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BUILDING OUTLINE RECONSTRUCTION FROM ALS DATA SET WITH A PRIORI INFORMATION

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ABSTRACT: Extraction of building boundaries is a n important step towards 3D buildings reconstruction. It may be also of interest on their own, for the real estate industry, GIS and automated updating of cadastral maps. In this paper we propose a comprehensive method for an automated extraction and delineation of building outlines from raw airborne laser scanning data. The presented workflow comprises three steps. It starts with identification of the points belonging to each singular building. The second step is to trace the points that compose a building boundary. In the last step an adjustment process is applied, that aims in boundary lines regularization. The first step - building detection is a most computationally expensive process and has a fundamental importance for the whole algorithm. A proposed approach is to include building address points that give exact information about building location. This additional information highly reduces the complexity of the building points extraction.

1. INTRODUCTION

1.1 Motivation

Mobile mapping systems currently undergoes a rapid development, which increases their application for efficient geodata capturing. Systems based on laser scanning pose a leading role in the field of mobile mapping. Although mobile LIDAR systems feature higher scanning resolution and better accuracy than their airborne counterparts, they are composed of the same components and they face similar challenges with data processing. One of the most complex task is to extract implicit information from laser point clouds. Especially for objects with complicated topology, such as buildings, this problem is still a challenging research topic. Two-dimensional building outlines are needed in many disciplines dealing with spatial data. They are applied in real estate industry, GIS and automated updating of cadastral maps. Building footprints serves also as an intermediate step for 3D building reconstruction, which is a challenging topic in a current research.

1.2 Aims

In this paper we propose a comprehensive method for an automated extraction and delineation of building outlines from raw airborne laser scanning data. Our approach consists of three parts. The first step is building detection. It starts with identification of the points belonging to each singular building. Points belonging to the building are then investigated in order to find those of them that make up the outline. On that stage the outline is substantially jagged. Thus, there is a need for outline simplification reducing insignificant points. Finally, extracted boundary is subjected to regularization. The first step - building detection is a most computationally expensive process and has a fundamental importance for the whole algorithm. A proposed approach is to include building address points that give exact information about building location. The address point is a planar point located within building outline, which position is determined by x and y coordinates. This additional information highly reduces the complexity of the building points extraction.

1.3 Related works

In the last years, the research on the building outline reconstruction has been mostly performed using aerial images. The expansion of laser scanning technology requires developing independent methods based solely on the LIDAR data. However, the extraction of 2D features is more accurate using 2D inputs than 3D data (Kaartinen, Hyyppa, 2006), hence, in many approach 3D points are transformed into planar, grid structure (Alharty, Bethel, 2002; Rottensteiner, Briese, 2002).

Another group of method use additional information, like ground plans (Haala et al. 1998, Vosselman, Dijkman, 2001) or multi spectral imagery (Awrangjeb et al., 2010). 3D point clouds feature random distribution, therefore, they do not match necessarily building boundaries. Including of GIS or multi spectral information brings equal distribution, thus, reduce the searching space for the purpose of adjoining planar faces estimation.

In our method we apply a direct footprint extraction from raw LIDAR data. This approach is motivated by the lost of the data during interpolation of laser scanning points into 2D grid and unavailability of GIS and multi spectra images for some parts of area. Vosselman (1999) presents an approach for building reconstruction using planar faces in dense height data. Plane detection is performed by Hough transform. Regularization of a building outline is performed using main orientation of the building. Sampath and Shan (2007) present a new procedure for tracing the boundary. The first step is separation of the data into building and non- building points. This is performed by slope-based algorithm. Detected points are segmented in order to obtain single buildings. The contour is traced by Jarvis (1977) algorithm. Finally, the boundary is regularized by a hierarchical least squares adjustment. Similar steps are proposed by Neidhart and Sester (2008). They start from data classification using two groups, terrain and non-terrain. The data is divided into the stripes, which is followed by 2D polynomial fitting. Then, points marked as non-terrain are investigated in order to find connected building blobs. This is performed using Delaunay-Triangulation. Finally, three version of outline simplification are proposed, modified Douglas-Peucker algorithm, graph-based approach and RANSAC algorithm.

Revision on the different method for outline reconstruction is outlined in Vosselman and Maas (2010). Another application of footprint extraction - 3D building modeling is a complex process consisting of several parts. An overview on the existing methods, algorithms and possible solutions for each step are presented by Dorniger and Pfeifer (2008) and Haala and Kada (2010).

2. BUILDINGS DETECTION

2.1 Input data

The majority of available in the literature approaches contain as the first step classification of points into two classes, ground and non-ground. Application of a priori information about building location enables to avoid this part, thereby to simplify an algorithm and increase its time performance. The input to the whole boundary extraction process contains an unstructured, raw 3D point cloud and a list of building address points, available in cadastre. Each of these points is assigned to one building and has a random location within planar building outline.

