MODEL BASED ROAD EXTRACTION FOR THE REGISTRATION AND INTERPRETATION OF REMOTE SENSING DATA

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ABSTRACT

Due to the increasing number of digital remote sensing data taken by aeroplane and satellite which are used for the updating of maps and the environmental or agricultural monitoring, there is a need to automate the registration and interpretation of these images. The approach described here treats the segmentation of roads (linear objects) in different sensor data (SAR, IR, VIS and maps) which is employed for registration and interpretation. The information from the GIS (Geographic Information Systems) is used by the registration to reference the tiepoints. For the interpretation the information of a GIS database is exploited to generate reliable hypotheses for expected roads which are verified in the data.

1 INTRODUCTION

1.1 Summary

The paper presents a model based algorithm for road extraction in remote sensing data from difference sensors. The functionality of the algorithm and the approach of *how to use* it for registration and interpretation of images and the inclusion of GIS information - automatic verification of GIS data and GIS updating - is described.

In the literature, different procedures for the extraction of roads were presented. In Aviad and Carnine (1), roads are a longer sequence of antiparallel edges. Barzohar (2) advanced this approach by a stochastic model. He permitted changes of the road width and of the direction. The use of the radiometry and geometry of the roads was described by Baumgartner et al. (3). In this approach many of these aspects are included. In the first chapter the algorithm is described followed by possible applications and results in the last chapter.

In the chapter about the algorithm the used model and the extraction of image information is described. The next step is how to find secure stripes (as start position). These start positions are expanded to a road net by using an A* search algorithm for locating the best way. Partly covered roads are detected by a separate search mode. At the end of the chapter, there is a description of how additional context knowledge and the GIS information is used for verification or registration.

The third chapter briefly outlines the applications (registration, interpretation, verification and GIS update). At the end some examples from different sensor data are given. We have used VIS, IR, SAR and maps as input data.

2 THE ALGORITHM

2.1 The used model

In the algorithm a model of the objects we are looking for in the image data is used. A road is a long strip and its width and luminance are within a certain range. It can be winding and it is connected to a roadnet. The road contrast with itself through luminance changing at its edges of its environment. These features are identical in all employed sensors. Fig. 1 shows an aerial photo within the visual range, Fig. 2 shows the same section in the SAR sensor.

Figure 1: Visual Image

Other features are imprinted differently on different sensors. In such a way for example the luminance of the roads in the SAR image is small while it has a middle to high luminance value in visual images. Since roads appear lighter or darker than the environment in most sensors, it suffices to have a model presention of areas, with antiparallel edges (Fig. 3.a). This gradient course is called antiparallel since the signs of the gradients are different. In order to detect a road whose luminance (parallel edges) is between the luminace of the two sides of the environment (Fig. 3.b) the algorithm can be changed by a switch.

The idea is now to adjust the parameters of the algorithm for each individual case by only providing information about the type of sensor and the image resolution.

At first secure road segments are extracted from the image by using this parameterized model. To expand this segment an A* search algorithm is used. The employed model is adjusted more tolerantly during this A* search so that deviations from the model also become permissible. In this manner, it becomes possible to extract roads which deviates in part from the model. In such a way, roads can deviate from the model that are i.e. covered by parking

