Context–Supported Road Extraction

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Abstract

Contextual information can facilitate automatic extraction of objects from digital imagery. This paper addresses the use of context for the automatic extraction of roads from aerial imagery. Context is restricted to knowledge about relations between roads and other objects and is hierarchically structured. More specific, context is used to guide road extraction on a global and on a local level. On a global level it is used to emphasize characteristic parts of the road model (context regions). On a local level it initiates contextual reasoning (context sketches).

1 Introduction

The automatic extraction of objects from digital imagery is a very complex task. It is widely accepted that the complexity can be reduced by integrating context information into the extraction process, e.g. (Strat 1992). Generally speaking, context means that there exists knowledge not only about the object of interest but also about other relevant facts and their relations to the object of interest.

Apart from buildings roads are the type of object most of the work on automatic extraction of man-made objects from digital aerial imagery deals with. Common methods for road extraction are extraction or tracking of lines in small scale imagery and profile matching or detection of roadsides in large scale imagery, e.g. (Geman and Jedynak 1996, Grün and Li 1996, Vosselman and de Knecht 1995). The approaches vary in the way in which different methods are combined as well as how additional knowledge, e.g., geometrical constraints, are incorporated.

In this paper examples for the support of context within a fully automatic road extraction scheme are presented. Section 2 describes how context can be used efficiently. Section 3 presents the road model and the structure of the contextual knowledge. The road extraction scheme and examples for the support of context are presented in Section 4. Conclusions are given in Section 5.

2 About Context

In the most general sense context comprises all circumstances which are relevant to a particular situation. With respect to image analysis, this means that every information about the image (resolution, sensor), imaging conditions (viewpoint, lighting), object (geometry, radiometric properties, functionality), and relations between objects can be regarded as context information. The importance of context stems from the fact that it allows to design less complex schemes for object extraction. What makes things rather difficult is that it is not possible to decide in general and a priori which kind of context is the most important one for a given situation.

As shown in (Strat and Fischler 1995) information about the image and imaging conditions can be exploited to select appropriate image understanding algorithms. For each algorithm a packet of rules is defined to delimit its scope of applicability. Because there are no "universal" image understanding algorithms (Eckstein 1996) it is necessary to ensure that their assumptions are satisfied. This can be done by using approximate models of a scene as contextual information for focusing algorithms on special regions of interest (Burlina et al. 1995).

This paper addresses the role of context for road extraction. Context is restricted to knowledge about relations of the object of interest to other objects (so-called background objects). Two levels of context are distinguished:
Global context is used to emphasize characteristic parts of the road model and to focus on special attributes and aspects of roads which depend on the presence of other objects in large regions. It is used to find areas where the road network can easily be extracted. The global context is similar to the contextual information described by so-called "outer characteristics" of roads, like "land cover area" and "bordered by" (cf. (Bordes et al. 1996)).
Local context describes knowledge about spatially restricted relations between roads and other objects, e.g., buildings and trees. This knowledge supports completion of the road network under unfavorable circumstances, like shadows or occlusions, based on contextual reasoning, i.e., already available information about objects or object parts is used to guide further extraction. In (de Gunst 1996) contextual reasoning is used to detect and to track roads branching from a given road network. Here, contextual reasoning is employed to search for additional evidence for roads and to bridge gaps, when there are hints that the previous road extraction failed.

3 Modeling Context

The context model described in this section has been developed within the framework of a multi-resolution road extraction scheme (Baumgartner et al. 1997). Roads are modeled as a network consisting of intersections and road-links, i.e., roads connecting the intersections. Due to distortions by occlusions etc. the road-links are split into short road-segments, and the road-segments into even shorter road-parts. Because distinct characteristics of roads can be detected best at different resolution levels the road network is modeled at small and at large scale.

This basic model uses mainly geometric and radiometric attributes of roads and does not describe relations between roads and background objects (e.g., buildings, trees, cars). On the one hand, a reliable extraction of roads is difficult in areas, where there exist a lot of background objects. On the other hand, details and background objects do not only hinder road extraction, the information about their presence can also support the extraction (e.g., road markings).

