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Polyhedral Building Model from Airborne Laser Scanning Data**

1. Introduction

Lidar, also known as laser scanning, is a new, highly automated technique supplying data of high accuracy, reflecting scanned space surrounding us. The collected data are commonly called "points cloud" or 3D image. Among data collecting systems we can discriminate these located on board of airplanes, called airborne laser scanning, and these performing measurements from the ground, called terrestrial systems. Independent on the type of system, measured data are giving us three-dimensional information which can be understood as a product. Nevertheless, for many works such product is only a starting point for obtaining the final product, e.g. in the form of DTM, DSM or models of buildings, trees. Transition from raw data to final product is usually by means of automatic or semi-automatic data processing procedures.

1.1. Related Work

In relation to worldwide literature, buildings detection consists of two stages [4]. First step is the detection of a building from data and possible determining of the contour of this building. The second stage is three-dimensional geometrical construction of detected buildings.

Among methods of detection and reconstruction of buildings we can distinguish two methods of approach:

- supporting of ALS with additional information, i.e. aerial photographs, satellite photographs, or file maps;
- using ALS data only.

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Taking into account solution difficulties, this second approach is more demanding and labour absorbing than the first one. Nevertheless, using ALS data only is a challenge both from scientific and practical point of view, because it is not necessary to use additional data, which are not always of proper quality and they often require financial support.

Detection of objects in the approach based only upon ALS data is divided into two subgroups. This division takes into account the character and distribution of lidar data. The first solution consists in the interpolation of points, passing in this way to the form of regular network. The objects detection itself is performed by means of a commonly known digital image analysis, i.e. filters, segmentations [5, 8]. However, second solution concentrates on the analysis of original cloud of points [6, 7]. Building reconstruction consists in determining the planes of the roof and side walls. Currently, modeling of buildings is based on two main streams that in effect lead to obtaining various models: parametric model and non-parametric (general) model.

Parametric model is based on prior defining of the characteristic features of the building – geometric parameters. Then, the building models are obtained by minimizing the difference between the expected and the real model described by laser points. The non-parametric method is based on the analysis of points cloud, where planes are detected, the shape of the edge of the roof is determined and the entire model can be improved due to integration of all available information, e.g. obtained from an orthophotomap or photogrammetric stereoscopic model.

1.2. Position of Proposed Approach

The method presented in this article is based on obtaining the information related to buildings from lidar data only. Nevertheless, it does not belong as a whole to any of the methods described above, taking into account the character of the data. A stage method has been proposed. The first stage of extraction consists in obtaining of possible places of buildings presence. For this purpose, lidar data are interpolated to the regular form – grid. Such data form enables using digital images processing methods for buildings extraction. This is always a multifactorial analysis and the final result is a result of composing of intermediate images. Then, after the identification of initial regions of building presence, a return to analysis of original points cloud takes place, but with limitation to indicated subareas. Passing from regular to scattered points will enable obtaining better accuracy of the edge of the roof of the building.

The second stage of building model reconstruction is based upon scattered data, but it is not supported by any information originated from other sources.

2. Building Extraction Based on Regular and Irregular Tesselation

2.1. Detection of Buildings

The first stage of extraction consists in obtaining possible places, in which buildings can be present. For this purpose, lidar data are interpolated to the grid, which represent the image. To get places where are buildings the multifactorial analysis images has been made.

On the basis of performed inspections, it has been found that the first stage of building detection consisting of grid analysis is satisfactory for the areas of diversified terrain coverage and buildings. Nevertheless, building detection is on an average level of 85% [1]. The resulting image which will be used for further tests is a binary image, representing the buildings contour only. An example of such image has been presented below (Fig. 1).

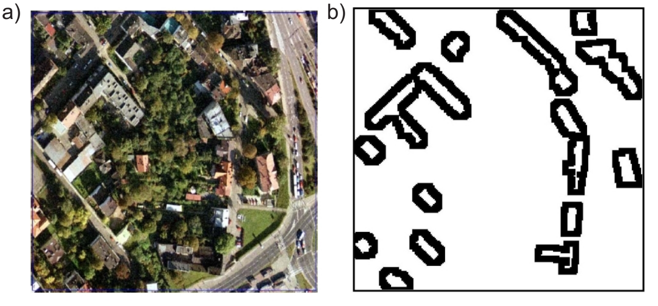

Fig. 1. Detected buildings (a) as a result of grid analysis with corresponding ortophotomaps (b)

Further method description has been presented on the example of selected building with a two-side roof. This building comes from the area presented on the above picture. On figure 2 selected building has been shown in the form obtained from lidar measurement.

