Network Snakes-Supported Extraction of Field Boundaries from Imagery

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Abstract. A fully automatic method to extract field boundaries from imagery is described in this paper. The fields are represented together with additional prior knowledge in the form of GIS-data in a semantic model. The approach consists of two main steps: Firstly, a segmentation is carried out in a coarse scale resulting in preliminary field boundaries. In a second step network snakes are used to improve the geometrical correctness of the preliminary boundaries taking into account topological constraints while exploiting the local image information. Focussing on the network snakes and their specialties the results demonstrate the potential of the proposed solution.

1 Introduction

Field boundaries have come to be objects of increasing interest during the last few years. One application area are geo-scientific questions, for example the derivation of potential wind erosion risk fields, which can be generated with field boundaries and additional input information about the prevailing wind direction, wind shelters and soil parameters [1]. Another area is the agricultural sector, where information about field geometry is important for tasks concerning precision farming [2] or the monitoring and control of subsidies, which are paid by the European Union to the farmers.

In the past, several investigations have been carried out regarding the automatic extraction of man-made objects such as buildings or roads [3, 4]. Similarly, the classification of vegetation areas in coarse scales [5] and investigations concerning the extraction of trees [6] have been accomplished. In contrary, the extraction of field boundaries from high resolution imagery is not in an advanced phase: a first approach to update and refine topologically correct field boundaries by fusing raster-images and vector-map data is presented in [7]. Focussing on the reconstruction of the geometry and features of the land-use units, the acquisition of new boundaries is not discussed. In [8] a so called region competition approach is described, which extracts field boundaries from aerial images with a combination of region growing techniques and snakes. To initialize the process, seed regions have to be defined manually, which is a time and cost-intensive procedure. A technique for predicting missing field boundaries from satellite images is presented in [9], using a comparison of modal land cover and local variance. The approach involves manual post processing, because

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only fields with a high likelihood of missing boundaries are identified, not field boundaries directly.

The goal of this paper is to highlight a fully automatic method to extract field boundaries from aerial imagery or high resolution satellite imagery. Consequently, the proposed strategy differs from the mentioned approaches: Initially, the integration of imagery and topographic GIS-data[1] in one semantic model is described to obtain an overview of the numerous relations between the objects to be extracted and the prior knowledge. Afterwards, the two main parts of the algorithm are explained in detail: At the beginning, a segmentation is carried out in a coarse scale resulting in preliminary field boundaries, which are topological correct but geometrical inaccurate. The following refinement is accomplished with network snakes, an enhanced approach of snakes (active contour models) [10] taking into account topological constraints of the initialization while exploiting the local image information. Only little work can be found in the literature concerning network snakes [11]. A main focus of this paper lies on network snakes with a special attention on the control of the nodal and end points of the snakes. The results demonstrate the potential of the proposed solution within the complex environment of vegetation. Finally, further work required is discussed in the conclusions.

2 Model and Strategy

In general, the recognition of objects with the help of image analysis methods starts with an integrated modelling of the objects of interest and the surrounding scene [12]. Furthermore, exploiting the context relations between different objects leads to an overall and holistic description, see for example [13]. The use of prior knowledge supporting object extraction can lead to better results as shown in [3]. These aspects are incorporated into the model for the extraction of field boundaries and are reflected in the resulting strategy of the proposed approach.

2.1 Semantic Model

Describing the integration of imagery and GIS-data in one semantic model is our starting point for object extraction, as highlighted in detail in [14]. The semantic model is differentiated into an object layer, a geometric and material part, as well as an image layer (cf. Fig. 1). The model is based on the assumption, that the used images imply an infrared (IR) channel and are generated in summer, when the vegetation is in an advanced period of growth.

The use of prior knowledge plays an important role, which is represented in the semantic model with an additional GIS-layer. Vector data of the ATKIS DLMBasis (German Authoritative Topographic-Cartographic Information System) is used, which is an object based digital landscape model of Germany: (1) Field boundaries are exclusively located in the open landscape, thus, further investigations are focussed to this area. The open landscape is not directly modelled in the ATKIS DLMBasis, this is why this information has to be derived by selecting all areas, which are not settlements, forests or water bodies. (2) Roads, railways, rivers, tree rows and hedges

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[1] Topographic GIS-data include settlements, forests, roads, rivers etc., but not field boundaries.

can be used within the open landscape as prior knowledge: The locations of these GIS-objects are introduced as field boundaries in the semantic model with a direct relation from the GIS-layer to the real world (cf. Fig. 1). For example, the ATKIS-objects 3101 (road) and 3102 (path) are linked to the road of the real world and, thus, can be used as field boundaries (i.e. a road is a field boundary). Of course, the underlying assumption is based on correct GIS-objects. The modelling of all GIS-objects in the geometry and material layer together with the image layer is not of interest, because they do not have to be extracted from the imagery (depicted with dashed lines in Fig. 1). Nevertheless, additionally extracted objects which are not yet included in the GIS-database can be introduced at anytime.

