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Automatic non-ground Objects Extraction based on Multi-Returned LIDAR data

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Keywords: photogrammetry, LIDAR, DSM, DIFF, segmentation, classification, ground objects, 2D building outline

Summary: A series of processes for fully automatic non-ground objects detection, classification and reconstruction based on LIDAR data is presented in this paper. Ground and non-ground objects were been separated directly from the DSM grid image, which was interpolated from first returned echo of laser measuring pulse with point height related to gray value, without any other accessorial information of pure terrain character. The DSM image has been segmented into many internal height homogenous regions by analyzing the second derivative of DSM surface heights. Feature of height changes inside each segment of DSM was homogenous. Classification of these homogenous regions was implemented based on a DIFF (First-Last-Echo-Height-Difference) image, which was interpolated from multi-returned LIDAR data with the height difference between first and last echo of a single measuring pulse related to gray value. The homogenous regions can be classified as buildings, trees and ground objects (streets, squares, etc.) by the quantity of first-last-echo height difference signals inside them. For the vegetations, a single tree-crown delineation process has been implemented. In each building region, a fine polygon for building footprint was been reconstructed by a least square line fitting process on first last echo height difference signals along the building border. With the footprint polygon as the basic form and the average height of LIDAR points inside the polygon to be building height, simple 3D model of buildings were constructed.

Zusammenfassung: *Automatische Extraktion von Nicht-Boden-Objekten auf der Grundlage von Multi-Reflektions-LIDAR-Daten.* In dieser Veröffentlichung werden Prozessabläufe zur automatischen Erfassung, Klassifizierung und Rekonstruktion von 3D-Objekten auf der Basis von LIDAR Daten präsentiert. Die 3D Objekte werden direkt aus einem DSM Grid extrahiert. Das DSM wird dabei aus dem ersten Laserecho interpoliert, wobei die Grauwerte direkt auf Punkthöhen bezogen sind. In einem weiteren Schritt wird das DSM, basierend auf der zweiten Ableitung, in viele homogene Höhenregionen unterteilt. Die Klassifizierung dieser Höhenregionen erfolgt dann auf der Basis eines Differenzbildes (Differenz aus erstem und letztem Laserecho). Aufgrund der Echodifferenz innerhalb der homogenen Höhenregionen kann eine zuverlässige Zuordnung zu Gebäuden, Bäumen (3-D Objekten) und Boden (z. B. Straßen, Plätze, Wiesen) erfolgen. Zur weiteren Delinierung von Bäumen und Sträuchern innerhalb der Regionen wird ein spezifischer Algorithmus, wie er bei WEINACKER et al. 2004 beschrieben ist, verwendet. Die Abgrenzung von Gebäuden, innerhalb von Gebäuderegion, erfolgt auf der Basis eines ,,Least Square Fitting" entlang der Gebäudekanten, die durch starke Differenzsignale zwischen dem ersten und letztem Echo gekennzeichnet sind. Basierend auf dem daraus abgeleiteten Grundrisspolygon und der durchschnittlichen Höhe, gemessen innerhalb des Polygons, wird dann eine angenäherte Gebäudehöhe errechnet und einfache 3-D Gebäudemodelle rekonstruiert.

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1 Introduction

Since LIDAR has been considered as an efficient technology for 3D data capture in recent years, the extraction of non-ground objects based on LIDAR data with or without help from other information such as multispectral images has been an active research region for several years. Extraction of trees and extraction of buildings are the two main study orientations while trees and buildings are the two main components of non-ground objects.

More efforts will be given to the extraction of buildings in our research. Even so both vegetation regions and building regions will be detected from DSM at the same time by segmentation on DSM and classification with help from First-Last-Echo-Height-Difference (DIFF) image.

According to Brenner (2000), extraction of building can be divided into firstly, building detection and secondly, building reconstruction. That means, building regions should be detected and 2D building outlines been approximated before generating 3D polyhedral building models.

