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Road Part Extraction for the Verification of Suburban Road Databases[1]

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Summary: In this paper, a new strategy for the verification of road databases in suburban areas using aerial orthoimages is suggested. It consists of two stages: the extraction of road parts and the comparison with the database roads. High resolution aerial images are used for the road part extraction which comprises the steps segmentation, grouping and evaluation. The segmentation is designed to yield a good division between road areas and the surroundings. We use the Normalized Cuts algorithm, which is a graph-based approach that divides the image on the basis of pixel similarities. The initial segments have to be grouped due to an enforced oversegmentation. The criteria for both segmentation and grouping are based on colour and edge properties. The grouped segments are then evaluated in order to extract road parts, based mainly on shape criteria. In the second stage, the extracted road parts are compared to the database roads, leading to the acceptance or rejection of each database road. This paper focuses on road part extraction in suburban areas; the verification stage itself is beyond the scope of the current article. Nevertheless, the general approach is briefly discussed as part of the overall strategy. Preliminary results for the road extraction stage show that reliable road parts can be extracted with the presented approach; ideas for the procedure in the verification stage are presented as outlook.

Zusammenfassung: *Extraktion von Straßenstücken zur Verifikation von Straßendatenbanken in Vorstadtgebieten.* In dieser Publikation wird eine neue Strategie zur Verifikation von Straßendatenbanken in Vorortgebieten mit Hilfe von Luftbildern vorgeschlagen. Sie besteht aus zwei Stufen: der Extraktion von Straßenstücken und dem Vergleich mit den Straßen in der Datenbank. Die Straßenextraktion, für die hoch aufgelöste Luftbilder verwendet werden, wird in drei Schritten durchgeführt: Segmentierung, Gruppierung und Evaluierung. Die Segmentierung ist so ausgelegt, dass sie eine gute Unterscheidung zwischen Straßenflächen und der Umgebung liefert. Wir nutzen den Normalized-Cuts-Algorithmus, eine graphbasierte Methode, die das Bild mit Hilfe von Pixelähnlichkeiten segmentiert. Die vorläufigen Segmente müssen dann aufgrund einer erzwungenen Übersegmentierung gruppiert werden. Die Kriterien für die Segmentierung und die Gruppierung beruhen auf Farb- und Kanteneigenschaften. Die gruppierten Segmente werden anschließend evaluiert, hauptsächlich anhand von Formeigenschaften, um Straßenstücke zu extrahieren. In der zweiten Stufe werden die extrahierten Straßenstücke mit den Straßen in der Datenbank verglichen, was zur Annahme oder Ablehnung der Datenbankstraße führt. In dieser Publikation liegt der Schwerpunkt auf der Extraktion von Straßenstücken in Vorstadtgebieten, die Verifikation selbst geht über den Rahmen dieses Artikels hinaus, die allgemeine Vorgehensweise wird aber als Teil der Gesamtstrategie kurz beschrieben. Für die Straßenextraktion werden erste Ergebnisse vorgestellt, die zeigen, dass mit dem vorgestellten Ansatz zuverlässige Straßenstücke extrahiert werden können; für die Vorgehensweise bei der Verifizierung wird ein Ansatz im Ausblick vorgestellt.

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1 Introduction

Today, GIS data are widely used and incorporated in decision finding procedures, navigation systems and many other applications. As users rely on the correctness of GIS data, it is necessary to check databases frequently to eliminate errors and to add new objects. Manual database assessment is very time-consuming, which is why many approaches have been developed over the past years to automate this process. In many of these approaches, up-to-date aerial or satellite images are used to automatically extract objects and to compare them to objects contained in the database (Baltsavias 2004).

