BUILDING EXTRACTION FROM ALS DATA BASED ON REGULAR AND IRREGULAR TESSELLATIONS.

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ABSTRACT:

For the past dozen years, data which enable the use of Digital Terrain Model as well as Digital Surface Model have been widely used. One of the modern techniques of gaining information about terrain is the Airborne Laser Scanner. We can obtain the spatial coordinate points using the laser scanner, which creates a set of large density points commonly called the "cloud of points". These models are reliable and accurately reflect the reality surrounding us. For pictorial character purposes, this kind of data is sufficient. However in the case of modeling buildings, structure and engineering objects, it is necessary to process data which includes: filtration (removing noise and excessive data) in order to detect points and essential lines needed for spatial object description and to organize a vector description of the modeled objects.This paper presents a new method of extraction. It also presents a preliminary roof edge extraction based solely on laser data, without the help of additional information. The idea of the proposed method is based on regular and irregular tessellations, made utilizing the last echo.

1. INTRODUCTION

Owing to GIS development a strong demand for terrain models (DTM) and models of surface determined by terrain overlay (DSM) is observed. These models are used in various types of GIS analysis, i.e. municipal and rural area's changes planning, definite spatial occurrence's effects forecasting (i.e. propagation of noise or air pollution). As a consequence of high demand for 3D models, the automatic extraction of natural and artificial elements placed on the ground surface is a subject of many publications.

One of methods, in which DTM and DSM is acquired is stereodigitalisation of photogrammetrial models. However, the photography's resolution not always enabled having a high precision object models. Therefore, a field for a new method progressing turned out, allowing acquisition of spatial models; this is the LIDAR technology. During last two decades, a broad application and use of airborne laser scanning (ALS) in process of 3D objects modelling is emphasized in many publications.
The demand for 3D buildings models (DBM) is growing particularly fast. Up to now the buildings are saved in GIS systems as a 2D objects, which strongly limits possibilities of spatial analysis. It is worth to mention, that single buildings shape modelling in three dimensions is a high complexity rank task, much more composite than to build a generalized DTM type areas for the geographical data systems purpose.

1.1 Related work

ALS' result is "points cloud", which is composed of points located either in a terrain or on overlay elements. That is why, the first step in the process of laser data processing is a distribution of points to these, which form the terrain and these which belong to terrain overlay objects. Many solutions of grouping points to both mentioned classes can be found in publications. The 3D objects extraction is strictly linked to points grouping. 2 approaches can be distinguished among methods of building detection:

a) supporting of the ALS of additional data i.e. airborne and satellite photos or registry maps,
b) exploiting only ALS data.

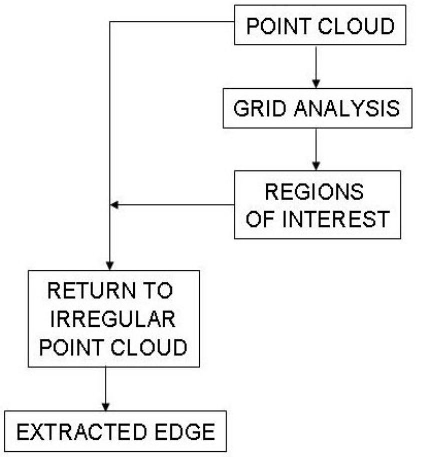
Taking into consideration the difficulty of solution, the second approach is more demanding and work consuming than the first one. However, despite arising difficulties, using ALS data only to object detection is both a scientific and a practical challenge. In this approach there is no need of making use of additional data, which are not always of appropriate quality, and often require high financial costs.

Objects detection in the approach based on ALS data only is divided into two subgroups. The division complies with the character and lidar data layout. First solution is to interpolate a regular grid from irregular cloud of points. Further process is done through commonly known digital image analysis, i.e. filters, segmentations (Maas, 1999; Tóvári and Vögtle, 2004). However, second solution concentrates on the analysis of original cloud of points (Morgan, Habib; 2001; Schwalbe, 2003). Operating on irregular data of high capacity is less recognizable, and one of the barriers is the data capacity. In sum: grid data analysis are easier but less precise, whereas dispersed data analysis are harder to perform but they potentially should bring better results.

