UPDATE OF ROADS IN GIS FROM AERIAL IMAGERY: VERIFICATION AND MULTI-RESOLUTION EXTRACTION

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ABSTRACT

Aerial imagery is an important source for the acquisition and update of GIS data. By using digital imagery it is possible to automate some parts of these tasks. In this context this paper proposes a new approach for the automatic update, i.e., verification and extraction, of roads from aerial imagery. The verification process evaluates road axes from GIS data based on the analysis of profiles taken perpendicularly to the axes. It is possible to handle inaccurate axes, as well as to detect initial points for branching roads. The process for the extraction of roads is independent of the GIS data, but relies on knowledge about roads provided by a road model. This model comprises knowledge about geometrical, radiometrical, topological, and contextual properties of roads at different resolutions. Multi-resolution extraction is applied because distinct characteristics of roads can be detected best at different resolution levels. By fusing results of different resolution levels the distinct characteristics of roads are integrated. Examples for the verification as well as the road extraction are given.

1 INTRODUCTION AND OVERVIEW

Data capture and update are very important tasks to improve or preserve the value of data in geographic information systems (GIS). Update is equivalent to the verification of old data and the extraction of new objects which have to be integrated into the GIS. It is usually done manually by an operator and is time consuming and expensive. Therefore, a lot of research work is dedicated to the development of more efficient ways for update of GIS data. Research on the automatic extraction of man-made objects, like buildings or roads, from aerial or satellite imagery has been carried out since the seventies, e.g., (Bajcsy and Tavakoli, 1976). In the beginning the attention was focused on automatic data-capture for maps and GIS. However, the support that GIS data can give for the interpretation in the context of update was only realized recently.

Whereas a lot of work exists on the extraction of roads, which is the type of object that is dealt with in the remainder of this paper, relatively little work has addressed the verification. The verification scheme described in (Plietker, 1994) is based on the extraction of edges close to and parallel with the given road axes. If a certain percentage of the edges, i.e., hypotheses for roadsides, can be matched to the road axes, the GIS data is assumed to be correct.

For the extraction of roads methods like profile matching and detection of roadsides are used. The approaches vary in the way how different methods are combined as well as how additional knowledge, e.g., geometrical constraints, is incorporated. A main criterion to distinguish the works is the interaction of a human operator. In semi-automatic schemes an operator selects an initial point and a direction for a road tracking algorithm (McKeown Jr. and Denlinger, 1988, Heipke et al., 1994, Airault et al., 1994, Vosselman and de Knecht, 1995). In (Gruen and Li, 1994) the operator marks a few points of a road segment and a dynamic programming based algorithm finds the road which connects these points. This is advantageous because the path of the road is more constrained and a more reliable handling of obstacles is possible. A similar approach based on so-called "ziplock" snakes is given in (Neuenschwander et al., 1995). A fully automatic approach is presented in (Barzohar and Cooper, 1995). Stochastic methods are used to find seeds for the road extraction. Roads are found based on a grey level model and on assumptions about the geometry of roads by dynamic programming. In (Ruskoné et al., 1994) seed points for the extraction of the road network are centers of elongated regions found by a segmentation. Based on the elongated regions and their directions, road segments are extracted using the homogeneity of the road surface. In order to extract the road network geometrical constraints are taken into account, and hypotheses about connections between single road segments are checked.

This paper proposes a new approach for the automatic update of roads from aerial imagery. The verification of roads employs a simple model based on the analysis and tracking of profiles taken perpendicularly to the given GIS axes. Strong edges in the profiles are linked and checked for colinearity, parallelism, and their distance to the GIS axes. The result distinguishes *verified*, *inaccurate*, and *rejected* GIS axes as well as initial points for new, branching roads. A detailed description and results are given in section 2. In section 3 the automatic extraction of roads from aerial imagery is described. It is independent of GIS data but uses a more detailed road model incorporating different kinds of knowledge about the characteristics of roads. Due to the fact that different characteristics of roads can be detected best at different resolution levels, evidence for roads is extracted at different resolutions. The original image has a ground resolution of about 25 cm. To detect roads as homogeneous areas with parallel edges it is slightly smoothed to reduce the effect of noise and small disturbing features (high resolution). In an image reduced to a scale where roads are only a few pixels wide (low resolution) road axes are extracted. A combination step fuses both results. The result of the fusion step is taken to direct the search for road markings to get more evidence for the roads. Road markings are very weak in the images and therefore the image is nearly not smoothed when extracting them. This only gives reasonable results because the place where to search for is known á priori. Finally, in section 4 conclusions are given.