The influence of background objects on the characteristics of roads and on their appearance in aerial imagery is considered in the context model. Typical relations between roads and background objects of the local context are assigned to so-called *context sketches*. Because the relevance of relations to background objects varies in different areas the context sketches are assigned to different *context regions* representing the knowledge about relations to background objects at the level of global context.

Context Sketches: The concept "context sketch" is introduced to describe typical relations between road objects and background objects. A few examples are given to illustrate context sketches: *Building_driveway_road-segment* (cf. Fig. 1) models the relations between a road-segment, a driveway, and a building at the end of the driveway. The driveway is often almost perpendicular to the road-segment and the building is in many cases parallel to the road-segment. The context sketch *occlusion_shadow* consists of a hypothetical road-part which connects two road-segments and a high object next to the hypothetical road-part. Figure 2a illustrates the occlusion situation, and Figure 2b the situation when a high object casts a shadow onto the road. Another context sketch describes the relation between road-segments and driveways to agricultural fields (*rural_driveway*). *Vehicle_road* describes a dark or bright blob on a road-part or a road-segment. The relation between roads and parallel objects, like sidewalks and cycle-tracks, is defined in *parallel_object*. There are a lot of other relations which could be described in a similar way. The most important fact about context sketches is that they primarily describe relations between a small set of *objects*.

The basic context sketches are modules that can be aggregated into more complex context sketches depicting, e.g., the interaction between *building_driveway_road-segment* and *occlusion_shadow*.

Context Regions: Not every context sketch has to be taken into account everywhere. The relevance of objects and relations depends on the global context. Roads in urban or suburban areas look quite different and have other relations compared to roads in rural or forest areas. In contrast to buildings in rural areas, buildings in downtown areas are very close to

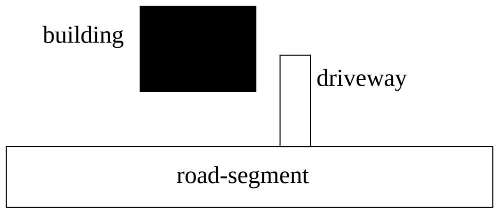


Fig. 1: Context sketch *building_driveway_road-segment*

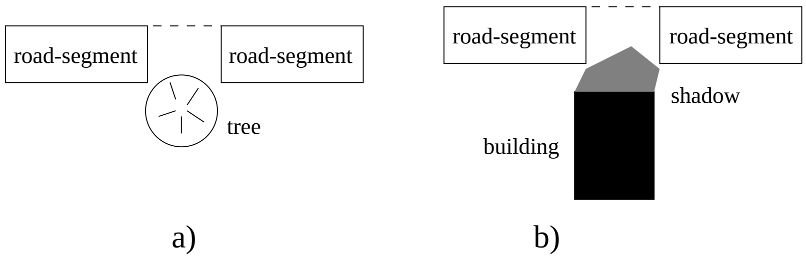


Fig. 2: Context sketch *occlusion_shadow*

and highly parallel to roads; sidewalks and cycle-tracks are more likely to appear in urban areas; in rural areas single trees and single buildings might hinder extraction, whereas in forest regions mainly shadows and occlusions pose problems. Therefore, this paper proposes to use different objects and context sketches not only at multiple resolution levels but also within so-called context regions. *Suburb_urban*, *forest*, and *open_rural* area are distinguished here.

Information from a geographic information system (GIS) or a segmentation of the image into these regions provides global a priori information about the characteristic objects and their relations, and thus can be used to select the appropriate context sketches for a given area to be investigated. Moreover, the information about the probable existence or proximity of background objects makes it possible to choose the most appropriate extraction algorithm and to determine the meaning of distinct road-parts and road-segments. The assignment of the context sketches to the different type of context regions is shown in Figure 3.