1.2 Position of proposed approach

The method presented in the article is based on emerging building data from lidar data only. Whereas, as a whole it does not belong to none of above described solutions taking into consideration the data character. Its particular attribute is a stage configuration, on particular stages grid or - originally – dispersed data are used.

First stage of extraction consists on emerging probable place of a building appearance. For this purpose lidar data are interpoled to regular grid form. Such data form enables using digital image processing methods in buildings extraction. It is always multi-factor analysis, and eventual outcome is a result of indirect images composition. After the identification of initial regions of buildings occurrence a return to original cloud of points analysis is performed, but with limitation to advisable sub areas. A return to original data allows having higher precision of buildings' roof edge.



Scheme 1. Work flow for building extraction.

2. DATA

In research the data made available by Spatial Planning Office of City of Cracow Municipal Government Office. Lidar survey comprised Cracow city area and its surroundings.

Air target run was performed in 2006, using Fli-Map surveying system. Density of points is various and varies between 11 and 30 points per m^2. It signifies, that laser data particularly well deliver terrain profile and any overlay's elements details.

The purpose of research is the detection and modelling of buildings, therefore, to perform reliable complex analysis, a selection of representative areas was necessary. During the selection of test areas one followed buildings' shape and geometry. Moreover, not meaningless was building's layout, their mutual arrangement and greenery prevalence, which impedes the automatic building extraction to a large degree.

Performed research are in the initial phase for the time being, therefore for the beginning test areas were chosen, on which free-standing buildings of uncomplicated shape are located.

3. DETECTION OF BUILDING

Needs related to urban agglomeration's development entails strong demand for 3D city models, in which individual buildings or it's groups are 3D objects. Initial phase for 3D models creating is a detection, so indicating areas of building prevalence.

3.1 Interpolation laser data – last and first pulse

"Cloud of points" is presented as a set of dispersed points in 3D space. To facilitate the calculations, irregular survey data layout is a subject of interpolation. As a result of interpolation of dispersed points, regular structure grid is obtained, so pseudo GRID, structure of which is analogous to digital image (later on "image" name will be used).

To retain actual values obtained by lidar measuring, nearest neighbour method was used in interpolation. This method was chosen, because it does not require high computing powers of computer and simultaneously most constantly maintains original points' values. As an interpolation result a regular grid is obtained, where flat X, Y coordinates answer for the situation pixel position, whereas Z coordinate answers for the pixel brightness. Evidently having points' interpolation a resolution of desired image should not be forgotten. Taking into consideration the average measured points' density, it is presumed that a sample interval (SI) amounts to

$$SI = \frac{1}{\sqrt{density}} \text{ [Tarsha-Kurdi,2006].} \qquad (1)$$

In a brief, in this type of operation a regular points' layout is obtained, where density is similar to "cloud of points" of average density.

ALS have a possibility of recording several reflection of singular laser impulse. First reflection records data on objects located on the top. On the other hand, the last reflection, as a result of impulse penetration of tree branches, gives the data concerning the terrain. Recording of the first and the last reflection allows determining i.e. terrain overlay elements' height, as well as indicating the differences between elements. why the interpolation of points has been done for the first and the last reflection (Fig. 2) in order to compare images and visualize their height.

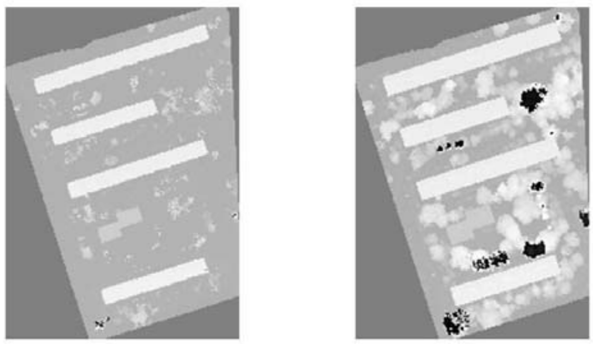


Figure 2. Images obtained as a result of dispersed points' interpolation derived from airborne laser scanning. On the right: image obtained from the first reflection, on the left: image obtained from the last reflection.