For the generation of 2D building outlines, nDSM (normalized Digital Surface Model) based method was the most popular one. Building regions were detected by a height threshold on nDSM, which was calculated by subtracting DSM (Digital Surface Model) with DTM (Digital Terrain Model). Morphological algorithms, texture classification and other edge detecting algorithms have been used to generate primitives of building outlines (Rottensteiner 2002, Elberink 2000 etc.). Beside nDSM, existed 2D ground plan of city are been used directly as the primitive of building outline in some researches (Vosselman 2001, Brenner 2003). Some other works are trying to get the 2D building outlines directly from LIDAR raw data (Cho et al. 2004).

For the nDSM based methods, the result of building extraction relied highly on the precision of nDSM. Therefore, calculation of DSM and DTM has played a decisive role in those procedures. Generation of different kinds of digital ground models obtained from the original point clouds by data filtering and interpolation has been a special research topic for years. Today it is still the most important utilization of LIDAR data (Brenner 2003). Although many efforts have been achieved, there are still many problems when the terrain structure or the land-use situation is relative complex. For example, buildings with large flat roof such workshops might be considered as part of terrain and existed in both DSM and DTM, thus to be lost in nDSM. Another problem case is that the structure of building roof might be destroyed by calculation of nDSM when the building sites on a steep slope (Fig.1), and then cause a false detection of building 2D form.

To use the 2D ground plan of city is much easier, but in some cases there might be no existing GIS 2D ground plan or there might be some problems with GIS data updating. However, 2D ground plan could be part of building detection, but might not be the only source of 2D building feature.

In this paper, we intend to detect buildings directly from DSM, because it takes too many efforts to generate a DTM from LIDAR data which is eligible for calculation

Fig. 1: Problem building case on nDSM.

of nDSM to make the building extraction, especially in changeful terrain area, and there will be much less chance for building structure deformation in DSM than nDSM.

The study is based on multi-returned LIDAR data. Beside the DSM image, a calculated grid image, which is called in this paper as DIFF image, has played an important role in the research. More detailed information about this DIFF image will be given in the second part of the paper. Algorithms for non-ground objects detection and classification will be main content of the third part. In the forth part, we concentrate with the detected building regions, 2D building structure will be found out and simple 3D block building model will be reconstructed. Short conclusion of this study and the prospect view of next approach will be given in the last.

The DSM segmentation method has been tested with LIDAR data from Engen, Memmingen and Mannheim (Provided by Toposys GmbH) which with different point density from 2 ~ 3 points per square meter (Engen, Memmingen) to over 10 points per square meter (Mannheim). The algorithms for classification of the segmentation results and reconstruction of building model has been tested with Memmingen and Mannheim data, cause data from Engen is single-returned LIDAR data which not fulfill the condition of the algorithms.

2 Hypothesis for the used method

2.1 *First and Last echo of one measuring* pulse

Since the laser pulse has an angular beamwidth, it will cover a circular area when it hits the ground object. The laser beam can penetrate some transparent objects like trees due to its physical characters. In this case, some of its energy will be reflected back from the object top surface and other portions might penetrate to different depths inside the pulse area, some of them will reach the ground surface. Thus for objects which can be penetrated by laser pulse more than one echo can be recorded for each single measuring laser pulse, the first echo intents to represent the top of the object and the last echo shows that how deep the laser beam can reach through the object.

Based on the different physical characters of ground objects, we can deduce that there will be no significant height difference between the first and last echo in solid object area such as building roofs and grounds. While a relative significant height difference will be showed in the reflected echoes by vegetation or trees in contrast, because most of them can more or less be penetrated by the laser beam. Building boundaries will also show a high response of height difference between first and last echo, the reason for this is, when the laser beam reaches to the ground surface it will have a footprint with a size in the range of 15–30 cm or more, so if the laser beam hits the edge of a building