2 VERIFICATION

Verification of GIS data means to find the parts of the data which have not changed. One way is to compare the results of an automatic road finder with the given data. But this is disadvantageous because the given data is not used to guide the road extraction and the matching is computationally expensive. A way to check the data which avoids this is to compare the data “directly” with the image data. This has the following advantages: The area to be investigated is known; there is highly reliable information about the spatial position and, what is more, about the topology of the roads because most of the roads normally are unchanged. Using this information, it is possible to close gaps if they are enclosed by verified sections. By and large, there is a good chance to verify roads using a simple model. This section presents an approach for the verification of GIS data using high resolution image data (pixel size 10–50 cm) and simulated GIS data representing the axes of the roads.

2.1 Model and Fundamental Idea

The proposed approach is based on a simple model which comprises two fundamental assumptions about the appearance of roads in aerial imagery: (1) Roads have mostly straight and parallel roadsides. This means that if a road in the image corresponds to an axis of the GIS data both roadsides will be approximately parallel to the axis. (2) Roadsides correspond to strong edges in the image and the gray values along a road axis are expected to be more or less constant.

The fundamental idea of the approach is that both roadsides are close to an axis if the GIS data corresponds to a road in the image. Therefore, the first step consists in searching for the two strongest edges at both sides of the axis. This is done with loose constraints. For that reason some edges which are no roadsides will be detected. If the axis corresponds to the road the number of these false detections will be relatively small, otherwise many randomly distributed edges which are no roadsides will be found. The decision whether the axis corresponds to the road in the image is made in the second step using the following criteria: Straightness, parallelism of the extracted edges, and homogeneity of the gray values within the expected road.

2.2 Verification procedure

2.2.1 Edge Detection To find the two strongest edges a gradient image using the modified Deriche edge operator (Lanser and Eckstein, 1992) is computed. This operator yields good detection quality, accurate location, few multiple responses, and isotropic response. Along each axis points with constant distance to each other are calculated. At these points relatively wide, symmetric profiles are taken from the gradient image perpendicular to the axis similar to (McKeown Jr. and Denlinger, 1988). The positions of the two strongest edges within each profile are determined. The only constraint on the position of the two edge points within the profile is a minimum distance to each other. In Figure 1a) the detected edge points are shown as black points superimposed on the test image (cf. Fig. 3 for the corresponding GIS axes). There are a lot of outliers due to disturbances near the road.

2.2.2 Width Estimation Because of the outliers in the edge detection it is important to estimate the actual width of the road. The center of the two edges and the distance of the center to the old axis is calculated for each profile. If this distance is less than a certain threshold (depending on the given level of accuracy), the two edge points are labeled as roadsides. The longest sections where the edge points are labeled as roadsides are computed using the imperfect sequence detector (ISD) described by (Aviad and Carnine Jr, 1988). For these sections the mean road width is estimated. After adapting the width of the profiles to the road width, the search for the two strongest edges is repeated for each profile. By this means, disturbing edges further away from the road are eliminated. In Figure 1b) the result after the estimation of the road width is shown. The benefits of this step can be seen especially at the curved road in the upper part of the image. In Figure 1a) (before the estimation of the road width) the edge points are widely spread, while in Figure 1b) (after the estimation of the road width) most of the edge points correspond to roadsides.

2.2.3 Evaluation of the GIS Axes Two kinds of errors can occur when labeling edge pairs: An error of the first kind is committed if an edge pair is labeled as not corresponding to the roadsides, although both edge points correspond to them. An error of the second kind is committed if the edge pair is labeled as corresponding to the roadsides although this is not the case. These errors cannot be detected for each edge pair individually. Therefore, the continuity of extracted edge points is checked along the direction of the axis.

A frequent reason for an error of the first kind is a slightly inaccurate position of the axis. This leads to a constant bias of the GIS axis and the center point of both edges. Therefore, the edge pair will be labeled as not corresponding to the roadsides. This error typically occurs for many successive edge pairs. To detect this kind of error, the string of centers is checked for straightness along the GIS axis. Each point and its two neighboring points are connected by two vectors. The criteria for “straightness” are that the angle between the two vectors, as well as the difference between the mean direction of the two vectors and the direction of the GIS axis are small. First, all center points are labeled individually. Then it is checked if a gap in the string of edge points preliminary labeled as roadsides can be closed by a continuous string of center points labeled as straight. If this is the case, the corresponding edge points are labeled as roadsides as well.

