GEOMETRIC REFINEMENT OF ROAD NETWORKS USING NETWORK SNAKES AND SAR IMAGES

Matthias Butenuth

Technische Universität München, Remote Sensing Technology
Arcisstr. 21, D-80333 München, Germany
matthias.butenuth@bv.tum.de

1. INTRODUCTION

In this paper, a new approach for the geometric refinement of road networks using network snakes and SAR images is presented. The geometric refinement of road networks to improve GIS-databases is topic of current investigations to correct the basis for traffic navigation or infrastructure planning purposes. The proposed iterative approach is either able to deal with roads from a database as initialization in an automatic system or, alternatively, within an interactive framework to derive a geometrically optimized road network.

In the past, great efforts have been accomplished concerning road extraction from remotely sensed imagery. A road extraction system with a top-down strategy using a cartographic database to generate road hypotheses is presented in [1]. Road extraction is constrained in the optical image by road hypotheses evaluated afterwards. A similar contribution is a reconstruction approach for road networks from aerial images using knowledge-based image analysis [7]. The wide availability of high resolution SAR images involves the development of methods dealing with this data type, too, research is for example given in [3], [5]. But, quality measures concerning completeness and correctness of road extraction are worse compared to the approaches exploiting high resolution optical data.

However, databases containing roads and further attributes are nowadays existent in most countries providing data for a variety of applications. Thus, latest research deals with the automatic assessment of existing geospatial data to derive quality measures. One approach using reference information automatically derived from up-to-date remotely sensed images is presented in [4]. But, the provided result is only a quality assessment, not an improvement of the database in terms of a geometric refinement of the roads.

In contrast, in this paper an enhanced approach using network snakes as introduced in [2] is applied dealing with SAR images for geometric road network refinement. Network snakes are based on the well-known active contour models of [6], but in addition to the image energy and internal energy the topology is introduced incorporating a complete topological and shape control during the optimization [2].

2. NETWORK SNAKES

Network snakes are based on the concept of parametric active contours, often called snakes, defined as a parametric curve $C(s) = (x(s),y(s))$ where $s \in [0,1]$ is the arc length, and x and y are the coordinates of a 2D-curve [6]. The core of active contour models is to let the curve C evolve in an image I delineating the object of interest. This aim is reached by minimizing an appropriate energy functional $E(C(s))$:

$$E(C(s)) = \int_0^1 \left[E_{img}(C(s)) + E_{\text{int}}(C(s))\right] ds \ .$$

The energy functional consists of the image energy $E_{img}(C(s))$ representing an optimal description of the object of interest in the image and the internal energy $E_{int}(C(s))$ introducing modeled object knowledge concerning the shape and movement behavior of the object. A solution of the energy functional can be derived by solving the corresponding Euler equations deriving the final equation [6]:

$$C_t = (A + \gamma \mathrm{I})^{-1} (\gamma C_{t-1} - \kappa f_C(C_{t-1})) \ .$$

A is a pentadiagonal band matrix, which depends only on the parameters α and β controlling the shape of the contour, γ is the step size, I is the identity matrix, f_C are the derivatives of the image energy and κ controls the weight between internal and image energy.

The new method of network snakes is represented by a graph to incorporate the topological characteristics of a contour network (cf. Fig. 1). The introduction of the topology to the model of parametric active contours is identified as the crucial point, why the approximated derivatives with finite differences controlling the shape of the contour are defined in a new manner at nodes with degree $\rho(C) \neq 2$, details are described in [2]. All contour parts $C_A, \ldots, C_Z$ intersect in joint and single nodes C_n and can be optimized simultaneously (cf. Fig. 1). Thus, the energy definition allows for an energy minimization controlling the shape of each contour part separately up to the common nodes C_n and, at the same time, the exploitation of topology is ensured during the energy minimization process due to the connectivity. Network snakes require an initialization to start the iterative optimization, which can be taken in dependence on the application from a preprocessing step or a GIS. The topology is derived automatically from the given initialization.

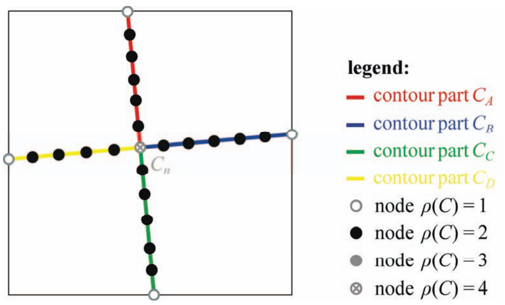

Figure 1: Topology of network snakes

3. RESULTS AND DISCUSSION

In Fig. 2 an airborne SAR image with a ground resolution of 1.0 m is shown, displayed is a part of 600 × 1000 pixels. The geometric refinement of the road network is initialized with road data taken from a GIS database (Fig. 2, left). The contour network consists of 27 contour parts represented by 1200 nodes. The end points of the contour network are chained to the image borders allowing to move only along the borderlines. The image energy is derived from the Laplace of Gaussian (LoG) operator of the SAR image, because it represents roads in a discriminable way compared to the local background. The initial road network database is compared to reference data obtaining a completeness of 92 % and a correctness of 100 %, the reduced completeness is caused by few missing roads in the database (lower right part of Fig. 2). However, the focus is on the geometric accuracy as expressed in the horizontal root mean square value with computed 9.6 pixel equivalent to 9.6 m.

The result after applying the network snakes is compared to the reference data, too: obviously, the completeness of 92 % and the correctness of 100 % are kept constant, but the geometric accuracy increases to 2.6 pixel or 2.6 m. This improvement is very good, in particular considering the complex properties of the SAR image caused by the typical speckle-effect, layover and shadowing. The benefit of network snakes exploiting the topology during the graph-based optimization together with the image energy and the internal energy is evidently and turns out to be a powerful method to deal with noise or disturbances in the imagery when refining road networks.

Figure 2: Geometric refinement of a road network from an airborne SAR image using network snakes: initialization (blue), optimization steps (white) and final result (red)

4. REFERENCES

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