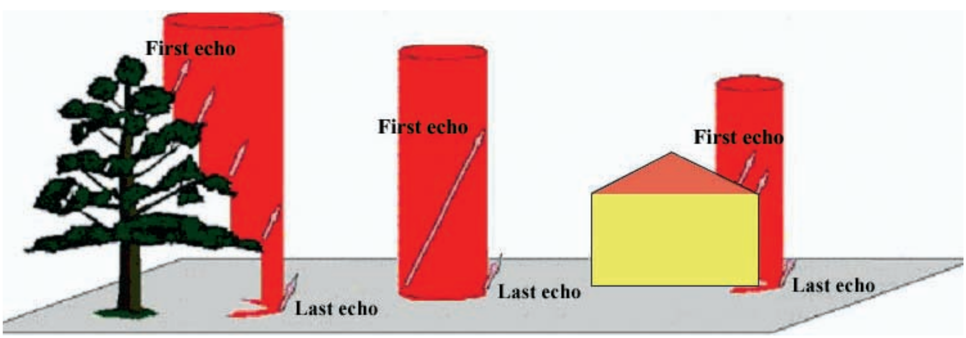


Fig. 2: First and Last echo in different kind of objects (IPF 2003, modulated by WANG).

then part of the beam will be reflected from the roof of the building and the other part might reach the ground (Fig. 2). These different features of first-last echo height difference for different ground objects can be main factor of ground objects classification.

2.2 Generation of DSM and DIFF image

Both DSM and DIFF were generated by Treesvis, a software system for LIDAR process and visualization developed at Department of Remote Sensing and Landscape Information Systems (FeLis) (WEINACKER et al. 2004). The DSM image was interpolated from the first returned echo with point height as gray value, and the DIFF image took the height difference between first and last echo for each measured point as gray value.

2.3 Work flow

The main work flow includes three major steps:

First, segmentation, DSM has been segmented into separated regions where the surface height changes inside each region shows a homogenous character.

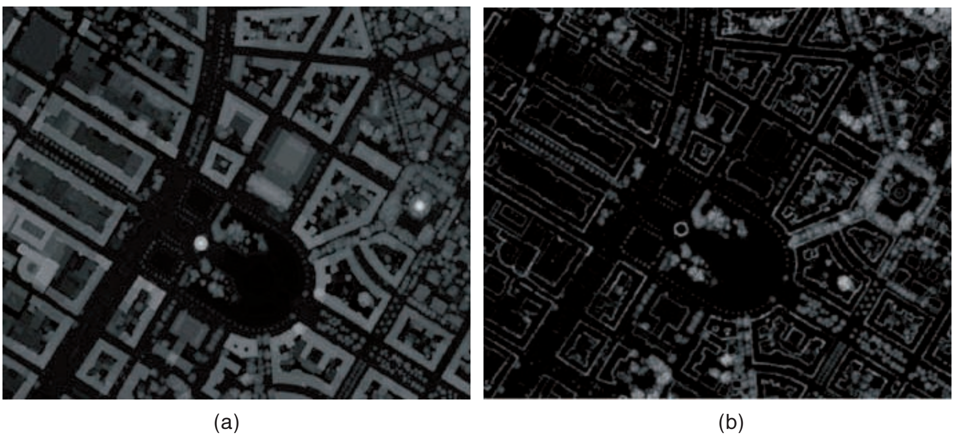


Fig. 3: (a) DSM image; (b) DIFF image; (Part of city Mannheim center, resolution 0.5 meters).