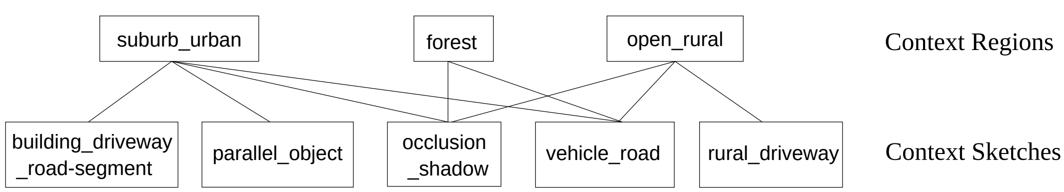


Fig. 3: Context regions and context sketches for roads

4 Use of Context for Road Extraction

The main strategy of the road extraction scheme is to extract the most salient objects first. Context consequently supports the use of this “easiest first”-strategy. Depending on the area where roads are to be extracted, different features are easiest to detect. Contextual information is a part of the control mechanism and decides where to look first, where to search for additional evidence, and where to complete the road network. Section 4.1 describes the multi-resolution approach. Section 4.2 gives examples for the use of context.

4.1 Road Extraction Scheme

The road extraction scheme is based on a multi-resolution approach. Results of edge extraction in a high resolution image (0.25 m) and line extraction in a low, i.e., reduced, resolution image (2 m) are fused and hypotheses for roadsides are derived. From these roadsides the road objects *road-part, road-segment,* and *intersection* are generated. Road-parts have a simple geometric description, i.e., the minimal quadrilateral constructed by two parallel and overlapping roadsides. Road-segments are created by aggregating adjacent road-parts. At low resolution intersections are junctions of three and more lines. At high resolution they are regions described by the enclosing polygon. If a road-segment connects two intersections, it is called road-link. For details about the construction of these road objects see (Baumgartner et al. 1997).

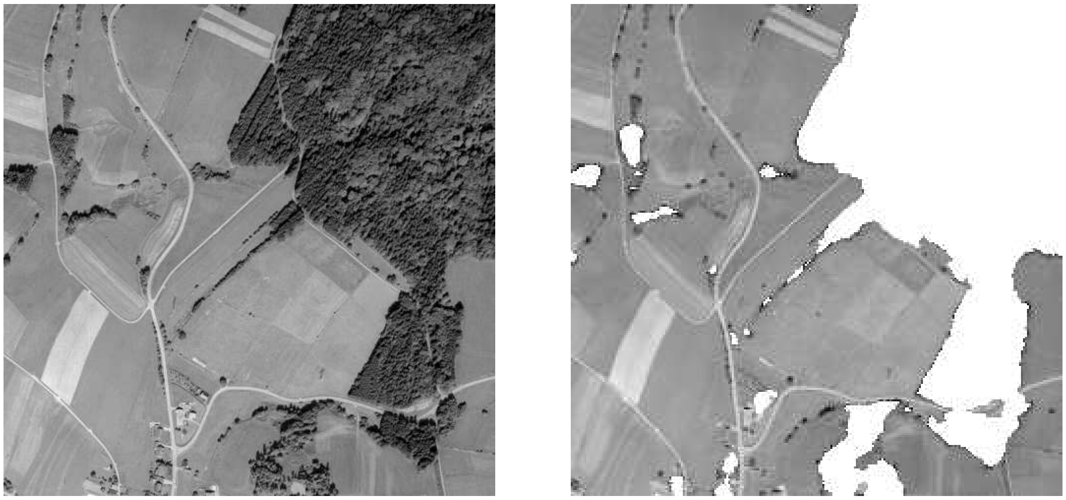
4.2 Examples for the Use of Context

Besides its use for structuring of knowledge, context is important for the control of the road extraction on different levels. Firstly, on a global level, context makes it possible to select certain parts of the model and to define appropriate extraction techniques. Secondly, on a local level, context sketches can be used to start a “top-down” process. It makes the search for additional evidence like road markings tractable and helps to explain gaps and therefore to complete the road network.

