Semi-Automatic Road Extraction Algorithm for High Resolution Images Using Path following Approach

Vandana Shukla	R.ChandraKanth	R.Ramachandran
ADRIN,DOS,INDIA	**ADRIN,DOS,INDIA**	**ADRIN,DOS,INDIA**
vandu_shukla@yahoo.com	rc_kanth@hotmail.com	adrinramu@hotmail.com

Abstract

An approach for the semi-automatic extraction of roads from high-resolution satellite imagery is proposed. Scale space, Edge-detection techniques are used as pre-processing for segmentation and estimation of road width. The detection of road is based on the cost minimization technique. The cost is estimated by taking various factors into consideration like variance, direction, length and width of the road. The process starts with the selection of seed points provided by the user. The approach is called as ***'path following'*** *as it follows the path having minimum cost repetitively. Thus the path having minimum cost will be considered as a part of the road. The algorithm puts weights on the directions for estimation of cost of the path. The algorithm works successfully for roads having junctions and minimum obstacles and detects central line of the roads in any orientation with moderate curvature accurately. Current limitations are that the algorithm may not work on the road cast by shadow and the user must select valid road seeds since algorithm cannot judge the validity of input seeds. The algorithm requires input roads of considerable width. The roads that will not give edges in edge detector will not be extracted . The high-resolution images are preferable due to use of width and variance information for road extraction. The contribution of this paper is that it showed cost minimization and path following approach with pre-processing by scale-space and canny edge detector works well for road extraction. It also handles tracing of junctions of the road. Seed points need not be selected on road central lines and each road segment need not be given separate seed points.*

1. Introduction

Extraction of roads from digital aerial/satellite imagery is not only scientifically challenging but also of major importance for data acquisition and update of geographic information system (GIS), databases or site models and thus can be a big help in car navigation systems or any emergency (rescue) system that needs instant maps. In high-resolution images identification and/or understanding man made objects are important. Especially road network is one of the most important features in GIS layer. Techniques to extract this feature from an urban scene have numerous applications in urban mapping, urban planning and Geo-Information Engineering.

Until now various road extraction methods have been proposed. Barzohar and Cooper 1996[3] proposed an automatic method of extracting main roads in aerial images. The aerial image is partitioned into windows, road extraction starts from the window of high confidence estimates, while road tracing is to perform a dynamic programming to find an optimal global estimate. German and Jedynak 1996[4] proposed a semi-automatic method where given a start point and start direction a road is extracted from a panchromatic SPOT satellite image by playing "tests" about the "true hypothesis". Gruen ET. Al[1] developed linear feature extraction method using Active Contour models called snakes. They combined characteristics of snakes and Adaptive Least squares Correlation method. This method might need large computation time on high-resolution images because of its linear systems. Latest research efforts can be found in Park and Kim, 2001[6] which presents a road extraction algorithm using template matching. But its limitations was that it requires initial seed points on the road central lines and each road segment requires separate seed points.

Traditionally the algorithms dealing with this topic are mostly semi-automatic, which means they need human operators to give the starting points of the roads during the process. This paper proposes a road extraction algorithm, which analyzes high-resolution (1m) satellite image and extracts road network by using some pre-processing operation and user's initial seed points. This algorithm finds the direction and width of the road at those points. Then the cost is estimated in different directions and the direction having minimum cost is followed as next path on the road. The process continues till the end of the road. Thus the decision to follow a path is decided dynamically. A 1 m resolution image was used to test this algorithm. The algorithm extracted central lines in any orientation and with moderate curvature successfully after selection of road seeds.

Current limitations are that the algorithm may not work on the road cast by shadow and one must select valid road seeds since algorithm cannot judge the validity of input seeds. The roads that will not give edges in edge detector will not be extracted. These limitations are currently being examined.

The contribution of this paper is that it showed cost minimization and path following approach works well for road extraction, which also handles tracing of junctions of the road. Seed points need not be selected road central lines and each road segment need not be given separate seed points unlike the template matching algorithm for road extraction presented by Park & Kim, 2001[6]. In the following section, the principle of this algorithm is explained and the road extraction results from this approach with a 1 m resolution image are presented.

