ROAD EXTRACTION FOR THE UPDATE OF ROAD DATABASES IN SUBURBAN AREAS

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KEY WORDS: Image understanding, Road extraction, Computer Vision, Feature extraction, Updating

ABSTRACT:

This paper deals with road extraction in suburban areas from high resolution aerial images. The extraction results are intended to be used for updating a road database. The road extraction algorithm follows a region-based approach in which the image is first segmented using the normalized cuts algorithm with colour and edge criteria. Then, the initial segments are grouped to larger segments in order to overcome the oversegmentation which is a result of the first step. The segments are subsequently evaluated by shape criteria in order to extract road parts. Large segments that contain several roads are shaped irregularly; therefore, large segments are split prior to the road part extraction. The splitting is based on the skeleton of the segment. After the road part extraction, most roads in the image are covered by one extracted road part. However, some roads are covered by several road parts with gaps between them. In order to combine these road parts to one road, neighbouring road parts are connected if they have a similar main direction and a relatively high continuation smoothness. Results for some test images show that the approach is suitable for the extraction of roads in suburban images.

1. INTRODUCTION

Up-to-date road databases are important for many applications, for example map production, traffic management and spatial planning. As the need for up-to-date road data increases, so does the need for automatic road extraction methods, because manual acquisition of road data is quite time-consuming and expensive. Therefore, road extraction has been extensively researched in recent years.

For rural areas, many approaches already exist, for example (Bacher and Mayer, 2005; Géraud and Mouret, 2004). For urban and suburban areas, on the other hand, there are only few approaches. The main problems with road extraction in urban areas are the more complex scene content and the different structure of the road network compared to rural areas. Urban or suburban scenes consist of many different objects like houses, trees and vehicles, which leads to a scene that is composed of many small regions. Urban roads typically do not have the distinct line-shaped appearance that they have in rural areas, and the main network function is not a short connection between two distant places but the connection to the major road network for every building. Roads in urban areas often are laid out in a regular grid, which can be exploited by road extraction algorithms (Price, 1999; Youn and Bethel, 2004). But especially in Europe, urban road networks can be quite irregular. Effective strategies for road extraction in urban areas often work from small entities to bigger entities (for example Hinz, 2004), where lines are grouped to lanes, carriageways and road networks, according to a detailed road model. It is also helpful to include both local and global features in an extraction strategy (see for example Doucette et al., 2001; Doucette et al., 2004). Road extraction only from grey value images seems to be impossible in urban areas. Most approaches for urban areas take some additional information into account: Hinz (2004) uses a DSM and multiple overlapping images; colour images are widely used (for example Zhang and Couloigner, 2006; Doucette et al., 2004), also information from geographic databases, often combined with a verification or update of the database (Gautama et al., 2006; Sims and Mesev, 2007; Zhang, 2004). Hu and Tao (2007) use hierarchical grouping of line segments to extract the main roads in an urban area from satellite images. Another promising approach is described by Hu et al. (2007); it is a road tracking approach where very little user input is necessary. They use a region-based model to extract reliable road parts from which the tracking starts.

In this paper, we describe an approach for road extraction in suburban areas based on previous work about the extraction of road parts for the verification of database roads in suburban areas (Grote et al., 2007). Road parts are extracted as described there, but without the database information, because the focus of this paper is the extraction of new roads for database update. We employ a region-based approach on high resolution aerial images working from small local regions to roads as groups of road parts. The image is first segmented using the normalized cuts algorithm (Shi and Malik, 2000). The resulting relatively small segments are grouped to form larger segments, and from these grouped segments road parts are extracted. To cover cases where the road is fragmented (due to different road surfaces or context objects) road parts with similar main directions are assembled into strings of road parts or subgraphs.

2. APPROACH

2.1 Overview

The goal of the work described in this paper is to extract roads in suburban areas for the updating of a road database. The focus of this paper lies on the extraction of road parts and their assembling to road strings or subgraphs.

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For the road extraction the image is first segmented with the normalized cuts algorithm using edge and colour criteria. The main goal of this step is the separation of road areas and non-road areas. The parameters of the normalized cuts algorithm are selected such that an oversegmentation is achieved because we do not want to miss any road boundaries. Therefore, a grouping step follows, in which the segments are grouped again according to colour and edge criteria, this time not of single pixels but of the regions. Then, the segments have to be evaluated in order to extract potential road parts, based mainly on shape criteria. If the roads are undisturbed and clearly visible, several different roads often are grouped together as one segment, resulting in irregular shapes which cannot easily be identified as road parts by shape criteria. Therefore, large segments are split up according to the branches of their skeletons before the road part evaluation. The goal is to extract road parts that cover a large part of the road surfaces while keeping the number of false positives low. After the extraction neighbouring road parts with similar directions are assembled to chains because sometimes the road is covered by several road parts, for example due to disturbances caused by context objects or different road surfaces. As only road parts with similar main directions are linked, junctions are not considered in this step.

