

TOWARDS AUTOMATIC DETECTION OF COASTLINES FROM SATELLITE IMAGERY

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Abstract: An approach towards automatic coastline detection from satellite imagery through edge detection techniques is presented. Linear transformations, such as Gaussian filtering and nonlinear transformations, such as median, adaptive and morphological filtering, were combined towards image smoothing and enhancement. Two edge detectors were applied, a morphological Laplacian operator and the classical Canny threshold detector. The coastline connectivity was recovered with a combination of nonlinear morphological transformations. The results appear promising.

1. INTRODUCTION

Updating maps through digital photogrammetry and remote sensing from any resolution imagery has gained strong confidence among mapmakers and surveying practitioners [1]. The present paper focuses on automatic coastline detection from commonly used satellite imagery. The bands selected and their ground resolution are as following: LANDSAT TM4 (30m), SPOT HRV PAN (10m), IRC-1C PAN (6m) and IKONOS PAN (1m). Coastline detection is crucial when mapping coastal regions. Cartography, geographical evolution studies and automated navigation require accurate coastline information.

Attempts to coastline detection were recently made with the use of synthetic aperture radar (SAR) images [2]. On the one hand SAR images are becoming more and more popular, because of their capacity of imaging even in case of adverse meteorological conditions, but on the other hand their poor quality makes difficult the extraction of information and even more the exact positioning of the detected features.

In this paper automatic coastline detection from optical satellite data is examined. Detecting a coastline is not much different than detecting any other linear feature on an image and can be considered generally as an edge extraction task. The objective here is to investigate the application of edge extraction methods that can result to promising coastline detection.

A successful edge detector for image segmentation depends upon a number of criteria. These include edge continuity, minimal width (sharpness), accurate location and completeness in terms of discriminating all relevant edges [3]. Basic steps involved during edge detection are enhancement, smoothing and edge extraction, still active areas of research [3,4,5,6,7].

In addition the resolution of the original image that contains the information to be extracted has much to do with the specific parameters that are chosen during any step of the processing. A coastline can be described with a thin edge (one or two pixels) in small scale and low resolution imagery such as LANDSAT TM and at the same time can be described with a step edge, containing

a number of pixels, in large scale high resolution satellite imagery such as IKONOS.

2. BACKGROUND

Edges are defined as discontinuities in the image intensity due to changes in scene structure. These discontinuities originate from different scene features and can describe the information that an image of the external world contains. Enhancement and smoothing attempt to make these discontinuities apparent to the detector, so edges can be extracted. Linear transformations, such as a convolution with a kernel ($n \times n$ dimensions) and nonlinear such as median or adaptive filtering, are familiar processes used during enhancement and smoothing. Morphological set transformations used for binary images and shape analysis can extend to graylevel images and have numerous applications in low and middle vision tasks [8, 11]. They have been adopted here, as coastlines are described with a mixed texture with curves and other fractal geometrical shapes and these morphological filters have an advantage compared to other nonlinear transformation [8,9,10,11,14].

The removal of sudden peaks and a further smoothing are performed with the help of a median filter. Median filters and their generalization, rank operators (rank-order operators or order-statistic filters), are a class of nonlinear and translation-invariant discrete operators [10]. These operators are attractive because they are easy to implement and can suppress impulse noise while preserving the edges of the image. In the following a brief summary of rank operators taken from [8] is given simplified for one dimensional signals.

Let $f(x)$ be the input signal defined on space Z^d and a finite window $W \subseteq Z^d$ with $|W| = n$ points, where $|W|$ denotes set cardinality. The k -th rank of a signal $f(x)$ by W is the signal

$$(f \cdot_k W)(x) = k\text{-th rank of } \left\{ f(y) : y \in (W^r)_{+x} \right\}$$

where $1 \leq k \leq n$, and $(W^r)_{+x} = \{x-y : y \in W\}$ denotes

the set W reflected and shifted at location x . The k -th rank operator by W is a signal operator whose output is the k -th rank of the incoming signal by W .