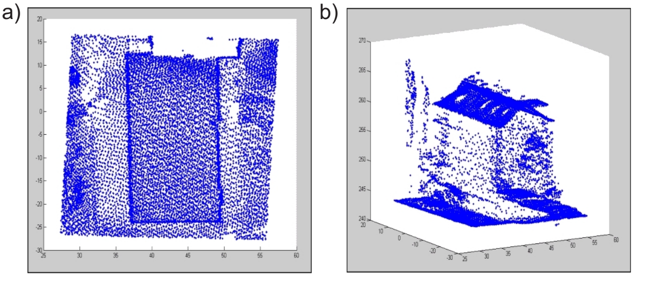

Fig. 2. "Cloud of points": a) orthogonal view of building; b) isometric view of the same building

2.2. Edge Extraction

After the identification of initial regions of buildings presence, a return to original "points cloud" takes place, but with limitation to indicated subareas. A decision has been taken to come back to scattered data, because one image pixel corresponds to at least one point, but more frequently there are many more such points. This substantially increases the amount of information, which will enable a more precise extraction of the edge of the roof.

An analysis of the scattered points has been performed by covering them to a Triangular Irregular Network. To limit and reduce the number of triangles to these located on the edges of the roof, declivities of edges of all triangles have been calculated. Declivities enabled to select only these triangles that have at least one vertex located on the roof. Among the triangles with sides with largest declivities, as a result of height classification, only the points located on the roof have been selected [1].

In order to group the set of points on four parts containing points describing each edge separately, a solution has been proposed consisting in determining building sizes and its orientation (on a plane). This problem has been solved calculating variance-covariance matrix and estimating probability ellipse. The probability ellipse has been determined for building contour obtained as a result of grid analysis [1].

Ellipse parameters have been calculated and then, as a result of ellipse directions analysis, points have been divided into four groups. As a result of the analysis and elimination of points not fulfilling conditions in each group only the points determining as accurate as possible location of the edge were included. On a selected set of 2D points an approximation of straight line was done, by root mean square method. Parameters of straight lines representing initial location of edges will be used in later stages.

3. Reconstruction of Building Model

Reconstruction of building model is connected with mathematical description of the shape of the roof and the external walls of the building. Having specified the outline of the roof of the building, it is possible to start with determining the planes of the roof and the exact description of the shape of the object.

3.1. Split-Merge Plane Detection

Detection of the planes of the roof on the basis of lidar points is the next stage leading to the construction of tne appropriate building model. For that purpose, 2D edges detected in second stage have been used; these edges enable the selection of only those points representing the roof from the entire "points cloud" (Fig. 3). Planes will be detected already in 3D space.

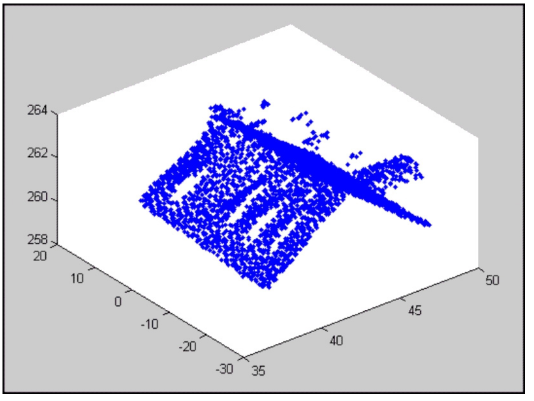

Fig. 3. "Cloud of points" which represent only roof of building

The method used for detection of the planes of the roof is based on split – edge rule. In other words, looking for these planes is performed according to the principle of passing from a detail to a whole. First, a rectangular prism is defined, including entire set of points representing the roof. Then, the initial rectangular prism is divided into smaller and equal rectangular prisms – voxels (Fig. 4).

