality of the motor ways is a very important problem.

The cartographical base for a particular scale is necessary for the designing of the motor ways. It takes much time to obtain this information during the designing. Now the most perspective method of obtaining of the coordinate base is the airborne laser scanning. However, its efficient use is connected to the solution of several problems.

The main problem is to create the digital elevation model (DEM) that to the large extent will respond to the real situation and at the same time it will contain the minimal number of laser points for the typical forms of the relief. DEM is the base on which the design documentation for the construction of the motor ways is executed, including the creation of longitudinal and cross-section profiles and also the calculation of the groundwork volumes.

The works of the national scientists: Antipov, Boyko, Grigoryeva, Kornilov, Medvedev, Melnikov, Naumenko, Pavlov, Seredovich., Slepchenko,

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Sukhov, Cherkesov, Essin, Khamitov (Antipov, 2010; Vinokurov, 2009; Kuzin, 2013; Medvedev, *et al*., 2007; Mischenko and Mischenko n.d.) and also the foreign ones: Peter Axelsson, Emmanuel Baltsavias, Andzhej Borkowski et al. (Ackermann, 1999; Axelsson, 1999; Baltsavias, 1999; Briese, *et al*., 2012) were dedicated to the study of the problems of the reflection of ground surface by means of remote sensing methods including the laser location. However, there are still unsolved problems of the minimization of laser points participating in the creation of DEM for the typical forms of the relief, the estimation of the quality of the obtained digital elevation models of the relief built according to the data of the airborne laser scanning and some other problems.

METHOD

The complex of studies was performed that consisted of the geophysical well logging modeling of the various relief; the methods of the statistical analysis to determine the accuracy of the data of the airborne laser scanning; the comparison of the results of the airborne laser scanning and the results of the tacheometrical survey.

Now the method of the airborne laser scanning becomes more popular. The data of the airborne laser scanning is a cloud of laser points that is used to create the digital elevation models of the relief. Following the results of the airborne laser scanning (ALS), the laser points (LP) are obtained; their density reaches 8-10 points per 1 m^2. Even after filtration, there are a large number of laser points; that is why there is a problem of down sampling of the density of laser points. The improvement of use of the technology of ALS consists of the determination of the minimal number of laser points per 1 m^2 for the various reliefs (Gor'kavyy, 2011; Komissarov, 2006; Mischenko, *et al*., 2014; Khromykh, *et al*., 2007).

Among the variety of the various relief classifications, the areas were distinguished according to the characteristics of the relief and having maximally prevailing angles of slope (according to the Instruction of topographic survey on scales 1:5000, 1:2000, 1:1000, 1:500):

- plain reliefs with the angles of slope up to 2°;

- hilly reliefs with the angles of slope up to 4°;

- high reliefs with the angles of slope up to 6°;

- mountain and piedmont reliefs with the angles of slope up to 6°.

In this regard, the geophysical well logging of the relief modeling along the designed motor ways was performed.

At the same time, it is offered to perform the modeling of the relief in several stages:

1. The first stage of the modeling is a creation of the digital elevation model that includes all points belonging to the ground surface. This DEM was accepted conventionally as the "ideal model". It was compared with the digital elevation models with the less density of the laser points. The down sampling of the density of laser points was performed.

2. The second stage of the modeling is a creation of the digital elevation model according to the markings obtained taking into account the rated errors of the laser scanner (m=0.1 m). Similarly, to the first stage of the modeling, the obtained DEM includes all points belonging to the ground surface. It was compared with the digital elevation models of the relief with the less density of the laser points.

RESULTS

The comparison of the models with different density of the laser points per 1 m^2 is possible in geophysical well logging ArcGIS. On the base of laser points with the different density the GRID-surfaces were created, the size of a pixel of which was 0.10 m × 0.10 m (for plain, hilly, high reliefs with the angles of slope up to 6°), 0.05 m × 0.05 m (for mountain and piedmont relief with the angle of slope app. 6°). The GRID-model is a regular matrix of the elevation values obtained during interpolation of the initial data. For every cell of the matrix, the elevation is calculated on the base of the interpolation. Actually, this is a net the size of which is set according to the requirements of the accuracy of the particular solving problem. To estimate the created models with the number of the laser points necessary for the reflection of the relief of the surface, the elevations of the compared sparse DEMs were deducted from the reference DEM. This operation can be performed by means of the functional possibilities of the module Spatial Analyst of the geophysical well logging ArcGIS. For every pair of the compared DEMs, the GRID-scanning pattern was created, the pixels of which were given the values of the height differences.