2. Road Extraction

The algorithm requires pre-processing operations of input image, which includes scale-space based and edge-detection based techniques. Once the initial seed points on a road are selected, it automatically detects center of the road by estimating the width of the road through edge-detected image. It also finds the direction of the seed points in which to proceed. Next, three directions are traversed according to the width of the road and some weights are assigned to these directions. Cost estimation is performed in each of the three directions by calculating variance from the image after applying scale-space technique. The path having minimum cost is considered as next valid path on the road and the procedure is continued till the end of the road[2]. The junctions of the road will be having width exceeding the width of the previous paths. So backtracking is also performed to handle crossroads, which indicates that the previous width is considered for traversing further. Thus the process goes on. As it is possible to move in forward direction with given seed points, similarly backward traversing is also possible so that utmost no. of the roads can be detected with minimum seed points.

The flow diagram of semi-automatic road extraction process is shown in **figure 1**.

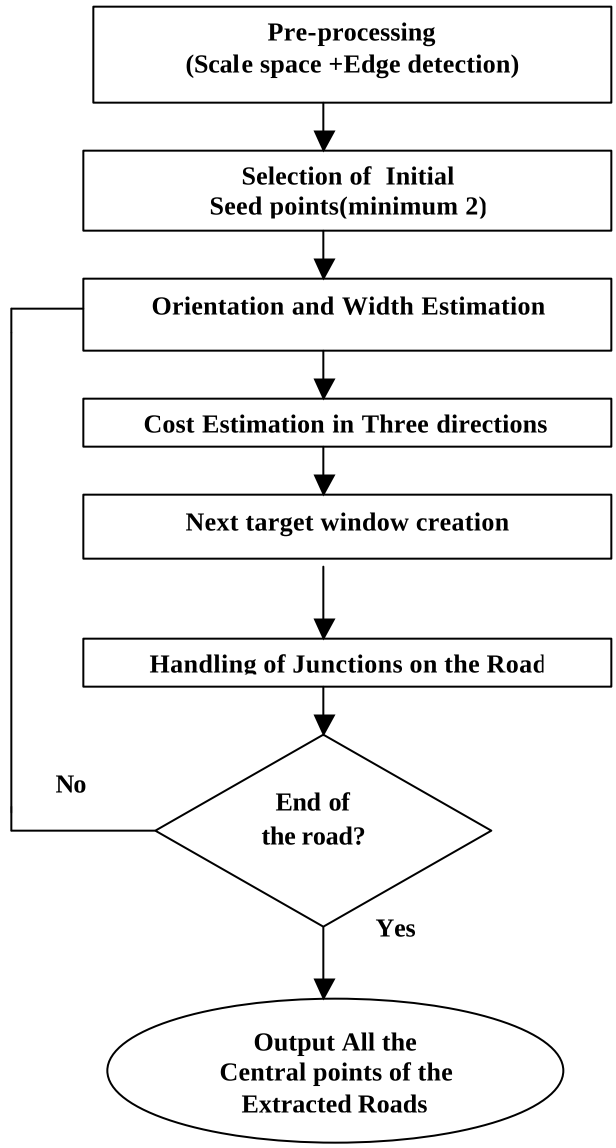


Figure 1: Flow diagram of Road Extraction

2.1 Pre-processing

The current algorithm requires some pre-processing which includes scale-space and edge detection routines.

2.1.1 Scale Space

Scale space is a data structure that consists of sequence of images at different scales[5]. Diffusion process establishes a scale space. It is a transport process that tends to level out concentration differences. We are using Non-Linear Ansiotropic Coherence diffusion as minimizing further the variance along the road, which is used for the estimation of cost. So the main purpose of this diffusion is to bring the variance on the road at the same level. Hence this type of diffusion fulfills our requirement. **Figure 2.1.1** shows the original image and the diffused image after applying diffusion (non-linear coherence anisotropic) on the input image.