The errors of the second kind are detected by checking all edge pairs which are labeled as roadsides. This is based on measures for straightness, parallelism, and homogeneity. Typically roadsides are straight. Therefore, all edge points which are colinear with their neighbors are assumed to be faultless, all others to be faulty. A measure is computed for each roadside separately. To check the edges for parallelism, the direction of the edge points is taken from the direction image calculated with the Deriche edge operator as well. A measure for parallelism of the two edge points within each profile is derived by comparing their directions. It is not advisable to assume homogeneity of the gray values for the whole road as there are too many disturbances, like cars or shadows. However, a great part of the road is homogeneous. What is more, an area depicting no road will often be distinguished by inhomogeneous gray values. The gray values of the center points are accumulated into a coarse histogram. A homogeneity measure is derived by an investigation of this histogram. The highest relative frequency will mostly be higher for roads than for other areas. Furthermore, the number of histogram sections with more than a certain frequency will be less for roads.

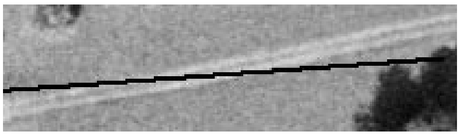
Finally all derived measures are combined to decide whether an GIS axis can be verified or not.

2.2.4 Handling of Inaccurate Axes At some places GIS axes don’t coincide accurately with the road axes in the image. Some parts of a GIS axis lie within the road, whereas other parts do not. Typically, there is a skip in the position of the edge points at the intersection of the GIS axis with the roadside. The edge which is intersected by the axis will be detected continuously, whereas the corresponding roadside will only be detected if the axis lies between the two roadsides (cf. Fig. 2). A good hint for

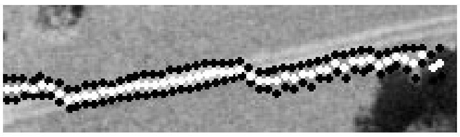
(a) (b)

Figure 1: Edge points a) before and b) after the estimation of the road width

this situation is given by a skip in the position of the center points. To detect this skip, the gradients along the GIS axis are checked for significantly high values. This results in partitioning the GIS axis into several parts. To find out which part of the axis is lying between the roadsides, they are verified one after the other, using the algorithms explained in sections 2.2.2 and 2.2.3.



(a)



(b)

Figure 2: a) Inaccurate axis b) Skips in edge detection

2.2.5 Detection of Branching Roads An important part of the verification task is to detect possible branchings of new roads. A new road is connected with the existing road network. Hence, there will be changes in the area around the GIS axes because of new junctions. Often it is sufficient to check the immediate vicinity of the GIS axes to detect branching roads. For this task two different operators are used. The first investigates the whole road to find new junctions whereas the second only checks areas where it was not possible to recognize roadsides. The first operator evaluates gray value profiles perpendicular to the GIS axis that are approximately symmetric to the expected roadside. Normally the standard deviation σ will be high for each profile, since a part of it is lying outside the road. A sequence of profiles with low σ indicates a junction if its length is in the range of the expected road width. The second operator uses the fact that roadsides often are not detectable in the area of junctions. In areas where it was not possible to detect roadsides a gray value profile is taken parallel to the GIS axis, but lying slightly outside the road. If this profile has a roadlike shape, i.e., if a bright region is detected, the center of this bright region will serve as the starting point of a profile perpendicular to the GIS axis. This profile connects the starting point with the GIS axis. If this new profile has more or less constant gray values, a junction hypothesis is generated.

2.3 Results

For the presentation of the results of the verification the GIS axes are superimposed onto the image (cf. Fig. 3). If an axis is found to be correct, i.e., *verified*, it is displayed in white. Axes totally displayed in black are *rejected*. Axes that are partly plotted in black and partly in white are *inaccurate*, with the black segments being not verified.

Figure 3: Result of the verification (white line = *verified*, black line = *rejected*, partly black and partly white line = *inaccurate*)

3 ROAD EXTRACTION

3.1 Model

To extract roads without using GIS-data it is necessary to have a more sophisticated idea about the concept *road*. Hence the model has to be more elaborate and should comprise explicit knowledge about road width, parallelism of roadsides (geometry), reflectance characteristics (radiometry), network structure (topology), and relations to other objects like buildings or trees (context). The complex model of the real world object *road* can be subdivided in more specific submodels which are adapted to contextual environment (open area, forest, suburb; or more specific: crossing in suburb), sensor, and scale (resolution). The submodels emphasize certain characteristics of the objects and therefore they can be regarded as specialized models.