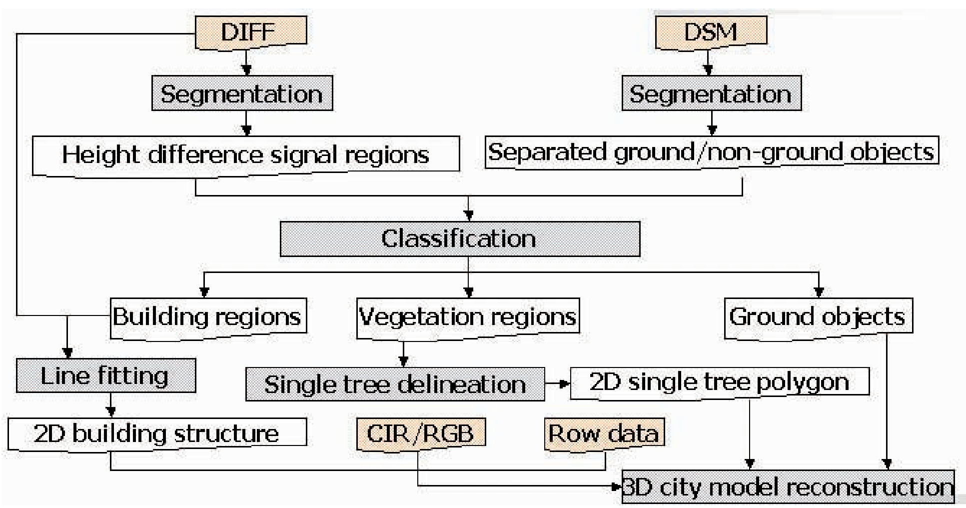


Fig. 4: Main Work flow.

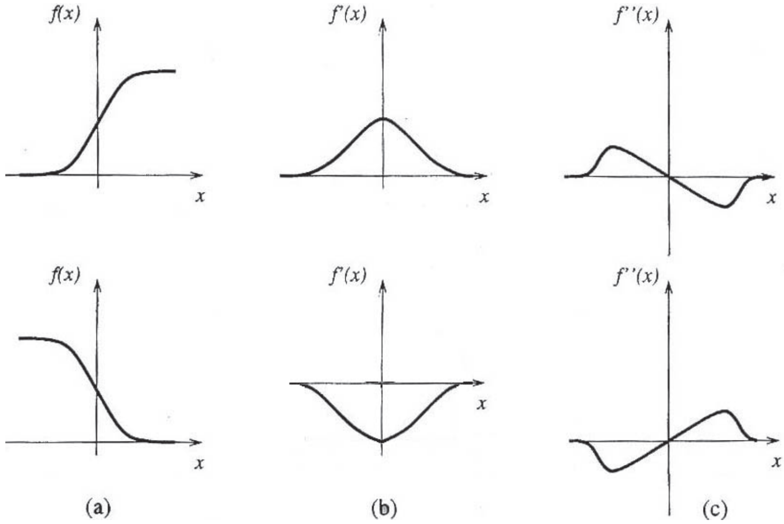


Fig. 5: Second derivative of increase and decrease step changes. (a) Original ascent and descent height change; (b) First derivative on height change; (c) Second derivative on height change.

Second, classification, the height homogenous regions have been classified into grounds, trees and buildings.

Third, 2D building outline reconstruction, to generate a polygon which describes the 2D building structure. Simple 3D building model can be generated with the 2D polygon as building form and the average height on building roof as building height.

3 Segmentation on DSM image

3.1 Second derivative of DSM

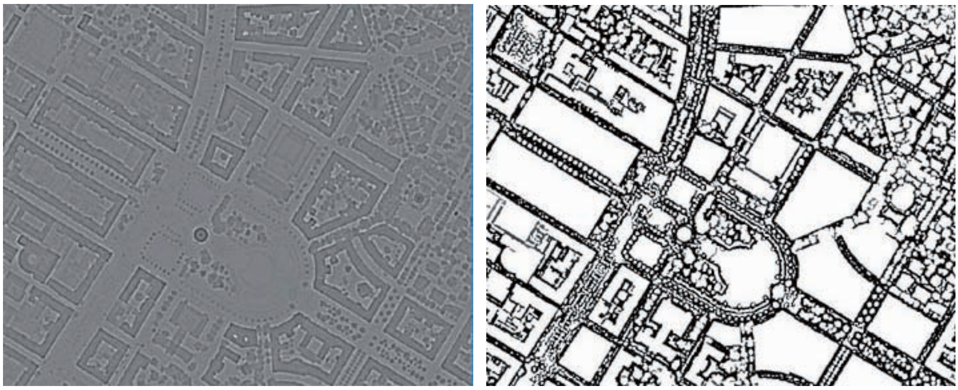
In a DSM image, there must be a significant height change (step change) between grounds and non-ground objects while the height change within a single object will be much more less. The second derivative of ground surface height is used to separate ground and non-ground objects, because the value of second derivative must be negative after a significant increasing height change until another obvious decreasing height occurred, and it will be zero along the edges of objects (Fig. 4).

