CHANGE DETECTION FOR UPDATING MEDIUM SCALE MAPS USING LASER ALTIMETRY

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Commission III, WG III/3

KEY WORDS: Laser scanning, LIDAR, Classification, Change detection, Mapping, Updating

ABSTRACT:

To increase the update rates of topographical databases, research is performed to automatically detect changes using airborne laser scanning data. After the determination of the bare-Earth points, the remaining points have been classified as either points on buildings or points on vegetation. Additional usage was made of registered colour imagery taken during the laser scanning survey. The results show that buildings can be detected reliably using laser altimetry data sets. However, they also show that mapping rules (which buildings should be in the map and which can be neglected) need to be implemented accurately. Otherwise, the change detection procedure would signal a need for map updating for buildings that are not to be mapped.

1. INTRODUCTION

To satisfy the demands for more frequent updates of topographic databases, mapping agencies are looking into the possibilities to partially automate their production processes. Automated mapping still seems to be far out of reach. However, new technologies like laser scanning can help to speed up the production process. When revising a topographical database, much time is currently spent on checking whether the information is still up to date. Significant costs savings can be obtained if one would be able to automatically flag the objects in the database that need to be updated. In this way an operator would no longer have to look at map areas where no changes took place. This paper reports about studies on the usage of laser scanning data for automated change detection of buildings for the purpose of updating a medium scale map (1:10.000 scale).

In general, change detection can be performed on multi-epoch data or by comparing data of a single epoch to a map. Surface model differences generated from multi-epoch data of laser scanners immediately show newly constructed or demolished buildings and roads (Murakami et al. 1998, 1999). In most cases, such data will, however, not be available. Alternatively, one can compare object extracted from laser data of a single epoch to the objects of a map. For this purpose one first needs to segment the laser data and classify the segments. This approach is followed in this paper.

In Section 2 related literature on the classification of laser scanning data and the usage of laser scanning data for change detection is briefly reviewed. Section 3 discusses the segmentation and classification of laser scanner point clouds into bare Earth, building, and vegetation segments. Results of this classification are presented in section 4. The segments classified as building segment are compared to the building objects of a topographical database. The purpose of this comparison is to detect buildings that are new, changed in size or shape, or demolished. For this step to be successful, it is important to implement the same object selection rules as described in the mapping catalogue used for the production of the topographic database. Differences caused by generalisation of the building shapes in the database also need to be accounted for. The developed procedure for change detection is described in Section 5. The results are discussed in Section 6.

2. RELATED LITERATURE

The classification of laser point clouds into points on the bare Earth surface and other points is of large importance for the production of digital elevation models with laser scanning. Many studies have been devoted to this subject. Sithole and Vosselman (2004) provide an overview on these filter algorithms together with an experimental comparison.

For the purpose of change detection it is required to further classify the points that do not belong to the bare Earth surface. Maas (1999) and Oude Elberink and Maas (2000) extract texture measures from height co-occurrence matrix. These texture measures, together with differences between first and last pulse laser data and the heights of a normalised digital surface model are used as the input for an unsupervised K-means classification. Depending on the number of object classes to be distinguished, 90% to 97% correct classifications were obtained.

Matikainen et al. (2001, 2003) use a bottom up region merging algorithm to create segments. For these segments attributes like texture measures from a co-occurrence matrix, the homogeneity of the intensity and the average edge length are derived. These attributes are combined in a classification using fuzzy logic. 90% correct classifications are reported.

Voegtle and Steinle (2003) also use a region merging algorithm and a subsequent fuzzy logic classification. As attributes of the segments they use the gradients on the segment borders, the differences between first and last pulse laser data and shape and height texture measures. With three classes (bare Earth, building, and vegetation) 93% correct classifications are obtained.

Less results have been published on the actual change detection using laser scanning data. Murakami et al. (1998, 1999) extracted changed buildings from multi-epoch laser scanning data. Changed segments were delineated in an image created by subtracting two images with digital surface models. Steinle et al. (1999) compare laser scanning data with an existing 3D CAD model of an urban environment. By point wise comparison of heights changes can be seen. Although no attempt is made to automatically detect the changes, the potential of laser scanning data for this purpose is clearly demonstrated.

Recently, Matikainen et al. (2003) presented a study on change detection which compares classified segments of laser data to buildings of a map. The comparison was performed with a rule based system. A building was considered to be recognised if e.g. 70% of the area of the building in the map was covered by laser data that was classified as building points. With a point density of 2-3 points/m^2 91% of buildings larger than 200 m^2 and 42% of buildings smaller than 200 m^2 were correctly recognised.