For $k=(n+1)/2$, whenever n is odd, consider the operator acting as the median filter, a function f by W , denoted as $\text{med}_w(f)$. The main morphological operators erosion and dilation can be considered as rank operators for specific k values.

The erosion of a signal $f(x)$ by a window W is a signal operation

$$(f \ominus W)(x) = \bigwedge_{z \in (W^r)_x} f(z),$$

considering the window W shifted to locations x . The signal erosion by a window W can be interpreted as the pointwise infimum of backward-shifted versions of the input signal f by all points in W , or the moving infimum of f inside moving window W . Equally the dilation of a signal $f(x)$ by a window W is a signal operation

$$(f \oplus W)(x) = \bigvee_{z \in (W^r)_x} f(z)$$

and can be viewed as the pointwise supremum of forward shifted versions of the input signal f by all points in W , or as a moving supremum of f inside the moving reflected window W .

By combining the definitions of rank operators with the definitions of the main morphological filters erosion and dilation, can be viewed that the first ($k=1$) rank of any signal by a window W coincides with its dilation by W . Similarly, the n -th rank, where $n=|W|$, is equal to the erosion by W . Eroding a signal f by a window W and then dilating the result by W does not recover the original signal f , but it yields a new signal the opening of f by W .

$$f \circ W = \hat{(f \ominus W) \oplus W}.$$

Similarly the closing of f by W is defined as a dilation followed by an erosion by the same window W

$$f \bullet W = \hat{(f \oplus W) \ominus W}.$$

3. METHODOLOGY

In the approach presented below three basic steps were applied.

1. Image enhancement and smoothing
2. Coastline extraction through edge detection and
3. Connectivity of edges to form coastlines.

For each type of imagery the above basic steps were kept the same and only the parameters of the linear and nonlinear transformations were differentiated.

3.1 Enhancement and smoothing

The goals of image enhancement and smoothing include the improvement of visibility and perceptibility of the various regions into which an image can be partitioned. These goals include tasks such as: cleaning the image from various types of noise; enhancing the contrast among adjacent regions of features; simplifying the image via selective smoothing or eliminating of features at certain scales and retaining only features at certain desirable scales.

A variety of transformations for enhancing and smoothing were implemented and tested by a trial and error investigation, resulting to an effective order of operators shown in Figure 1 and described below.

First, standard histogram manipulation techniques were applied, such as histogram equalization for contrast enhancement. Continuing with a convolution with a linear smoothing operator and to avoid an edge blurring result, a filter with a large kernel size was chosen and with a minimal smoothing effect [4]. The Gaussian smoothing filters provide an optimal compactness both in space and frequency and furthermore an easy manipulation of their standard deviation, controlling their smoothing affect. For each type of imagery the selected parameters both for the size of the kernel (a convolution matrix with dimensions $n \times n$) and the standard deviation value σ of the Gaussian operator are shown in the Table 1 and Table 2. Small standard deviation values were used for low resolution imagery (thin edges) such as LANDSAT TM and higher values for high resolution imagery such as IKONOS, controlling the coastline's smoothing effect in accordance with image resolution. Since two edge detectors, the classical Canny and the morphological Laplacian were going to be applied (see section 3.2), different parameters were necessary for enhancing and smoothing, such as lower standard deviation values for the Canny detector in relation to the Laplacian. Table 1 refers to smoothing parameters for the Canny edge detector and Table 2 for the morphological Laplacian detector.

Adaptive filtering was employed so that to smooth the image, homogenize regions and at the same time to prohibit edge blurring, since high frequency areas in the image were "protected" [7]. In Tables 1 and 2 appear the chosen dimensions of adaptive filters, for each type of imagery.

After the application of the Gaussian and adaptive filtering, a median filter - $\text{med}_w(f)$ rank operator- was applied to remove sudden peaks of the image which could have lead to pseudo-edges while applying the edge detector. The windows W used for median filtering for each type of imagery are shown in Table 1 and Table 2. $W=ones(3 \times 3)$ refers to a 3×3 pixel square window with its values equal to one (1).