Regions within a closed edge, which have same sign on second derivative value has been considered as internal height homogenous. According to the height feature of non-ground objects, the second derivative value must be negative within a single non-ground object, which can be extracted easily by detecting the sign of second derivative.

The second derivative of DSM image can be computed with Laplace of gauss algorithm easily. The DSM should be smooth firstly so that the height change within a single building roof or trees could be neglected. After a simple threshold on the Laplace image (take out all the negative regions), heights within each separated region are homogenous.

3.2 Height Homogenous Regions

After the refinement of the separated regions with morphological closing and opening algorithm, the feature of height change within those separated regions must be relatively homogenous and can be called height homogenous regions, which means that the height changes within the region are smooth and continue. As has been mentioned in 3.1, objects within the height homogenous regions must be non-ground objects, in fact, the possibilities of the objects inside such a



(a) (b)

Fig. 6: (a) Laplace image of DSM; (b) Height homogenous regions (segmentation results).

single height homogenous region can be generalized as follows:

- Grounds (roads/squares etc.)
- Building(s) (single/ conjoined)
- Tree(s) (single/conjoined)
- Conjoined building(s) and tree(s) (when building(s) were overlapped by tree crown(s))

A classification process was applied to classify those regions into Grounds, Buildings and trees.

4 Objects Classification

4.1 Extraction of Trees

As it has been shown in Fig.6 (b), some of the height homogenous regions are combined with buildings and trees. The reason is, when trees have similar height with adjacent buildings, in another word, when building roofs are overlapped by near tree crowns, the second derivative of height is not sensitive enough to separate them because there is no significant height change between the buildings and trees.

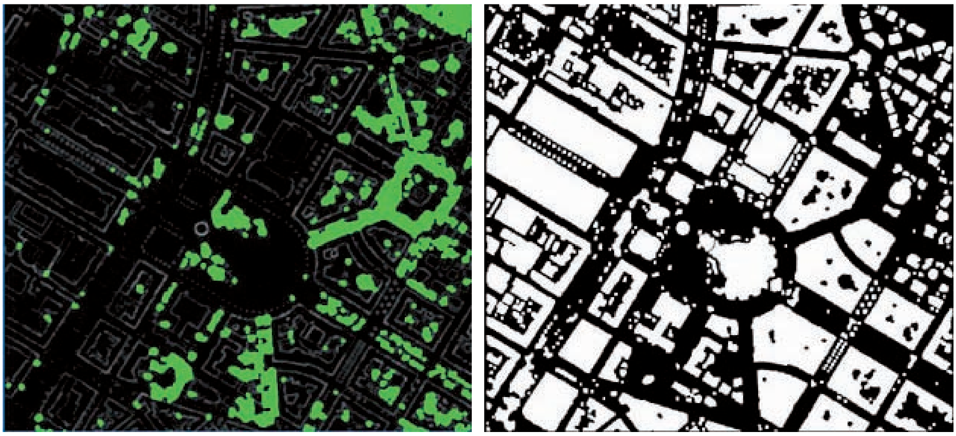
To get a better result for classification of those height homogenous regions, it's better to make the regions more purely. That means to extract the trees out of the height homogenous regions in which trees and buildings are combined together, so that to make sure there is only one kind of object within a single homogenous region.

Big area of trees can be detected directly by their morphological character in DIFF image. They always showed a cloud-like feature in DIFF while the edges of buildings showed a line-like feature. Those line-like objects can be erased out by a morphological-skiz and closing process, the remains are those cloud-like regions, which can be considered as trees. This procedure is used for the extraction of big area of vegetation, smaller tree objects will be extracted by the classification algorithm in the next step.