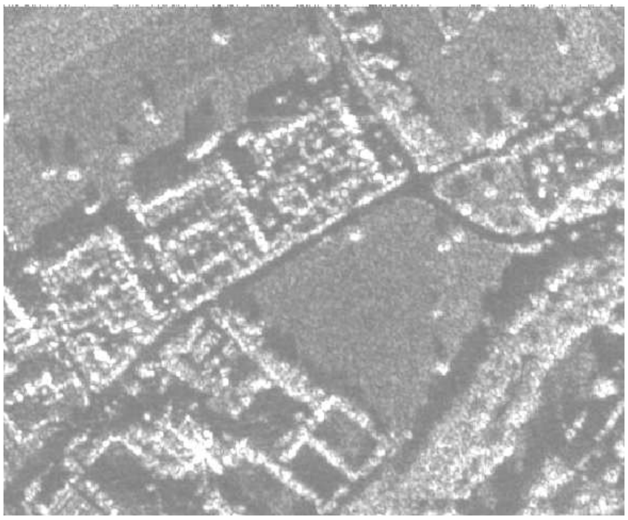

Figure 2: SAR Image

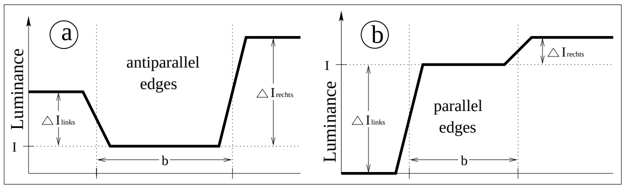

Figure 3: Road sectional gradient

cars.

2.2 Extraction of basic information

In a first step a gradient image is determined by using a Sobel operator. From the gradients, the direction of the gradient process is determined and this quantized in eight directions. The gradient image is then standardized.

2.3 Finding secure areas

In this steps road segments which can be recognized with great certainty and which exceed a minimum length are located. With the aid of the described model, edge pixel pairs which correspond to the cross section of a road are first determined. Consequently, an edge pixel pair consists of two pixels with the following qualities:

- the gradient values of the edge pixel pair are large enough
- gradient directions are either opposite or identical
- the enclosed pixels have a value within a given range
- the variation of the included pixel values is small

In addition to the border points, the centre of the road segment is determined.

If different road cross section compete around a centre pixel then the one whose image emerges as the clearest is accepted. This becomes recognizable in greater gradient to the road edges, that is at the sum of the greater edge pixel gradient in the standardized gradient image. In a further step the detected edge pixels are combined to longer road segments.

From the number of single road cross section the largest possible subsets are formed which together support the thesis of the course of a road. In order to achieve this adjoining road cross sections of the same direction are combined. Road cross sections which cannot be combined into greater groups are rejected. Here the imagined model is included:

- The resulted road segments must achieve a minimum length here in order to be accepted as road candidates.

Secure road segments which have been found are depicted in Fig. 4 with edge line and center line.

Figure 4: Detected secure start positions

2.4 Expanding the areas

Since a complete and faultless segmentation cannot be assumed the road segments that have been found are extended in a further step. The isolated road segments should be combined to larger connected road segments that have a net-like structure.

It can then be attempted to continue this by starting at the ends of the segments. In the case of alternative possible ways of extending the road segments a decision must be made as which course is to be pursued. For this one needn't check any more whether the model is served or not, but one should determin the degree of correspondence. This agreement supplies an evaluation or safety measure and serves in the employed A* algorithm (10) as a measure of the costs. The course with the lowest cost is the one which best fulfills the model. In other words this is most probably the best way that is based on the image.

2.4.1 A* Algorithm

A modified A* algorithm is employed for the expansion of road pieces. All those edge pixel pairs that are marked as starting points form the roots for the search. Here the *aim* is the connection of the segment end in questinon to an other road segment.

The consistent *expansion* of the way corresponds to an expansion of the left and right road edge with one edge pixel and is discussed later. The *costs* for the A* result from the degree of agreement of the found section with the model. The estimate of the lower limit of the *remaining costs* can only be carried out as a general estimate and therefore, poses a special problem. A further *aim* is the attainment of a variable search depth. While reaching this search depth, A* lookup is suspended and the attained edge pixel pair is marked as a new starting point. This is a discontinue due to *failure* if all ways are higher than the permissible maximal *costs*.

Expansion: On expanding the detected way it should be noted that both edges are extended in accordance with the model. It must be prevented, that the road edges are continued independently of each other. It must also be recognized when one road edges as compensation should receive additional edge pixels.

For this, three different subdirections are defined as follows:

1. Direction of the centerline:
   The search direction is orthogonal to the road cross section to be extended and points away from the already found way (Fig. 5.a).

2. Direction of the left edge:
   The left edge direction represents the present course of the left road edge. It results from the position of the penultimate and of the present left border point (Fig. 5.b).