Opening and closing –and their combinations i) close-opening: a closing followed by an opening ii) open-closing: an opening followed by a closing- perform a further enhancement and smoothing and were applied last in the employed order of transformations, due to their ability to stabilize in one pass [8]. The chosen windows W for the morphological filtering with opening and close-opening operators are shown in Table 1 and Table 2.

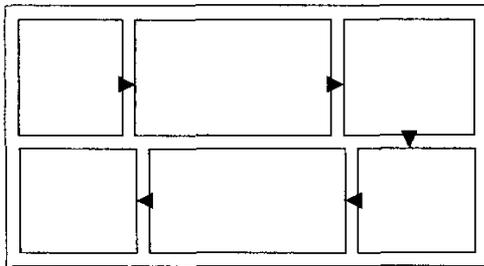


Figure 1. Enhancement and smoothing processing order.

3.2 Edge detection

Abrupt intensity changes that correspond to physical changes in some property of the coastline need to be extracted. After enhancement and smoothing, an edge detector must be applied, so the edges that describe the coastline to be extracted. The edges that form the coastline are described in the output binary image in a raster form. Two edge detectors seemed to perform well, after a trial and error experimentation: the classical Canny detector and a nonlinear Laplacian one.

A vast variety of application of the Canny's method can be found in the literature [5] and this acceptance was gained mainly since the method before applying the edge extraction (Laplacian of Gaussian $-LoG$) first estimates where edges might appear and then it prevents smoothing perpendicular to the edges, to avoid edge blurring.

The second edge detector adopted for coastline detection is the nonlinear edge operator proposed for edge extraction by Vliet, Young and Beckers [12]. The operator is a nonlinear Laplacian and its zero-crossings can yield edge locations. The Laplacian operator, a linear second-order differential operator $\nabla^2 f$ of an image f , can be approached with nonlinear transformations with the application of the morphological dilation and erosion

$$\nabla^2 f = dil(f, W) + ero(f, W) - 2f.$$

Edges were extracted after computing the zero-crossings and a binary image was taken as an output.

3.3 Connectivity of Edges to Form Coastlines

Binary images taken after the edge detection describe edges, which form the coastline. When the coastline texture contains a certain complexity and thus enhancement, smoothing and edge detection fail to perform ideally, edges in the output binary image are not connected and micro pseudo-edges (little number of pixels or even isolated ones) may appear and harm the result. In digital binary images the concept of connectivity can be often ambiguous but in general a region of 1-pixels is called connected if for each two pixels p, q in this region (neighborhood) there exists a path $(p_0, p_1, p_2, \dots, p_n)$ that connects them.

Morphological transformations can restore connectivity to an appreciative degree and thus they are useful tools for this purpose. In the Matlab image processing toolbox by Math Works Inc. [13] some of those transformations are available and the following

scheme and combination has been adopted after evaluating the output of the successive application of these transformations [14].

Firstly a 'clean' transformation and then a 'fill' one, were applied. Five times a 'bridge' transformation was applied and then a 'tophat' one. Three 'skeletonize', a 'thin' and a 'closing' followed and finally four 'skeletonize' and a 'clean' one. Finally small connected components -those which contained less than fifty pixels- were erased from the binary image, as they did not consist of any useful information.

4. RESULTS - DISCUSSION

Figures 2, 3 and 4 show the original images and the corresponding final output (focusing on the extracted coastline as the wanted target). A LANDSAT TM4 image (with 30 meters ground resolution) and the final extracted and connected edges resulting from enhancing, smoothing, nonlinear Laplacian operator and edge connectivity, are shown in figure 2. River boundaries have also been extracted. An IRS_1C image (6 meters ground resolution) and the binary result using the Canny edge detector, are shown in figure 3. In figure 4 an IKONOS image (1 meter ground resolution) and final extracted edges resulting from enhancing, smoothing, nonlinear Laplacian operator and its edge connectivity, are shown.