4.2 Classification of Height homogenous regions

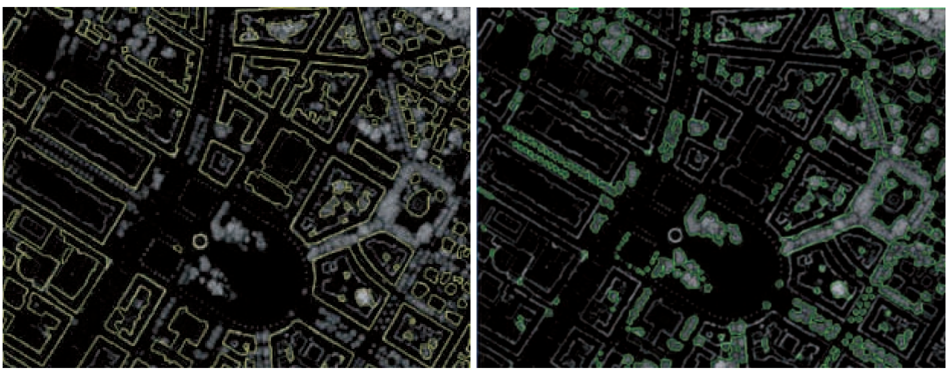
As has been mentioned in 2.1, there is nearly no height difference between first and last echo of a single laser pulse in the ground, while only a few height difference can be recorded along the border of building. Trees in contrast will show a high density of height difference between first and last pulse inside. Therefore, the classification of separated height homogenous regions into grounds, buildings, or trees can be carried out by counting the amount of the height differences between first and last echo within them.

The DIFF image is used to get information on the character and amount of the height differences between first and last echo



(a) (b)

Fig. 7: (a) Trees Extracted from DIFF; (b) Rest of Height homogenous regions.



(a) (b)

Fig. 8: (a) Detected buildings; (b) Detected trees (combined with results from 4.1 and 4.2).

inside a height homogenous region. Firstly, a simple threshold on DIFF image can get the signal regions in which height difference has been captured. Secondly, the intersections of height homogenous regions and the signal regions from DIFF image have been detected. The parameter for classification can be estimated by following expression:

$R = A_I / \mathrm{A}^R$

in which

A_I: Area of intersection region between a single height homogenous region and DIFF signal region, which means amount of height difference signals within a single height homogenous region.

A_R: Area of the corresponded single height homogenous region.

The classification of those height homogenous regions can be accomplished with the following criteria of ***R*** that:

Ground, when $\boldsymbol{R} < 0.1$
Building, when $0.1 \leq R \leq 0.9$
Tree, when $\boldsymbol{R} < 0.9$

Thresholds 0.1, 0.9 are experience values.

R should be zero for ground, which means that there should be no height difference between first and last echo inside the height homogenous region, while ***R*** should be 1 for trees since the homogenous region should full of height difference signals. The rest homogenous regions, which are partly covered by height difference signals should be buildings. Considered to the noise on the image and the other possible errors, a relatively loose criteria has been given to ground and trees with a interval of 0.1 as buffer.

4.3 Delineation of single tree crown polygon within tree regions

After the combination of the detected tree regions from 4.1 and 4.2, a single tree crown delineation process has been fulfilled within these regions. A group of polygons, which described the single tree crowns have been calculated, the single tree objects have been simply classified by the rate between tree crown width and tree heights, more detailed descriptions about this single tree extraction algorithm can be found in (WEINACKER et al. 2004).

5 Building Reconstruction

5.1 Line detection within a single extracted building region based on DIFF image

After detection of building regions from DSM, the outlines for the building or conjunct buildings inside them need to be extracted.