3. CLASSIFICATION

The extraction of the building segments from the laser scanning data is performed in two classification steps. First, the points are classified as bare Earth points or object points. Next, the object points are classified as building points or vegetation points. Both classification steps are performed on segmented laser point clouds.

The separation of the bare Earth points from the other points is performed with the algorithm described in (Sithole and Vosselman 2003). The point cloud is divided into sets of parallel thin slices in the XY-plane. The points of each slice are considered as a profile. A minimum spanning tree is computed for each profile. By removing the tree edges that exceed a certain slope or length threshold, the minimum spanning tree is split into line segments. All profiles are thus segmented. This procedure is repeated for other sets of profiles running in different orientations in the XY-plane. Next, the resulting line segments of the different orientations are merged to surface segments. Two line segments of different orientations are joined if they contain a common laser point. The surfaces that are created have height discontinuities all around their contours.

An advantage of this segmentation approach is that it is able to deal with multiple overlapping surfaces. Thus layers of vegetation as well as bare Earth points below this vegetation can both be captured in segments.

The surface segments are classified based on the sign of the height discontinuities at the ends of all line segments of a segment. Only segments with a low proportion of line segments that are above neighbouring line segments are classified as bare Earth.

The remaining object segments are then further classified as building or vegetation based on the values of one or more of the following attributes:

- **Surface roughness**. Planes are fit to the points in small neighbourhoods around each point of a segment. The median of the standard deviations of all plane fits is used as a measure for surface roughness.
- **Segment size and height**. A minimum segment size and a minimum height above ground level can be specified to select potential building segments.
- **Colour** (if available). Most providers of laser scanning services nowadays offer the simultaneous recording of imagery. When registered, a colour value can be assigned to the laser points by projecting the points into the imagery and interpolating the colour value. In particular the hue value of colour imagery can be used to distinguish vegetation from most roof materials, but also the intensity value proved to be useful. Median values can be computed for the laser points within each segment.
- **First-last pulse difference** (if available). The difference between the first and last pulse recording is known to give a good indication for the presence of vegetation (Oude Elberink and Maas 2000). Although large differences can also be observed at the edges of buildings, the median value of the height differences of all points within a building segment should clearly be lower than the medium value of the height differences within a vegetation segment.

The different attributes are combined in a K-nearest neighbour classification to obtain the classification for each segment. After the classification, the building segments that are adjacent in the XY-plane can be merged to form larger segments. These segments should then correspond to complete buildings.

4. CLASSIFICATION RESULTS

The above classification method was applied to laser scanner data of (a part of) the city centre of Nijmegen. The data was recorded with an Optech ALTM1225 scanner with an average point spacing of 1.2 m. Colour imagery was recorded simultaneously. The result of the classification is shown in Figure 1 and quantified in Tables 1 and 2. The segment-based filter showed no problems in removing larger buildings, a well-known problem for morphological filters (Sithole and Vosselman 2004).

The separation of buildings and vegetation was performed using the roughness and colour information of the segments. Compared to manually classified data used as ground truth, 85 % of the building points and 78 % of the vegetation points were classified correct. The overall classification accuracy over the three classes bare Earth, buildings and vegetation was 90%. The ground truth of those points that were classified incorrectly is shown in Figure 2. Several kind of errors can be observed in this figure:

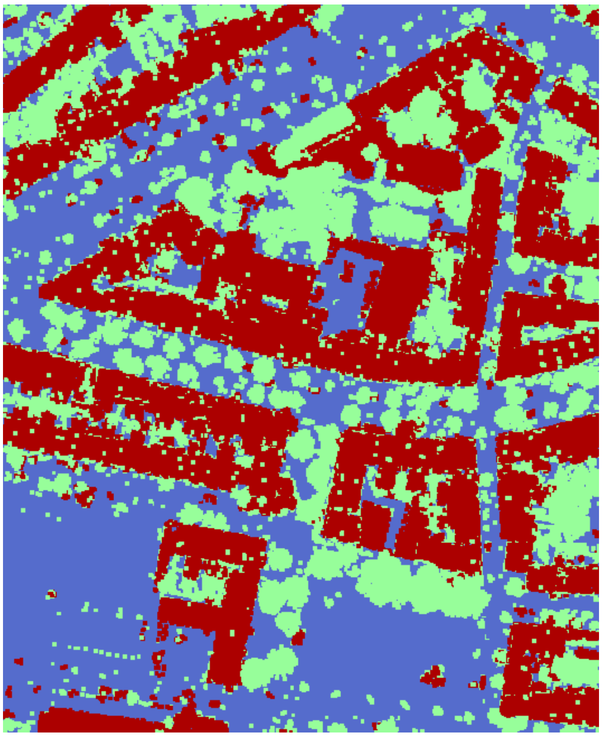

Figure 1: Classification of laser points into classes bare-Earth (blue (middle grey)), building (red (dark grey)), and vegetation (green (light grey)).

Ground truth	Classified as			
	Bare Earth	Building	Vegetation	Total
Bare Earth	41956	42	113	42111
Building	193	30368	5018	35579
Vegetation	2294	2764	17580	22638
Total	44443	33174	22711	100328

Table 1: Classification results in number of points

Ground truth	Classified as			
	Bare Earth	Building	Vegetation	Total
Bare Earth	99,6	0,1	0,3	100,0
Building	0,5	85,4	14,1	100,0
Vegetation	10,1	12,2	77,7	100,0

Table 2: Classification results in percentages.

- One building and larger parts of another building were classified as a vegetation segment. These buildings had relatively small steep roof faces. With the point distance of 1.2 m, the roughness attribute was similar to those of vegetation segments. With a higher point density, one could probably obtain a better distinction.
- The classification of the small segments is relatively unreliable. The number of points within these segments was often too low to generate representative attribute values. In a post-processing step these small errors could easily be repaired. It can be argued that small vegetation segments that are rest on building segments should also be building segments. Similarly, small building segments that are surrounded by bare Earth points and vegetation points also need to be reclassified.

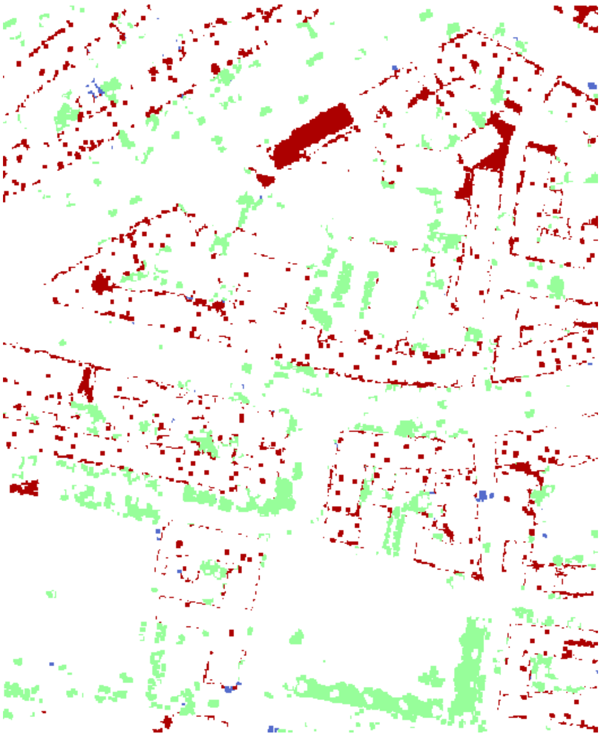

Figure 2: Ground truth for those points of Figure 1 that were classified incorrectly. See Figure 1 for the legend.

- Points on walls of buildings were also often incorrectly classified as vegetation points. These points stand out clearly in Figure 2. Wall points accounted for about 80% to the 5018 building points classified as vegetation. A correction in a post-processing step could therefore significantly improve the classification accuracy. However, for the change detection this is of less importance, since the sizes of the building segments will not increase when the wall points are included.
- Some patches of vegetation adjacent to buildings were grouped in segments with building points and classified as building. Such errors may impact the change detection as it may be concluded that a building has been extended. A larger point density in combination with stricter thresholds in the profile segmentation may reduce the number of these errors. The stricter thresholds will result in smaller segments. The increased point density is then required to enable the reliable computation of the segment roughness.
- The large area of vegetation classified as bare Earth near the bottom of Figure 2 is an area with very low vegetation that was merged with the surrounding bare Earth.

