AUTOMATED ROAD SEGMENT EXTRACTION BY GROUPING ROAD OBJECTS

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ABSTRACT:

This article presents an automatic methodology for extraction of road segments from high-resolution aerial images. The method is based on a set of four road objects and another set of connection rules among road objects. Each road object is a local representation of an approximately straight road fragment and its construction is based on combination of polygons describing all relevant image edges, according to some rules embodying road knowledge. Each road segments is composed by a sequence of connected road objects, being each sequence of this type can be geometrically structured as a chain of contiguous quadrilaterals. Experiments carried out with high-resolution aerial images showed that the proposed methodology is very promising for extracting road segments. This article presents the fundamentals of the method, and the experimental results as well.

1. INTRODUCTION

Road extraction is of fundamental importance in context of spatial data capturing and updating for GIS (Geographic Information Systems) applications. Substantial work on road extraction has been accomplished since the 70's in computer vision and digital photogrammetry, with pioneering works by, e. g., Bajcsy and Tavakoli (1976) and Quam (1978). At times the use of term 'extraction' is vague, invoking varied meaning among a diverse image analysis community. In this context, the task of road extraction is related to two subtasks, i.e.: recognition and delineation. By convention, road extraction algorithm is categorised according to the extend to which it addresses either subtask, thereby implying the relative level of automation (Doucette et al., 2001). Usually, road extraction methods that in principle do not need human interaction is categorized as automatic, and the opposite as semi-automatic. Thus, automatic methods address both road extraction subtasks and semi-automatic methods address only the geometric delineation of the roads, leaving the high-level decisions (i.e., the recognition) for a human operator, who uses his natural skill to set the meaning to the object 'road'.

Concerning fully automatic methods, two basic steps can be identified. The first one is the road segment extraction, in which the local road properties tested are geometric (e.g.: roads are smooth) and radiometric (e.g.: roads are usually lighter than the background) in sense. As a result, only road segments or a fragmented road network can be extracted. The second phase is the road network completion, which requires a skilful integration of contextual information (i.e., relations between roads and other objects like trees and buildings) and other *a priori* road knowledge into the road extraction methodology (Baumgartner et al., 1999).

This paper only addresses the first phase of process for fully automatic road network extraction. The motivation is the fundamental importance of the road segment extraction for the subsequent phase, as the potential success of this last phase is significantly determined by the quality of the results of first

phase. This paper is organised in four sections. Section 2 presents the proposed methodology for automatic road segment extraction, which is essentially based on radiometric and geometric road constraints. Preliminary results are presented and discussed in Section 3. Conclusion and future perspectives are provided in Section 4.

2. METHODOLOGY FOR AUTOMATIC ROAD SEGMENT EXTRACTION

We propose a methodology for road segment extraction that is based on a set of four road objects. Each road object is a local representation of an approximately straight road fragment. The road objects are sequentially connected to each other according to a rule set, allowing road segments to be formed.

In the following, the extraction of road objects and the way they are combined to construct road segments, are described with enough details.

2.1 Extraction of Road Objects

The road objects are defined using straight line segments belonging to two different polygons with characteristics that are compatible to a road.
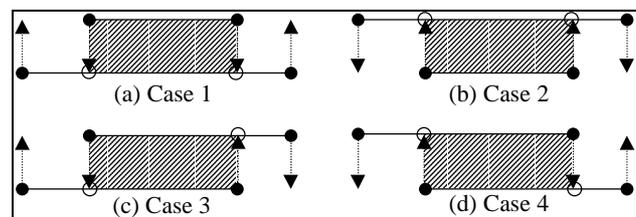

Figure 1. Road objects

Figure 1 shows the four road objects found in any road segment. In the building of a road object, by convention the inferior straight line segment is called *base* and the superior one