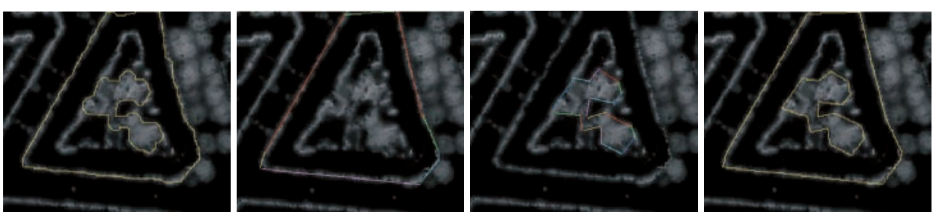
Based on the fact that height difference between first and last echo in a single measuring pulse can be captured at the edges of buildings. Although these height difference signals in DIFF image might not be consecutive along the building edges, it is possible to extract the primitive structure of building form from them. The reconstruction of 2D building outlines is therefore started from those primitive building structures given by the height difference signals.

Based on an assumption that all the line-like height different signal groups within a detected building region represent a part of building edge. The first step is to extract the pixels that represent height difference signals in the DIFF image. Then, a least square line match procedure was applied to the single pixels. The algorithm used here is a Weighted "least squares" line fitting, where the impact of outliers is decreased based on their distance to the approximated line. Several line segments are found by the line fitting procedure, the coordinates of start point, end point and the normal vector are given as parameters of fitted line segments. There are lots of available "least squares" based line fitting algorithms, more investigations are needed to decide the most appropriate algorithms for various kinds of height difference signals.

5.2 2D building outline reconstruction

The anticipant result of 2D building outline reconstruction should be a closed polygon which described the main form of the building, so a post processing is needed to accomplish the reconstruction of building outline polygon with those fitted line segments from 4.1. The main assignments of the post processing are:

- Combine two line segments, where the distance between the end point of first line and the start point of the second line is



(a) (b) (c) (d)

Fig. 9: (a) Detected building region; (b) outer polygon; (c) inner polygon; (d) final polygon.