The digital elevation models of the relief were compared that include all laser points of the class "ground" and the digital elevation models with the reduced number of laser points (Fig. 1).

In this case, the digital elevation model created according to the class "ground" was accepted as ideal regardless of the impact of the rated errors of the laser scanner. The standard values of accuracy were accepted as the limits of the maximal deviations of the results of modeling, that is, for the topographic plan of the scale 1:1000 at the contour interval of 0.5 m the average square error shall not exceed 0.18 m and 0.26 m (for forest lands). And the average errors of the relief survey shall not exceed 0.13 m and 0.19 m (for the forest areas of relief).

Using the same method, the digital elevation model that includes all laser points of the class "ground" was compared with the digital elevation models of relief with the smallest number of laser points. But in this case when creating the digital elevation model the elevations were obtained taking into account the rated errors of the laser scanner (m=0.1 m). The research was performed taking into account this

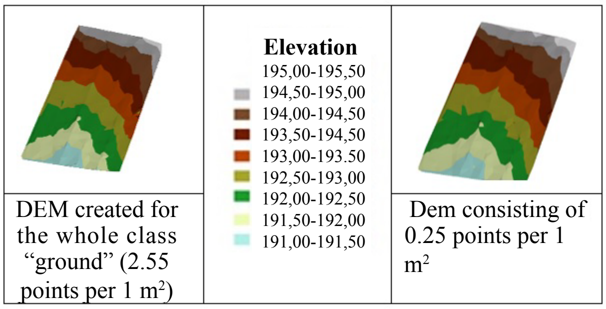

Fig. 1 The examples of the created DEMs in the geophysical well logging ArcGIS with a various density of the laser points.

tolerance, and the results are shown in the Table 1 and graphs (Fig. 2-4).

The dependence of the density of laser points from the angles of the relief slope is shown in Fig. 3 and 4, taking into account the impact of the rated error of the laser scanner (Fig. 4) and regardless of the impact of this error (Fig. 3). The diagrams show the minimal, maximal and average value of the number of laser points. The low discrepancy of the density of the laser points is noticed on the diagrams that will help to determine in the future the necessary number of points to create the accurate digital elevation model of the scale 1:1000 for the relief with different angles of scope.

The following conclusions were obtained during the statistical analysis of the results of modeling on the base of the module Spatial Analyst of geophysical well logging ArcGIS (the average density of laser points per 1 m^2 for different characteristics of the relief):

- the minimal number of laser points for the creation of the digital elevation model of the plain relief with the angles of slope up to 2° regardless of the impact of the rated error of the laser scanner is 0.23 p/m^2. Taking into account the rated error of the laser scanner it is 0.41 p/m^2.

- the minimal number of laser points for the creation of the digital elevation model of the hilly relief with the angles of slope up to 4° regardless of the impact

Characteristics of the relief and maximally exceeding angles of slope	Characteristics of DEM	First test area	Second test area	Third test area	Fourth test area	Fifth test area	Sixth test area
Plain relief with the angles of slope up to 2°	Regardless of the rated errors of the laser scanner	0.25	0.24	0.24	0.20	0.22	0.23
Number of laser points per 1 m^2	Taking into account the rated errors of the laser scanner	0.43	0.31	0.40	0.42	0.43	0.40
Hilly relief with the angles of slope up to 4°	Regardless of the rated errors of the laser scanner	0.49	0.48	0.47	0.46	0.48	0.49
Number of laser points per 1 m^2	Taking into account the rated errors of the laser scanner	0.66	0.63	0.74	0.66	0.67	0.66
High relief with the angles of slope up to 6°	Regardless of the rated errors of the laser scanner	1.00	0.95	0.81	0.88	0.94	0.99
Number of laser points per 1 m^2	Taking into account the rated errors of the laser scanner	1.20	1.14	1.21	1.22	1.20	1.24
Mountain and piedmont relief with the angles of slope up to 6°.	Regardless of the rated errors of the laser scanner	1.5	1.61	1.69	1.55	1.64	1.55
Number of laser points per 1 m^2	Taking into account the rated errors of the laser scanner	1.8	1.93	1.96	1.99	1.95	1.97