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is called *candidate*. For each road object case, the endpoints of both straight line segments (base and candidate) are orthogonally projected from one to each other, resulting only in two points projected between endpoints. For example, in the figure 1(a) the endpoints of the candidate straight line segment are projected into two points of the base straight line segment. The opposite occurs with case 2 (figure 1(b)). In relation to cases 3 and 4, as respectively illustrated in figures 1(c) and 1(d), only one endpoint of a straight line segment is projected between endpoints of other straight line segment, and vice-versa. In all cases, two end points belonging to the base and/or candidate straight line segment and two projected endpoints are combined to build quadrilaterals very close in shape to rectangles. Each road object gives rise to a quadrilateral, being each one identified as crosshatched area in the figure 1. The axis of each quadrilateral coincides with a short road centreline. The building of the four road objects is based on a rule set constructed from a priori road knowledge. The main rules used to identify and build road objects are described below:

1. **Anti-parallelism rule**: According to this rule, two image gradient vectors taken at two opposite road edge points, and belonging to the same road cross section, are in approximately opposite directions. Beside this, they are approximately orthogonal to the road edges. This also means that if the road edges are approximated by polygons, the image gradient vectors computed at edge pixels fitted to each straight line segment (of a polygon) are close to parallel. Thus, a compact and effective representation for the image gradient vectors, computed for each straight line segment, is the mean image gradient vector;

2. **Parallelism and proximity rule**: by this rule, two straight line segments, base and candidate, are compatible to a road object if they were approximately parallel and sufficient close to each other;

3. **Homogeneity rule**: the road pixel grey levels do not vary too much, at least within short road segments. Thus, the area inside each quadrilateral must be approximately homogeneous;

4. **Contrast rule**: roads usually contrast sharply with the background, meaning that each road object quadrilateral and its background must show a high contrast;

5. **Superposition rule**: a base and candidate straight line segments are compatible if only if two of their endpoints can be orthogonally projected onto each other. It is just this rule that gives rise to four cases of road object depicted in the figure 1. For example, in the case 1 the two endpoints of the candidate straight line segment are orthogonally projected onto the base straight line segment, giving rise to the quadrilateral of road object of case 1;

6. **Fragmentation rule**: as roads are usually smooth curves, polygons composed by short straight lines are not usually related to roads. For examples, image noise can generate short and isolate polygons. However, parts of polygons with very short straight line segments can be extracted from a road crossing where the curvature is much more accentuated. Another case is related to very perturbed road edges (by shadow or obstruction, for example), which may give rise to many short straight line segments connected to form a polygon. In these places the road objects are difficult to be formed, as the two first rules are hardly satisfied at all. Thus, cases involving short straight line segments are not considered and possible extraction fails (for examples, road crossings not extracted) are left to be handled by other strategies, which are based on previously extracted road segments and other road knowledge, as e.g. context - relation between roads and other objects like trees and building.

The order of application of the rules presented above is important, mainly when the base and candidate straight line segments are incompatible, as it can avoid in most cases the verification of all rules for road object construction. The first rule to be applied is the sixth as it allows parts of or whole polygons potentially not related with road objects to be eliminated. The next rule to be applied is the fifth, avoiding the use of another set of rules in the case this rule is not satisfied. In the following, the order of rule to be applied is the 2nd rule, the 1st rule, the 3rd rule, and the 4th rule. A road object is accepted if all rules are satisfied.

2.2 Road Segment Extraction by Grouping Road Objects

As described above, the road objects are constructed by combining the base and candidate straight line segments, which in turn belong to polygons representing all relevant image edges. Each road object is a local representation for the longest straight segment of a road segment. Thus, the problem we have in hands is how to connect the road objects to form the road segments.
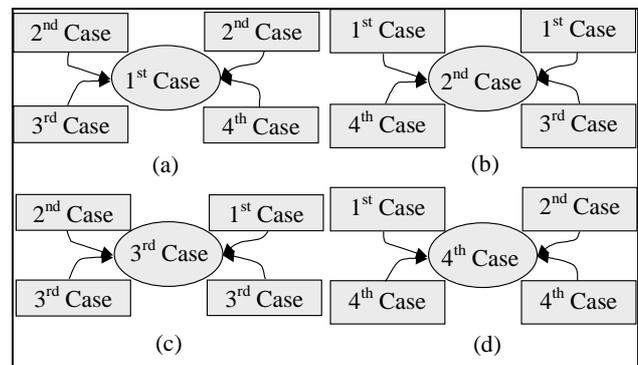

