

# Using snakes with asymmetric energy terms for the detection of varying-contrast edges in SAR images

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## Abstract

*Active contour methods like snakes, have become a basic tool in computer vision and image analysis over the last years. They have proven to be adequate for the task of finding boundary features like broken edges in an image. However, when applying the basic snake technique to synthetic aperture radar (SAR) remote sensing images, the detection of varying-contrast edges may not be satisfying. This is caused by the special imaging technique of SAR and the commonly known speckle-noise. In this paper we propose the use of asymmetric external energy terms to cope with this problem. We show first results of the method for the detection of edges of tidal creeks using an ENVISAT ASAR image. These creeks can be found in the World Heritage Site "Wadden Sea" located at the German Bight (North Sea).*

## 1. Introduction

Active contours are curves that move dynamically within a given (image) domain depending on defined energy terms. The contour itself may move as long as the energy terms pull it in some directions. The energies are usually defined such that the snake will fit to image edges or other features of interest inside the image (see [4]).

Snakes are often used to bridge gaps in the image gradient information. This is achieved by an energy term, that favors smooth, connected curves and penalizes to much bending. Since we want to apply the snakes on synthetic aperture radar (SAR) images, we will give a brief overview of this radar based sensor technique that has become very popular in the research field of ocean and coastal remote sensing over the last years (cf. [1] [3]). The snake technique can also be used for other remote sensing tasks, e.g. to support automatic registration of remote sensing images (see [6]).

The SAR technique is an active microwave technique that is capable to measure high resolution radar backscattering. In this paper, we will only refer to space-borne SAR. It uses a synthetic aperture, which means that the satellite carries a small radar antenna but simulates a large one using its own movement and the Doppler effect. More information about the SAR technique can be found in [8].

Although these sensors do not measure photometrically, they are capable of imaging features that result in different radar backscatter. These differences are often induced by different surface materials or surface roughness parameters. The wavelength of the emitted microwaves (e.g. 58 mm for C-band) is large enough to pass through clouds without interference.

In the SAR image we used, the edge of the tidal creek is formed by a homogeneous water surface on one hand and a heterogeneous silt surface on the other hand. Thus, we cannot use commonly known edge detectors like the canny edge detector or texture based methods (cf. [7]). Moreover, the structure of this edge does not allow the use of classical SAR shoreline detection algorithms because of the strong variation of the contrast along the edges (see [5] [7] [9]).

From a model-based approach, snakes seem to be a good choice for modeling the boundaries of such edges. However, the classic energy definitions that have been used widely [4] for the detection of edges did not seem to be adequate for the detection of varying contrast edges in SAR images in empirical tests. Hence, we propose the introduction of a new asymmetric external energy definition for the snakes.

## 2. The snake model

Traditionally, a snake is modeled as a parametric curve  $\vec{s}(p) = [x(p), y(p)]$  with  $p \in [0, 1]$ . The curve moves through the image domain while minimizing the following functional:

$$E(s) = \int_0^1 E_i(p) + E_c(p) dp \quad (1)$$

Where  $E_i$  is the internal energy of the snake itself and  $E_c$  denotes the external energy that is caused solely by the image. The minimization of both parts along the curve causes the snake to move with respect to certain shape- and image constraints.

Besides this brief introduction, further basics of modeling snakes can be found in [4]. For the implementation, we used a B-Spline approximation of the parametric snake in Eq. 1. This approximation has some major advantages over other possible approximations (see [2]). We will now discuss the energy terms used for both the internal and the external energy in more detail.

## 2.1. Internal energy

The internal energy term represents the intrinsic energy of the snake. Hence, it does not depend on any image information. In our approach, we divide the internal energy  $E_i$  into two internal energy parts:

$$E_i = a_s E_s + a_c E_c \quad (2)$$

The strength of the different energy terms is controlled by the two coefficients  $a_s$ , the spacing coefficient, and  $a_c$ , the linearity coefficient, which controls the strength of the curvature dependent term. The internal spacing energy  $E_s$  is given by:

$$E_s = \sum_{i=0}^{n-2} \left( \frac{|\vec{d}_i|}{l} - 1 \right)^2 \quad (3)$$

where the vectors  $\vec{d}_i$  denote the differences between two neighbored control points  $\vec{c}_{i+1}$  and  $\vec{c}_i$ . There are  $n$  control points, which yield  $n - 1$  difference vectors;  $l$  gives the goal length for the segments. This segment length is a parameter of the snake as well and may be set programmatically. By default it is set to the average segment length and is calculated once when the snake is initialized.

$$l = \frac{\sum_{i=0}^{n-2} |\vec{d}_i|}{n - 1} \quad (4)$$

Obviously,  $E_s$  will be zero if and only if all the segments have a length of  $l$ . It will approach  $n - 1$  if the snake shrinks to a point and will grow with the square of the length of the snake as it is stretched further and further.