One prominent class of objects in geospatial databases are roads. Road databases are very important for many applications, for example navigation systems or spatial planning. As they are also subject to frequent changes, road database assessment and update is a major topic. Accordingly, many approaches deal with road database assessment and update in rural areas, for example (Zhang 2004) or (Gerke 2006). In contrary, only few approaches work in urban or suburban areas due to the highly complex structure found in urban scenes, which complicates the task of automatic road extraction. Many approaches have been developed to extract roads, some of them are summarized in (Mayer et al. 2006), but only few of them are designed for urban areas. In (Price 1999, Youn & Bethel 2004) the road network is expected to be a more or less regular grid, but this constraint is not suitable for many European urban areas. Another approach uses a very sophisticated road and context model and is based on grouping small extracted entities to lanes, carriageways and road networks (Hinz 2004). It employs a large set of parameters that must be carefully adapted for different scenes. In recent work, colour properties are exploited, for example in (Zhang & Couloigner 2006): the authors perform a pixel-based multispectral classification and use shape descriptors to reduce the number of misclassifications, but the completeness and correctness rate is only about 50 %. In our opinion, a reason for this fact is that the multispectral classification does not take into account the spatial relations of the pixels and colour and shape properties are treated separately.

In this paper, a new approach for the extraction of road parts in suburban areas for the verification of road databases is presented. From the above mentioned approaches we can deduce that a proper segmentation algorithm is essential as a first step for road extraction in suburban areas and that it is important to combine several features in the segmentation step because of the complex surroundings. A simple line based road model, as used in many road extraction approaches for rural areas, is not applicable. Therefore, we use Normalized Cuts (Shi & Malik 2000) for the segmentation. One advantage of this method is the possibility to combine several different criteria in one step, which can be selected according to the application. In this way, it is possible to use modelled knowledge about roads already in the segmentation step. Another important advantage is the incorporation of both local and global characteristics of the objects present in the image. Afterwards, the initial segments are grouped to reverse oversegmentation. The resulting segments are then evaluated in order to find road parts. The verification stage follows the approach of (Gerke 2006). The verification itself is not part of this paper; nevertheless, the verification strategy is briefly explained.

In the next section the general strategy for road database verification in suburban areas is explained. The specific approach for road part extraction (segmentation, grouping and evaluation) is described in section 3, results are presented in section 4. Some conclusions and an outlook on further work are given in section 5, including an example demonstrating the concept for the verification strategy.

2 Verification Strategy

The aim of our research is the assessment of a road database. This process consists of two stages (cf. Fig. 1):

- Road part extraction
- Comparison to the database road.

As mentioned before, road extraction in suburban areas is more complicated than in rural areas due to the inhomogeneous background. We use an area-based road model and apply our strategy to high resolution CIR images.

The two stages are carried out for each database road individually. A region of interest is defined around the database road, whose length matches the length of the road to be assessed and whose width exceeds the expected road width in order to avoid segments to be forced into a roadlike shape by the region borders, thus distorting the evaluation. The following road extraction steps are carried out in each region of interest.

The first stage of the verification strategy, the road part extraction, consists of three steps: segmentation, grouping, and evaluation. The region of interest within the image is segmented using the Normalized Cuts method as described in section 3.1. The aim of the segmentation is a distinct separation between road segments and non-road segments. The result is an oversegmentation, which is necessary to obtain as many parts as possible of the road border belonging to a segment border, even if the image information is weak. In a second step the initial segments have to be grouped to larger segments, before they can be evaluated and divided into road segments and non-road segments. As will be shown later, it is not possible to evaluate the initial segments correctly based on their shape characteristics, because they are too small for deriving reliable shape attributes. The grouping is currently done using a simple iterative algorithm merging initial segments with similar mean colour, weak edges at shared borders and low overall colour variance. Details are described in section 3.2. Next, the grouped segments have to be evaluated in order to select the road segments. The evaluation is based on shape and colour criteria of roads like elongation, maximum width and homogeneity. The aim of this step is to extract only reliable road parts, in order to avoid false road parts in the comparison with the database road.

