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Using snakes for the registration of topographic road database objects to ALS features

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ABSTRACT

For historical reasons many national mapping agencies store their topographic data in a dual system consisting of a Digital Landscape Model (DLM) and a Digital Terrain Model (DTM). The DLM contains 2D vector data representing objects on the Earth's surface, such as roads and rivers, whereas the DTM is a 2.5D representation of the related height information, often acquired by Airborne Laser Scanning (ALS). Today, many applications require reliable 3D topographic data. Therefore, it is advantageous to convert the dual system into a 3D DLM. However, as a result of different methods of acquisition, processing, and modelling, the registration of the two data sets often presents difficulties. Thus, a straightforward integration of the DTM and DLM might lead to inaccurate and semantically incorrect 3D objects.

In this paper we propose a new method for the fusion of the two data sets that exploits parametric active contours (also called snakes), focusing on road networks. For that purpose, the roads from a DLM initialise the snakes, defining their topology and their internal energy, whereas ALS features exert external forces to the snake via the image energy. After the optimisation process the shape and position of the snakes should coincide with the ALS features. With respect to the robustness of the method several known modifications of snakes are combined in a consistent framework for DLM road network adaptation. One important modification redefines the standard internal energy and thus the geometrical model of the snake in order to prevent changes in shape or position not caused by significant features in the image energy. For this purpose, the initial shape is utilized creating template-like snakes with the ability of local adaptation. This is one crucial point towards the applicability of the entire method considering the strongly varying significance of the ALS features. Other concepts related to snakes are integrated which enable our method to model network and ribbon-like characteristics simultaneously. Additionally, besides ALS road features information about context objects, such as bridges and buildings, is introduced as part of the image energy to support the optimisation process. Meaningful examples are presented that emphasize and evaluate the applicability of the proposed method.

1. Introduction

1.1. Motivation

In many countries, e.g. in Germany, digital topographic data bases are available in a dual system consisting of a Digital Landscape Model (DLM) and a Digital Terrain Model (DTM). The DLM describes the objects on the terrain using 2D vector data and additional attributes, whereas the DTM is a continuous 2.5D representation of the Earth's surface modelled by terrain points in a regular grid or in a Triangulated Irregular Network (TIN). Today, 3D modelling, processing and visualisation of the topographic objects are necessary for many applications in administration, research, and industry. For this purpose, an integration of the 2D vector data and the DTM is required. However, there are discrepancies between the DLM and the DTM due to different methods of acquisition, processing, and modelling, which may result for instance in bodies of standing waters having impossible height variations or streets with invalid gradients. As a consequence, integration of the data sets without properly fusing their geometry leads to semantically incorrect results.

The DTM used in this paper is generated from Airborne Laserscanning (ALS). ALS delivers a Digital Surface Model (DSM), from which the DTM is generated by filtering. The DSM also contains information about objects on the terrain. Vector data adapted to the ALS data should also match the DTM. We are mainly interested in roads. Roads typically have an accuracy of 3–5 m in topographic data bases of National Mapping Agencies (NMA), with local deviations that may reach 10 m. In this paper we present a new

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algorithm for improving 2D road vector data using ALS data. This algorithm is based on snakes and integrates several concepts concerning the internal energy, expanding it by terms that preserve the original shape of the vector data and by a new combination of the concepts of ribbon (Fua, 1996) and network snakes (Butenuth and Heipke, 2011). The new definition of the internal energy increases the robustness of the algorithm against changes of the parameter setup and enables the integration of information of road cross sections in the image energy, thus improving the geometrical accuracy that can be achieved for the road centre lines.

This paper is organised as follows: After a discussion of related work in Section 1.2, a brief overview of the basic snake model is given in Section 2. Our method is described in Section 3 with a focus on our definition of the energy terms. In Section 4, the capability of the method to improve the geometrical accuracy of road centre lines is evaluated using two test areas in Germany and Switzerland. The paper ends with a summary and a conclusion in Section 5.

1.2. Related work

The integration of a DTM with 2D GIS data has been analysed for several years. Initially, methods such as height attributing of object points or adding interactive DTM interfaces to GIS software were used (Fritsch and Pfannenstein, 1992; Weibel, 1993). They do not achieve a real merging process of the two data sets. Later, some authors incorporated the 2D geometry of the vector objects into a TIN structure of the DTM (Pilouk, 1996; Klötzer, 1997; Lenk and Heipke, 2006). As these algorithms do not consider the inconsistencies between the vector data and the DTM, they do not achieve a semantic correctness of the merged data set. Rousseaux and Bonin (2003) model 2D linear objects such as roads and dikes as 2.5D surfaces by using attributes of the GIS data base and the DTM heights. Slopes and regularization constraints are used to check the semantic correctness of the objects, and a new DTM is computed using the original DTM heights and the 2.5D objects of the GIS data. However, if the check fails, correctness will not be established. Koch and Heipke (2006) extend the integration methods based on TIN by a least squares adjustment using equality and inequality constraints in order to incorporate the semantics of the objects. However, this approach is sensitive to the definition of the weights, in particular if position and height observations are adjusted simultaneously. Furthermore, the implicit information about the vector objects contained in a DTM such as abrupt slope changes at road embankments is not considered. In this paper these deficits are tackled by using the DTM features as image energy for active contours to correct the position of the objects considering their appearance in the height data.