3. Direction of the right edge:
   Corresponding to the left side (Fig. 5.c).

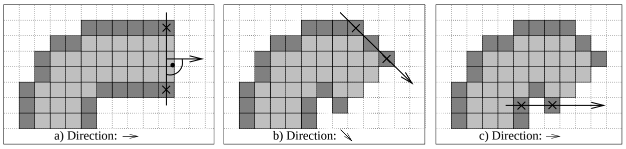

Figure 5: Direction of the road edges

If these three directions correspond, both edges can be extended in search direction by one step. The edge directions stay roughly parallel and neither edge advances faster than the other. In order to balance the different edge pixel numbers in a bent road the advancing border point is slowed down (Fig. 6a-e).

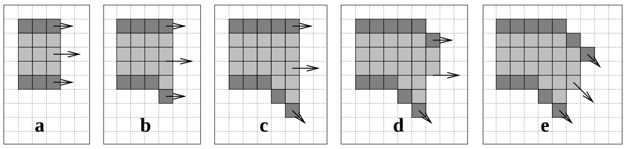

Figure 6: One sided step by step expansion at curves

The road detect in this way can reveal bends and are characterised by edges that constantly remained parallel.

Costs: The *costs function* makes the selection of the best expansion of the road segment possible for the A* algorithm and in this way, it mainly determines the quality of the segmentation success.

The value of the costs function should present the degree of correspondence of the found road with the model. The model is parameterized and the a priori knowledge for the extraction is presented in these parameter and the procedural knowledge.

Listing of the model parameters:

1. Direct model parameters
   a) minimum road width
   b) maximum road width
   c) minimum shade of grey of the road
   d) maximum shade of grey of the road
   e) gradient of the road edges

2. Feature based influences
   a) mean value of the pixels of a road cross section
   b) standard deviation of the pixel values from the road cross section
   c) road width
   d) relative variation of the road width
   e) correspondence of the two edge directions
   g) gradients of the border points
   h) connection to already found border points
   b) estimated remaining costs

Remaining cost
The remaining costs are estimated for the remaining search depth of the A* algorithm since the true remaining costs cannot be determined. The estimate is based on the fact, that the average costs for the already found partial way are transferred to the remaining search depth. In order to get an optimistic estimation these calculated costs are multiplied with a factor less than one.

2.4.2 An approach of failure

If the costs for all search paths increase above a maximum value the A* search breaks off unsuccessfully. Therefore, the road course cannot be extended by using the A* search. This situation existes for example when the road is concealed or in shadow. The algorithm then returns to the place at which the road could still be detected with certainty and turns into another mode (pook mode).

The direction of the road at this point is then determined and attempts are made by retention of this direction to bridge the interference. The search width is more limited here and this search mode remains active, until a connection is made or until a road that corresponds ot the model is found. If a connection was found, the A* is employed for the further search again. Otherwise if there is no connection after a maximum depth the search for this road candidate is broken off.

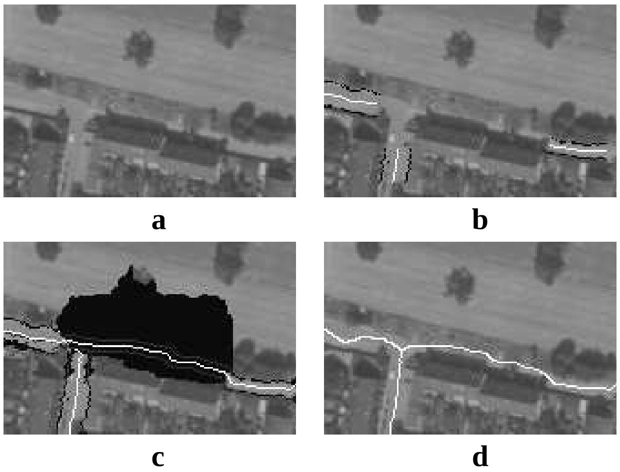

Figure 7: Covered road by shadow

The basis for this procedure is the assumption that roads are mostly rectilinear.

Fig. 7 illustrates this procedure. Picture 7.a shows a smal section/part of the visual image (figure 1). A part of the road is covered by the shadow from the house. In picture 7.b the secure road center segments are depicted in white in addition the two roadsides are additional drawn black. The A* algorithm cannot extract the shaded road and the algorithm switches to the *poke mode*. The functioning of this mode is shown in Fig 7.c. The resulting road centers are white and the black area is the search range of the *poke mode*. The result is presented in Fig. 7.d. The center line is shifted since the road is not completely covered.