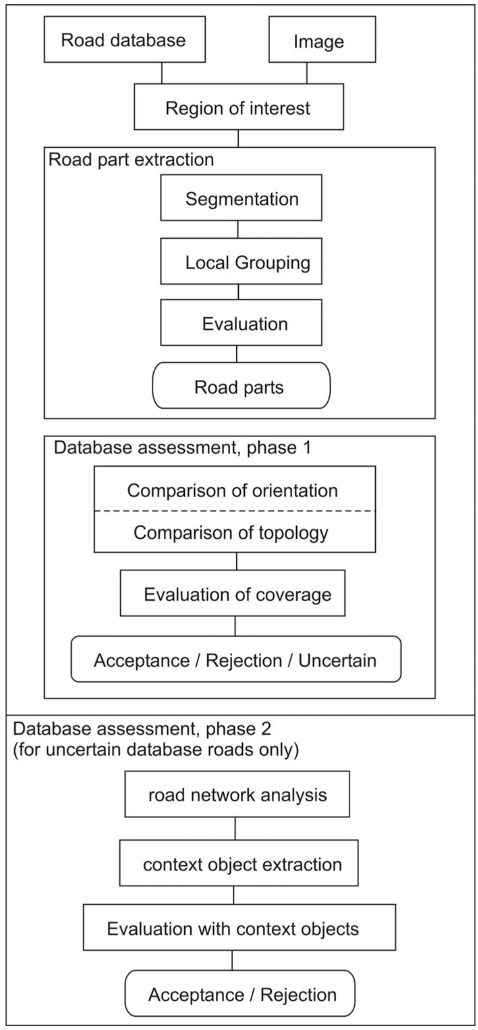

Fig. 1: General strategy.

In the second stage of the verification strategy, the database road is compared to the extracted road parts in order to assess the database road. The assessment is based on the road database assessment method described in (Gerke 2006). A brief description of the general concept is given here. If road parts could be extracted, their topology and orientation are compared to that of the database road. The orientation should be approximately the same, and the buffer around the database road should contain the extracted road part. This is checked for each extracted road part. After the comparison we check to what extent the database road is covered with extracted road parts. Based on the results of this check, the database road is labelled accepted, rejected or uncertain.

The database roads labelled uncertain are re-examined. For this purpose, the road network properties and context objects are used. If the uncertain database road is important for the road network, context objects are extracted in the region of interest and it is tested whether they can explain the failure to extract reliable road parts in the first stage. The result is a final acceptance or rejection.

3 Approach for Road Part Extraction

3.1 *Segmentation*

The Normalized Cuts method is used for the initial segmentation. Normalized Cuts is a graph-based method using an undirected graph with weighted edges that is to be divided into segments with similar features (Shi & Malik 2000). Pixels are defined as nodes which are connected by weighted edges. The edge weights describe the similarities between the pixels. This graph is cut into segments to meet the following minimization criterion, dividing dissimilar pixels into different segments:

$$Ncut(A_1, \ldots, A_n) = \sum_{i=1}^{n} \frac{link(A_i, V \setminus A_i)}{link(A_i, V)} = \min \quad (1)$$

Using Equation 1, the graph is divided into n sets of nodes A_i. V is the set that contains all nodes in the whole graph. *Link* is the sum of all weights of the connecting edges between two sets:

$$link(P, Q) = \sum_{p \in P, q \in Q} w(p, q) \quad (2)$$

where $w(p, q)$ is the weight between two nodes p and q belonging to the two sets P and Q. The calculation is based on computing eigenvectors of a matrix containing all similarity weights, each segment is defined by one eigenvector. Details of the calculation can be found in (Shi & Malik 2000).

The aim of the segmentation is to separate the road parts in the image from the non-road parts. The similarity criteria are derived from the road model:

- Presence and strength of edges between two pixels
- Colour difference
- Hue difference
- Road colour derived from database information.

Roads are divided from their surroundings by edges, therefore edges are used as a criterion: if there is an edge between two pixels, the pixels are considered to be dissimilar. The similarity measure depends on the edge strength: a high edge strength leads to a low similarity.

The second criterion is colour because roads usually have homogeneous surfaces and the pixel colour stays approximately the same. A measure for the colour similarity of two pixels is the distance between these two pixels in colour space. If the distance is short, the pixels have a high similarity regarding colour.

As a third criterion hue is used because a significant hue difference almost certainly indicates a different object. On the other hand, in parts darkened by shadows the hue of an object remains the same if certain conditions are met (Perez & Koch 1994). Thus, if the hue difference is large, the pixels are considered dissimilar. There is certainly some correlation between the colour and the hue criterion; however, our experiments have shown that the use of both yields rather good results.