Control: Context Regions. The control of the road extraction scheme strongly depends on the global information provided by the context regions. The segmentation of the image in context regions is even more here: It is prerequisite to decide where to start with road extraction — as a consequence of the “easiest first”-strategy roads are extracted in the *open_rural* areas first. In these areas a reliable extraction is possible mainly based on radiometric and geometric knowledge about roads. Using the results of the segmentation the road extraction focuses on these most promising regions.

A segmentation of the aerial image into the context regions can be obtained by given GIS data or by texture analysis. Texture energy computed at a reduced resolution is used as criterion. Figure 4 shows the result of a texture based segmentation of *open_rural* areas.

Using the segmentation results road-segments and intersections are extracted in the *open_rural* area (cf. Fig. 5). The results show the applicability of the road model but exhibit also some problems of the extraction scheme. At places where more than two parallel edges



a) b)

Fig. 4: a) Aerial image b) *Open_rural* areas

are found, additional and partly overlapping road-segments are generated. Furthermore, some parts of the network have not been found, mainly due to shadows and occlusions. In the remaining part of this section it is shown how the use of additional context further improves the results.

Road Markings: Additional Evidence from Context. Additional and very strong evidence for roads comes from the presence of road markings. In images with a resolution of about 0.25 m road markings appear as faint lines. Therefore, a robust extraction of road markings is only possible if the search region is restricted using the context of a hypothetic road area. Figure 6 shows an extracted road-segment and road markings found on the hypothetic road which in turn increase the evidence for the road-segment.

Bridging Gaps: Context Based Search. Context can initiate a model-based search for road-parts. Usually the extraction of roads only based on geometric and radiometric knowledge fails to extract a complete road network, even in the *open_rural* area. There are always gaps caused by local disturbances like shadows cast by trees or single buildings.

The procedure to bridge gaps and to complete the road network can be split into three steps:

1. Generate hypotheses for links between road-segments.

2. Explain gap using context sketches.

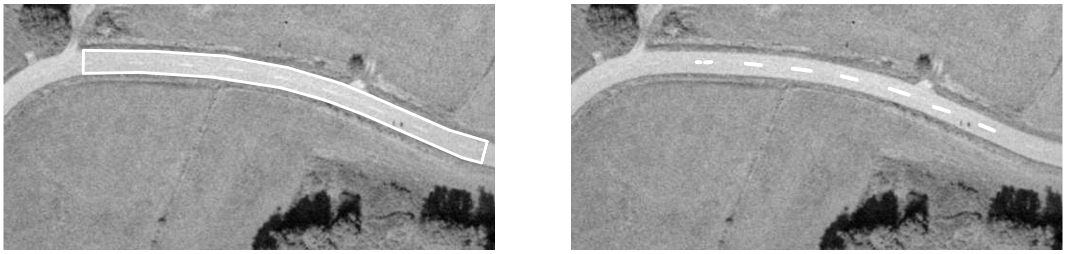
3. Construct road-part to connect the segments.

For the generation of hypotheses for links see (Steger et al. 1997). The reasoning about gaps using contextual knowledge requires information about the relevant facts, e.g. presence of other objects, shadows, and occlusions. This information can be provided by

Fig. 5: Roads extracted in *open_rural* area (image size: 4000^2 pixels)