The result obtained can be characterized promising. Both Canny and the nonlinear Laplacian operator performed quit well with almost similar results, with an advantage to the nonlinear Laplacian operator when comes to curves and complex texture coastlines. In 'simple'-texture though images, the Laplacian operator can lead to pseudo-edge appearance. Edge detectors, suffer generally from weakness not only in relation to noise, but also to poor performance near corners of structures [4] and although edge extraction is the first step to object recognition and image understanding, it still remains one of the most complicated problems in image analysis and computer vision. It turns out that the processing system must be able to implement a model structure/ processing scheme, the complexity of which is directly related to the structural/ textural complexity of the problem under consideration in the external world [5].



Figure 2. Top: LANDSAT TM 4 (30m) image. Bottom: Output using nonlinear Laplacian edge detector

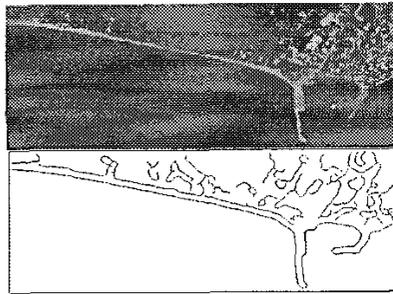


Figure 3. Top: IRS-1C PAN (6m) image. Bottom: Output using Canny edge detector

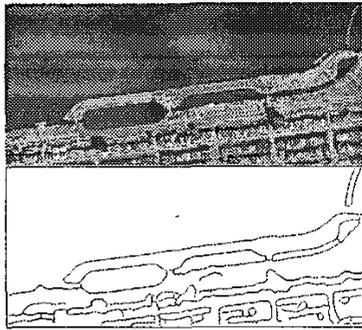


Figure 4. Top: IKONOS PAN (1m) image. Bottom: Output using nonlinear Laplacian edge detector

5. CONCLUSIONS

A coastline detection method from satellite imagery was implemented with a potential to be upgraded to a vector cartography form. The separation of coastlines from other linear features that are simultaneously extracted must follow, perhaps with a segmentation of water and land cover areas. To this end the digital signatures of water and land areas are required. Edge localization and the quality assessment are also objects for further research.

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Table1. Enhancement and smoothing parameters for the Canny edge detector

	LANDSAT TM	SPOT HRV PAN	IRC-1C PAN	IKONOS PAN
Gaussian convolution	$\sigma = 2,9$, $n \times n$ $= 13 \times 13$	$\sigma = 2,5$, $n \times n$ $= 11 \times 11$	$\sigma = 3,8$, $n \times n$ $= 13 \times 13$	$\sigma = 4,0$, $n \times n$ $= 13 \times 13$
Adaptive filtering	$n \times n =$ 5x5			
Median filtering	$w = ones$ (5x5)	$w = ones$ (5x5)	$w = ones$ (3x3)	$w = ones$ (3x3)
Morphological filtering	Opening $w = ones$ (5x5)	Opening $w = ones$ (5x5)	Opening $w = ones$ (5x5)	Opening $w = ones$ (5x5)

Table2. Enhancement and smoothing parameters for the nonlinear Laplacian edge detector

	LANDSAT TM	SPOT HRV PAN	IRC-1C PAN	IKONOS PAN
Gaussian convolution	$\sigma = 2,4$, $n \times n$ $= 8 \times 8$	$\sigma = 2,2$, $n \times n$ $= 11 \times 11$	$\sigma = 2,5$, $n \times n$ $= 11 \times 11$	$\sigma = 3,8$, $n \times n$ $= 13 \times 13$
Adaptive filtering	$n \times n =$ 3x3	$n \times n =$ 3x3	$n \times n =$ 3x3	$n \times n = 3 \times 3$
Median filtering	$w = ones$ (3x3)	$w = ones$ (3x3)	$w = ones$ (3x3)	$w = ones$ (3x3)
Morphological filtering	Close-opening $w = ones$ (5x5)	Close-opening $w = ones$ (5x5)	Close-opening $w = ones$ (5x5)	Close-opening $w = ones$ (5x5)