The database information is used to obtain colour information about the roads: assuming that the position of the road is approximately correct, we compute the average colour values from the position of the database road centerline. This information is used to increase the chance that segments are divided along a road border: if the colour of one pixel is close to the average road colour, while the other is not, the pixels are dissimilar.

The similarity measures are combined to one similarity weight for each pixel pair. The Normalized Cuts method is performed with these weights. The number of segments, which must be specified before the calculation, must be large enough to prevent merging of road and non-road segments.

3.2 *Grouping*

As mentioned before, the image segmentation algorithm results in an oversegmentation. This is necessary to minimize the risk of losing road borders. Therefore, in the next step the initial small segments have to be grouped to larger, more meaningful segments before they can be evaluated. We follow the approach suggested by (Luo & Guo 2003). The authors aim at a general grouping algorithm as a bridge between image segmentation and high-level object extraction algorithms. The region properties they use include, among others:

- Colour mean difference between two regions
- Edge strength along shared border
- Colour variance of cross-border area
- Contour continuity between two regions

The first two criteria are particularly suitable for our approach, because the enforced oversegmentation often produces segment borders where the image information does not really justify a separation. The edge strength along a shared border and the mean colour difference between both segments are suitable criteria to group these initial segments to larger ones.

At present, we use a simple iterative approach for grouping the segments. For each pair of initial segments, several criteria are calculated. Based on the similarity criteria used by (Luo & Guo 2003) we use the difference of mean colour (separately for the three channels) and the edge strength of the intensity channel in the region around the shared border (border region). The border region is a small band along the shared border. Instead of the colour variance of the cross-border area we use the joint standard deviation of colour of the merged regions (separately for the three channels) because tests have shown this to be the better criterion for our application. For all seven criteria, the calculated values have to be below predefined thresholds for the segments to be considered for merging. In each iteration step, only the two segments with the best values for all criteria (the least colour differences, the least edge strength and the least colour standard deviations) are merged. The iteration continues until the values for every segment pair exceed at least one threshold.

3.3 *Evaluation*

After grouping, the segments can be evaluated in order to extract road parts. The evaluation is based on shape and spectral characteristics of roads. The following characteristics are used for evaluation:

- Elongation
- Rectangularity
- Width
- NDVI

The elongation indicates the difference of the object from a circle. It is given by the ratio of the squared perimeter and the area, which is high for elongated objects. A road part should have a high elongation. The rectangularity is a measure for the similarity of an object with a rectangle. It is calculated using the Discrepancy method described in (Rosin 1999). Road parts should be close to rectangular. The width of a road part should not be much larger than the average width of a road. The average NDVI (Normalized Difference Vegetation Index) is calculated for each segment. The NDVI is the difference between the infrared channel and the red channel normalized by the sum of both channels. For road parts the NDVI should be low. In our tests, thresholds are defined for each of these criteria and segments are extracted as road parts if they fulfil all of them.

4 Results

The first stage of the strategy, the approach for road part extraction, was tested on CIR aerial orthoimages with a resolution of 0.1 m. The images depict a suburban scene in Grangemouth, Scotland. Road database data were simulated by manually digitizing the visible roads in the images.

For segmentation with Normalized Cuts, the regions of interest are divided into subsets of approximately 200 × 200 pixels for computational reasons. Each subset is segmented by the Normalized Cuts algorithm yielding 20 segments, an empirical value that is suitable for this image size and scene complexity. The width of the region of interest is set to approximately three times the expected road width.

Fig. 2 shows an example of a suburban road with the database road centerline shown in green. In Fig. 3 the Normalized Cuts segmentation result obtained with the similarity criteria described in section 3.1 is displayed. Segment borders are indicated by yellow lines. The result demonstrates that the segmentation in general has succeeded: road and non-road areas are in most instances clearly divided by initial segment borders. Exceptions can be found in shadow areas or where the contrast between the road and the surroundings is low, for example in the right part of the image.

After segmentation, the initial segments are grouped as described in section 3.2. Fig. 4 shows the grouping result from the segments of Fig. 3. The following grouping parameters are used: the mean colour of two segments to be merged should be the same, the width of the border region is 7 pixels, the maximum for the mean edge strength is set to 50, and the maximum standard deviation for two merged segments is set to 40.

