Surface Water Body Detection in High-Resolution TerraSAR-X Data using Active Contour Models

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Abstract

This paper presents the application of two different active contour models for the segmentation of high-resolution TerraSAR-X data. Both methods facilitate the detection of land-water-boundaries in semi-automated procedures and can be used to delineate flood extent and to map open water surfaces in general. For the extraction of smooth water bodies amplitude thresholding approaches are quite common and often applied. For rough water bodies however the application of amplitude thresholding methods is not successful. This paper demonstrates the potentials and limitations of active contour models for mapping both smooth and rough water bodies in high-resolution SAR data. Examples of both different segmentation methods are presented.

1 Introduction

SAR satellites have the ability to penetrate cloud cover and to produce images of the Earth's surface without requiring daylight. Thus, SAR allows mapping of land cover features independent of weather and illumination situations. Especially SAR satellite data with very high spatial resolution (up to one metre) as from the German TerraSAR-X sensor is increasingly used to map flood situations, e.g. [1]. In the scope of the TanDEM-X project [2] it is envisaged to produce a global map of surface water bodies using X-Band SAR amplitude (with 12 metres ground resolution) and coherence data [3].

Mapping smooth water bodies by amplitude thresholding methods is a relatively straightforward task (e.g. [1] [4]). Smooth water bodies act as specular reflectors and thus reflect most of the transmitted energy away from the sensor. This results in very low backscatter values for these water bodies. Especially coastlines are however often influenced by wind induced waves that cause increased backscatter values. In such situations amplitude thresholding methods are not sufficient to completely map the water surface. Further effects that complicate reliable water detection in SAR data are e.g. terrain and vegetation influences [5]. Active contour models (snakes) have been applied for water and flood boundary detection in SAR images in recent years [6-10]. These studies have shown advantages of this kind of models compared to the thresholding approach. In this paper the application of two different methods of active contour models for SAR image segmentation as well as the results of both models to TerraSAR-X imagery with smooth and rough water surfaces is presented.

2 Methodology

Active contours (snakes) are curves that evolve to recover object shapes in 2D digital images. They can be characterized as energy-minimizing splines with smoothness constraints that are influenced by image forces. The two main categories of active contour models are the Parametric Active Contours and the Geometric Active Contours.

Parametric Active Contours are parametric curves with explicit representation. They have been first proposed by Kass et al. [11]. Internal image forces control both rigidity and smoothness of the curve. External forces attract the curve to object boundaries. A disadvantage of Parametric Active Contour models is that they cannot change topology (e.g. splitting or merging of the curve), which complicates the simultaneous detection of multiple objects in an image. Model parameters can be interactively adapted by the user during curve evolution. The segmentation result obtained depends on the contour initialisation. Parametric Active Contours are quite computationally efficient.

In Geometric Active Contours the curve exhibits an implicit representation in a level set function. This level set evolution method was initially proposed by Malladi et al. [12]. The advantage of this approach is that multiple objects in an image can be found simultaneously, i.e. topological changes are possible. Drawbacks are computational inefficiency, complexity of implementation and image noise sensitivity [16]. Interactive parameter adjustment during model evolution is not feasible.

The two above introduced active contour model techniques are investigated in this study. On the one hand a Parametric Active Contour model proposed by Hamarneh et al. [13-14], on the other hand a Geometric Active Contour model (level set) implemented by Wasilewski [15]. The softwares provided by the authors are exemplarily applied for the segmentation of extracts of two high-resolution TerraSAR-X scenes.

3 Experimental Results

Two test sites in Southern Germany were selected for the application of the segmentation methods.

The TerraSAR-X SpotLight scene showing Lake Forggensee (figure 1) with smooth water surface was acquired on 17 July 2008. A TerraSAR-X StripMap scene of Lake Ammersee (figure 2) with strong wind and wave influence was captured on 30 November 2007. This dataset exhibits a very rough water surface. Both datasets were acquired with horizontal polarisation (HH).
Figures 3 to 6 show the segmentation results that were obtained for both scenes applying the procedures by Hamarneh and Wasilewski respectively.