Figure 2. Connections between road objects

Figure 2 shows the possible connections to the left and to the right between the road objects. Figure 2(a) shows that 1st case road object can connect to the left with the 2nd and 3rd cases and to the right with the 2nd and 4th cases. The 2nd case road object (figure 2(b)) can connect to the left with the 1st and 4th cases and to the left with the 1st and 3rd cases. Note that the 3rd and 4th cases (figures 2(c) and 2(d), respectively) can connect themselves to both the left and the right cases.

In order to construct a road segment by combining road objects, two polygons are selected and their straight line segments are combined two-by-two and the resulting road objects are connected sequentially. The advantage of using the connection rules is that the construction of any new road object is limited to one or two cases (figure 2). The great problem of the polygon combination is the large search space if no heuristic is used. For high-resolution images, an efficient way for drastically reducing the search space is to use strategies based on the space scale, which allow the elimination of most part of previously extracted polygons (Baumgartner et al., 1999).
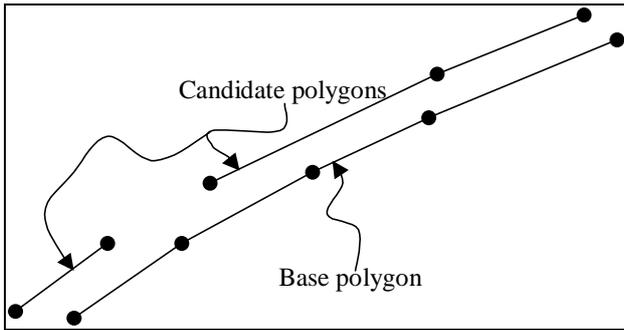
Figure 3. Examples of possible combinations between the base and candidate polygons

Figure 3 shows the combination of polygons representing the edges of a same road. One of polygons being combined is labelled *base* and another one is labelled *candidate*. As also shown in figure 3, the base polygon can be compatible with more than one candidate polygon. This means that a base polygon needs to be combined with candidate polygons until the whole base polygon is combined. Assuming that every combination gives true results, parts of or whole polygons (base or candidate) are removed from the search space after they are combined.
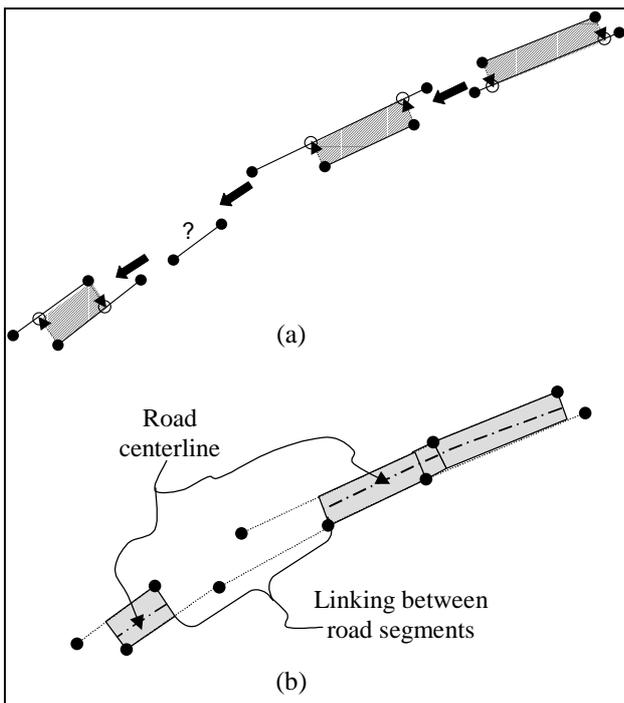

Figure 4. Extraction of road segments. (a) Extraction of road objects; and (b) Connection of the road objects

The application of methodology described above to the illustrative example of figure 3 would allow the result shown in figure 4 to be obtained.