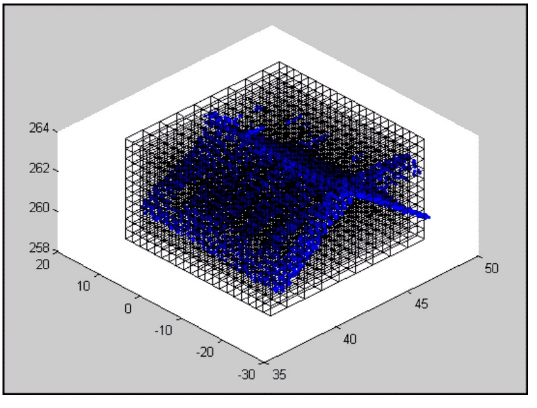

Fig. 4. Voxels build on lidar data which represent the roof

In the first phase of planes detection, each voxel is analyzed separately – first, the number of points is determined. If this number is larger than 5, then on the basis of these points the plane is approximated. The parameters of the plane parameters are calculated by means of root mean square method, minimizing the sum of square distance of individual points to fitted plane.

In 3D Euclid space, 3D plane is described by the following formula:

$$Ax + By + Cz + D = 0 \tag{1}$$

where four parameters are calculated: A, B, C, D, which precisely determine the best fitting of plane into lidar points in each rectangular prism (Fig. 5).

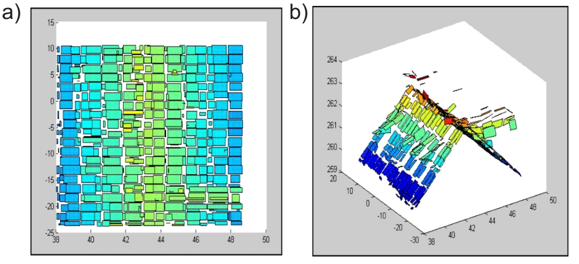

Fig. 5. Approximation plane in each voxel: a) top view; b) isometric view

The last stage, leading to determining of the planes of the roof, is segmentation of rectangular prisms, consisting in unitizing rectangular prisms into larger clusters. For this purpose, properties of each plane are defined: normal vector, azimuth, declivity and average height. In this process, firstly, central rectangular prisms are selected, where each central rectangular prism can have 26 neighbours. Central rectangular prism is a focus of cluster which can grow by attaching adjacent voxels.

Connection criterion is based upon the definition of limit values of the following plane parameters. If the values of adjacent voxels fulfils specific conditions, the points of these voxels are connected to one set and then the plane is approximated, again. The process of connecting runs iteratively, until the main planes are obtained (Fig. 6).

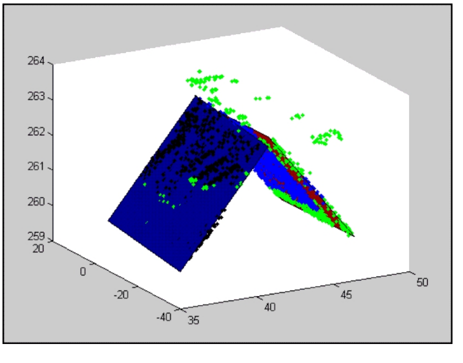

Fig. 6. Two main building planes with lidar points

Planes that have not been connected in first stage are analyzed again. Re--verification of their parameters enables obtaining the existing side planes (Fig. 7).

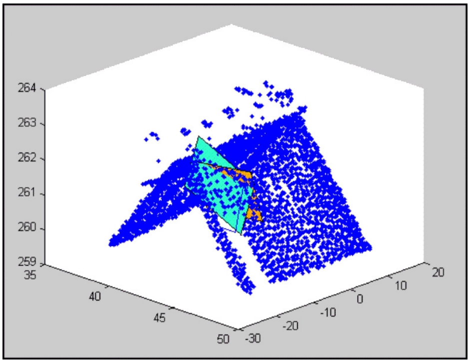

Fig. 7. Detected two side planes with lidar points

3.2. Model Generation

The final effect is the determination of multilateral building model. Mathematical description of building model requires determining corners coordinates and bend points of the planes. Determining coordinates is possible thanks to the knowledge of the equation of straight lines (edges) describing individual planes of the roof of the building. Consecutive equations of straight lines have been obtained in individual stages. The external outline of the building is described by edges extracted in the edge extraction stage. Straight lines in intersection point of the two planes are main and side ridges of the roof. The knowledge of coordinates of most protruding points creating side planes and slopes of the outlines of the building enabled determining the side edges of the planes. Intersection points of individual straight lines and planes have determined the coordinates of the roof of the building.