In the proposed road extraction scheme only resolution dependent submodels are employed. The development and integration of submodels for the contextual environment and with lower priority for other sensors is considered an important task for future work. For the resolution dependent submodels there are a lot of partly interwoven problems: How many resolution levels are necessary for a reliable road extraction? Which resolutions provide additional evidence for the road recognition? Which characteristics of objects should be used at the chosen resolution? Essential theoretical clues to these questions can be found in the relationship between abstraction and scale-space events (Mayer, 1996). The general answer is that the resolutions depend on the inner and the outer scale of the object to be extracted. This means that the required resolutions can be expressed as a function of the size of smallest details of importance for the application and of the extent of the whole object. Since it is mostly impossible to see global characteristics of an object and every detail as well at the same resolution it is proposed in this paper to use more than only one resolution level to get a reliable road extraction.

In the approach described below road extraction is based on the extraction of parallel edges which border homogeneous areas from an image with a ground resolution of about 25 cm and on the extraction of lines in a version of reduced resolution of the original image. By fusing the results of the two resolution levels most of the errors in the individual results are eliminated.

3.2 Road Detection at Low Resolution

The notion "low resolution" cannot be fixed to a certain scale. In this paper "low resolution" means that roads are only a few pixels wide and appear as light or dark lines. Therefore, the resolution considered as low depends on the width of the roads in the imagery. If the road width varies widely in an image, e.g., between 4 m (path) and 30 m (motorway), more than one "low resolution" level, e.g., one for paths and normal roads and one for motorways, would be needed.

Figure 4: Image at low resolution

Figure 4 shows a version of reduced, i.e., low, resolution of the original image. The ground resolution is 2 m. Light lines are extracted with an approach based on differential geometrical properties of the image function. Points which have a vanishing gradient and a high curvature in the direction perpendicular to the line are considered as line points and linked into contours. For more details see (Steger, 1996). The contours are approximated by polygons. The extracted polygons are hypotheses for road axes (cf. Fig. 5).

Figure 5: Hypotheses for road axes at low resolution

3.3 Road Detection at High Resolution

At high resolution roads are modeled as bright homogeneous areas bordered by parallel edges. Edges are extracted from the original image and approximated by polygons. These polygons are grouped into relations of pairs of parallels, and the area enclosed by the parallels is examined (Steger et al., 1995). The area to be investigated is indicated in Figure 4.

3.3.1 Edge Extraction and Polygonal Approximation The edge extraction is performed using a modified Deriche edge operator (cf. section 2.2.1). After a thinning operation by a non-maximum-suppression algorithm one pixel wide edges are obtained. The computation of contours from these edges and a polygonal approximation is done as in section 3.2.

3.3.2 Perceptual Grouping of Parallel Edges In the next step relations of parallel polygons are computed. Polygon segments are included in the parallel-relation if several criteria are fulfilled. First, the segments have to be approximately parallel. Since roadsides are never perfectly parallel, two roadsides are labeled as parallel if the angle between the line segments is below a certain threshold. Because longer line segments determine the direction more accurately the threshold becomes the smaller the longer the involved segments are. Second, parallel segments have to overlap. Third, since roads have a certain width, the distance between the parallels has to be smaller than a certain threshold. Results of this intermediate step are shown in Figure 6.

3.3.3 Selection of Parallels Bordering Homogeneous Regions Up to now only geometrical properties have been employed for road extraction at the high resolution level. This step makes use of the radiometric characteristics of roads. It is assumed that the intensity of roads is relatively constant in the direction of the road, whereas it can vary considerably across the road due to road markings and tire tracks. To check this, the homogeneity of the rectangle enclosed by a pair of parallels is determined by examining slices which are parallel to the centerline. The slices are 1 pixel apart and the intensity within each slice is computed by bilinear interpolation. If the mean in each slice is within a certain

Figure 6: Parallel line segments

range and the variance within each slice is lower than a threshold, the region is assumed to be part of a road and the parallel lines are accepted as roadsides.