The object to be extracted, the *field*, is divided in the semantic model in *field boundary* and *field area* in order to allow for different modelling in the layers: The field boundary is a 2D elongated vegetation boundary, which is formed as a straight line or edge in the image. The field area is a 2D vegetation region, which is a homogeneous region with a high NDVI (Normalized Difference Vegetation Index) value in the colour infrared (CIR) image.

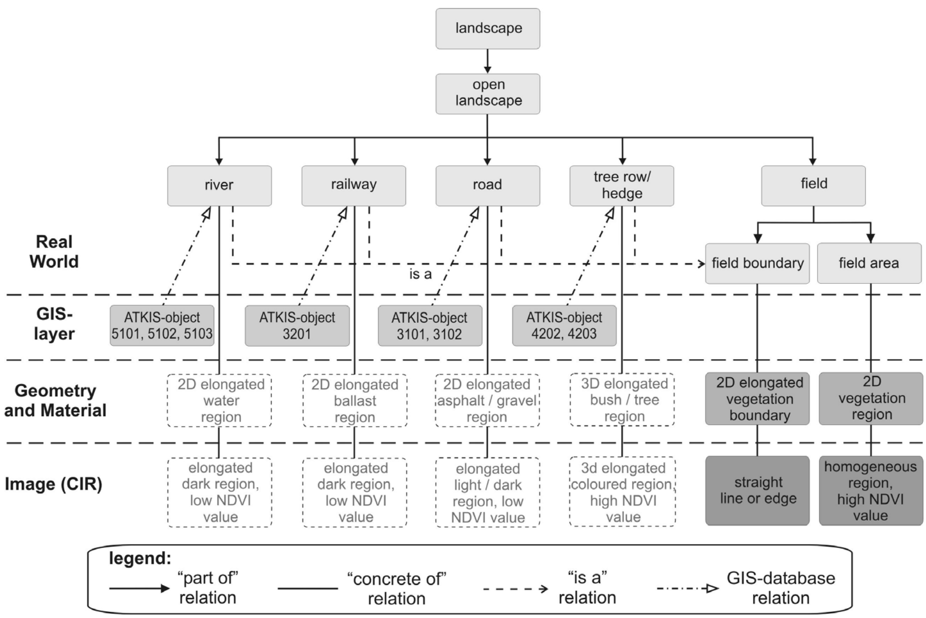


Fig. 1. Semantic Model

2.2 Strategy to Extract Field Boundaries

The general strategy for the extraction of field boundaries is derived from the modelled characteristics of the fields and their surrounding boundaries taking into account the realization of an automatic processing flow. Imagery and GIS-data are the input-data to initialize the process: First, the open landscape is derived from the GIS-data (cf. section 2.1). In addition, within the open landscape, regions of interest are selected using the roads, railways, rivers, tree rows and hedges as borderlines (cf. the thick black lines in Fig. 2 and 4). Consequently, the borderlines of the regions of interest are field boundaries, which are already fixed. The following image analysis methods are focused to field boundaries within the regions of interest.

The main approach extracting field boundaries within the regions of interest is divided into two parts: Firstly, a segmentation is carried out in a coarse scale ignoring small disturbing structures and thus exploiting the relative homogeneity of the vegetation within each field. The aim is to obtain a topological correct result, even if the geometrical correctness is not very high. Secondly, network snakes are used to improve the preliminary results. These two steps are described in detail in the next two sections.

3 Segmentation

In each region of interest a segmentation is carried out to exploit the modelled similar characteristics of each field. The border area is masked out due to disturbing heterogeneities, which are typical for fields and derogate the subsequent steps. As data source the RGB- and IR-channels of the images with a resolution of few meters are used to perform a multi-channel regiongrowing. The four channels give rise to a 4-dimensional feature vector: Neighbouring pixels are aggregated into the same field region, if the difference of their feature vectors does not exceed a predefined threshold. Also, in concert with the modelled constraints, the resulting field regions must have a minimum size.

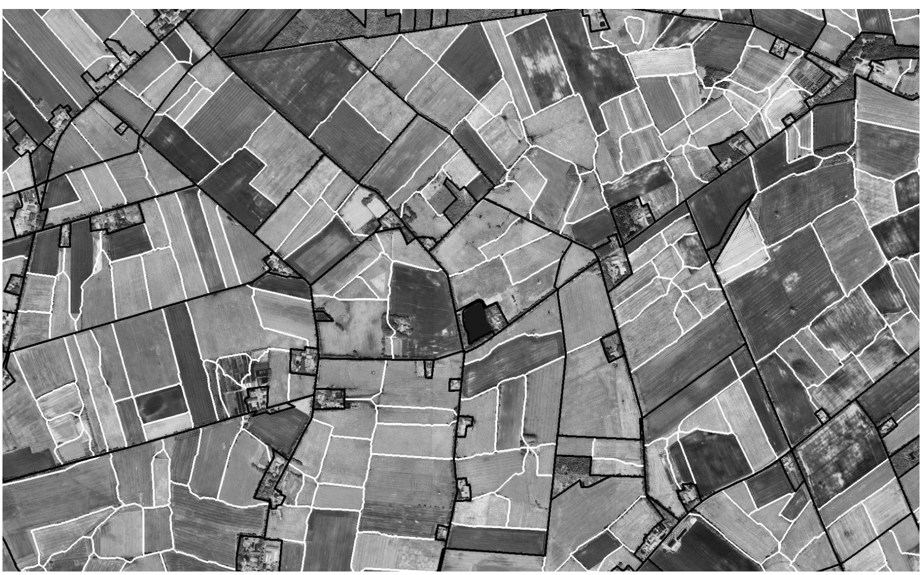


Fig. 2. Exemplarily result of the segmentation: black lines are the borders of the regions of interest generated from the GIS-data, white lines are the preliminary field boundaries

The case of identical vegetation of neighbouring fields leads to missing boundaries, which is not yet taken into account: Accordingly, the standard deviation of the grey values in the image within a quadrate mask is computed. High values typically belong to field boundaries. Extracted lines [15] from the standard deviation image within only sufficiently large field regions are evaluated concerning length and straightness. Positive evaluated lines are used to split the initially generated field regions.

One result is shown in Fig. 2: borders of the regions of interest are depicted in black, preliminary field boundaries are depicted in white, the underlying and used imagery are IKONOS-data. The completeness and topological correctness is good, as a comparison with reference data has shown: only few boundaries are missing. Problems occur, when there are large heterogeneities within a field, in particular in grassland.

4 Network Snakes to Improve the Preliminary Field Boundaries

Snakes were originally introduced in [10] as a mid-level image analysis algorithm, which combines geometric and/or topologic constraints with the extraction of low-level features from images. A traditional snake is defined parametrically as [10, 11]

$$v(s,t) = (x(s,t), y(s,t)) \ , \tag{1}$$

where s is the arc length, t the time, and x and y are the image coordinates of the 2D-curve.
The external energy (image energy) is defined as

$$E_I(v) = -\frac{1}{|v|}\int_0^{|v|} |\nabla I(v(s,t))| ds \ , \tag{2}$$

where I represents the image, $|\nabla I(v(s,t))|$ is the gradient of the image at the coordinates $x(s)$ and $y(s)$ and $|v|$ is the total length of v. In practice, the external energy $E_I(v)$ is computed by integrating the gradient values $|\nabla I(v(s,t))|$ in precomputed gradient images along the line segments that connect the polygon vertices.
The internal energy is defined as

$$E_{v(s,t)} = \tfrac{1}{2}\left(\alpha(s)\cdot|v'(s,t)|^2 + \beta(s)\cdot|v''(s,t)|^2\right), \tag{3}$$

where the arbitrary function $\alpha(s)$ controls the first-order term of the internal energy: the elasticity. Large values of $\alpha(s)$ let the contour becomes very straight between two points. The function $\beta(s)$ controls the second-order term: the rigidity. Large values of $\beta(s)$ let the contour becomes smooth, small values allow the generation of corners.

The total energy of the snake, to be minimized, is defined as $E_{snake} = E_{v(s,t)} + E_I(v)$. A minimum of the total energy can be derived by embedding the curve in a virtual viscous medium solving the equation

$$\frac{\partial E_{v(s,t)}}{\partial v(s,t)} + \kappa\frac{\partial E_I(v)}{\partial v(s,t)} + \gamma\frac{dv(s,t)}{dt} = 0 \ , \tag{4}$$

where γ is the viscosity of the medium and κ is the weight between internal and external energy. After insertion of

$$\frac{\partial E_{v(s,t)}}{\partial v(s,t)} = A_{\alpha(s),\beta(s)} v(s,t) \quad \text{and} \quad \frac{dv(s,t)}{dt} = \left(v(s,t) - v(s,t-1)\right) \tag{5}$$

in equation 4 a final solution for the contour at point t depending on point t-1can be computed:

$$V_{s,t} = (A + \gamma I)^{-1} \gamma V_{s,t-1} - \kappa \frac{\partial E_I(v)}{\partial v(s,t-1)} \text{ , } (I\text{: identity matrix}) \tag{6}$$

$V_{s,t}$ stands for either X or Y, the vectors of the x and y coordinates of the contour. A is a pentadiagonal matrix, which depends only on the functions $\alpha(s)$ and $\beta(s)$.

A main problem of snakes is the necessity to have an initialization close to the true boundary. Methods to increase the capture range of the image forces (e.g. pressure forces [16]) are not useful in our case, because there are lots of disturbing structures within the fields, which can cause an unwanted external energy and therefore a wrong result. Thus, only the local image information is of interest. As described in section 2, the result of the segmentation is used to initialize the processing (cf. Fig. 2 and 4a).

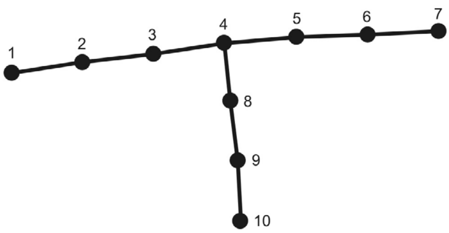
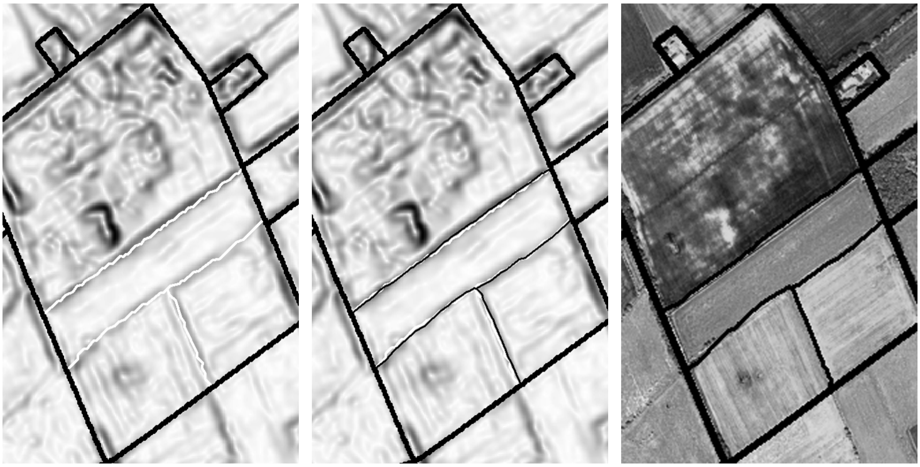


Fig. 3. Topology of a network snake

Most important is in addition to the good initialization the derivation of the *topology* of the initial contours (cf. Fig. 3 for an example). The global framework of the accomplished segmentation (cf. section 3) gives rise to a network of the preliminary field boundaries: Enhancing traditional snakes, network snakes are accessorily linked to each other in the *nodal points* (point 4 in Fig. 3) and thus interact during the processing. Similarly, the connection of the *end points* of the contours to the borders of the region of interest must be taken into account (point 1, 7 and 10 in Fig 3): In contrast to the nodal points, a movement of the end points is only allowed along the borders of the regions of interest. These topological constraints are considered, when filling the matrix A in equation 6 with the functions $\alpha(s)$ and $\beta(s)$, which are in our case taken to be constant.

5 Results

First results concerning the use of network snakes to extract field boundaries from IKONOS-images are shown in Fig. 4: Zooming to the lower right part of Fig. 2, one region of interest is selected to demonstrate the different steps during the processing. Fig. 4a shows the preliminary field boundaries after the segmentation, which are used to initialize the network snakes. The result of the network snake processing is depicted in Fig. 4b together with the initialization to demonstrate the movement of the snake. Fig. 4c shows the image superimposed with the result of the extracted field boundaries. The example demonstrates, that network snakes are a useful possibility to improve the geometrical correctness of topologically correct but geometrically inaccurate results.



a) b) c)

Fig. 4. First result of the use of network snakes within one region of interest: a) initialization of the network snake superimposed to the absolute values of the gradients; b) initialization (white) and result after the movement of the snake (black); c) extracted field boundaries superimposed to the image.

6 Conclusions

A method to extract field boundaries fully automatically from imagery is presented in this paper. The objects of interest are represented with their surrounding scene and prior knowledge in the form of GIS-data in a semantic model. Derived from the modelled knowledge the initial step of our approach is the generation of regions of interest, thus, further investigations are only focussed to the field boundaries within these regions. The process is divided into two parts: First, a segmentation in a coarse scale gives a topological correct framework of the field boundaries. The inaccurate geometrical correctness is improved in a second step with network snakes, which use the local image information for a precise delineation taking into account the topological constraints. The presented results demonstrate the potential of the proposed solution in the complex environment of vegetation. Further work is required: The segmentation could be enhanced by a multi-resolution approach to stabilize the basic step of the strategy. In addition, a texture channel could be used to prevent wrong field boundaries, which occur, when there are large heterogeneities within a field and the predefined thresholds fail. The control of the network snakes could be improved by selecting variable values when filling the matrix A to increase the geometrical correctness furthermore.

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