Table 1. Minimal amount of the laser points per 1 m^2 for various characteristics of the relief

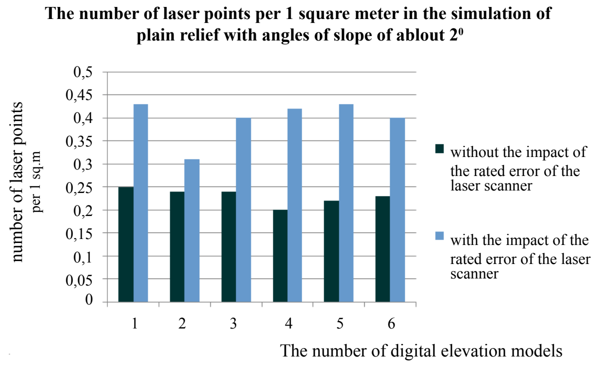

Fig. 2 Number of laser points per 1 m² for the plain relief.

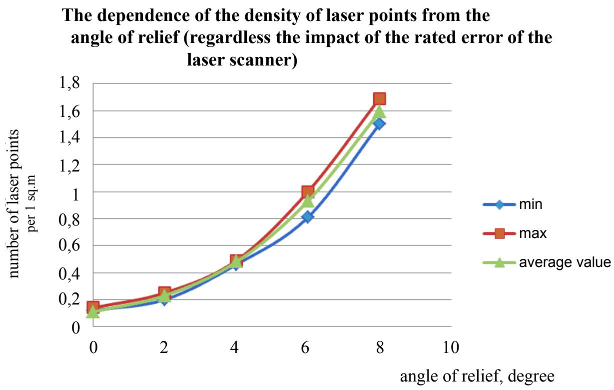

Fig. 3 Dependency diagram of the density of laser points from the angle of relief slope.

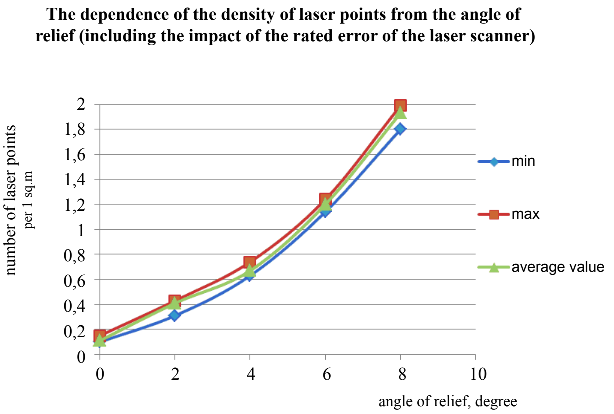

Fig. 4 Dependency diagram of the density of laser points from the angle of relief slope.

of the rated error of the laser scanner is 0.48 p/m². Taking into account the rated error of the laser scanner it is 0.67 p/m².

- the minimal number of laser points for the creation of the digital elevation model of the high relief with the angles of slope up to 6° regardless of the impact of the rated error of the laser scanner is 0.93 p/m². Taking into account the rated error of the laser scanner it is 1.93 p/m².

- the minimal number of laser points for the creation of the digital elevation model of the mountain and piedmont relief with the angles of slope up to 6° regardless of the impact of the rated error of the laser scanner is 1.59 p/m². Taking into account the rated error of the laser scanner it is 0.41 p/m².

Estimation of quality of the digital elevation models of the relief

The estimation of quality is an important part of a geodetic survey. As the airborne laser scanning is a rather new type of survey, the necessary normative and technical base for the creation and updating of topographic plans is missing now. Therefore, there is a problem of control of the data accuracy of the airborne laser scanning. It is necessary to perform the estimation of the accuracy of the digital elevation models comparing the data of the airborne laser scanning with the data of tacheometric survey that are accepted as the reference data.

For the quality estimation of the data of areal laser scanning, the following areas were determined:

1. Anthropogenic character of the relief is the forms of the relief arising as a result of the industrial activity of a human; those are excavations, open cuts, canals, fills, piles, etc.

2. The areas located on the territory with the highest angles of slope such as hilly relief with the angles of slope approx. 4° and the high relief with the angles of slope approx. 6°.

It is necessary to estimate the quality of the digital elevation models of the relief obtained as a result of the airborne laser scanning comparing with the digital elevation model received due to the tacheometric survey.