The curvature dependent term  $E_c$  is given by:

$$E_c = \sum_{i=0}^{n-3} \left( 1 - \frac{\vec{d}_i \cdot \vec{d}_{i+1}}{|\vec{d}_i| |\vec{d}_{i+1}|} \right) \quad (5)$$

This energy will be in the range  $[0, 2(n-2)]$ . A value of zero signals a straight line and the more the snake is bent the higher this energy becomes.

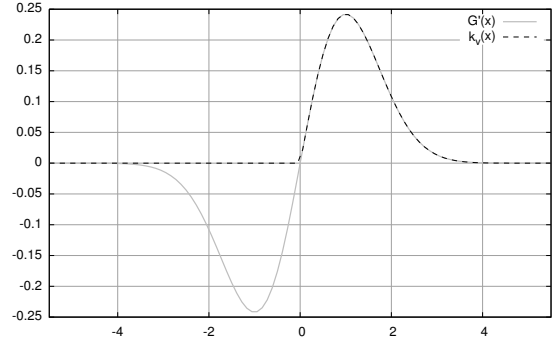
## 2.2. External energy

For the detection of varying-contrast boundaries in a SAR image, we propose the use of two different image dependent energy terms. The first one detects edges; the other one punishes differences in the image intensity on the waterside of the snake. The edge detector is the complement of the two dimensional Gaussian bell function differentiated in the  $y$ -direction (see Fig. 1).

$$E_g = \sum_{i=0}^{n-1} \nabla I_s(\vec{s}(p_i))^2 \quad (6)$$

where  $\nabla I_s(\vec{s}(p_i))$  denotes the image gradient perpendicular to the snake direction at position  $\vec{s}(p_i)$ .

This edge detector is applied to the image at all points of the snake and rotated to match the snake's direction. All filter responses are squared and summed up to obtain the edge related energy term  $E_g$ . This allows the snake to find dark/bright as well as bright/dark edges.



**Figure 1. External energy terms**

Kernel functions for the computation of the external energy (plotted using  $\mu = 0$ ,  $\sigma = 1$ ).

However, the squared gradient magnitude alone is not sufficient to determine boundaries of varying contrast in SAR images. The variation of the contrast along these edges is very heterogeneous. Therefore, we propose the use of a second energy term:

$$E_v = \frac{1}{n-1} \sum_{i=0}^{n-1} \left( \nabla I_v(\vec{s}(p_i)) - \overline{\nabla I_v(\vec{s}(p_i))} \right)^2 \quad (7)$$

where  $\nabla I_v(\vec{s}(p_i))$  is defined as the image convolved with the kernel  $k_v$  perpendicular to the snake direction at position  $\vec{s}(p_i)$ . The kernel  $k_v$  is the same where the image gradient is positive and it is set to zero otherwise (see Fig. 1). Thus its response is proportional to the image intensity of a small region on one side of the snake. Note that, instead of summing up the responses, we use their variance to determine the second energy term  $E_v$ .

The rationale behind this is that water appears quite smooth in a SAR image since the wind and hence the waves do not change on a small scale. It follows that a strong variance of the intensities on the waterside is a sure sign that the snake does not follow an edge of a tidal creek.

To weight the two image-related energies a third parameter needs to be introduced:  $\alpha$  sets the relative weight of the variance term in the image energy.

$$E_I = \alpha E_v + (1 - \alpha) E_g \quad (8)$$

If alpha is set to zero, only the edge detecting energy will be used. Contrary, a value of one leads to a use of only the variance dependent term. In the later case it will not be likely to find an edge at all, but simply seek a featureless location.

### 2.3. Optimization strategy

In the current implementation, the optimization algorithm of the Snake is based on a multi-resolution coarse to fine gradient back-step algorithm. The gradient is computed by a variation of the control points' coordinates and a recording of the change of the energy.