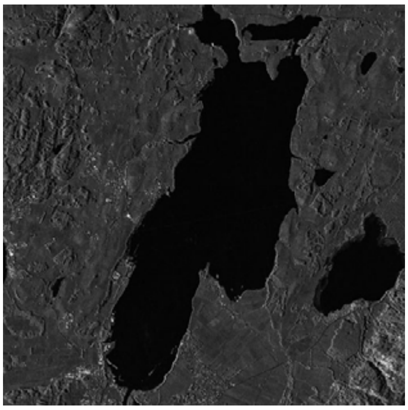

Figure 1 Lake Forggensee (Germany), TerraSAR-X (TSX) SpotLight data; © DLR (2008)

Figure 2 Lake Ammersee (Germany), TerraSAR-X StripMap data; © DLR (2007)

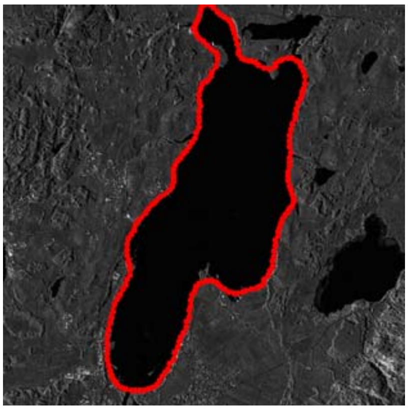

Figure 3 Segmentation result for the TSX scene of Lake Forggensee applying the method by Hamarneh

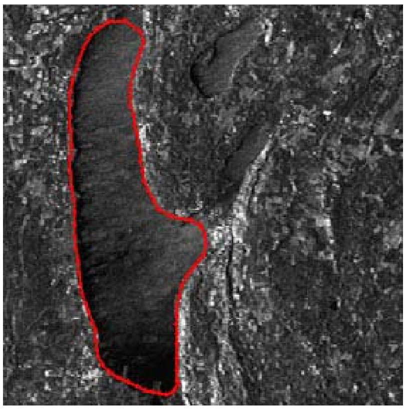

Figure 4 Segmentation result for the TSX scene of Lake Ammersee applying the method by Hamarneh

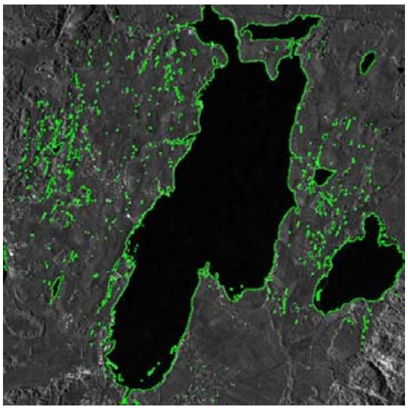

Figure 5 Segmentation result for the TSX scene of Lake Forggensee applying the method by Wasilewski

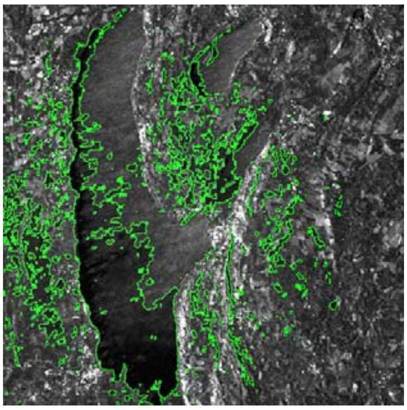

Figure 6 Segmentation result for the TSX scene of Lake Ammersee applying the method by Wasilewski

4 Discussion

Both tested methods are semi-automatic procedures. User input is needed for the initialisation and parameter adjustment of the active contour models. The algorithm implementation of Hamarneh (Parametric Active Contour model) requires the digitization of a few start points that are situated inside of the object to be detected, i.e. a water body in our study (figure 7). While the snake model is evolving, so called forced points can be determined by the interpreter to improve the result. The forced points are placed at or near the land-water-boundary. For the level set approach by Wasilewski the manual digitization of a small polygon within a water body is necessary for the initialisation of the model (figure 7)

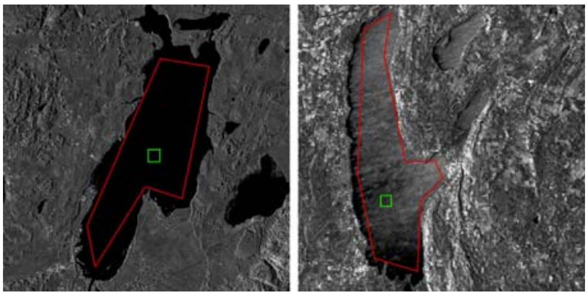

Figure 7 Seed vector initialisation for the Active contour models (left: Forggensee, right: Ammersee; red: Hamarneh method, green: Wasilewski method)

