# Sea Ice Boundary Detection in SAR Satellite Images Using Conflicting Strength

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#### Abstract

In this paper, a boundary detection algorithm based on conflicting strength between edge and boundary in SAR (synthetic aperture radar) sea ice images is presented. In SAR sea ice images, different ice types can have the same intensity signature but the floe size and shape can be different. To measure the flow size and shape, proper boundary detection is crucial. Due to the inherent speckle noise with SAR satellite images, boundary detection in SAR images can be challenging. The implemented technique eliminates the unwanted edges from the overestimated boundary to obtain the desired boundaries by measuring the strength of each edge and the boundaries to which it belongs. Edges are removed if edge strength does not conflict with the boundary strength. Test results using operational SAR sea ice imagery are presented and results are encouraging.

### 1. Introduction

Boundary detection is one of the bottlenecks for many image analysis and computer vision applications such as medical [3] [12] and satellite images [4]. Due to the inherent speckle noise in SAR images, boundary detection is very challenging. Due to the lack of acceptable ice type separation algorithm in SAR sea ice images, ice boundaries are visually estimated on SAR sea ice images at Canadian ice services (CIS).

The boundary of an object in an image is perceptually very significant and conveys considerable image information. In addition, in some applications [6] the image structures are characterized by shape and size measures. A pre-processing stage that does not preserve the boundary can make the computed measures useless. One of the problems in sea ice SAR images is that the floe boundary may not be clear. One floe can touch an adjacent floe in such a manner that even a human observer will find it difficult to estimate the ice boundary. Generally, there is no unique solution for SAR sea ice boundary detection. This algorithm will try to determine boundaries in SAR sea ice images which the ice analyst will find useful.

The relation between an edge and its boundary is shown in Fig 1. Edges exist between two regions. In Fig 1,



Figure 1: Relation between edge and boundary

thick solid lines  $e_1, e_2, e_3, e_4$  and  $e_5$  are all individual edges. All of these combine to form the boundary of the center region *R*. An individual edge has two regions on both sides of that edge.

Boundary detection can be edge-based [2][9][12], region-based [1][7][8] or active contour-based [5]. In edge-based approaches, edges are found using an edge detection technique and a closed boundary is found by connecting the missing links. This method is dependent on the initial edges found by edge detection method. Often edge detection in SAR image produces false edges while missing weak but important edges to preserve the boundary. The sole use of this method is not considered in this paper.

Region-based boundary detection segments the image into different regions by using region-based characteristics such as mean and gradient [7]. The region-based method has a tendency to merge regions of similar mean with a weak boundary between them. The algorithm presented in this paper addresses these issues by not only considering the strength of an edge but also the strength of the boundaries to which it belongs. Many region growing algorithms [1] use some kind of initial starting point (a seed). The final result of these seeded region growing depends on the proper selection of the initial seed. The algorithm presented in this paper falls in this category but does not use any initial seeds. Active contour-based boundary detection depends on initial contour setup and is mostly used for single object detection. Typically, an initial contour is setup outside the desired boundary which then shrinks to fit the boundary [5]. In medical applications [3], boundary detection often used to find the outline of particular body organs. The process will be complicated when attempting to find the boundaries of many organs in the same image. In SAR sea ice images, there is no automated method to setup the initial contour due to the lack of prior information about the floe boundary. This method, as a result, is not considered here.

The proposed method is a three step algorithm. It uses watershed algorithm, region growing and edge elimination based on non conflicting edge and boundary strength. First, a watershed algorithm [11] is used to segment the image into smaller regions to estimate the initial boundaries. The merits of the watershed algorithm are that boundaries are always closed and the desired boundaries are always present in the initial image along with unwanted edges. The goal is to eliminate unwanted edges from the overestimated region boundaries. The next step uses a simple region growing algorithm to reduce the number of regions. Because region growing has a tendency to merge regions of similar mean with weak edges between them, it is not used to obtain the final boundaries. This step is only used for reducing number of regions while retaining the desired boundaries. The final step iteratively eliminates unwanted edges based on measured edge strength and boundary strength until final boundaries are obtained.

Section 2 describes the different components of the algorithm. Results are presented in Section 3 followed by conclusions in Section 4.

# 2. Algorithm Description

The proposed algorithm presented in this paper follows a number of steps as shown in Fig. 2. Three main blocks are marked by dotted lines. The objective of the first block is to produce all possible edges in the image. The second block, reduces the number of regions which eventually eliminates very weak edges. The third block, which is the core of the proposed algorithm, eliminates the remaining unwanted edges.

#### 2.1 Sobel operation

A simple 3x3 box operator is used to reduce the inherent noise in SAR images. Then the Sobel operator is used to obtain the gradients in the image. In the Sobel operation, x and y directional gradients are found using the directional masks and the final gradient is calculated by taking the square root of the sum of these directional gradients. Usually thresholding these gradients will detect the edges in the image. Because false edges appear and some real edges are missing, the gradients found in this stage will not be used for boundary detection. Instead they are used as input to watershed algorithm to obtain initial boundaries.