The land lot of the square 3900 m² with the anthropogenic character of the relief was chosen as the first lot for the analysis. The estimation of accuracy of the obtaining of the elevation of the digital models of the relief received due to the data of the airborne laser scanning was performed.

The software program of geophysical well logging ArcGIS was used for the statistic estimation of the accuracy of heights of the airborne laser scanning.

The following initial data were taken for the comparative analysis:

- array of the laser points that corresponds to the class "ground";

- survey pegs of tacheometric survey obtained for the scale 1:1000 with the section of the relief 0.5 m. The comparative analysis of the digital elevation model was performed that was made according to the survey pegs of the tacheometric survey (it was accepted as reference) and also the digital elevation model obtained according to the data of airborne laser scanning. When analyzing the data, the local coordinate system was used. The coordinates of the laser points by means of the coordinate transformation systems were transformed into the local coordinate system. The created digital elevation models were converted into the GRID-scanning patterns (GRID-surfaces) for the convenience of the comparison of two scanning patterns (Ackermann, 1999).

The value of the discrepancy of the elevations of the digital elevation model was determined, it was obtained according to the data of tacheometric survey of the relief and the digital elevation model received according to the data of the airborne laser scanning.

The comparison of two digital elevation models was performed in the software product-geophysical well logging ArcGIS according to the uniform grid of the square cells with the length of one side 0.5 m. The elevations were extracted and the discrepancies of the elevations (ΔH) were calculated for the obtained points of the analyzed digital elevation models.

The final result is shown in Fig. 5, in the form of a diagram: 70.5%, 0.15 m to 0.19 m; 7.5, 0.10 m to 0.15 m, 9.5%, less than 0.10 m, and 12.5 % of the total number have the discrepancy more than 0.19 m.

The land lot of the square 14,364 m^2 located in the high-terrain relief with the angles of slope approx. 6° was chosen as the second land lot.

By analogue with the first land lot, the following initial data were taken for the comparative analysis:

- array of the laser points that corresponds to the class "ground";

- survey pegs of tacheometric survey obtained for the scale 1:1000 with the section of the relief 0.5 m.

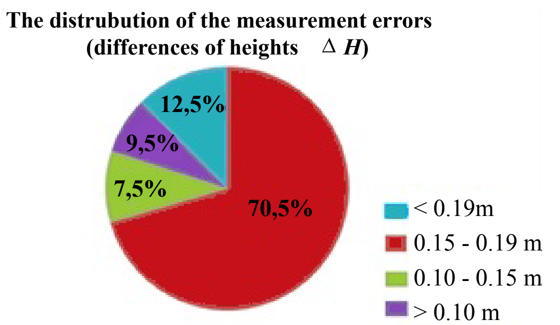

Fig. 5 Distribution of the measurement errors for the first control land lot.

The comparative analysis of the digital elevation model was performed that was made according to the survey pegs of the tacheometric survey (it was accepted as reference) and also the digital elevation model obtained according to the data of the airborne laser scanning. The created digital elevation models were converted into the GRID-scanning patterns (GRID-surfaces) for the convenience of the comparison of two scanning patterns (Fig. 6).

It is necessary to reveal the value of the discrepancy of the elevations of the digital elevation model obtained according to the data of tacheometric survey and the digital elevation model received according to the data of the airborne laser scanning.

The comparison of two digital elevation models was performed in the software product geophysical well logging ArcGIS according to the uniform grid of the square cells with the length of one side 0.5 m. The elevations were extracted and the discrepancies of the elevations (ΔH) were calculated for these points of two analyzed digital elevation models (Ackermann, 1999).

The final result is shown in Fig. 7, in the form of a diagram: 10.3% has the height discrepancy of 0.15 m to 0.19 m; 75.5%, 0.10 m to 0.15 m; 5.0% less than 0.10 m, 9.2% of the total number have the discrepancy of more than 0.19 m.

It can be concluded that the land lots on the open, hilly relief with the angles of slope approx. 4° have a height discrepancy ΔH equal to 8.0% that is not in the range of errors. The land lots located in the high relief with the angle of slope approx. 6° have the discrepancy of 9.2% and the land lots with the anthropogenic relief have 12.5% (Fig. 8).