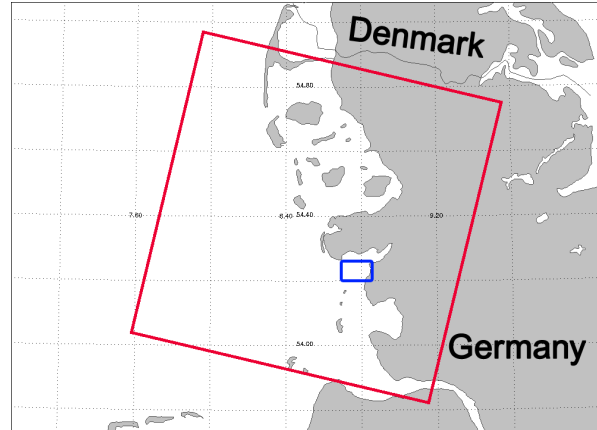
Although this may be much slower than using a dedicated gradient calculation method, it is the most general approach possible and allows for easy adaption of other energy terms in our experimental implementation.

The gradient back-step is not pure, a post-processing step is added to prevent jumping. We add this step because the image energy tends to contain rather sharp valleys or peaks where the relevant features lie, while most portions are rather flat. Thus using the pure gradient back-step algorithm will either lead to extremely slow crawling if the snake is not very close to the optimal location or to a snake that jumps back and forth between the two sides of the edge. In some cases both behaviors are generated by the same parameters.

## 3. Results

We will now present some results obtained using snakes with an asymmetric energy term on a SAR image. The image was captured by the ASAR sensor

aboard the ENVISAT satellite in October 2007 with a resolution of 12.5 meters per pixel covering an area of approx.  $105 \times 105 \text{ km}^2$  (see Fig. 2). The imaged area, the World Heritage Site "Wadden Sea", is a tidal flat area located at the German Bight (North Sea).



**Figure 2. Location of image data**

The large red region denotes the complete SAR image taken by the ENVISAT ASAR at 2007/10/18 09:55:38 UTC. The smaller blue region is the ROI, where we applied the algorithm.

The image was taken during low-tide, showing some dry fallen areas in front of the coastline. These areas appear heterogenous compared to the surrounding water surface (see Fig. 3).

To run the algorithm, we manually set the initial control points of the snake first. After this initialization, we started the algorithm with two different settings:

The first setting is

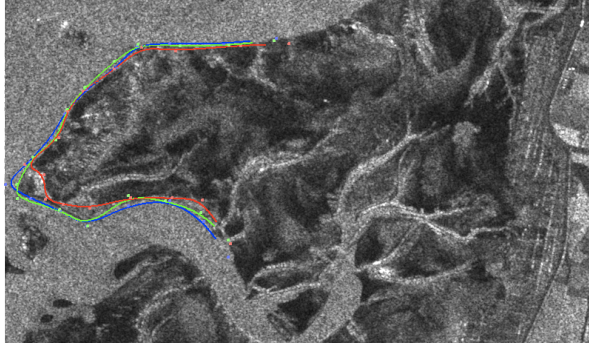
$$E = E_g + 500E_s + 500E_c,$$

which results in a snake optimization that is purely affected by the image's gradient magnitude and the internal snake energy. This case corresponds to the classical definition of a snake and is shown in Fig. 3 (red graph).

For the second run, we use a setting of  $\alpha = 0.9$ , which leads to a combination of both external energy terms:

$$E = 0.9E_v + 0.1E_g + 500E_s + 500E_c.$$

The result of this setting is shown in Fig. 3 in green color. We see a better approximation to the real tidal creek border using this setting. Note that it is hard to determine the real position of an edge of a tidal creek, although we assume that the dark areas in Fig. 3 all belong to dry-fallen areas and thus must not be crossed by edge detecting snakes.



**Figure 3. Results of boundary detection**

The different colors correspond to snakes with different settings. Initial snake (blue), resulting snake with  $\alpha = 0$  after 100 steps (red), and resulting snake with  $\alpha = 0.9$  after 100 steps (green).

Data provided by the European Space Agency and by the German Aerospace Center.

## 4. Conclusions

We have presented a novel approach for the modeling of B-spline approximating snakes. The energies of the snakes were defined for the task of varying contrast edge detection in SAR images. Moreover, we have shown that the proposed asymmetric external energy function yields promising results compared to the commonly known gradient magnitude alone in the domain of SAR imagery.

We have selected the detection of tidal creek borders for this example. However, the algorithm is not limited to the detection of these special boundaries. Snakes that are modeled according our proposal can be used to generally detect edges with variable contrast in SAR images.

For the future, we will investigate the detection of other boundary features in SAR images and the automatic initialization of the snakes using higher knowledge (e.g. from nautical charts). Another issue will be the comparison with ground truth about the location of the tidal creeks' edges. The determination of such lines requires a lot of domain and remote sensing knowledge and thus has to be done by domain experts like oceanographers. We further plan to enhance the speed of the snake's optimization step in future.

## 5. Acknowledgements

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