Figure 2: Block diagram of proposed method

### 2.2 Watershed

The watershed algorithm was introduced for the purpose of image segmentation by Lantuejoul and Beucher [15]. Later, Vincent and Soille [11] devised fast implementation methods for both sequential and parallel computation. This watershed algorithm becomes the basis for many boundary detection techniques [1][10][13][14]. The idea of a watershed is drawn by considering an image as a topographical surface. The image intensity (the gray level) is considered as an altitude. A high value corresponds to a peak and a low value corresponds to a valley. If a drop of water were to fall on any point, it would find its way until it reached a local minimum. For image segmentation, the watershed algorithm is applied on the gradient image produced by Sobel operation in the previous step. In the gradient image, the homogeneous region becomes the inner region of a crater and the region boundary becomes the crater's borders.

Suppose that holes are pierced at every local minima and that the image surface is immersed into water, then water will start to flood areas adjacent to regional minima. As the image surface is immerged, some of the flood areas (catchment basins) will tend to merge. When two or more different flood areas touch, infinitely tall dams (watershed lines) are constructed between them. When finished, the resulting networks of dams define the watershed of the image. In other words, the watershed lines partition the image into nonintersecting patches, called catchment basins. Fig. 3 illustrates the concepts of regional minima, catchment basins and watershed lines. Since each patch contains only one regional minima, the number of patches is equal to the number of regional minima.



Figure 3: Watershed with catchment basins and local minima

Due to the noisy nature of SAR sea ice images, the watershed algorithm produces an oversegmented image with many small regions. Fig. 6(b) shows the boundaries of these small regions. The watershed algorithm always produces closed boundaries and the desired object boundary is always present. So, in this paper, it is used as a starting point for boundary detection. The goal is to remove the unwanted edges until the desired boundaries are obtained.

### 2.3 Region growing

The overestimated boundaries found after applying the watershed algorithm are shown in Fig. 6(b) which provides little information with respect to identifying the true boundaries. The edge length, gradient and direction of the small edges are often misleading. So, to reduce the number of regions for further processing, regions are merged based on mean and gradient information. This step uses a low threshold for mean difference and edge gradient to merge regions to make sure that only regions with very weak edges in between them are merged. The region growing is a iterative process. At the beginning a very low threshold which represents a very weak edge is used. In each iteration, the threshold increases. From the experimental results, it is observed that the true boundaries start breaking with an increasing number of iterations. Instead of using full iterations, merging is continued only for low thresholds representing very weak edges. The results of this stage are an image with overestimated boundaries but the numbers of regions are fewer than the initial overestimated boundaries produce by watershed. Edges in this overestimated image can provide some meaningful information regarding edge gradient, direction and relationship with its neighboring edges for further processing.

### 2.4 Edge and boundary strength

After reducing the number of regions, the edge strength for each edge and the boundary strength for each boundary on both sides of an edge are measured. Later in this Section, describes how edge strength and boundary strength are measured. Based on these edge and boundary strength, unwanted edges are eliminated until the final boundaries are obtained.

For any region boundary, all edges around that boundary are sorted based on edge strength. An edge with edge strength below a threshold is considered as a potential candidate for removal. Later, if the boundary strength for any edge is below a certain threshold, it is marked for removal. Finally, any edge is confirmed for removal when both edge and boundary strength mark an edge for removal. Edges are not removed if there is any conflict between edge and boundary strength to mark an edge for removal. Once any edge is removed, edge and boundary strengths are recalculated for the affected edges and boundaries. Similarly, all the edges around the boundary of a region are checked for removal until no more edges can be removed. In this stage, the boundaries may not be the desired one and some unwanted edges may still exist. Because edge and boundary strength depends on the neighboring edges and boundaries, any change in the neighboring boundary can affect the boundary strength. Once each region's complete boundary is visited, then the process starts over at the next region in the image. The process terminates when no boundary in the image changes.

#### 2.4.1 Edge strength

Edge strength can be expressed as E(g,d,m,l) which is a function of average edge gradient g, direction d, mean m and length l. The average gradient of an edge is calculated by summing the gradient along the edge divided by its length. Gradients are normalized between 0 to 1. From the observation in SAR sea ice images, it is found that any edge with average edge gradient more than 20 and line length more than 10 pixels is a strong edge. So, average edge gradients between 0 and 20 are scaled to the range [0, 1] (any value greater then 20 is mapped to 1, which represents a strong edge). Similarly, edge length between 0 and 10 are scaled to the range [0, 1](any length greater then 10 is mapped to 1). The normalized gradients are weighted by normalized edge length to obtain the final normalized average edge gradient. The idea is that the smaller the length, the less reliable its gradient. It may be a false edge which usually has shorter length.