Original Image **Zoomed part of marked area**

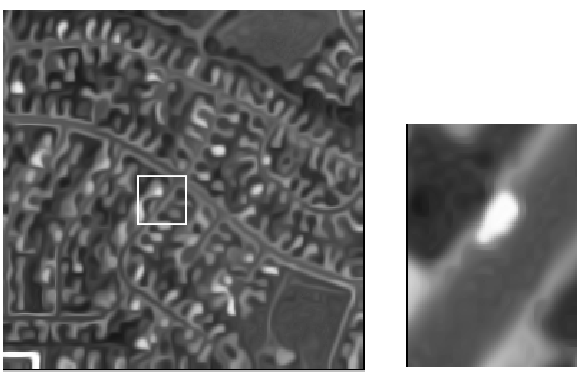


Image Diffused by Coherence Anisotropic Diffusion **Zoomed part of marked area**

Fig. 2.1.1

The diffused image is used in our algorithm for computation of variance of the pixels in the image.

2.1.2 Edge Detection

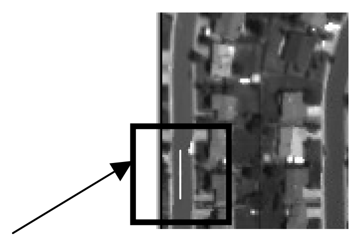
A proper Edge detector is also required for the estimation of width of the road. Canny edge detector is suitable for our algorithm as it provides the thin and continuous edges of the image. The sharper edges of the road will help in giving more accurate estimation of the width of the road. **Figure 2.1.2** shows the canny edge detected output of the original image.

Original Image **Canny Edge Detected Image**

Fig. 2.1.2

2.2 Selection of Initial Seed points

Because the current algorithm proposed here is not fully automatic, hence one must select initial input points on the road. Minimum two seed points will trigger the proposed algorithm. These seed points need not be on the center of the road. The algorithm automatically detects center of the road by finding width of the road through the edge-detected output of the input image. Also one must be aware that this algorithm may not work on the road cast by shadow and hence must avoid selection of such points. **Fig. 2.2** shows the selection of two seed points in a road segment.



Two Seed points selection

Fig. 2.2 Selection of two seed points

2.3 Orientation and Width estimation

Once initial input points are selected, orientation on the initial input points is calculated. The orientation on that point tells the road direction in which to proceed. Simultaneously width of the road at that particular point is also calculated by considering edge-detected image into account.

Width is estimated as shown in the **fig. 2.3.1**

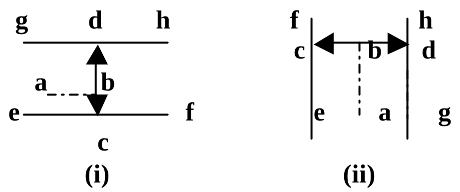


Figure 2.3.1: Perpendicular directions to the seed points

The figure shows the perpendicular directions to the seed points for the width estimation. **ef** and **gh** are the road edges , **ab** is the current direction on the road in which to propagate, **bd** and **bc** are the two perpendicular directions to **ab**. Orientation of the initial seed points helps in manipulating the perpendicular directions. Two perpendicular directions to the current seed point are propagated in the canny detected image for the width estimation until the edge boundary is found on the both sides. Those two positions(**c** & **d** in the fig. 3.2) are recorded and then the center position on the road is calculated. **fig. 2.3.1 (i)** shows that the seed points **ab** are not exactly at the center of the road. Now central point of the road can be easily detected by this method such that in **fig. 2.3.1 (i)** center point becomes **b/** instead of **b** as shown in **fig. 2.3.2**

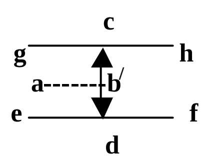


Figure 2.3.2: Adjustment of node to the center of the road

Thus **b/** will be now the current working node. The width of the road at each current working node is stored along with it for comparison in future.