2.2 Segmentation and grouping

2.2.1 Segmentation: The first step is the segmentation of the image, which is done with normalized cuts. The normalized cuts algorithm is a graph-based segmentation method in which the pixels are seen as nodes of a graph, connected by weighted edges. The edge weights describe the similarity of the pixels. The graph is divided into segments by minimising the normalized cuts criterion, which maximises the similarity within each segment as well as the dissimilarity between different segments. Details of the algorithm can be found in (Shi and Malik, 2000). One advantage of this method is that it aims for a global optimisation of the segmentation while in determining the edge weights local features are taken into account. Another advantage is that the similarity measure is generic, so it can be adapted to the application, and several criteria can be combined. The goal of the segmentation is a good division between road areas and non-road areas. Three criteria are used for the determination of the weights: colour, edges and hue. The choice of these criteria is based on the appearance of roads in high-resolution aerial images as homogeneous regions bordered by edges. The number of segments has to be predefined in the current application. It is chosen to be high enough to detect the majority of road borders, which leads to an oversegmentation. For details of this step refer to (Grote et al., 2007).

2.2.2 Grouping: In the next step, the segments are grouped in order to reverse the oversegmentation. The grouping is based on shape and edge criteria, like the segmentation, but this time the features of the regions, not of single pixels, are considered. The features used are:

- mean edge strength in border region of edges parallel to the shared border
- standard deviation of colour in the merged region
- difference of colour histograms
- length of shared border in proportion to the border length of the smaller region

The first criterion, the mean edge strength, should prevent regions to be merged when there are strong edges in the shared border region. The mean edge strength is taken from a Canny edge image. It should not exceed a defined threshold. As an improvement of our previous work, here also the direction of the edges in the border region is taken into account: only edges that run approximately parallel to the border are considered in calculating the mean edge strength. In addition, the part of the shared border region which contains parallel edges is put in proportion to the whole border region, so the separating influence of a small part of the border region with a strong edge remains small.

For the second criterion, the standard deviation of colour, the three channels are considered separately. In each channel the standard deviation of the merged region should not exceed a threshold.

The third criterion is the difference of the colour histograms between the regions. This criterion is the replacement for the previously used mean value of colour; it is more robust. For each channel, the colour histograms in both regions are calculated and compared with the chi-square measure (Press et al., 1992). The chi-square distances should not exceed a defined threshold.

The fourth criterion, the length ratio of the shared border to the border of the smaller region, is applied only if the main directions of both regions, computed via the orientation of the best fit ellipses, differ. In this way the composition of elongated regions is not disturbed, but the formation of protruding parts through merging is discouraged. When the directions of both regions differ, a significant part of the region must constitute the shared border.

All conditions must be met for two segments to be merged. The process is done iteratively; in each iteration the ten best pairs of regions are merged, until no more regions can be found that fulfil the conditions. The result of the segmentation and grouping are segments which are relatively homogeneous in colour, and most segments belonging to road areas are large enough to be evaluated by shape in the next step.

2.3 Road part extraction

In order to extract road parts from the segments, the segments are evaluated using shape criteria and some radiometric criteria. Large segments are subdivided before the evaluation because often one road segment covers several roads connected via junctions. These road segments cannot be detected using shape criteria because their shape is irregular.

For the subdivision the skeleton of the region is calculated. Before the skeleton calculation the region is smoothed with morphological operations (opening, closing) in order to obtain a smoothed skeleton. Note that this step may result in different unconnected skeletons for one segment because the opening operation can break up the segment into several parts. After an elimination of short branches, each remaining skeleton junction is examined. First the branches are divided into two groups according to their direction. The direction of one branch is taken as reference for one group, and branches whose directions differ more than 45° from this direction are placed in the other group. The group with fewer branches (usually one) defines the secondary direction. If there is the same number of branches in each group, the group with the shorter total length defines the secondary direction. Then for each branch that belongs to the secondary direction it is determined at which point the branch should be separated from the region. For this purpose, a line whose length equals the average road width and whose orientation is perpendicular to the secondary direction is moved along the secondary branch. The first place where the line intersects with the borders of the region on both sides of the skeleton branch is the place where the region is divided. After all branches have been examined, a second step follows in which the region is divided at places where the skeleton of the smoothed segment was disconnected due to the smoothing operation. Fig. 1 shows how one segment is partitioned.

Figure 1. Partition of large segment. Original segment borders in yellow, skeleton in green, dividing lines in red.