The gray level mean differences between adjacent regions are scaled to the range [0, 1] (mean difference more than 35 is mapped to 1). Again from the observations, two regions are belongs to two different objects if their gray level mean difference is more than 35 and region size is more than 250 pixels. The area size also scaled to the range [0, 1] (any area size more than 250 pixels is mapped 1). The bigger the area size the more reliable its mean. Before calculating the normalized mean difference, each area mean is weighted by its normalized area size.



Figure 4: Angles between an edge with its neighbors.

The angle differences between the direction of an edge with its neighboring edges are calculated. Among the angle differences, the best matching angle is taken and normalized between 0 to 1. Angle difference 0° is normalized to 1 and 180° is normalized to 0. Fig. 4 shows how angles are measured. The solid line is an edge and an arrow shows the direction of that edge at one end. Dotted lines are neighboring edges.  $\phi_1, \phi_2$  and  $\phi_3$  are the angles between the direction of an edge with its neighbors. Similarly angles at the other end are calculated and the minimum angle among all of them is considered and normalized between 0 to 1. Here, 1 represents that the edge has a strong directional tie with its neighbors.

The final edge strength is calculated by summing the normalized components of gradient, mean difference and direction. The maximum value of an edge strength can be 3. Any edge with edge strength below a threshold (here it is 1) is considered a potential candidate for removal.

#### 2.4.2 Boundary strength

Boundary strength B(bg, lr, bd) which is a function of average boundary gradient bg, length ratio lr and the best boundary direction bd. The best boundary direction is the minimum angle difference between an edge and its boundary at both end of an edge. Fig. 5(a) shows how the angles are measured. Among the two angle differences at both end of an edge, the smallest one is



Figure 5: Boundary strength (a) Angle between an edge with its boundary (b) A scenario of high length ratio, solid line is an edge with weak edge strength

taken and normalized between 0 to 1. The smaller angle differences suggest continuation of the boundary where as larger one suggests the opposite one. Along the boundary, the average gradients of the boundary are measured and normalized between 0 to 1. The length ratio is the ratio between the boundary length and an edge length within the boundary. Every edge belongs to two boundaries on both sides of that edge. The large boundary length to edge length ratio at both side of any edge will discourage to remove that edge as shown in Fig. 5(b). Failure to keep these weak edges can merge two objects into one that is undesirable. This usually happens when two objects touch each other. Among the two length ratios, smallest one is taken and scaled to the range [0, 1]. Length ratio greater then 10 mapped to 1. Experimental results show that this number works fine for SAR sea ice images. The higher the number the more possibility that the edge lies between two separate objects which will discourage to remove that edge. The boundary strength is obtained by summing all individual normalized components of boundary gradient, best boundary direction and length ratio. Boundary strength below a certain threshold is considered the edge as an potential candidate for removal.

When edge strength is low which is pointing to remove an edge but boundary strength is high which indicates not to remove is a conflicting situation. Edges are not removed when conflicting situation arises between edge strength and boundary strength. So, an edge is removed only when there is no conflict between edge strength and boundary strength. For each region, if there are no more edges to be removed, the process is repeated for the next region. Once all the regions are finished, next iteration starts again from the first region and the same process is repeated. The process is terminated if no region changes its boundary during any iteration.

### 2.3 Experimental results

The proposed algorithm is tested using SAR sea ice images and the results are shown in Fig. 6. This method presented here is able to find the closed boundaries even though there are some places in the boundaries where there is no clear separation between adjacent objects. This algorithm successfully eliminates noisy edges which is inherent in SAR images and keeps weak edges which are important to preserve the close boundary. The algorithm preserves the boundary for most of the floes which are important for ice analysis. This algorithm does not require any seed that is the basis for boundary detection in many region growing algorithms. This algorithm is implemented using MATLAB© and is computationally expensive. It takes two to three hours to run a 256x256 image. Work is underway to reduce the computational cost. The results show that the algorithm successfully detects the closed boundary for most of the objects and eliminates noisy edges.



Figure 6: Experimental results of three SAR images (a) Original image (b) Results of watershed (c) Results after region growing (d) Final boundary using conflicting edge and boundary strength

# 2.4 Conclusions

A new approach for sea ice boundary detection in SAR images is presented. This is a three step approach, watershed segmentation, region growing and edge elimination based on edge and boundary strength. Unlike other region growing algorithms, it does not required any initial seed to start which is crucial for success for many region growing algorithms. It always divides the image into several closed boundaries. Edge strength and boundary strength is a two way confirmation which help to eliminate the noisy edges while preserving the weak edges required for proper boundary detection. The success of this boundary detection in SAR sea ice images can improve the ice type separation by exploiting the size and the shape of an object based on detected boundary.

## Acknowledgments

The authors would like to thanks CIS (Canadian Ice Services) for SAR sea ice data and CRYSYS (Cryosphere System in Canada) for funding the project.

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