BUILDING EXTRACTION FROM LASER DATA BY REASONING ON IMAGE SEGMENTS IN ELEVATION SLICES

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ABSTRACT:

Remote sensing in urban areas has been a challenge for quite some time due to complexity and fragmentation of objects and the combination of man-made features and natural features. Airborne laser altimetry data offer possibilities for feature extraction and spatial modelling in urban areas. There are many approaches of deriving buildings and other features currently available in literatures. However, there are many cases, which are still difficult for particular features to be extracted by using these approaches. For instance, in an urban area where many roads are raised above ground level with special characters similar to buildings. Building extraction in such a complicated urban context is still a difficult task for these available approaches. The proposed approach was developed to solve this type of cases. It tries to extract buildings through reasoning in a layer space in general. In the proposed approach, airborne laser altimetry data in raster format was segmented by using several thresholds with 1-meter interval of altitude. These image segments were then labelled and assigned with unique label values, which are treated as image objects. Hence, a number of properties can be derived based on labelled segments (image objects) such as size, shape, orientation etc. These properties are used for reasoning in the layer space. The layer space is defined as such that use altitude with 1-meter interval as a variable in X-axis and use these properties as functions of altitude in Y-axis. Vertically segmented image objects are linked and inferred vertically as well. A tree structure was created using links between different layers of segments vertically. Reasoning is based on patterns of these properties on the paths of each branch of searching tree in the layer space. Sequential experiments have been tested in a study area, southeast of Amsterdam based on the proposed approach. The test results show that the proposed approach is a robust and reliable approach in building extraction. It has potential capacities in extraction of other features. The theoretical framework, detailed description of major steps as well as experimental results are presented in this paper.

1. INTRODUCTION

One of the problems in automatically extracting buildings from airborne laser altimetry data is to discriminate between buildings and other protruding man-made structures such as flyovers, driveways, etc (see, *e.g.*, Shufelt, 2000; Axelsson, 1999; Brunn and Weidner, 1997; Haala and Brenner, 1999; Hug and Wehr, 1997). Instead of trying to solve the problem by pixel-based analysis of the DSM, we study the change of properties of image objects in elevation slices. We slice the DSM at a fixed vertical interval (1m in our test data) to obtain image objects at various levels, which are then subject to reasoning. The underlying assumption is that for a building certain properties of its image object hardly change from one level to the next, see Fig. 1. In the present study we detect buildings based two properties, *i.e.*, vertical change of size of an image segment and shift of its centre of mass. To this end, we have to link the image objects at the different layers by a tree structure. The degree of change from level to level also permits to produce uncertainty estimates of extracted buildings. We have tested the approach using high-resolution laser data of our Amsterdam test site.

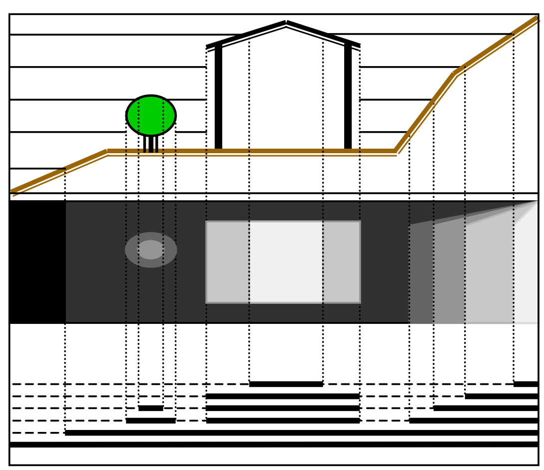

Figure 1. Profile of real world (a), laser image (b) and profile of image segments for building reasoning with interval of 1 meter (c).

2. FORMATION OF IMAGE OBJECTS AND THEIR PROPERTIES

We segment the laser altimetry data given in raster format (standard Dutch DSM, *AHN*) with a 1-meter interval starting from the lowest elevation in area and proceeding to the highest. The result is a set of binary images as illustrated by Fig. 2. Next, the image segments are uniquely labelled per image, thus obtaining identifiers of the image objects. Several properties of an image object--size, shape, etc--could be computed and may be useful for reliable analysis. Here we consider two obvious ones: size and location.