After the division of large segments, the evaluation in order to extract road parts follows. The criteria by which a segment is evaluated are:

- intensity
- NDVI (normalized difference vegetation index)
- elongation, combined with convexity
- width
- width constancy

Intensity and NDVI are radiometric criteria. The intensity should be higher than a threshold to exclude shadow regions, because shadow regions, for example of buildings, otherwise often have similar characteristics to road parts. The NDVI should be below a threshold in order to exclude areas with vegetation.

The other criteria concern the shape of the region. A road part should be elongated, that means the ratio between the squared perimeter and the area should be high. If the area has a high convexity value (the ratio between the segment area and the area of the convex hull), lower values for elongation are permitted in order to include shorter road parts but to exclude regions with ragged borders, which also have a relatively high elongation according to the criterion used here. The width of a road region should be close to the average road width, and it should be relatively constant. For the calculation of the width, first a centre line is calculated for the region. This is done by first finding the two points on the boundary that are farthest away from each other. At these points the region boundary is split into two parts and for both parts a distance transform is calculated. The points where both distance transforms have the same values make up the centre line. The average width of the region is calculated from the distances of the centre line to the region borders. Twice the average distance from the borders gives the average width of the region which for a road part should not be too far from the average road width. The width constancy is defined by the standard deviation of the width divided by the mean value of the width. This value should be below a threshold.
All regions are checked for these criteria, and those regions that fulfil all criteria are selected as road parts. The values for elongation, NDVI, width constancy and deviation from average road width are saved as evaluation results in order to give a quality measure of the road part. The results are mapped on an interval between 0 and 1 such that values that suggest higher probabilities towards road parts are close to one. Then the transformed values are multiplied to obtain a single quality measure.

2.4 Assembling of road parts

In many cases, one road part covers one complete road, from one junction to the next. But this is not always the case; sometimes one road is covered by several road parts with gaps between them. Therefore, in this step it is checked if the road parts have neighbours with which they can be connected.

The search starts with the road part that has the best evaluation results from the step before. The intersection points between the centre line and the segment borders are used for calculating the criteria which determine if a road part in the neighbourhood is added to the examined road part. The criteria are:

- distance between the segments, measured from the endpoints of the centre lines
- direction difference between the road parts
- continuation smoothness between the road parts

The direction difference is measured by comparing the directions defined by the endpoints of the centre lines of both road parts. The continuation smoothness is determined by calculating the direction differences between the directions of the road parts to the direction of the connection between both road parts (Fig. 2). The smoothness is low if the differences between the directions of the road parts and the direction of the connecting line are high. The distance and the direction difference should be low and the continuation smoothness should be high for two road parts to be linked. The search for neighbouring road parts continues until no more road parts can be added. If no neighbouring road parts are found, the road part constitutes a road subgraph on its own. Then, the search continues with the next road part with the best evaluation result until all road parts have been examined.

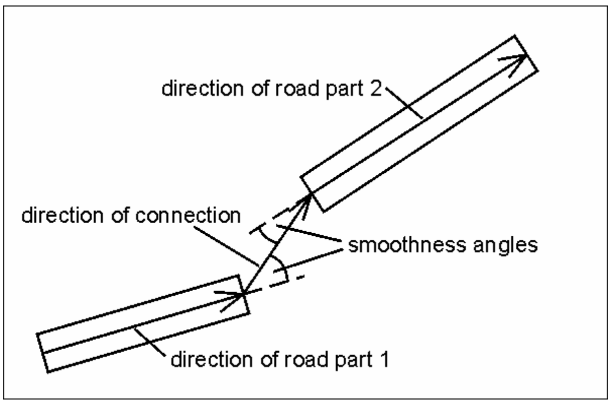

Figure 2. Measure of continuation smoothness.

3. RESULTS

The approach was tested on CIR images of a suburban scene in Grangemouth, Scotland. The images with a resolution of 0.1 m cover areas of approximately 250 m x 200 m.

For the segmentation the image has to be divided into subsets for computational reasons. The size of the subsets is approximately 200 x 200 pixels. Each subset is divided into 20 segments. Fig. 3 shows a segmentation example.

Figure 3. Segmentation with normalized cuts.

In the next step, the segments are grouped. The parameters used for the grouping are summarized in Table 1, along with the parameters for the following steps. Fig. 4 shows the grouping result.

Grouping	
max. mean edge strength	50
max. standard deviation of colour	40
max. colour histogram difference	0.4
min. length ratio of shared border (if direction difference > 60°)	0.2
Road part extraction	
min. intensity	40
min. elongation	70
min. elongation (convexity > 0,75)	40
max. NDVI	0
width	3m – 16m
width constancy (max. ratio of standard deviation to mean value)	0.6
Road part assembling	
max. direction difference	30°
max. distance	40m
max. parallel shift (direction difference between road parts and their connecting line)	30°

Table 1. Parameters for grouping, road part extraction and assembling.