2.4 Cost Estimation in three directions

Once the width of the road at the initial seed points is estimated, the orientation of the initial seed points tells the three directions in which to propagate. The three directions along the seed points given can be propagated according to the orientation of the seed points as shown in **fig. 2.4**

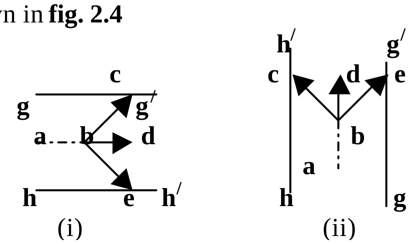


Figure 2.4: Search directions to the seed points 'ab' for further road extraction

The figure above shows the edges **gg/** and **hh/** of the road **ab** is the current direction on the road then **bc**, **bd, be** will be the three possible directions in which algorithm will proceed for manipulating cost factor. The minimum lengths of the three directions are considered as the width of the road at current node (here **b**). Each of the 3 directions will be assigned different weights. The direction having the same path as of the preceding node will be assigned minimum weight.The computation of the cost e.g. along path **bd** can be evaluated by the expression (1).

$$\textbf{Cost}_{bd} = \frac{(\textbf{variance}_{bd} * \textbf{direction of bd})}{(\textbf{length}_{bd})} \quad \textbf{(1)}$$

$$\text{where variance}_{bd} = \sqrt{\frac{\Sigma(\text{pixel value} - \text{mean}_{bd})^2}{(\text{length}_{bd})}}$$

Similarly cost along **bc** and **be** is calculated in similar manner. The costs along all these three paths can be stored for comparison.

2.5 Next Target Window Creation

Once the cost is estimated in the three directions the path having minimum cost will be considered to be the path on the road. This path will be stored and will be considered as next target window for the road detection. The process continues iteratively till the cost factor remains within the set values.

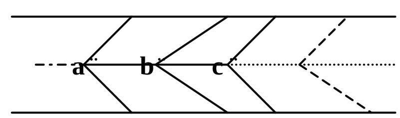


Figure 2.5 : Illustration of successive detected nodes on the road

The fig. above shows that a , b and c are the successive nodes on the road having minimum cost. Thus the iterative application of the algorithm provides the next target window and finally outputs the connected extracted central points on the road .If still few roads are left as undetected same algorithm can be invoked by giving few more seed points. Hence this approach is called as **path following** as it follows the path having minimum cost repetitively until the end of the road is reached. Thus the path having minimum cost will be considered as a part of the road.

2.6 Handling Junctions on the road

While detecting the roads, the junctions of the road also come into picture. The junctions will be having following features: -

a) The width of the road at the point on the junction will exceed suddenly as compared to the previous points traversed on the road.
b) The path along its all directions will be having minimum cost.

Case a) is handled by backtracking i.e. here the length of that point is reduced by considering the width of the predecessor point traversed.

Case (b) is handled by storing all the paths having minimu m cost and they are considered once again after one side of the road is traversed. Fig. 2.6 shows the nodes near junction of the road.

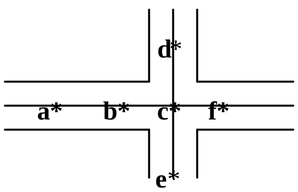
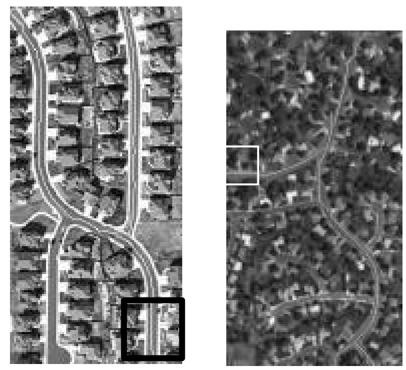


Figure 2.6: Junction of the road.

In the fig. above the width of the road at point **c** suddenly exceeds compared to point **b**, which indicates a possible junction. If it is a junction then considering width of the road at point **b** the three directions along that point are propagated**.** All the three directions **cd**, **ce** and **cf** will be having least cost as they all will lie on the road only .In that case two paths are stored for further processing and one path for current processing. Suppose **cf** be considered as current path. Then algorithm is repeated till one end of the road is reached. Once the end of road is detected, algorithm looks for any stored paths (here **cd** and **ce**).If any path is stored same algorithm is repeated for remaining undetected roads.