5. CHANGE DETECTION

Even if the topographic database is up to date and buildings are correctly extracted from the laser data, differences will exist between the database objects and the extracted building segments. These differences need to be taken into account during the change detection. Otherwise, many unchanged buildings will be presented to the operator for updating. Several reasons for differences between database objects and laser data segments of unchanged buildings have been identified:

- **Generalisation**. At the medium scale of 1:10.000 generalisation is applied to the objects in the topographic database. Small intrusions and protrusions in the contour of the building objects have been omitted, already in the original mapping process. To allow for removed intrusions in the database objects, it was checked whether the database object would fit inside the dilated laser data segment (Figure 3 top). To allow for removed protrusions, it was checked whether the eroded laser data segment would fit inside the database object (Figure 3 bottom). The kernel size of this dilation and erosion depended on the specifications of the generalisation process. This approach allows for larger differences than those that could have been caused by generalisation. Still, it proved to be effective for the change detection.

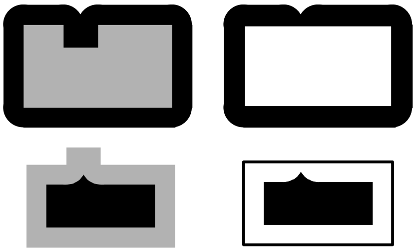

Figure 3: Dilated laser data segment of a building with an intrusion (top left). Generalised database object fits inside dilated laser data segment (top right). Eroded laser data segment of a building with a protrusion (bottom left). Eroded laser data segment fits inside generalised database object (bottom right).

- **Random data noise**. Noise, of course, is present in both the map objects and the laser data. The amount of noise, however, is much lower than the size of the generalisation effects. The differences caused by noise can be accounted for by slightly enlarging the morphological kernel introduced above. This will increase the tolerance in the change detection.
- **Systematic errors**. Systematic offsets were observed between the location of groups of buildings in the topographical database and the same buildings in the segmented laser data. Based on the shape and size of these buildings one would, however, conclude that many of these buildings were not changed. To avoid a detection of a change for these events, for each database object the optimal alignment with the laser data segment was determined. This shift was applied to the database object prior to the change detection.
- **Object selection**. The mapping catalogue of the map producer specifies which objects are to be mapped. In the case of used medium scale map, the catalogue specified that not all buildings are to be mapped. E.g., only buildings larger than 3x3 m should be included in the topographical database. It also specified that only those buildings should be mapped that are visible from a street. I.e., sheds behind buildings were not to be mapped even if their sizes exceeded the minimum size requirement. These kind of mapping rules first need to be applied to the building segments extracted from the laser data. Otherwise, many "new" buildings would be found that should not be inserted into the topographic database.

6. CHANGE DETECTION RESULTS

The above procedure has been implemented and tested. This section describes the data used in the experiment, the result of the building extraction step and the analysis of the detected changes.

6.1 Data description

The study was aimed at determining the potential of airborne laser scanning for the purpose of change detection for the revision of the Dutch TOP10vector database. This database was created for usage at a scale of about 1:10.000. The building objects have a location accuracy of 1-2 m.

The laser data was acquired by TerraImaging with an Optech ALTM1225 scanner. The data was recorded with an average point spacing of 1.4 m. An area was chosen in which many buildings were constructed recently. The area contained only little vegetation.

6.2 Extraction of building segments

All buildings were detected and extracted from the laser data. The building segments are shown in Figure 4 together with the road centre lines taken from the topographical database. A large number of small sheds in gardens behind buildings has been detected. The segments shown in red (dark) were automatically labelled as buildings "in the second row". For those buildings it was assumed that they should not be taken into the topographical database as defined by the mapping catalogue.

Figure 4: Segments in a part of the DSM that were classified as buildings. In red the building objects that were labelled as shed.

6.3 Offsets between the data sources

In the final step before the actual change detection, the laser data segments were optimally aligned with the building contours of the topographical database. Figure 5 shows the extracted building segments together with both the original position of the database objects (red) and the positions after the alignment procedure (black). A clearly systematic pattern of shifts between the database objects and the laser data segments can be observed. However, the shifts are not constant. The directions vary and the sizes range from 2 to 4 m. In the overlay of the laser data with a more accurate map no systematic offsets were observed. Most likely, the offsets shown in Figure 5 are caused by the monoplotting procedure used for the production of the topographical database. After applying the determined shifts to the database objects, this error should not lead to errors in the subsequent change detection step.