2.4.3 Vectorization the result

The result of the algorithm is the approximation of the axes of the detected roads. For this, the segmentation results are approximated by a linear regression. Roads that are too short are removed. The result of the extraction (black) and the approximation (white) is shown in Fig 8.

Figure 8: Result of road extraction

2.5 Using additional information

If there is detailed information about the area in the image it is possible to use this information to get better results.

2.5.1 Contextdependent extraction

The first possibility is to use contextdependent information. If you want to verify GIS data you can mask different regions by generating a label image from GIS data. This allows you to optimize the parameter from the algorithm i.e. for finding roads in wooded areas or in town areas.

2.5.2 Using GIS info

If GIS data are available for registration or verification, this can be employed for the detection. Here, a maximum value for the expected translation can be given. From the GIS data for the course of the road and the specified location inaccuracy, a *probability* image can be calculated.

Fig. 9 shows an example generated from GIS data for the bottom right corner in Fig. 1. The three direction have different grey values intervals. At these intervals, darker fields represents a higer probability. By the inclusion of this image in the extraction the outlines which match the direction expected by the GIS data are reinforce.

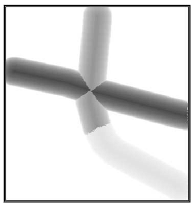

Figure 9: *Probability* image whith three direction and the grey values show the probability

The result of an extraction can be employed equally for the generation of the *probability* image. The transfer of the results to pictures of other sensors is herewith possible, if both pictures are registered or the corresponding transformation is known.

Now we have described the algorithm sufficiently and we move on to the application.

3 APPLICATION

3.1 Registration

For automatic image registration of remotely sensed images the tie point must automatically be found in the images to calculate the transformations function. If the registration is to made using a GIS then its suggestive to use such objects that are able to be detected in image data and are available in the GIS.

If crossroads are used as control points as described in (5) they can be extracted from the GIS. From image data, the control points are obtainable as intersection points of roads. In the described algorithm, the vectorized roads are described here in such a way, that at crossroads all the polylines concerned end i.e. to the used GIS (ATKIS see (6)). If the GIS data is projected into the image which is roughly registered by the flight parameters then the situation shown in Fig. 10 occurs. The extraction results are shown in black $\{a,..,d\}$, the GIS data in white $\{1,..,4\}$.

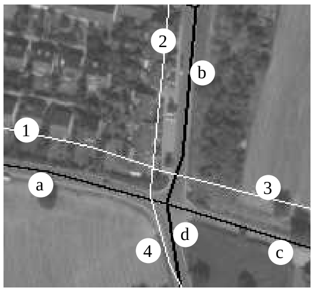

Figure 10: Results of extraction (black) and projecting GIS data (white)

The roads from the GIS can be assigned to the extracted roads by a relaxation (4). In this way the geographic coordinates can be calculated for the segmented crossroads. Through extraction of several control points in the same image registration is possible.

3.2 Verification and GIS update

Updating the GIS is important for its practical and economic value. Nowadays it is done manually. The visualized approach for the automatic verification of roads is a basic step towards a more automatic update procedure. The approach used digital area images and GIS data. Updating of GIS data is possible because the results of interpretation is conform to the GIS.

So it is posible to compare the road information from the GIS with the segmentation results by using the above mentioned relaxation. This comparison can be used to generate hypotheses for new road segments. If these new road segments are connected to the road net they can be used for the GIS update. Roads that are presented in the GIS data but cannot be verified in the image are candidates to be remove from GIS.

4 RESULTS

In Fig. 11 the extraction result in a visual image is shown.

Figure 11: Result of a visual image

The results in a SAR image are shown in Fig. 12. Because the noisy data material of the SAR sensor is problematic for us to interpret, so the number of the missegmentations is here higher than in the other employed sensors. The coure of the road which is not based on real roads in the image are extracted. On the other hand, existing roads are not detected. The objects can be separated since the entity characteristics unsatisfactorily resemble each other in the images.