The grouping result shows one distinctive road segment in the left part of the image. To the right, there is one big road segment that is more problematic: it contains one part of a parking lot and some parts of the pavement. The pavement parts are parts of an initial road segment and are not critical because they do not affect the overall shape of the road to a great extent. The parking lot poses more difficulties for an evaluation because it has the same colour characteristics as the road and is not separated by a distinct border so it is merged with the road segment, distorting its shape.

The grouped segments are evaluated using the criteria described in section 3.3. The thresholds used for the evaluation are: elongation more than 50, rectangularity more

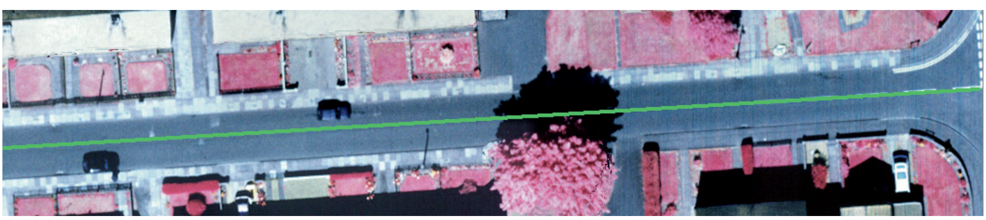

Fig. 2: Original image with database road.

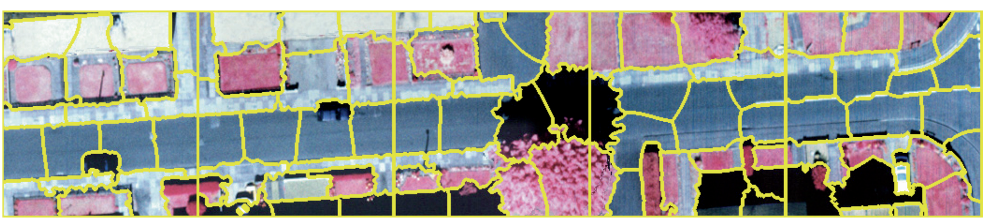

Fig. 3: Segmentation result.

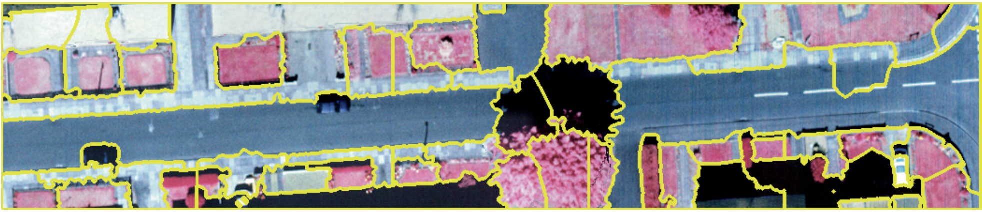

Fig. 4: Grouping result.

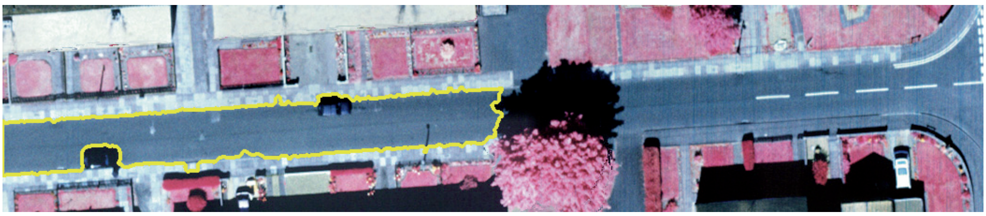

Fig. 5: Evaluation result.

than 0.7, width not more than 2 meters above assumed the road width, NDVI less than 0. The evaluation result for the grouped segments is displayed in Fig. 5. One segment is correctly extracted as road part. No false positives are extracted, which is important at this stage to prevent the verification from falsely accepting database roads. The other larger road segment seen in Fig. 4 on the right could not be extracted due to low rectangularity caused by the part of a junction on the right side and the inclusion of the parking lot on the left side.