The obtained result confirmed the assumption, that in the image obtained by first refection point's interpolation there are more elements other than buildings that protrude above the terrain, most often these are trees. Whereas in the set of points from the last reflection, trees are eliminated to the sizeable extent, therefore to further analysis an image from the last reflection was chosen. In this image the scope of brightness of particular pixels is smaller, what would ease the buildings' extraction.

3.2 Grid analyses

The first phase of detecting places of buildings' appearance is based on height image analysis. The image of last reflection served to detect places, where most likely buildings appear. The image analysis is performed as following: the first step is the reclassification, lying on establishing the threshold value. Threshold value is dependent on pixel's brightness (so on their height). Pixels' not fulfilling this criteria are attributed with „0" value, the rest stays the same.

Subsequently attention areas (buildings) are located with use of morphologic filters. In order to delete pixels representing the greenery, an operation called erosion was used. Erosion constitutes the minimal filter, which actually deletes minor pixel clusters, but also reduces the figures' surface area. However to retain as much reliable buildings shape as possible and to not minimise their area, minimal filter should be used for couple of times only. After minimal filter usage, apart from buildings' image still holds smaller groups of pixels, which represents i.e. cars, bushes. These minor objects still disturb the image and should be deleted. That is why the pixel amount belonging to each object is counted, and objects of the smallest clusters are deleted. (Fig. 3).

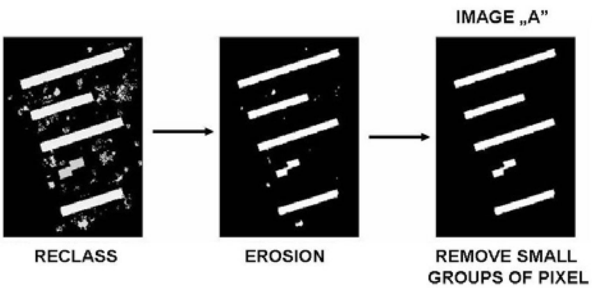


Figure 3. Phases of image analysis to select most probable areas of buildings' appearance.

Having the image cleared, a return correct dimension of the objects' area is made with the use of maximal filter. This filter enables obtaining objects' dimensions which occurred in initial process, as well as allows to enlarge the objects' area. Enlarging the area, user can obtain small buffer around the building. The logical difference of two images (image A – image B) determines preliminary spots of buildings' edge's occurrence (Fig. 4).

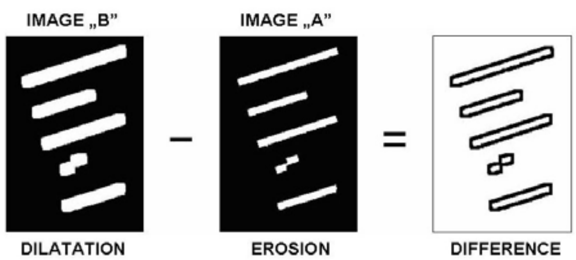


Figure 4. Initial definition of areas of building's edges appearance.

The grid analysis indicated places of building's occurrence, as well as defined probable position of the edge of building's roof. Therefore the scope of edge seek was considerably limited, what surely will ease it's exact indication.

Definition of the edge of building's roof and its reconstruction from lidar data is much more complicated task than building's position indication itself. Moreover, the density of reflected laser impulses is much higher on flat surfaces, than on surfaces with sloping and height versatile. Therefore, in places most important for buildings' modelling, by its edges, density of the data is usually lower, furthermore, blind spots can occur, which are places where a laser bundle does not reach. That is why using solutions, in which original cloud of points is replaced by interpoled regular grid, does not lead to exact indication of the edge in vector form, but is useful to initial determining of building's position.