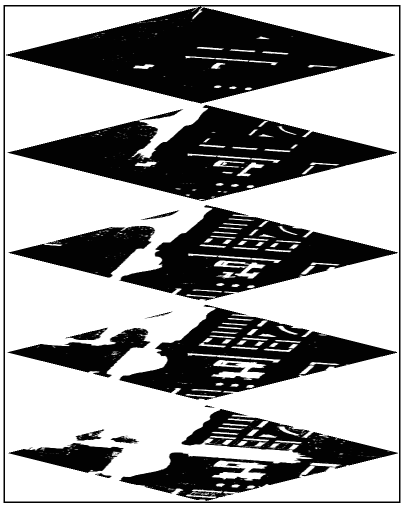

Figure 2. Vertical image segmentation of laser data

The size of an object is calculated as the actual number of pixels of the segment. The location is computed as the centre of mass of the segment.

Linking image objects in a tree structure is accomplished by association tables. The first one records the identifier of a segment in an image and its associated segments in the other images. The associated segments are identified by their position in the grid. Other association tables are generated in a similar manner for the size and the location of the image objects. These tables are used for reasoning in the "layer space".

3. REASONING FOR BUILDING EXTRACTION

The layer space is defined by a plot of the property of an image object (e.g., size of the object or percentage change of size by going up one layer) against layer altitude. For every vertically linked image object a plot results. The reasoning is then based on the patterns of a property as obtained from all the paths of each branch of the searching tree in the layer space.

3.1 Building Identification

A fair assumption for the majority of buildings seems to be near vertical walls within a certain height range and that this may help to distinguish them from flyovers, access ramps and alike. Accordingly, a requirement for identifying a building is image objects, which have little deviation in size and only a small shift of the centre of mass between adjacent layers.

We consider the following indicators computed for layer i and layer i+1:

$$\Delta_{Size} = (Size_i - Size_{i+1}) / Size_i$$

$$\Delta_{Location} = \sqrt{((X_{i+1} - X_i) + (Y_{i+1} - Y_i))^2}$$

3.2 Reasoning in Finding Buildings

To identify a building, we need to define thresholds for the tolerated change between layers.

In a 2-D image space I^2, a segment (*S*) can be identified as belonging to a building if it meets the following conditions.

$$S = \begin{cases} Building, & \Delta_{Size} < T_{Size} \wedge \Delta_{Location} < T_{Location} \\ Else, & \Delta_{Size} \geq T_{Size} \vee \Delta_{Location} \geq T_{Location} \end{cases}$$

In addition, local knowledge should be included such as the maximum and minimum possible size of a building (*e.g.*, a building cannot be larger than 5 hectares and smaller than 100 m^2). The above reasoning is unlikely to well differentiate between buildings and higher trees (see Fig. 1). Other information sources would have to be added (spectral information or first – last return laser data).

A small part of the laser range image, which is used in the case study, and the extracted buildings are shown in Fig. 3. Buildings, which are either lower or higher than the roads are extracted properly. The plot of relative size differences versus altitude is shown in Figure 4 for two selected buildings (1 and 2). Building 1 is located in a lower part of ground while building 2 raises from the level of an elevated road. The curve of building 1 shows a large size change from the bottom layer to the next layer of the segmentation, which reflects the fact that at the bottom layer segments are very large in the case of horizontal ground (Amsterdam). The same holds for building 2. For building 1, the curve then drops to close to zero for the next level and remains stable, indicating the near vertical walls build on low ground. For building 2, the decrease in size difference is slow while climbing up from the bottom to the road level. Once reached (at 2 m above sea level) the vertical walls cause the curve to stay stable.