2.2 Detection method

Extraction of points comprising an individual building is based on an assumption about differences in spatial distribution between the points. A cluster of points that present one building roof usually has an uniformly dense distribution. Hence, significant changes in the distribution give a hint that other, neighbouring object is detected. The building points recognition procedure starts from finding the point whose planar coordinates are the nearest to the given address point. This point defines a seed region for the region growing algorithm. A fundamental difficulty of using this algorithm consists in distinguishing between buildings and other adjacent objects, e.g. trees touching the roof. An exact rejection of non-building points has crucial importance for the quality of the final result, since the presence of outliers will disturb the further steps. Therefore, for the scene with a huge amount of points belonging to the high vegetation, the region growing algorithm has to be improved by taking into consideration additional information, like intensity and normal vectors.
The algorithm consists on the following steps:

1. Project the points on the plane.
2. For each address points detect a point within data set that is the closest in the 2D space.
3. Start with data point associated with the first address point.
4. Mark it as a query point.
5. Find in the 3D space the nearest neighbours within the given distance to the query point and add them to the stack.
6. Take the first point from the stack and mark them as a query point. Perform the Step 4 in a recurrence way until there are no points on the stack.
7. Add all detected points to the cluster.
8. If points associated with other address points were detected marked them as used.
9. Check another address point. If its associated data point is not used go back to the Step 3.
10. Stop when all address points are used.

On that stage the process aims in the detection of adjacent building clusters. The results of method execution are illustrated in Fig. 1.

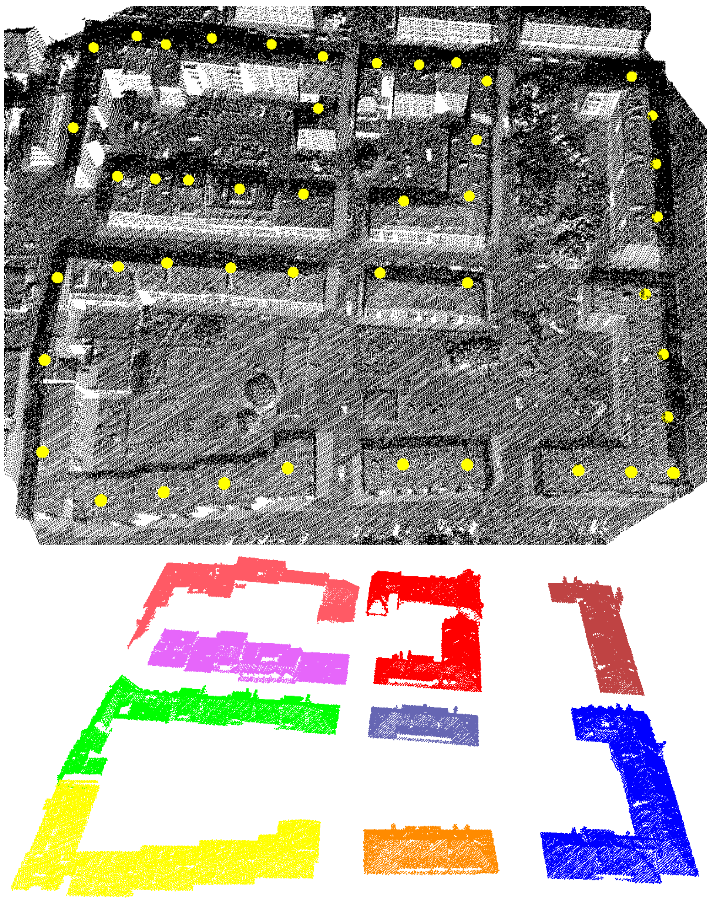

Fig. 1. Building detection: ALS dataset with address points (top) and clusters of detected building points (bottom).

3. OUTLINE RECONSTRUCTION

After the detection of points for each building, the next task is to determine the points that make up the boundary. Since interpolation, as for example grid sampling, may disturb the results causing artefacts, in our approach boundary is extracted directly from the raw LIDAR points assigned to an individual building. In the presented work we extract the outline as a footprint of the building roof.

3.1 Boundary detection

The extraction process comprises of two main parts. The first is to detect the points that create an external polygon and the second is to find the straight lines out of them.