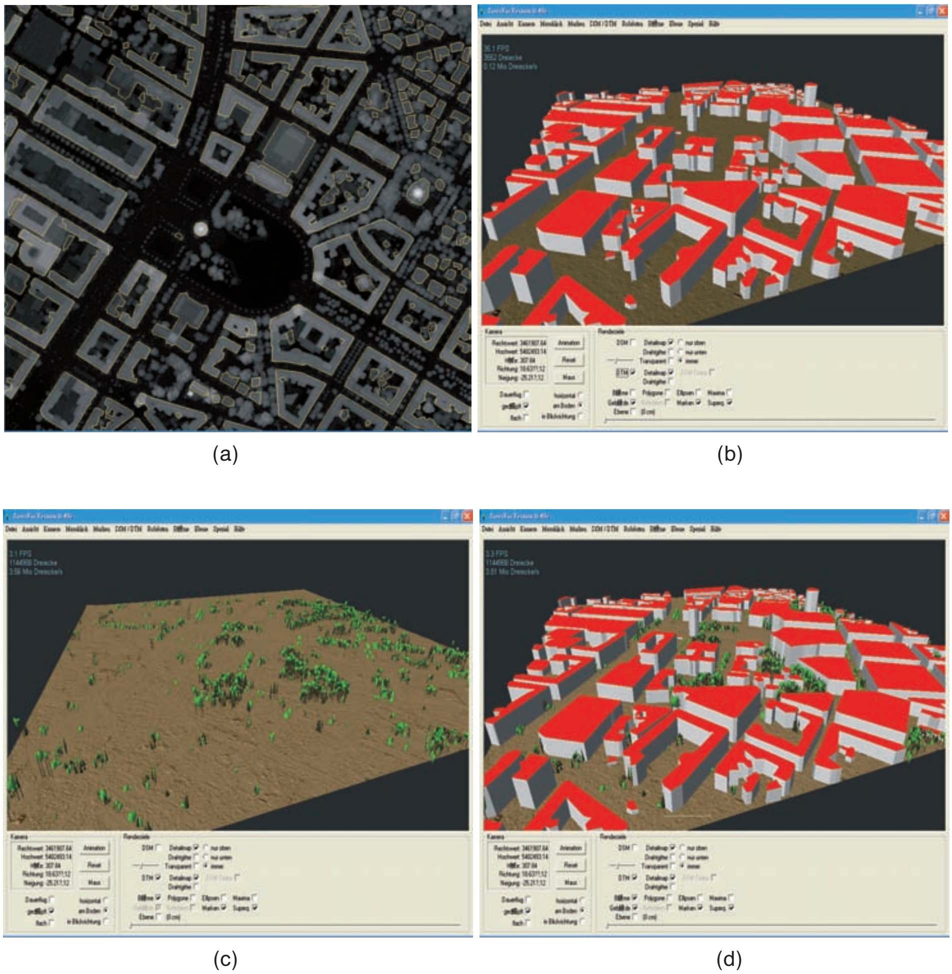


Fig. 10: (a) 2D building footprints; (b) 3D building block structure; (c) 3D single tree models; (d) extracted non-ground objects (b,c,d are visualized by Treesvis).

within an acceptable distance, and the angle of their normal vectors is smaller then a threshold (the directions of two segments are similar).

- Add a new line segment, when the distance between the end point of first line and the start point of the second line is within an acceptable threshold distance, but there is a large angle between there normal vectors. The additional line segment use the end point of the first line as its start point and the start point of the second line as its end point.
- Check if all the line segments are conjunct as a rational polygon.

  Finally, a closed polygon has been generated as the 2D building outline. The data structure of the polygon is an aggregate of arcs (line segments) and points (end points of line segments).

5.3 3D building model reconstruction

A simple 3D building model can already be constructed by using the polygon as the primary building form and the average height of the points within the polygon as the primitive height.

6 Conclusion

Height difference signals between first and last echo in a single measuring pulse of LIDAR can give an inspiring primitive structure of 2D building form, the problem is to confirm which of those height difference signals belong to one certain building, so the single building region must be detected from the data first.

Height threshold based on nDSM is the familiar method for building extraction before, but the calculation of DTM would have taken a higher priority in the research and consume more time than building detection itself. A method to extract buildings directly from DSM will make the things much easier, and the errors for building extraction, which caused by calculation of DTM or nDSM can be avoided. DSM image is segmented into several separated height homogenous regions by using a simple threshold on second deviation of it, then the regions are classified into grounds, buildings and trees with the help of the amount of the height difference signals inside them. The comparison between the detection of building regions according to the method described and visual observed buildings in the LIDAR and multispectral data, the outcome is quite precision, more than 90% of buildings are automatically well detected from the DSM image. The reason for losing building regions is false classification. The detected height homogenous regions for those lose building have been classified as ground objects caused by the weak DIFF signal records for these buildings. Since these building regions have been already separated from the DSM, it is possible to keep them by improving the classification method in the future.

Concentrate with a detected single building region, the height difference signals can now exert themselves to 2D building outline reconstruction. A least square line fitting procedure has been applied to these signals, after several post processing on the fitted line segments, a final polygon for 2D building outline has been reconstructed. Such kind of polygon can deal with buildings of complex form such as triangular or ring based buildings, even the round or radian edges of buildings can be approximated with more arcs as parts of the building outline polygon. A problem is to find the precise building edge (Fig. 9, c), when the building is partly covered by a tree crown. The covered part will be lost and there will be a false assumption of the building edge based on the rest information. The other problem is that some detailed information, especially the marginal structure along the border, has been lost during the least square line fitting procedure. Finally, the building might be separated into different parts, if there is significant height difference within the building roof. There is a chance to solve these problems by the further investigations on LIDAR point clouds within a single building region directly.

The 2D building outline polygons can to be used for a better result of DTM generation by extracting the point clouds within the building regions. They will also play an important role in next steps of 3D city model construction in the future. Rough 3D building models are already constructed with the 2D building outline polygon produced, more efforts are needed on the reconstruction of detailed roof structure of building by using point clouds within the building outline. Multi-spectral image is expected to support the detection of break lines within the roof area.

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