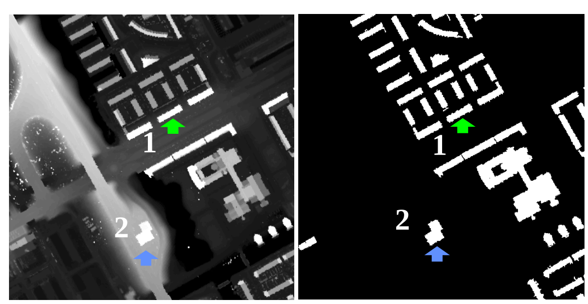

Figure 3. A small part of original laser image and extracted buildings

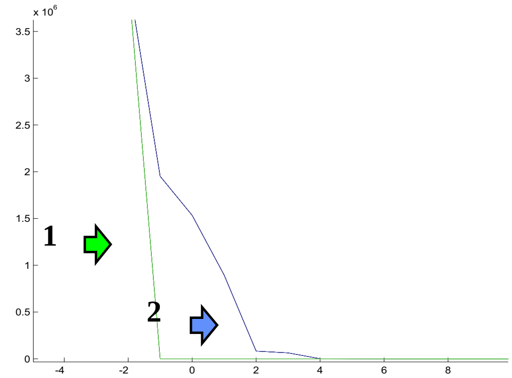

Figure 4. Plots of size differences for 2 buildings

3.3 Additional Reasoning in a Building

Building basement

The lowest segment along the vertical line, which meets the criteria of a building, will be treated as the basement (ground floor) of the building.

Building height

When a segment has been defined as the basement of the building, the difference between altitude of its layer and the altitude of the DSM at this position can be taken as height of this building (with an accuracy determined mainly by the interval between layers (1 m in our case), which is still sufficient for counting number of floors).

Outline of a building

Since in particular the lower segments may contain noisy pixels caused by adjacent vegetation or structures in gardens as shown in Fig. 5, it is up to the user or application objectives to decide from which layer to extract the outline of the basement. If a building has vertical walls, the upper layer may give the better outline.

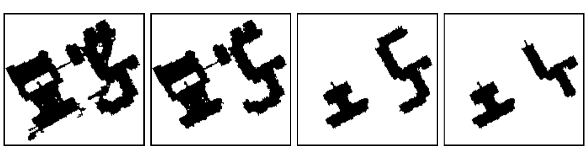

Figure 5. Outline differences of a building from basement to its upper layers (from left to right).

4. CASE STUDY

4.1 Study Area

A 9 km^2 (3 km × 3 km) area, Southeast of Amsterdam, was selected for the experiment (see Fig. 6). Approximately 200,000 people live in this sub-urban district. Several types of residential as well as commercial areas, parks, lakes and canals can be found in the study area. Built-up area, green space and water are the three land cover classes in this study.

Fig. 7 shows the result of the building extraction by the outlined approach. The building heights above ground level were extracted as shown in Fig. 8 based on the building basements shown in Fig. 7.

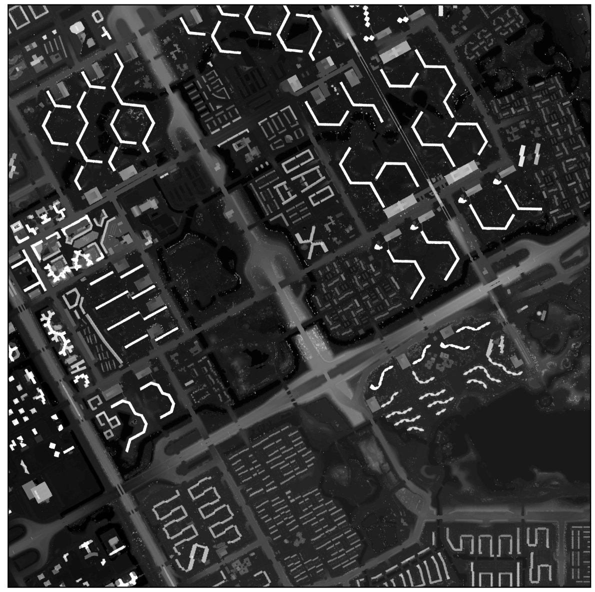

Figure 6. Laser scanning data (AHN) with 1 m resolution (Copyright hold by Rijkwaterstaat, the Netherlands)

Figure 7. Building extracted by checking the size differences.