3.3.4 Extension to Neighboring Homogeneous Regions For some parts of the roads, e.g., intersections and narrow curves, the geometrical model of parallel roadsides is not valid, and therefore no parallel polygon segments are found. To close gaps in these problematic regions all edges which are connected to the rectangles, i.e., parallel polygon segments accepted as roadsides (cf. section 3.3.3), are examined whether they border homogeneous regions. Rectangles are constructed that have the width of the neighboring rectangle. They are sliced as above and checked for homogeneity. The result of this extension process are hypotheses for roadsides at the high resolution level (cf. Fig. 7).

Figure 7: Hypotheses for roadsides at high resolution level: Lines which border homogeneous areas

3.4 Fusion of the Results from Low and High Resolution Level

Both resolution levels have several assets and drawbacks for road extraction. At the low resolution level the global network structure of the roads can be seen clearly, and small disturbances, like cars on the road or shadows cast by trees, do not pose so many problems as at high resolution level due to the smoothing of the image. A drawback of the low resolution is that the geometrical accuracy is poor compared to high resolution. To make optimal use of the advantages of both resolution levels, the results are fused. The input for this fusion step are hypotheses for road axes derived from the low resolution (section 3.2), hypotheses for roadsides selected in section 3.3, and original edge polygons. The basic strategy is to select the results of both levels which support each other. Hypotheses for roadsides that enclose a homogeneous area and have a hypothesis for a road axis in-between serve as initial hypotheses. The other roadsides are extracted gradually according to several rules. For a detailed description of the rules see (Heipke et al., 1995). Figure 8 shows the input to this fusion step. The final road hypotheses are presented in Figure 9.

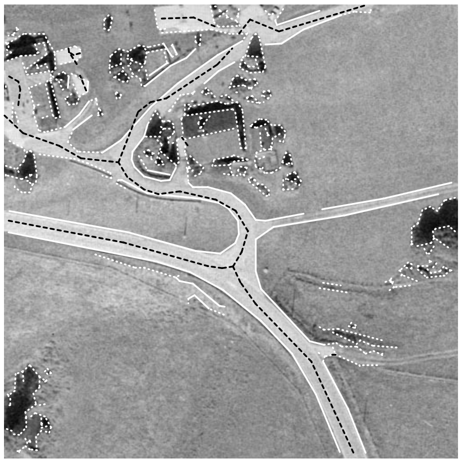


Figure 8: Input to the fusion: hypotheses for road axes (dashed, black), hypotheses for roadsides (solid, white) and other edges (dotted, white)

Figure 9: Final road hypotheses

3.5 Detection of Road Markings

Road markings give additional evidence for road hypotheses. In the high resolution image they appear as weak lines (cf. Fig. 10) and can therefore be extracted with the same algorithm applied for road extraction at low resolution (cf. section 3.2) but with smaller thresholds. Because of the weakness of the lines the image is nearly not smoothed when extracting road markings. If many short and almost colinear lines are extracted in the middle of the road area, they are likely to be road markings. Reasonable results are only possible because the extraction is restricted to the hypothesized road areas. The detection of road markings is also helpful for a classification of the detected roads because only roads of a higher category have road markings.

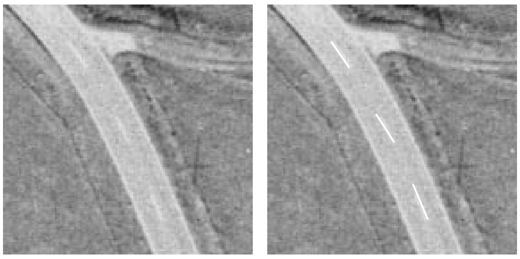


Figure 10: Detection of road markings

4 CONCLUSION

Automatic approaches for verification and extraction of roads from aerial imagery were proposed. The results show that the verification of roads in a GIS in digital aerial imagery can be achieved based on a simple model. A quite reliable classification of the GIS data into *verified, inaccurate,* and *rejected* road axes is possible. What is more, the detection of new, branching roads is feasible. Thus useful hints for a subsequent automatic road extraction are provided. The results of the multi-resolution road extraction are very promising. Future work will be dealing with the combination of verification and extraction to make use of the branching points detected in the verification phase. Additionally more knowledge of the road model, especially on the contextual environment, will be implemented, and it is planned to use color images and DTM information in the road extraction scheme. Integration of a more complex road model and additional knowledge will improve results and deepen the understanding of the problem. On this way the development of efficient reasoning and control strategies will be one of the important steps.

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