For a better extraction supplementary knowledge would have to be employed here. In such a way, the proposed relaxation addressed a good way of to find roads corresponding to the GIS data and to remove the roads that are extracted too much. Likewise it would be possible to generate hypotheses for missing roads segments which would be verified by a further use of the algorithm.

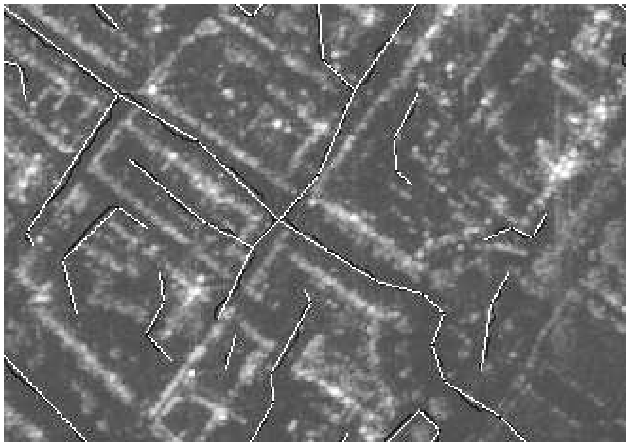

Figure 12: Extraction result in SAR image

The use of IR pictures leads to similar results as does the use of visual data because the inherent characteristics and those between the objects are similar.

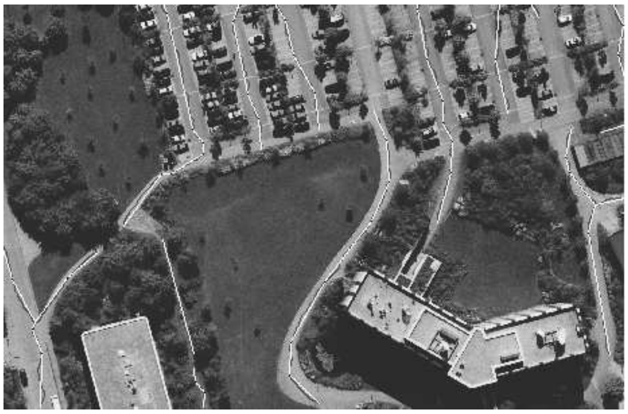

Figure 13: Extraction result in IR image

Maps are a kind of ideal image. The segmentation results could be corrected by suitable preprocessing if for example the signatures are removed from the image.

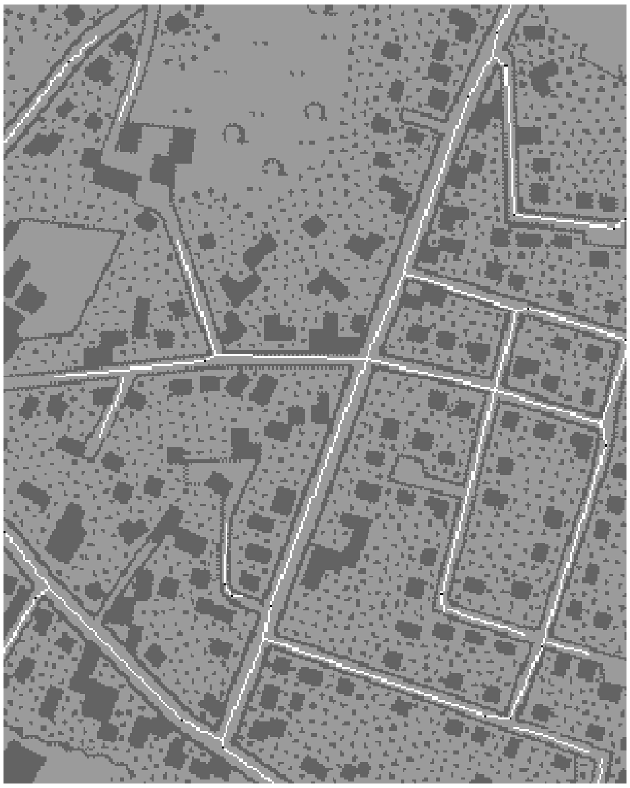

Figure 14: Result for a map example

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