3. Results

The algorithm proposed here was tested for many IKONOS images as well as for an aerial image. These images contain many different types of road at various orientations with minimal obstacles (vehicles, buildings, markers). They also consist of roads having junctions. **Figure 3.1(i, ii)** shows the results of road extraction on few segments of road. The black outlined boxes indicate the two selected initial seed points. The path following algorithm is invoked from these points for three directions and the width is also estimated simultaneously. The white line is the output, which is the result of connecting central points detected on the road. Figure 3.1 shows that the road extraction algorithm proposed here has successfully traced road center through the iterative path following approach.



(i) (ii)

Figure. 3.1: Extracted road Segments

Fig. 3.2 shows the more complex roads detected by path following approach .It also shows that how the intersections where there are no continuing road centerlines are being handled through this algorithm. There are several road segments at various orientations. There are also instances where road orientation changes abruptly.

Figure. 3.2: Multiple Road extraction

This algorithm can also work for aerial imageries as shown in the figure **3.3.** The image consists of shadows and having abrupt change in orientation of the road. Rectangular boxes shown again indicate the selected seed points, black lines shows the road extracted. This also shows that the algorithm could not detect shadow and it will stop at that point. So next seed point will again traverse the undetected road.

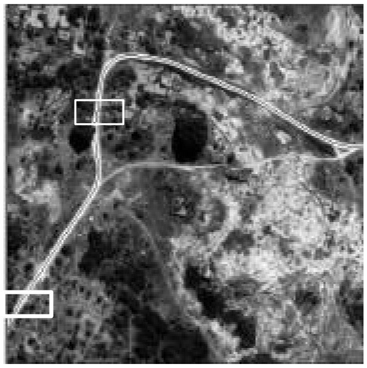


Figure. 3.3: Road Extraction from Aerial Image

4. Conclusions

In this paper, we showed semi-automatic road extraction algorithm. From the high-resolution satellite image, road segments are extracted by using path following approach. The experiments with IKONOS images showed that from a few input seed points maximum of road segments were extracted automatically. The contribution of this paper is that it showed cost minimization and path following approach with preprocessing by scale-space and canny edge detector works well for roads of considerable width. It also handles junctions of the road also with minimal seed points. The high-resolution images are preferable due to use of width and variance information for road extraction. These techniques are applied to one-meter and two-meter resolution images. Current limitations are that the algorithm may not work on the road cast by shadow and the valid road seeds must be selected since algorithm cannot judge the validity of input seeds. The roads that will not give edges in edge detector will not be extracted. The algorithm requires input roads of significant width. These limitations are currently being examined.

5. Acknowledgements

The authors are grateful to Dr. R. Krishnan, Director ADRIN for his encouragement in the development of this activity.

References

[1] A.W. Greun et. Al. Linear Feature Extraction with 3-D LSB Snakes, Automatic extraction of Man-made objects from Aerial and Space Images, vol.2,pp. 287-298,1997.

[2] Airault S., Ruskone R., Jamet O. Road detection from aerial images : a cooperation between local and global methods, image and Signal Processing for Remote Sensing, Satellite Remote Sensing I, SPIE,vol. 2315,pp. 508-518,Rome(Italy) (1994).

[3] Barzohar, m .D. B. Cooper. Automatic finding of main roads in aerial images by using Geometric Stochastic models and estimation, IEEE trans. PAMI, vol.18,no.7 , pp. 707-721,July,1996.

[4] German, D. B. Jedynak. An active testing model for tracking roads in satellite images IEEE Trans. PAMI, vol.18, no.1,pp 1-14,January 1996.

[5] Joachim Weickert. Non-Linear Diffusion Filtering, Hand book of Computer Vision and applications, Volume 2,Pages 424-446.

[6] Park S.R.,T. Kim, “Semi-Automatic road Extraction algorithm from IKONOS images using template matching, Proc. 22nd Asian Conference on remote Sensing, pp 1209-1213,2001.