First introduced by Kass et al. (1988), active contour models combine feature extraction and geometric object representation in image analysis in a sophisticated way. Two realisations of this model are distinguished in the literature. Whereas the *parametric active contour* (Kass et al., 1988; Blake and Isard, 1998), also called *snake*, is an explicit representation of the contour in its parametric form, the *geometric active contour* (e.g. Malladi et al., 1995) describes a curve as a zero level contour of a level set function. The main advantage of the level set approach arises from its flexible topology. For our task the given topology of the road network has to be preserved and should even be exploited to stabilize the process. This goal can be achieved by network snakes (Butenuth and Heipke, 2011). In high-resolution data, road edges are much better defined than the centre lines. This problem can be overcome by ribbon snakes, developed by Fua (1996) in order to determine centre lines of objects that could more precisely be located by their edges. This concept was used by Laptev et al. (2000) to locate the centre lines of roads in high resolution aerial images, using the gradients at two positions corresponding to the road edges for the definition of the image energy. Other applications of snakes relevant for our application are map generalisation (Burghardt and Meier, 1997) and break line detection for surface modelling (Borkowski, 2004).

Papers on road extraction from ALS data are relatively rare, because there are not many features in height data that indicate roads. Structure lines in the vicinity of roads are often not characteristic enough and do not have a continuous behaviour. Twin snakes (Kerschner, 2001) are used by Rieger et al. (1999) to model roads as parallel edges. This integration of model based knowledge stabilizes the extraction and is able to bridge gaps in the structure lines at one road edge. Road extraction can also be improved by fusing ALS and image data, e.g. (Zhu et al., 2004), as well as ALS and GIS data (Oude Elberink and Vosselman, 2006). In the latter work, no attempt is made to correct the positions of the 2D road vectors given the ALS data, though the assignment of a height can cope with a small misregistration of the two data sets. Alharthy and Bethel (2003) as well as Clode et al. (2007) extract roads from ALS data, exploiting the fact that ALS points on asphalt roads usually have small intensity values and are usually situated on the terrain. ALS data have also been used to detect bridges (Clode et al., 2005; Sithole and Vosselman, 2006).

In our own prior work (Göpfert and Rottensteiner, 2010) we used network snakes for adapting 2D road vector data to ALS data. One drawback of this approach results from the strongly varying reliability of ALS features for locating roads which causes difficulties in the determination of a global parameter set for the weights of the different energy terms. Larger shifts between the ALS data and the road objects in the DLM or the presence of noise demand a strong weight for the smoothness term of the internal energy, which however may result in oversmoothing in areas with weak ALS features. Another drawback of our previous method arises from the fact that the image energy of our network snake is calculated only at the centre line of the road, where the ALS features are not well-suited for determining its precise position.

The first problem is tackled by an alternative formulation of the internal energy, including a term that penalizes changes of the initial shape and thus creates a template-like snake with the ability to adapt locally to the image energy in a way similar to Radeva et al. (1995). This should both facilitate a suitable parameter setup and increase the robustness of the method. In order to solve the second problem, we propose a combination of network snakes (Butenuth and Heipke, 2011) with the ribbon snake model (Fua, 1996) that preserves the topology of the road network while including information about the cross-section of the road. The cross-section information supports the detection of the accurate positions of the road centre lines, but it also increases the range of influence of the ALS features. This should result in a considerable improvement of the accuracy of the geometrical positions of the adapted road centre lines.

2. Snakes: basic principles

It is the general idea of snakes to determine the position of a parametric contour $\mathbf{v}(s) = [x(s), y(s)]$ (the snake) in an image in an iterative energy optimisation process. The contour is parameterised by its arc length s. An initialisation of the contour is required. Three energy terms are introduced by Kass et al. (1988). The *internal energy* E_{int} defines the elasticity and rigidity of the curve. The *image energy* E_{image} should attract the snake to the desired position. The *constraint energy* E_{con} can be used to force the contour to fulfil predefined external constraints. The position and the shape of the contour are determined by minimising the total energy E^{*}_{snake} along the contour: