Quality analysis of voxel models obtained with remote sensing

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Abstract. Use of the resource potential of the Arctic is impossible without reliable information about the spatial and temporal characteristics of the developed territories. The topographic and bathymetric information are needed to solve engineering and logistic tasks. Furthermore, surveying, geodetic surveying and geological surveys in these territories are limited by climatic conditions and their infrastructural remoteness. That means, that it's needed to replace classical methods of performing geodetic works and surveys with the presence of workers on the object with modern automated methods of remote sensing of territories. That methods include the technologies of multipath echo-location, aerial or terrestrial laser scanning, photogrammetry and space sensing of the Earth. Despite the differences between these technologies, they are united by the result, the geospatial data, often called a "point cloud". Such point clouds are not regular in their structure and form 3D-model of the object due to the redundant data, which makes processing, systematizing and storing this kind of the information more difficult. The paper considers the method of generalization of geospatial data, that allows to reduce these disadvantages by approximating local sections of the model with planes that fit into a fragment of a point cloud using the least squares method. The model described in the paper allow to statistically assess the quality of the initial data, to simplify next mathematical processing for solving specific engineering problems, including geomechanical, environmental and glaciological monitoring.

1 Introduction

The development of mankind, which has determined the content and form of social relations, requires stable sources of natural resources for its preservation. The limit of the economic markets and occupied territories motivates society to use lands and resources, which accepted as technologically and economically unprofitable for development in the past. The development of the Arctic and the adjacent territories of the far North will preserve the economic and raw material balance, develop logistics and trade routes with strengthening stability in the world [1]. The existing experience of developing the territories of the far North connected with the specific nature of the climate and the fragility of the ecological systems.

Responsible and consistent development of the Arctic is impossible without knowledges about the nature of the relief of the land and the seabed of the Arctic Ocean. Despite the apparent simplicity and naturalness of the formulated task, its solution is not complete. For example, the volume of the Arctic territories of Canada that meet modern requirements is in the region of 6% of the total water area [2]. The land areas northern than 60 altitude are completely covered by the digital relief model ArcticDEM, but a number of published studies prove the limit of applicability in solving local problems. The actual errors of this model are about several meters in height [3], which implies the necessary additional surveying and geodetic surveys.

The solution of the problems of mine surveying, geodetic and hydrographic study of the Arctic is associated with difficulties caused by the poor development of the infrastructure of the region, systems of points of state geodetic networks [4] and the general severity of the climate. This implies the limited economic and production efficiency of using traditional methods of performing topographic and bathymetric works. Modern technologies of remote sensing, including laser scanning [5, 6], photogrammetric [6, 7] and space surveys [8] are increasingly used in solving various problems associated with the development of the Arctic. Monitoring of the state of glaciers [9-11], the thickness of the snow cover [12] and landslides caused by the melting of permafrost [13, 14] are increasingly performed using the above technologies.

2 Problem statement

The result of remote survey methods (in particular, laser scanning and photogrammetric surveys), produce huge irregular arrays of spatial data that form a model of the surveyed object as a “point cloud”. Such clouds can

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contain hundreds of millions of individual points, while remaining discrete. That means that the solution of practical problems requires the construction of surfaces that interpolate the space between adjacent points.

The solutions in applied practice consist in the construction of three-dimensional TIN surfaces that fill the space between the points with triangular polygons or DEM models - raster images, where the average elevation of the relief determines the color of the pixel for the corresponding area of the terrain. A TIN surface uses an excessive number of polygons, being not robust to errors in the initial data, which does not allow assessing the quality of the resulting model. A DEM model, on the other hand, does not differentiate relief changes within each pixel, allowing for the possibility of serious errors in case of a sharp relief change. The proposed method for processing point clouds is a kind of compromise between the approaches, reducing the disadvantages of each of the methods, while retaining most of their advantages.

3 The idea of work

The idea of work is to use a voxel model to structure data. This approach is often used in tasks requiring generalization of initial 3D data and allows to reduce the volume of points processed at a time. For example, in [15], it is used to segment a scan of a tree and highlight points related to its individual leaves, and in [16] to automate the monitoring of cultural heritage objects. The efficiency of voxel models directly depends on their scale - the size of the voxels used in the construction [17, 18]. The smaller the voxel size, the higher the detail and detail of the model, but the more difficult it is, in turn, to ensure its filling with a sufficient amount of initial data.

Dividing the original point cloud into relatively small areas will allow us to make an assumption of the linear nature of the change in the height of the points relative to their planned position. This assumption will allow replacing the original set of points within a single voxel with a plane that approximates it using the least squares method. The high density of the initial data makes it possible to guarantee the saturation of each voxel with points in an amount sufficient for calculating the plane and for assessing the accuracy of the parameters defining it. In that way, it is possible to assess the quality of the resulting model and the initial data.

4 Description of the experiment

The previously described calculation algorithm was implemented as a separate package of classes in the Python. An artificial relief model was used as an object of research. A three-dimensional point cloud was obtained photogrammetrically using the AgiSoft Metashape program.

The stability of the model to the influence of random factors (such as errors in determining points, their distribution within the model, errors in the external orientation of the model, etc.) was controlled statistically, for which the model was calculated using ten independent sets of images.

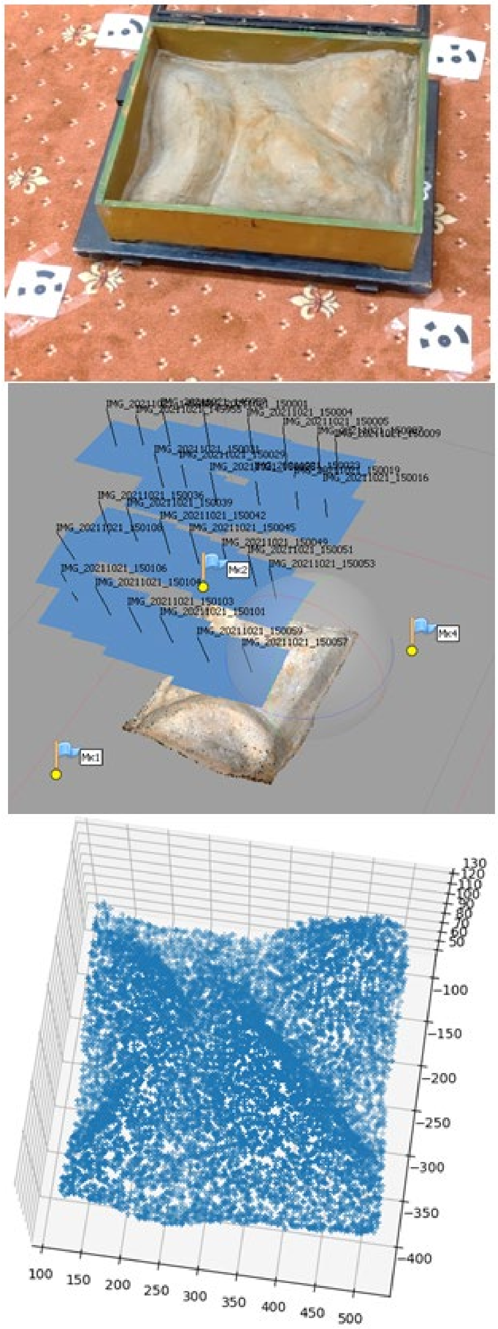

Fig. 1. Photo of the used model, an example of calculating a point cloud in the AgiSoft Metashape program, a cloud sparse to 10,000 points

The number of images in each series of measurements ranged from 15 to 20. The models were brought to a single coordinate system using four static exterior orientation marks. To increase the clarity of the experiment, the point clouds were brought to a general scale of 1000: 1. The number of points in each model was about 600-800 thousand points.

For each model, the calculation was performed for different sizes of the voxel grid. The grid spacing was equal to: 1 m, 5 m, 25 m, 50 m, 100 m and 250 m.

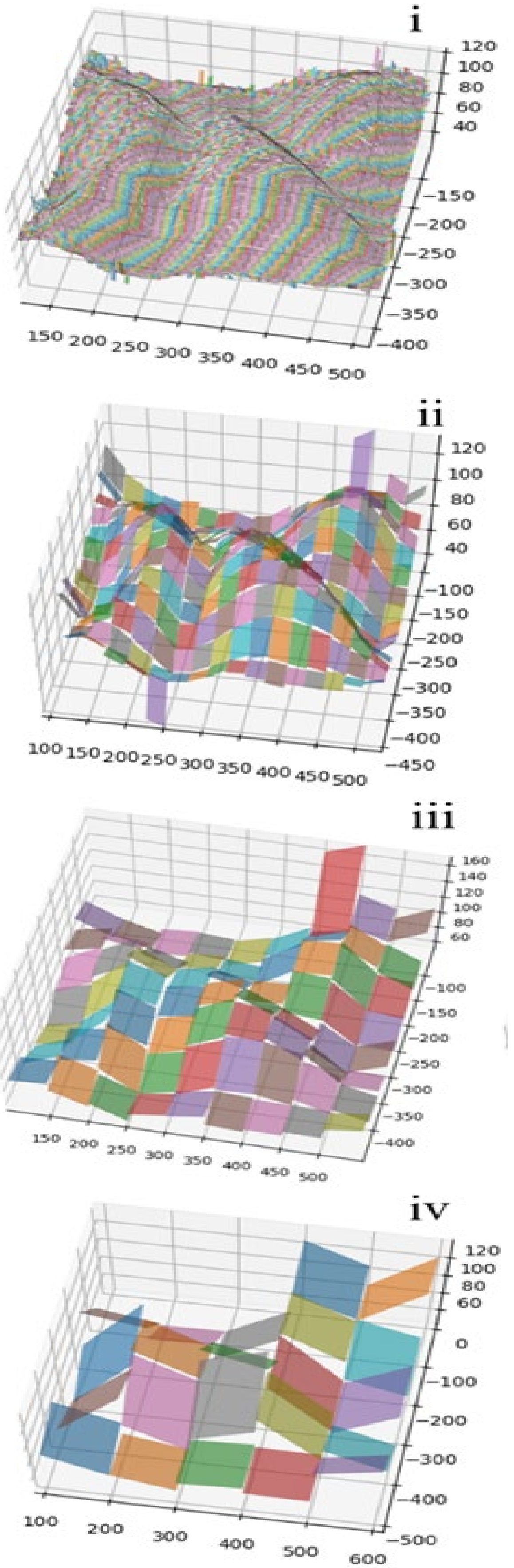

Fig. 2. An example of the calculated models at various scales of the voxel model: i) 5m; ii) 25m; iii) 50m; iv) 100m

For each voxel, the standard deviation (RMS) of points from the approximating plane was calculated, with an error map creation.

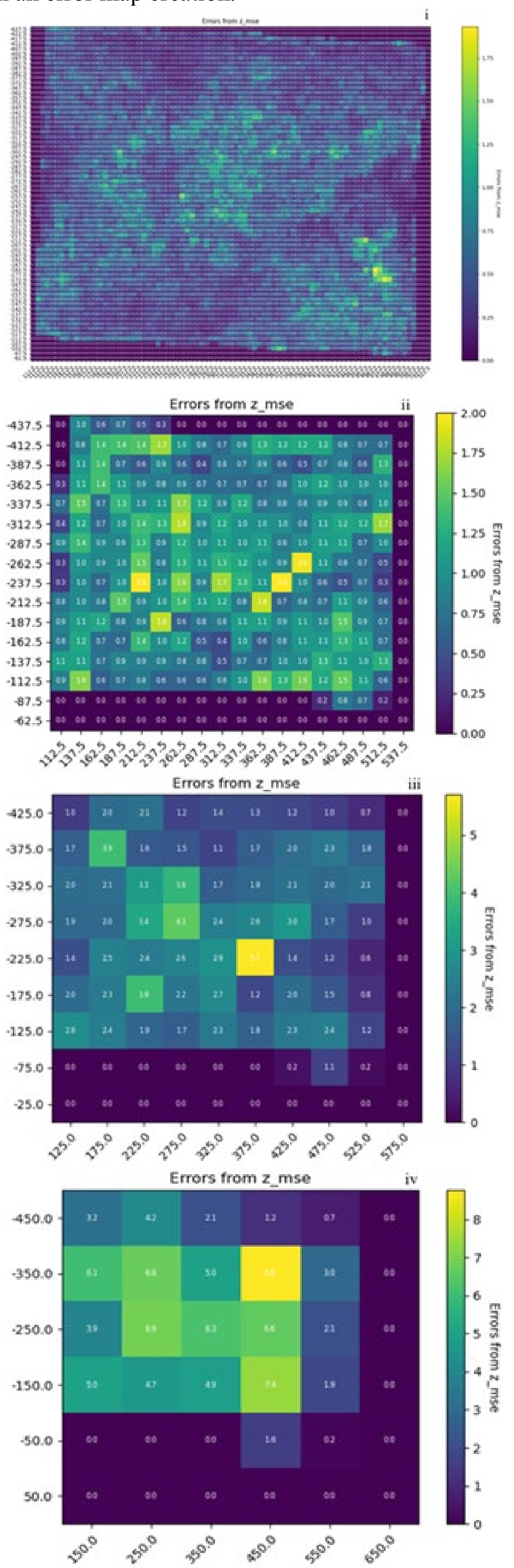

Fig. 3. The RMS of the approximating plane in height at various scales of the voxel model: i) 5 m; ii) 25 m; iii) 50 m; iv) 100 m

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5 Experimental results

From the Figure 3, it can be seen that the root-mean-square error of the approximation of points in the voxels is not evenly. Large error values fall on voxels where the nature of the relief change is not linear, with an increase in the density of the voxel grid and a decrease in the size of an individual voxel, the absolute value of the RMS approximation decreases.

The simulation results for mesh sizes 1 and 250 m are not presented due to the low clarity of the result. In particular, the model, built on a grid of squares of 250 meters, contains only 6 voxels for the considered area of the site, which does not allow to represent the nature of the relief of the original cloud. The model built on a 1 m grid, on the contrary, almost accurately approximates the original point cloud, but due to the low saturation of each of the voxels with the initial data, it does not allow to reliably evaluate its accuracy.