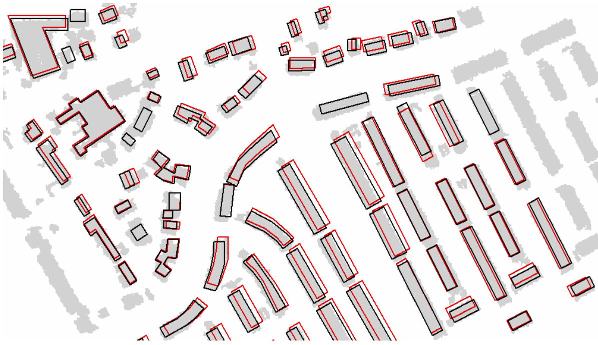

Figure 5: Systematic offsets between building segments in the laser data and the contours of the TOP10vector map.

6.4 Analysis of detected changes

The results of the change detection are visualised in Figures 6 and 7. Figure 6 shows the detected new and demolished buildings. The buildings classified as changed are shown in Figure 7. All demolished buildings are detected correctly. If a building was demolished and replace by a completely new building, this building was classified as changed. Also these type of demolished and rebuild buildings were detected correctly.

Figure 6: Results of detection of new and demolished buildings. The segments extracted from the laser data are shown in light grey and green. The map objects of the TOP10vector map are overlaid in black and red. The red objects are classified as demolished buildings. The green segments are classified as new buildings.

The detection of new buildings appeared to be more difficult. All new buildings are detected correctly, but in addition some sheds were detected in the laser data that are not present in the map. These incorrectly detected "new" buildings were caused by a different interpretation of the visibility rule in the mapping catalogue. Whereas our algorithm checks for a line of sight between the shed and the nearest road, the mapping agency first determines the main building to which the shed belongs and then argues whether the shed can be seen from the road at the front of the main building. Such a rule is actually quite complex and requires some scene interpretation that is difficult to implement.

Figure 7: Segments in the laser data classified as changed buildings.

The buildings that were classified as changed fell into three categories:

- Several buildings were indeed changed, or demolished and replaced.
- In a few cases vegetation adjacent to buildings led to enlarged laser data segments. These were incorrectly interpreted as building extensions.
- Finally, the change detection revealed several errors in the topographical database. One example is shown in Figure 8. Whereas the operator mapped three separate buildings, the laser data shows that these buildings are connected by lower parts with flat roofs.

Figure 8: Detected mapping error (see text). Left: laser data segments (grey) and database objects (green (dark)). Right: colour image of a three-line scanner

7. CONCLUSIONS

In this paper a study for automated change detection of buildings in a medium scale digital map using airborne laser scanning was presented. In a first step, the laser data has been segmented and classified. In the second step, the laser data segments of buildings have been matched against the building objects of a topographical database.

With respect to the classification results several conclusions can be drawn. In general, laser data can be classified relatively reliable. However, to really allow fully automatic change detection and to ensure a low percentage of incorrect change detections further improvements are required. The largest problem in this respect is caused by vegetation adjacent to buildings. If this vegetation is considered as an extension of a building, this error will generate an incorrect signal for the need of a database update and thus require extra operator time. In this research we used average point distances of 1.2-1.4 m. Higher point densities may allow better classifications.

For the classification experiments in this paper usage was made of both roughness and colour information. Colour information appeared to be a useful addition. The classification accuracy of buildings was improved by 3%. The additional value of colour information may, however, vary from project to project and depend on the season and the colours of the roofs. Classification results should further improve with the additional usage of multiple pulse data.

In the change detection experiment all newly constructed buildings were detected reliably. Differences between laser data segments and database objects caused by generalisation or data noise could effectively be handled by mathematical morphology. More challenging is the implementation of the object selection rules as laid down in the mapping catalogue. In the case of the TOP10vector database, the definition of what to map was sometimes vague and often required a certain amount of scene interpretation. For the purpose of automatic change detection the rules of the mapping catalogues need to be defined more precisely and preferably avoid the usage of definitions which require semantic modelling for the interpretation of the scenery.

In the performed experiments several errors caused by the mapping process of the topographical database have been found. This showed that automatic change detection can already now be a useful tool for quality control despite limitations in the classification accuracy and the interpretation of mapping rules.

ACKNOWLEDGEMENTS

The laser data for this study was provided by TerraImaging B.V. The TOP10vector data was provided by the Topografische Dienst Nederland. The authors would like to thank both organisations for their support of this research.

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