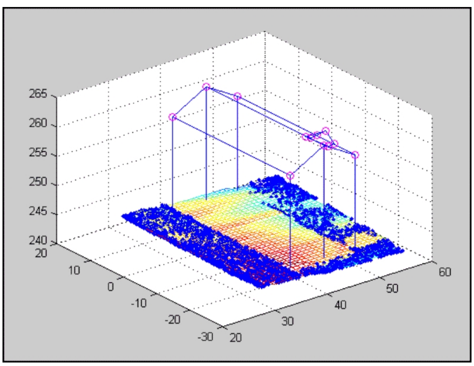

Fig. 8. Building model situated on DTM. Pink circle define the corners

The edges of the roof have been elevated to the height calculated on the basis of the average height of the points approximating straight lines. The final stage is the projection of all the coordinates of the edges on DTM and interpolating their height. The final effect is obtaining a model of the building located on DTM (Fig. 8).

3.3. Results

Model of the building is exported into dxf file. Such format enables its opening in any CAD-program. The results looks as follows (Fig. 9).

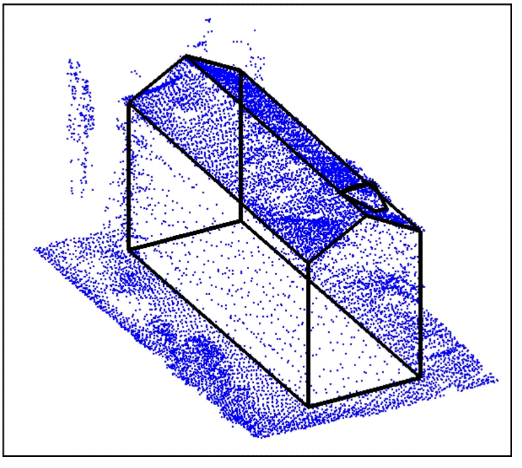

Fig. 9. Polyhedral building model exported to dxf format and lidar points

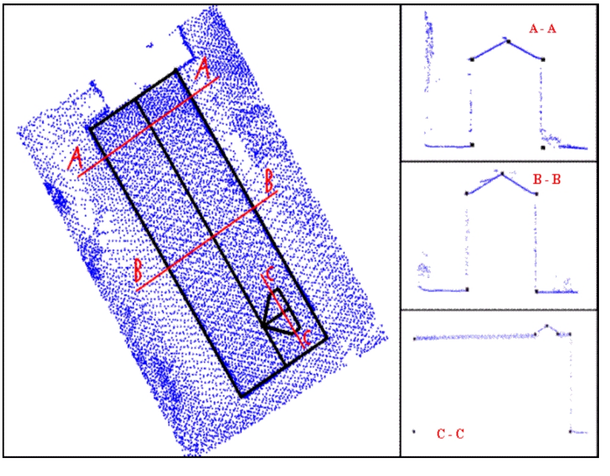

Fig. 10. Top view of building model (black line, points) and lidar data (blue points) with draw section

Correctness of the detected edges has been checked on cross-sections. On the figure below, several selected sections for results documentation purposes have been presented (Fig. 10).

4. Data

Lidar measurement included The area of the City of Kraków and its environs. Air raid has been performed in year 2006, when Fli-Map measuring system has been applied. Points density is variable and reaches from 11 to 30 points per m2. This means that laser data reflect the topographic profile and all details of coverage elements particularly well.

The tests presented above have been performed on buildings which were diversified regarding their size, geometry and shape.

5. Conclusion

This article presents the author's solution for buildings modeling on the basis of ALS data. Individual stages of building detection and reconstruction have been described.

The stage of buildings detection is based on lidar points classification and on their grouping into those belonging to terrain and those representing buildings. The analysis and processing of images leads to a highly accurate extraction of places of building presence.

It has been proved that the proposed method can construct a model of an uncomplicated building. Model verification has been performed recognizing that it is well fitted into the "points cloud", the edges have a proper run and building is properly located on DTM. It is worth stressing that the model is created only on the basis of ALS data.

To sum up, on the basis of the obtained results it is possible to state that modeling is a complicated process. Nevertheless, the tests performed on test fields with buildings having an uncomplicated structure brought positive results. Modeling of buildings with complicated structure requires more tests.

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