A visual inspection of the results of the investigated algorithms shows that for smooth water surfaces both methods generate satisfying results (Lake Forggensee, figures 3, 5). The level set approach creates a multiplicity of small water objects. A filtering step could be appended as a post-processing step to improve the result. Furthermore a minimum mapping unit for water bodies to be detected could be introduced to omit very small water polygons. This would result in a very good water mask.
The Geometric Active Contour algorithm further detects specular reflectors that have a smooth surface similar to smooth water bodies such as streets or airstrips. These objects have to be deleted manually from the result or filtered out using additional data sources like GIS vector data.

The disadvantage of the Parametric Active Contour model (by Hamarneh) is that no change of topology is feasible, therefore only that particular water body is detected, which was initialised by the manually digitized seed vector (figures 3, 4). If seed vectors would be available for all the water bodies these could be processed by the algorithm consecutively.
Water bodies with a rough surface (Lake Ammersee, figure 4) can be detected with the Parametric Active Contour model provided that some forced points are added. The parameter adjustments (e.g. tension, flexion, external forces, distances, and smoothing, inflation and damping factors) are important to generate a satisfying segmentation. For both image examples (figures 3, 4) different optimal parameter settings had to be found empirically.

The level set approach (by Wasilewski) creates only an incomplete and thus dissatisfactory water body mask when the water surface is roughened by wind and wave influence (Lake Ammersee, figure 6). Some land surfaces that feature similar image intensity and texture values like the seed area at the water surface are misclassified as water bodies by the algorithm.

Both methods were tested with relatively small image samples (500 x 500 pixels). Computing time performance is a critical issue when working with active contour models. The level set method is significantly slower than the Parametric Active Contour model. However, for the application of both algorithms to large images computational improvements in processing time are essential. Both approaches cannot be usefully applied for near-real-time image processing of large SAR satellite imagery (e.g. for flood mapping in natural disaster situations) at the moment.
When processing time is not a critical factor the Parametric Active Contour approach (by Hamarneh) can be applied to delineate the water to land boundary in SAR image data that feature rough water surfaces with sufficient accuracy.

For the Lake Forggensee scene (figure 1) some ground truth data from DGPS field measurements were available. A visual comparison of the reference data to the obtained water-land-segmentation results showed a very good agreement for the Geometric Active Contour model (by Wasilewski) and also a good correlation with the Parametric Active Contour model (by Hamarneh) was observed. The fit of the latter shows some inaccuracies, which may be caused by the difficult parameter adjustment.
For the Lake Ammersee scene no ground validation data is available. A visual inspection of the results shows however that at the western shoreline of the lake, which features a higher contrast of land and water surface pixels, the segmentation is better than at the eastern shoreline.

5 Conclusion and Outlook

Two different active contour models were applied to delineate land-water-boundaries in high-resolution TerraSAR-X data. The Parametric Active Contour model by Hamarneh [13] works well for smooth and rough water bodies. A main drawback of this approach is that no change in topology is possible. Furthermore a careful parameter adjustment is necessary. Both methods are semi-automatic. That means that

user input for the initialisation of the models is needed.
The Geometric Active Contour model by Wasilewski [15] shows good results for smooth water bodies with low backscatter values. Post-processing algorithms to remove small water bodies can be used to improve the result. Rough water surfaces however can not be extracted with satisfying results with this method. When using Geometric Active Contour models no interactive parameter adjustment is necessary.

It has been shown that the delineation of rough water bodies, which are induced by wind and wave influence, can be improved by using Parametric Active Contour models. This might especially help within the TanDEM-X [2] water mask (WAM) detection procedure [3]. For the production of the TanDEM-X WAM it is envisaged to use existing water masks for the improvement of the results obtained with active contour model methods. These water masks can be used as input for the active contour models.
Several water masks are available, e.g. from SRTM (Shuttle Radar Topography Mission), the GSHHS (Global Self-consistent, Hierarchical, High-resolution Shoreline Database) or the OpenStreetMap project. These masks differ however considerably in their quality, timeliness, completeness and geographical availability. Further research is necessary on how these auxiliary datasets can be included in the active contour models. This issue will be investigated in the near future.

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