On the base of the conducted analysis, it was revealed that to estimate the results of the airborne laser scanning we shall choose the land lots located in the area with the biggest angles of slope and also the land lots with the anthropogenic character of the relief.

CONCLUSIONS

The following conclusions can be made:

1. The method of creation of digital elevation models was developed and it optimizes them for the efficient design of the motor ways on the base of the analysis of the results of the airborne laser scanning.

2. The minimal number of the laser points per 1 m^2 for different reliefs with the prevailing angles of slope was established (the average density of the

	
Scale of height, m	
185,00 - 185,50 185,50 - 186,00 186,00 - 186,50 186,50 - 187,00	187,00 - 187,50 187,50 - 188,00 188,00 - 188,50 188,50 - 189,00 189,00 - 189,50
Relief obtained according to the data of ALS	Relief obtained according to the data of tacheometric survey

Fig. 6 DEMs created using the different initial data for the second control land lot.

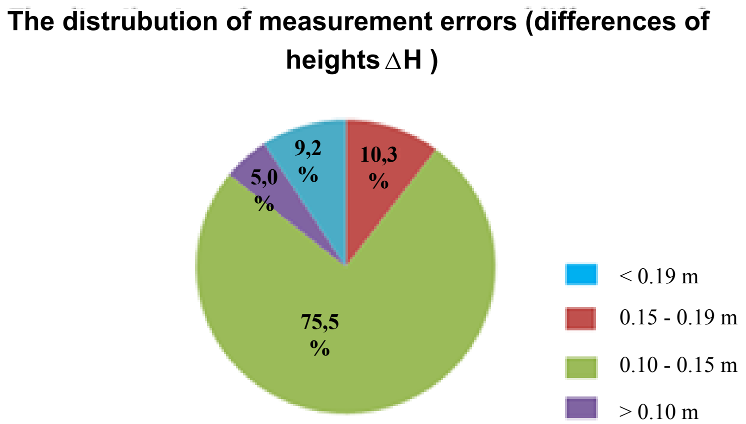

Fig. 7 Distribution of the measurement errors for the second control land lot.

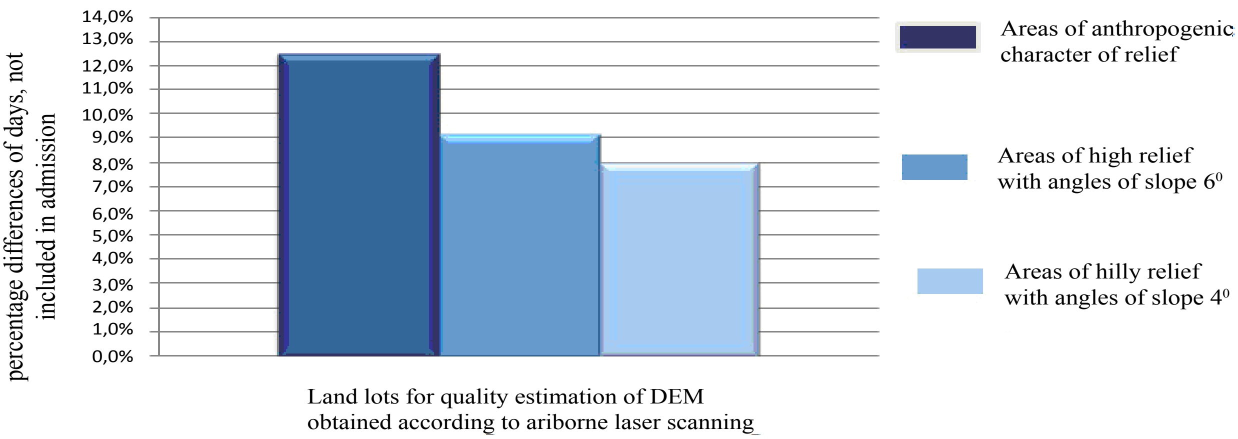

Fig. 8 Height discrepancy ΔH that exceeds the standard tolerance on the specially allocated control land lots.

laser points per 1 m^2 for various characteristics of the relief).

3. The method of accuracy control of the data of the airborne laser scanning was offered and grounded on the base of the conducted research for the scale 1:1000.

4. It was revealed that the estimation of the quality of digital elevation models created according to the data of the airborne laser scanning shall be performed on the land lots located in the area with the biggest angles of slope and on the land, lots with the anthropogenic character of the relief.

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