3.3 TIN analyses

After the identification of initial regions of buildings occurrence a return to original cloud of points analysis is performed, but with limitation to advisable sub areas. It was decided to return to dispersed data, because for one pixel of image falls on at least one point, and frequently there are more of these points (Fig. 5). And in this connection, original data increases of the data amount, which allows to define the roof's edge with higher accuracy.

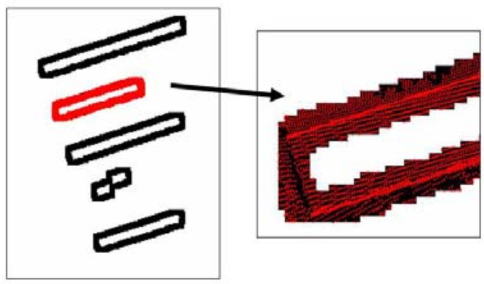


Figure 5. Dispersed points spread on the grid.

The analysis was performed on dispersed points, spreading the TIN (Triangular Irregular Network) grid on them. From various methods of two-dimensional triangular networks generation a Delaunay's triangulation was chosen. This method is one of most frequently used algorithms to build triangular networks and also enables full automation of triangle network building for arbitrarily complicated area (Fig. 6).

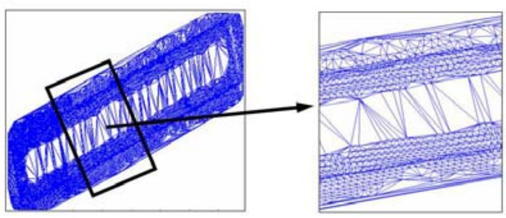


Figure 6. Triangulation performed on dispersed points set.

To limit and minimise the number of triangles to those, which are placed on the edges of roofs, decreases of all sides of triangles were calculated.

$$S = \frac{h_1 - h_2}{d} \tag{2}$$

where
- h_1 = value Z of first point
- h_2 = value Z of second point
- d = distance between two points

Decreases enabled to emerge triangles with one vertex on the roof only. Whereas, only those points were chosen from among triangles with sides of a decline higher than a terminal value, which are placed on the roof probably. Next, a height classification was lead, in which only Z coordinate higher than a threshold value points were chosen. A threshold value was defined as an arithmetic mean of points height in a determined area. Points choosing limited meaningfully the area of building's edges targeting. (Fig. 7)

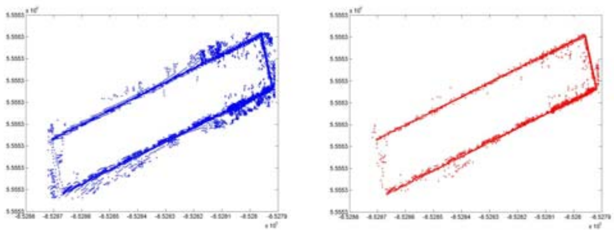


Figure 7. To the right – point before height classification, to the right – points after height classification.

4. DEFINITION OF BUILDING'S EDGE

In order to group the points' set into four parts containing describing points, every edge separately, a solution based on Principal Component Analysis was proposed. It enables to determine the model of data set dispersion in the form of probability ellipse. Every pixel on the image is defined by two variables, variable X and variable Y (column number, row number). Ellipse is drawn based on assumption, that given two variables are subject to two-dimensional normal distribution (Gaussian distribution). Ellipse's orientation depends on sign of the correlation coefficient between variables, magnitude of ellipse is determined according to separations, and its midpoint is specified by X and Y variables' mean. By the separation one should comprehend a root of characteristic number multiplied by certain value matched by user. Characteristic numbers can be interpreted as a proportions of variance defined by correlations between corresponding variables. Therefore solving the problem values of variance and covariance for X and Y variables of points creating determined object's perimeter were calculated.