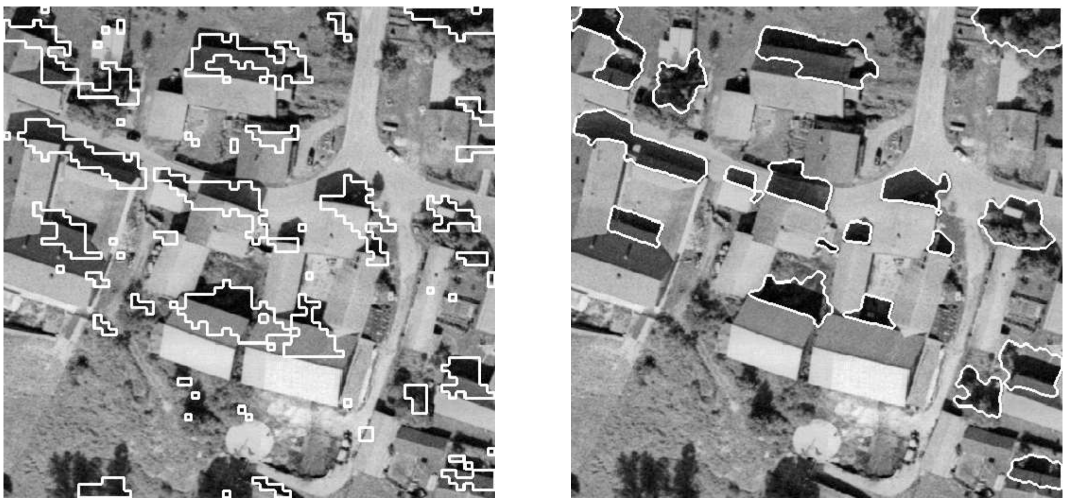
many sources. However, in order to avoid inconsistencies between additional information and image data, it is better to gain the information directly from the imagery.

As shown in (Eckstein and Steger 1996) an automatically generated digital surface model (DSM) can be used to find shadow regions. The extraction of shadow pixels cannot simply be carried out by collecting all dark pixels because dark objects may be present. Instead the DSM is illuminated. The segmentation of the image generated from the illuminated DSM provides the raw shadow areas (cf. Fig. 7a). Due to the low resolution of the DSM the segmentation has to be improved. Small areas are eliminated. Dark pixels of the remaining shadow areas in the image are then used as seed areas for region growing. The results are not perfect (cf. Fig. 7b). However, it is not the goal to perfectly segment shadow areas, but to obtain information about the context for road extraction. Based on texture analysis it is possible to classify the high regions into trees and buildings. This



a) b)

Fig. 6: a) Road-segment b) Road markings



a) b)

Fig. 7: a) Shadow regions (raw segmentation from DSM) b) Final shadow regions

distinction is useful for road extraction when a gap caused by a shadow has to be bridged, because the intensity of the shadow depends on the kind of object (building, tree) and therefore, different context sketches have to be considered.

If a gap can be explained by a context sketch using the available contextual information, the missing road-part has to be constructed. Because start-, endpoint, and an approximate value for the width of the missing road-part are given, techniques like ribbon snakes can be applied. The major advantage of the snake technique is the ability to achieve acceptable results even if there are only short or weak edges in the image. Moreover, it seems to be possible to use the results of snake optimization to evaluate link hypotheses (Laptev 1997). In Figure 8 a ribbon snake is applied to a clearly visible road, a shadowed road, and for control purposes to the background. The endpoints were marked manually. The snake optimizes first the centerline then the width. For the clearly visible road the width is very constant, for the shadowed road the variation of the width is acceptable. The result for the background can't be used to construct a road-part. These results indicate that it should be possible to distinguish shadowed roads from other objects.

a) b)

Fig. 8: Using snakes to bridge gaps: a) Road partly in shadow region b) Results of the application of a ribbon snake (black: centerline, white width) for clearly visible road (lower part), for shadowed road (center), and for background (upper part)

5 Conclusions

Context, i.e. knowledge about relations between roads and other objects improves the results of road extraction in different ways. In this paper the contextual knowledge is hierarchically structured: Context regions provide global information, context sketches yield local information. Context facilitates the overall control and the search for additional evidence. It is a prerequisite for a well-founded closing of gaps in the network and for the assignment of specific semantics to individual road-parts. A problem arising from the use of context is to obtain information about relevant facts, like shadows or road markings. Examples for the extraction of contextual information from images and the use thereof for road extraction are given.

Acknowledgments

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