Figure 4. Grouping result.

The next step is the evaluation of the segments to extract road parts after large segments (over 200 m^2) have been split. In order to speed up the computation, only large segments are considered for splitting. Small segments can be ignored because the splitting is done only at junctions with branches longer than 10 m. The segments that were extracted as road parts are shown in Fig. 5.

Figure 5. Road part extraction result.

On most roads in the image, road parts have been extracted, except for the road on the right. That road was not extracted because the width constancy criterion was not met due to areas at the sides of the road that were merged with the road areas, and could not be cut off by the splitting algorithm. This is the main reason for missed road parts. Some parts are falsely extracted as road parts; these are mainly roofs of buildings. Most of them are small and isolated and probably could be easily discarded in a later step when the road network is constructed.

Some roads are covered by several road parts with gaps between them. These are connected in the next step (Fig. 6).

Figure 6. Assembled road parts. Connections between road parts are shown as lines in the same colour. Intensity image used for clarity of display.

Road parts that lie on the same road have generally been found. In the case of the group of road parts displayed in yellow, at the top of the image, two road parts were connected to the same end of the first road part. This branching is permitted so that no road hypotheses are lost. In a later step both alternatives will be examined and the better one will be kept. The blue road part between the yellow ones was not added to the group because of the overlap with the left yellow one.

The figures 7 and 8 show the results of two further subset images. Here the roads were typically covered as a whole by one road part so that the assembling step had no effect.

Figure 7. Extraction result on second subset.

In these examples the majority of the roads are covered by extracted road parts. There are few false positives, and those are mainly small and could be eliminated in a later step. In summary, also considering subsets that are not shown here, 60-70% of the roads are found.

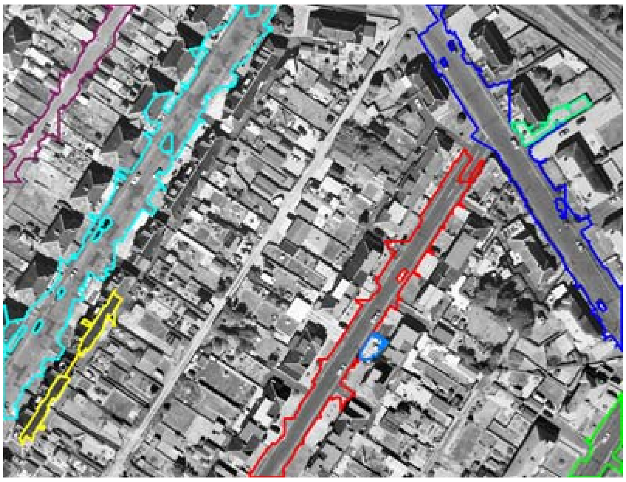

Figure 8. Extraction result on third subset.

4. CONCLUSIONS AND OUTLOOK

In this paper, an approach for the extraction of roads in suburban areas was presented. The results show that this approach is applicable to suburban areas. The majority of roads could be extracted as road parts. The number of false positives is small, and as the results presented here are of an intermediate stage, we are confident that these false positives can be eliminated in a following step.

Several parts of the algorithm still need to be improved. For example, the splitting step does not always succeed in dividing the regions in a meaningful way. If the border of the region is very irregular, the splitting can be incomplete. Also, loops, as in the not extracted road on the right hand in Fig. 7, are not handled properly by the current algorithm.

The width constancy value can only be calculated meaningfully if the road is not curved too much. If it is, the two endpoints of the centre line cannot be derived from the points on the border that are farthest away from each other. In this case the centre line is calculated wrongly and a road segment would fail the width constancy test. Fortunately, curved roads are rare in suburban areas. But this problem can also occur if two roads are connected in one segment at a junction and the splitting step does not separate them because the skeleton just has a sharp bend there instead of a junction.

The parameters are currently defined empirically which will probably lead to problems if the approach is applied to images of another area. The combination of the criteria for grouping, road part extraction and assembling is currently done in an all-or-nothing way; all criteria have to be fulfilled. A better method would include weighing the criteria against each other.

The next steps of our work will include dealing with the above mentioned issues as well as completing the road network extraction. For completing the extraction, first the road subgraphs which contain several branches, like the yellow one in Fig. 6, need to be examined in order to find the best solution to solve the ambiguity. Then, the roads can be connected to a road network by searching for junction hypotheses at the end points of roads. False positives can be eliminated in this step because they would mainly be isolated.

ACKNOWLEDGEMENTS

This project is funded by the DFG (German Research Foundation). The calculation of the normalized cuts was made with a C++ program partly adapted from a MATLAB program written by Timothée Cour, Stella Yu and Jianbo Shi. Their program can be found at http://www.seas.upenn.edu/~timothee/ software_ncut/ software.html (last checked April 2008).

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