3.1.1. Edge points identification

The points belonging to the roof are orthogonally projected onto the horizontal plane. The external points are detected by computing a modified convex hull. The difference between the original version and its modification lies in the restriction of the searching space from a global to a local neighbourhood. It enables to extract concave shapes, which commonly exist in building geometry (e.g. L-shape). The threshold for the neighbourhood is set according to the point density of the original data set. For all neighbouring points an angle between the candidate and the previous boundary point is calculated and the candidate assigned to the smallest angle is considered to be the next outline point. The procedure is repeated until the initial point is reached again.
The algorithms process as follows:
1. Project the points on the plane.
2. Establish topology relations between the points finding neighbours for each point within a given distance threshold. Store them in a *k*d-tree structure (Berg et al., 2007).
3. Start from a point with the min x coordinate. Mark it as a query point.
4. Compute the left angles between the query point and each of its neighbours. Choose the point with the minimal associated angle, add them to the boundary points set and mark as a query.
5. Continue the step above until the algorithm reaches the point detected in the Step 3.

On that stage, connecting points gives a substantially jagged outline (exemplified in Fig. 2).

3.1.2. Straight lines detection

In order to identify the straight lines within the subset containing outline points, region growing algorithm is applied. Before the growing process will start, the data must be complemented by additional information. Each data point has to be associated with one line. The line parameters are estimated using the point and its neighbours. Hence, we have to establish topology between the points and store them as a binary search tree. Ultimately, the residuals are calculated, which are the measure for line fitting quality.
When the data is prepared we execute line detection algorithm. It is composed of the following parts:
1. Start with the point with the minimum line residuals – referred to as a seed point. Add it to the temporary set **T**.
2. Check the next boundary point (seed index + 1). If the distance between the point and the seed point's line is smaller than the threshold and if the distance angle between the current line and the line assign to the candidate point is within the given threshold, add the point to the set **T** and repeat the step checking the next boundary point.
3. According to the Step 5 test the previous point (seed index – 1).
4. If the size of **T** is bigger than the size threshold, copy the points to the first line segment. Mark the points as used.
5. Clear **T**.
6. Within the points that are not used find the next point with the smaller residual and repeat the steps above starting from the Step 2.
7. The algorithm is finished when all the points are marked as used.

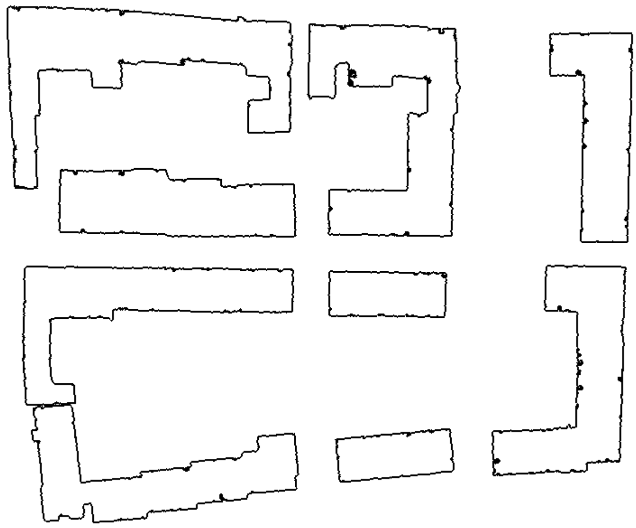

Fig.2. Connected edge points resulting in jagged boundary

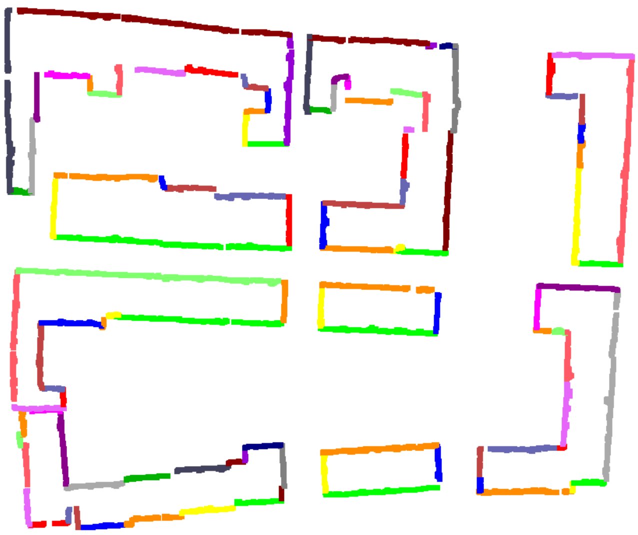

Fig. 3. Results of line detection algorithm – segments of points associated with one line

The output of the algorithm is a set of point segments, which are ordered clockwise. Each of the segments is associated with one line interval. To improve the results we have to update line parameters using all points belonging to the segment. Than, the order of lines is established and lines end points are detected. This information enables us to perform line merging algorithm. There are two conditions for joining line segments. For each consecutive line we calculate an angle between them and the distance between the end point of the current line and the start point of the next line. If the values are smaller than the given thresholds segments are merged and the line parameters are updated.

As the final result (presented in Fig. 3) we obtain a set of straight lines composing a building outline. Usually, the orientation of the lines is varied and the extracted shape can be very irregular. Therefore, as the last part of our approach, boundaries are subjected to the refinement.