5 Conclusions and Outlook

The results in this paper show the general usability of the approach for the detection of roads in aerial images of suburban areas. The Normalized Cuts method was shown to be suitable for the segmentation step. The combination of image features adapted to the appearance of roads yields a good division between road segments and non-road segments. By considering global aspects of the image as well as local ones, the algorithm is able to ignore noise, small surface changes and weak edges. The division of the image depends on the overall image content which allows the segments to be more coherent and perceptually meaningful than segments obtained by a local segmentation only.

One drawback of the Normalized Cuts algorithm is that the calculation is computationally expensive and the image has to be divided into smaller subsets to make the calculation possible. Another drawback is the fact that the number of segments has to be determined before starting the calculation. It is desirable to find a way to estimate the appropriate number of segments from the given data. One possibility is an iterative approach, repeating the Normalized Cuts algorithm with a varying number of segments and subsequently selecting the optimal segmentation.

The grouping result shows that it is possible to use the oversegmented results from the Normalized Cuts algorithm and group them to bigger segments whose shape can be assessed regarding their correspondence with the road model. The grouping works well for road parts without many disturbances by context objects. One problem are areas that are directly connected to the road and have the same colour as the road, like the parking lot in Fig. 5. Here, an additional grouping criterion, for example border continuation, could be helpful. Alternatively,

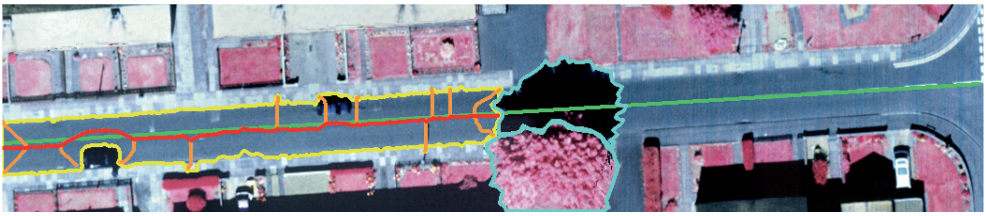

Fig. 6: Outlook on verification strategy.

the segments could be split such that protruding parts are removed.

Preliminary results for the evaluation show that the chosen extraction criteria seem to be suitable for the extraction of roads. However, the rectangularity criterion cannot be used for curved roads, which is why we plan to replace it with a criterion that combines elongation and constant width. The evaluation algorithm itself also has to be improved, at the moment we use hard thresholds without combining or weighing the criteria which is necessary to obtain a more reliable extraction in varying surroundings.

At the moment, we use thresholds for both the grouping and the evaluation. We plan to investigate how to reduce the number of these thresholds and how to select meaningful values for the remaining ones using image and object characteristics.

The next step will be the implementation of the verification strategy, which already has been shown to work in rural areas (Gerke 2006). We will need to adapt this approach for suburban areas because the road network properties and context objects play a different role: the connection function of the road network is less pronounced than in rural areas, dead ends are more frequent in suburban areas, for example. It has to be examined to what extent the network function can still be used. As for context objects, we plan to introduce a vehicle finder into our approach as vehicles are common context objects in suburban and urban areas. In addition, they may also be useful to deal with parking areas.

Using the example from section 4, the verification will roughly proceed as follows (cf. Fig. 6): in the region of interest around the database road (green) one road part was extracted in the first stage (yellow). The skeleton is then computed for this road part (orange) and the longest path between junctions in the skeleton is selected, which is then extended to the borders of the road part (red). This extracted road line is then compared to the database road: the orientation is about the same. The shape, which can for example be compared using moments as described in (Geke 2006), is again about the same, so the part of the database road that is covered by the extracted road can be confirmed. However, only about 50% of the database road is confirmed in this way, which is not enough to accept it. Assuming the road is an important part of the road network, context objects are considered in a second step, in this case a tree and a shadow (manually extracted, light blue). As the existence of a road is compliant with a tree standing beside it, this sufficiently explains the failure to detect a road in this part, so more than 60% of the database road can now be confirmed. This would still be not enough to accept the road, but after improving the road extraction stage as suggested above, more road parts will be extracted in the right part of the image, such that the database road can finally be accepted.

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