Variance's value, which defines population's diversification is equal to the sum of arithmetic average of squares of particular attribute's value deviation from arithmetic average of population.

$$s_x{}^2 = \frac{\sum_{i=1}^{n}\left(x - \overline{x_i}\right)^2}{n-1} \qquad s_y{}^2 = \frac{\sum_{i=1}^{n}\left(y - \overline{y_i}\right)^2}{n-1} \tag{3}$$

where

s_x^2 / s_y^2 = variance for X / Y calculated basing on a sample, so called unbiased variance estimator,

cov(X,Y) = covariance of X, Y variables set,
x,y = average value of the sample for X / Y,
$\overline{x}_i$ / $\overline{y}_i$ = value of X / Y variable for i-point,
n = test size

Covariance value, which defines linear dependence between X and Y random variables by average of product of every data point pair deviations, were calculated from following formulas:

$$\mathrm{cov}(X,Y) = \frac{1}{n}\sum_{i=1}^{n}\left(x - \overline{x_i}\right)\cdot\left(y - \overline{y_i}\right) \tag{4}$$

As a result of calculations which were carried out, a variance-covariance matrix $\begin{bmatrix} S_x^2 & \mathrm{cov}(X,Y) \\ \mathrm{cov}(X,Y) & S_y^2 \end{bmatrix}$ definite for X, Y coordinates was obtained. Basing on obtained matrix its characteristic number was calculated.

Obtained variance-covariance matrix and characteristic numbers served to calculate ellipse's parameters, i.e. orientation and magnitude of an ellipse acc. to Hausbrandt's formulas [Hausbrandt; 1970].

$$\Omega = \frac{\arctan\left(\dfrac{2\cdot \mathrm{cov}(X,Y)}{s_x^2 - s_y^2}\right)}{2} \tag{5}$$

where

Ω = omega angle between horizontal line and eigenvector's direction of higher characteristic number,

s_x^2 / s_y^2 = variance for X / Y calculated basing on a sample, so called unbiased variance estimator,

cov(x,y) = covariance of X, Y variables' set

$$e_1 = 2 \cdot \sqrt{a_1}$$
$$e_2 = 2 \cdot \sqrt{a_2} \qquad (6)$$

where

e_1 = value of length for smaller ellipse semi-axis,
e_2 = value of length for smaller ellipse semi-axis,
a_1 = smaller characteristic number of object from test area,
a_2 = greater characteristic number of object from test area.

In the above formula, square root of characteristic numbers was multiplied by 2, which indicates, that 95,5% of attribute's value lies in ≤ 2 distance than expected value.
Centre of area was calculated as an arithmetic average of X, Y coordinates, which was defined by ellipse's midpoint.
For studied case the following parameters were achieved:

$\begin{bmatrix} S_x^2 & cov(X,Y) \\ cov(X,Y) & S_y^2 \end{bmatrix}$	$\begin{bmatrix} 565.64 & -167.13 \\ -167.13 & 92.54 \end{bmatrix}$
a_1	39.453
a_2	618.72
Ω	$\approx 198^\circ$
e_1	12.562m
e_1	49.748m

Table 8. Ellipse's parameters achieved for studied building.

Obtained parameters allowed to determine the probability ellipse span and to assign main directions, longwise points are arranging (Fig. 9).

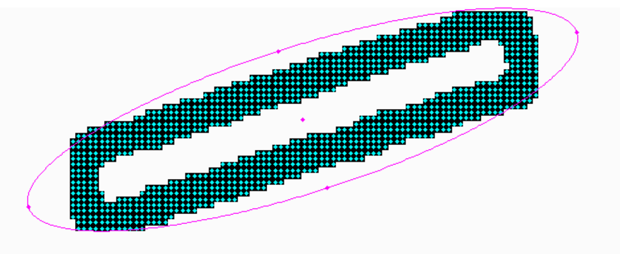


Figure 9. The view illustrating building's outline with probability ellipse.