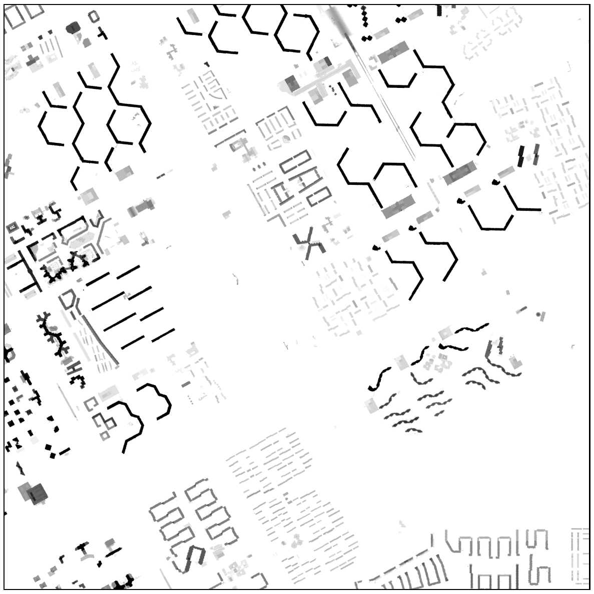

Figure 8. Building height above ground level produced from the DSM and basement levels (darker tone indicates higher building).

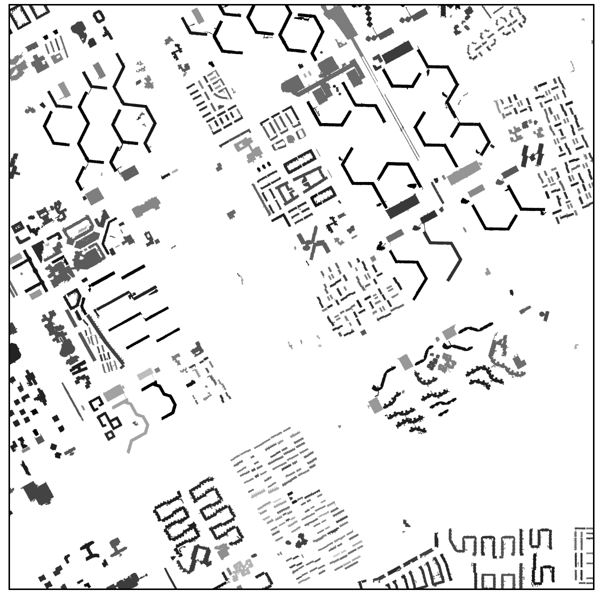

Figure 9. Uncertainty assessment result (lower tone indicates higher uncertainty, dark tone indicates higher certainty respectively).

4.2 Quality Assessment

Accuracy assessment

For the sake of comparison, we created a "ground truth image", which contained exclusively buildings (derived from image analysis and edited with reference to the 1:1000 scale cadastral maps). Accuracy assessment was made based on image-to-image comparison between the result of building extraction and the ground truth as shown in Table 1. The total number of buildings is different due to different interpretations what a building is. *E.g.,* the map did not include the metro stations and some other small buildings, while the extraction result did. On the other hand, several parking garages have not been detected due to the direct connection with raised roads. In general, high quality results have been obtained according to Table 1 and a map indicated the exact differences between them.

Table 1. Accuracy assessment of extracted results

	Building (Extracted)	Building (from map)
Total Number	727	730
Correct Number	683	704
Mistake Number	44	26
Correct (%)	93.95 %	96.44 %
Mistake (%)	6.05 %	3.56 %

Uncertainty assessment

For uncertainty assessment, we indicated for each segment if the defined criteria for a building were matched and stored in a tree table. Then we counted the number of segments existing above building basements and the number of segments that met the criteria we established for two adjacent layers. The uncertainty was expressed as the percentage of segments that met the criteria and is shown in Fig. 9. In case that several building branches existed above a basement, the average was applied.

5. CONCLUSIONS

The experiments show that proposed image-object based approach can be a robust method for building extraction. It works well even in a complicated urban context. Since the results are encouraging, we will pursue the object-based approach for extracting meaningful features.

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