3.2 Boundary regularization

Manmade structures typically consist of parallel and rectangular facades. In most cases it means that knowing a direction of one line we are able to adjust all the other lines direction within that building by imposing the regularity constraints, parallelism and orthogonality. Therefore, in order to solve regularization task Vosselman (1999) propose to detect the main building orientation. We modified the presented method, using the results of straight line detection executed previously.
The main building orientation detection (c.f. Figure 4) starts from the segmentation of data within one building (Jarzabek-Rychard, Borkowski, 2009). The results of that process are revealed in Fig.4. Next, the two adjacent roof planes with the biggest size are chosen. The intersection of those planes is supposed to be a roof ridge. In a certain type of object, however (hip roof), the line detected in such way is not along the building orientation. Therefore, to avoid misleadings, additionally the building contour is investigated and the direction of the longest line is analysed.

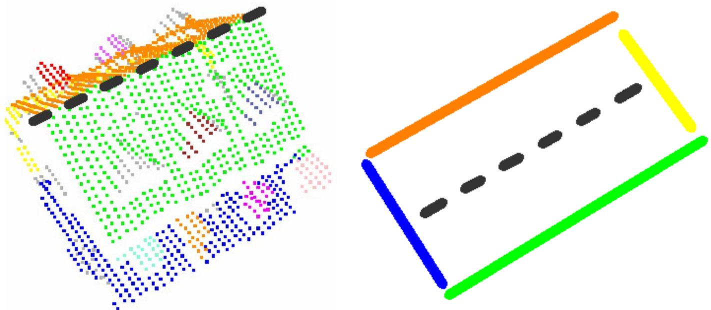

Fig. 4. Data segmentation (left) applied for the detection of the main building orientation (black dashed line). The process is performed for the purpose of building line segments (right) regularization

In the second part our method uses the lines segments detected in the previous step. In order to benefits from the neighbourhood relations, the segments are stored in a clockwise sequence. The lines are grouped into two sets, vertical and horizontal. According to the assigned label each line obtains an adequate condition. Therefore, the adjusted segments are either parallel or orthogonal to each other. If the subsequent lines are parallel than both of them are investigated in order to decide whether they should be connected or an additional, orthogonal segment has to be inserted. Ultimately, the vertices of the building boundary are obtained by the intersection of adjusted lines. Figure 5 presents the final results of the building reconstruction method.

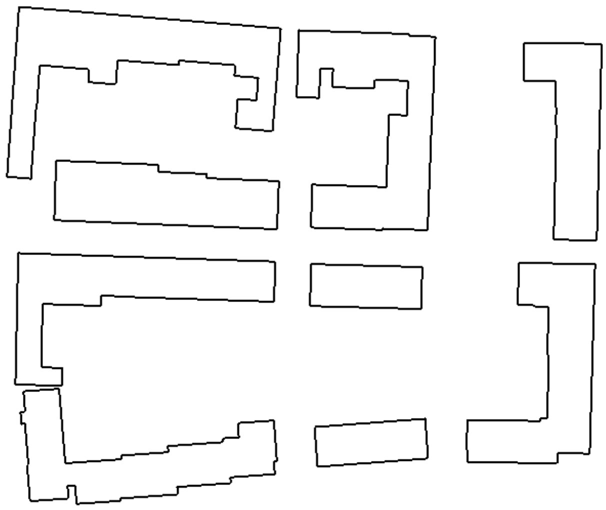

Fig. 5. Building outlines after regularization

4. CONCLUSION AND FUTURE WORK

The presented approach allows for proper reconstruction of building outline shapes. The reliability of building region detection is enhanced by incorporating information about the building address points. The algorithm was tested against raw, airborne acquired 3D point clouds presented in graphics.

Building detection process proposed in this paper aims at extraction of adjacent building clusters. In our future work we intend to develop methods for splitting up detected adjacent building clusters into single buildings.

In the presented approach the outline of the building was considered as a building roof footprint. Typically, the building outlines for the mapping purposes are corrected for roof overhangs (Oude Elberlink, 2010). Therefore, they represent the walls of the building. The area covered by roof is bigger than the counterpart marked out by walls. As well, both polygons can differ in shape. Solutions proposed in literature needs additional information, like terrestrial laser scanning data or cadastral information. Such additional information can be also obtained using reflectance from the walls. A proper algorithm for that purposes is under development.

Although, utilization of address points can highly simplify the outline reconstruction process, there are areas that have no address information. Therefore we plan to modify our algorithm, using the method proposed by Keller and Borkowski (2011). They applied wavelet decomposition for the building identification purposes. Numerical tests performed until now prove that the incorporation of such information allows significant optimizing of the 3D modelling process.

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