As a result of analysis and elimination of point which did not fulfil the conditions, only these points remained, which reflect the edge with highest fidelity. In every of four sets of points an straight-line approximation with minimum chi-square method was performed (Fig. 9). Approximation is an iterative process, which in consecutive iterations discards points differing from the line, until the moment of an accurate edge defining. Differing points are the points, which lies farther than average length of the points from the line achieved in consecutive iterations.

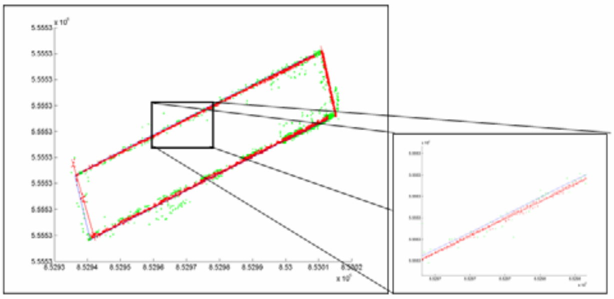


Figure 10. Extracted edge.

5. RESULTS AND DISCUSSION

Determining of the building's edge was performed on the building of non-complicated architecture. Whereas, the detection algorithm (grid analysis) of the buildings was used on the several test areas. Computational time for every area was changeable. Test areas contained different shapes, building structures and their arrangement was miscellaneous. With effect from dispersed development to more and more compact. On the figures below ortophotomaps were inserted and images obtained as a result of grid analysis. The matching of images with ortophotomaps is done with comparative purpose, and results concerning the detection of buildings on test areas were inserted in the table below.

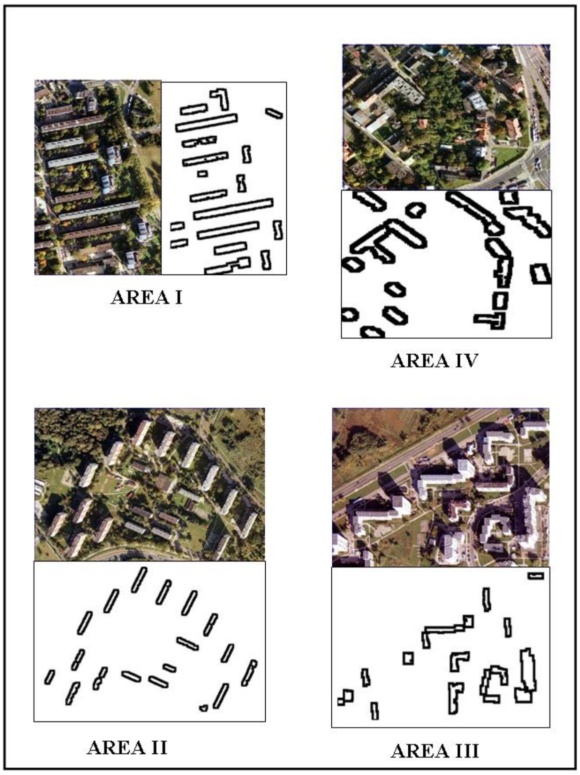


Figure 11. Detected buildings as a result of grid analysis with corresponding ortophotomaps.

Area	Number of detected buildings	Number of not detected buildings	Sum of buildings	Detection's rate[%]
I	18	0	18	100
II	18	2	20	90
III	14	4	18	78
IV	17	7	24	71

Table 12. Statistic of grid analysis building detection.

Basing on obtained results it can be found that the first phase of buildings' detection consisting of grid analysis is satisfactory for areas diversified in respect of terrain overlay character and buildings. Whereas exact determining of building's edges is more complicated process and requires farther studies. These are conducted by the Author, nevertheless eventual conclusions formulating is premature yet. However, seeing the effectiveness of the solutions basing on cloud of points analysis [Morgan,2001; Baltsavias, 2004] it can be presumed, that there are premises to achieve interesting results. It is worth emphasizing, that the greatest security of presented method is a utilisation of two methods – one operates on grid data and second on dispersed points. Every method is applied on another phase, which causes, that they complement each other.

All computational processes were personally developed by the author as informatics applications of MATLAB environment.

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