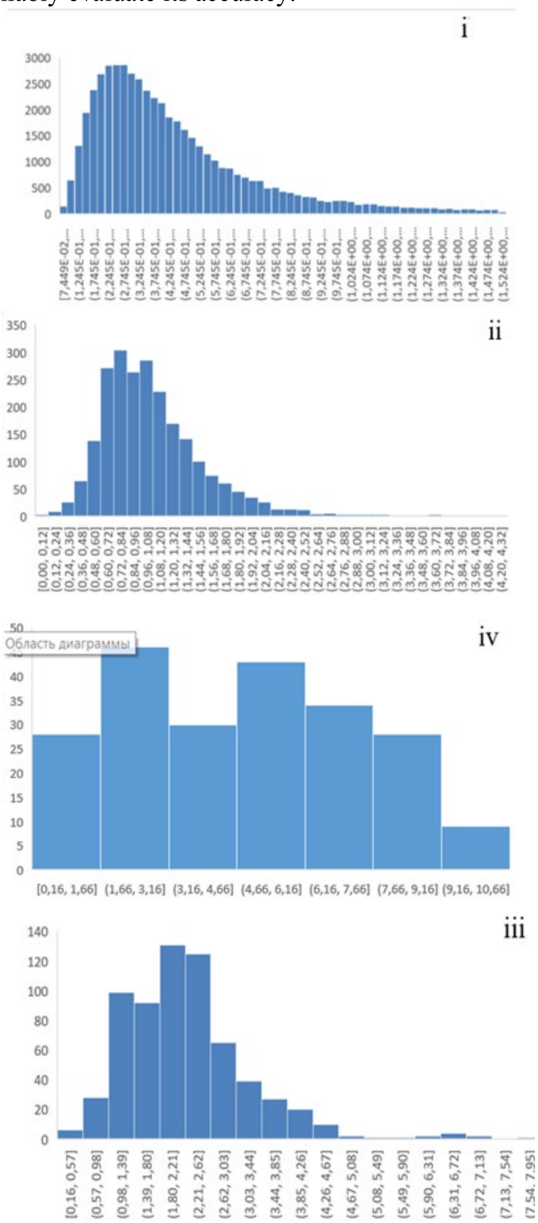

Fig. 4. Histograms of distribution of SKP approximation for different scales of the voxel model: i) 5 m; ii) 25 m; iii) 50 m; iv) 100 m

To check the robustness of the resulting models with respect to individual series of measurements, a one-way ANOVA was performed. The analysis results showed the equality of the mean value of the model error between the series for each of the voxel grid scales. The confidence level of the result ranged from 0.16 to 0.97. The hypothesis adopted in this way about the equality of the quality of models of the same scale with each other made it possible to combine them into one statistical sample for further analysis.

The nature of the RMS distribution of the model is shown on the frequency distribution histograms shown in Figure 4.

The histograms presented in Figure 4 show that the distribution of the approximation error within every individual voxel is a random variable, the distribution of which is consistent with the Pearson $\chi 2$ distribution. The asymmetry of the obtained distributions can be explained by the dominant influence of the change in the relief on the final quality of the approximation.

Reducing the model errors to a uniformly distributed approximation error is achievable by recursively refining the voxel grid in those areas where the error exceeds the specified tolerance. The depth of recursion can be roughly predicted from the dependence of the average value of the RMS approximation on the size of an individual voxel, shown in Figure 5.

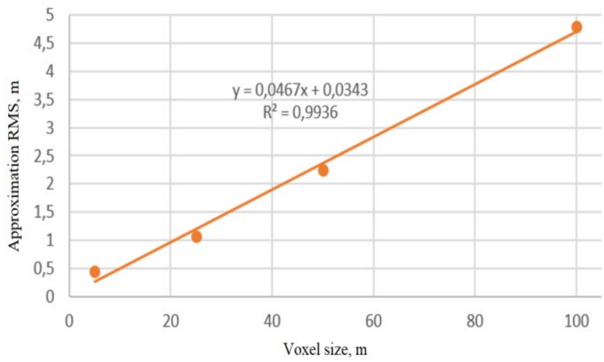

Fig. 5. Dependence of the average value of the RMS approximation on the size of an individual voxel

6 Conclusions and conclusion

The experiment proved the potential efficiency of using the proposed method for constructing a digital elevation model. The obtained regularities demonstrate a high correlation between the quality of the resulting model and the scale of the voxel grid used.

Assuming a constant voxel size and a fixed number of parameters describing the plane equation in three-dimensional space, the final size of the calculated model ceases to depend on the initial density of the processed point cloud. Each point of the model obtained during the survey will contribute to the improvement of the quality and reliability of the result, replacing the direct discharge of point clouds that is currently used. The predictability of the amount of data occupied will simplify the subsequent storage, processing and use of geospatial data.

The robustness of the obtained models with respect to input data errors allows the proposed method to be used to generalize and compare surveys at different times and to use them to solve the problems of geomechanical, ecological and glaciological monitoring.

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