Supposing that the base polygon is combined from the right to the left (figure 4(a)), two road objects are constructed by combining the base polygon with the first candidate polygon. The connection between these two road objects generate a first road segment (figure 4(b)), which in turn can be decomposed into three consecutive quadrilaterals. The vertices of these quadrilaterals allow the definition of a short road segment centreline. Now the combination of the base polygon with the second candidate polygon generates the second road segment constituted by only one quadrilateral. The straight line segment of the base polygon not integrating to both road segments extracted, may be a useful information for further analyses of the reasons for the missing road segment. It is an evidence that both extracted road segments are anyway related. For example, there could be a "T" or "Y" road crossing. Therefore, everything providing information on road segment extraction problem should be preserved for further use in automatic completion strategies of the road network.

3. EXPERIMENTAL RESULTS

In order to evaluate the potential of the methodology for road segment extraction, two experiments with real image data are carried out. As this methodology is appropriate for road segment extraction from medium- and high- resolution images of rural scenes, one image of medium-resolution and another of high-resolution are used.

Figure 5. Result obtained with the medium-resolution image

The first experiment is carried out with a medium-resolution image (500 x 500 pixels), in which the main roads manifest as ribbons with 6-pixel width. Figure 5 shows this image and the results overlaid on it. Parts of polygons used to construct the road segments and their centrelines are overlaid on the input image. In this experiment, an average road width of 6 pixels is used to set up the road objects, meaning that only main road segments can be extracted. The results obtained can be considered close to the expected one. Two exceptions are short road segments pointed out by arrows, which should be extracted. Thus, new control strategies are needed to increase the method efficiency. Other fails are expected due to the missing edges and other anomalies along both roads. For these places and especially for road crossings no road objects can be constructed and, as a result, a fragmented road network, composed by isolate road segments, is extracted. Specific strategies for road crossing reconstruction and road segments

connection are needed to be developed to make possible the extraction of the complete road network. Anyway, the method allows long road segments to be extracted, facilitating the posterior automatic completion of the road network. In terms of completeness, about 80% of the road network is extracted.

Figure 6. Results obtained for the high-resolution image

The second experiment (figure 6) is carried out with a high-resolution image (498 x 535 pixels), in which the roads manifest as wide ribbons with 40-pixel width. Figure 6 shows that the results reflect those theoretically expected. In fact, only road parts perturbed by illumination posts casting on the road, and the road crossing, are not extracted as those parts are incompatible with any road objects. As already mentioned in previous experiment, these fails are needed to be treated by specific strategies embody another types of road knowledge, like ones based on context and scale space (Baumgartner et al., 1999). Note that the vegetation edges adjacent to road edges do not cause false positives, showing the robustness of the method in these situations. As in previous experiment, the completeness is also about 80%.

4. CONCLUSIONS AND FUTURE PERSPECTIVES

This paper presented an automatic method for the road segment extraction from medium- and high- resolution images of rural scenes. The innovation in the proposed methodology is the way the road objects and the connection rules between them are defined.

With purpose of evaluating the method's potential in extracting road segments, two experiments were conducted using two test images, being one of high-resolution and another of medium-resolution. In all cases the results obtained can be considered satisfactory as they are in accordance to ones theoretically expected. Some little disconnections are expected, as the edge detection is sensible to the irregularities along the road margins. As a result, no road objects can be constructed for such road parts, given rise to the missing road segments. Also due to incompatibility with any road objects, road crossings were not extracted by the proposed methodology. Despite these theoretical expected fails, the methodology was able to extract

about 80% of the road network. The automatic road network completion methodologies will be the focus of our future researches, whose basic input will be the road segments extracted by the proposed methodology.

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