SAR Sea Ice Image Segmentation Based on Edge-preserving Watersheds

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Abstract

This paper presents a hybrid method for the segmentation of SAR sea ice images, which consists of an initial watershed segmentation followed by a region merging. Iterative bilateral filtering is used to reduce speckle noise and suppress irrelevant image details, which can significantly alleviate oversegmentation of watersheds. Since edges are well preserved by bilateral filtering, the watershed algorithm is capable of precisely locating object boundaries. Final segmentation is accomplished by applying an iterative region merging on the watershed regions by taking into account local boundary strengths and regional statistics. The efficiency of the proposed method has been demonstrated on the segmentation of SAR sea ice images. In comparison with traditional watershed algorithm, our method achieves better performance in identifying filament structures such as leads.

Keywords: Image segmentation; Synthetic aperture radar (SAR); Sea ice; Bilateral filtering; Watershed

1. Introduction

Spaceborne synthetic aperture radar (SAR), such as the Canadian satellite Radarsat-1, provides an efficient way to monitor sea ice conditions in polar regions, which are important for the safety of ship navigation and the research of global climate. At the Canadian Ice Service (CIS), a large amount of SAR images are received daily, and are further processed by ice analysts to produce ice charts for the user. Current manual labeling process is labor intensive and time consuming, while the results have limited accuracy and resolution. Automated interpretation of SAR sea ice images is therefore highly desired to assist in ice analysts for a better interpretation of sea ice images.

Automated sea ice image interpretation generally consists of a low level segmentation followed by a high level classification [1]. Based on certain region homogeneity criteria or definitions of region boundary, segmentation process partitions image pixels into a number of regions. Statistical or structural characteristics of these regions are then used by the classification process to derive the class of nature of each region. Obviously, the success of final interpretation of SAR sea ice relies on the performance of low level segmentation. On one hand, a precise segmentation of sea ice regions is expected, which enables a correct location of ice regions and a good estimation of shape characteristics of ice floes and ice fractures. As suggested by human visual interpretation, such high level knowledge is more robust in discriminating sea ice types in contrast to tone and texture features[1][4]. On the other hand, filament features, such as leads and ridges, should be well preserved in the segmentation results. Leads and ridges are important not only for sea ice research due to their distinctive ice structures and effects on heat transfer, but also for applications such as ship routing and the safety of offshore structure [2][8]. Moreover, these filament features can be used for the classification of associated sea ice. However, the SAR imaging process and changing environment produce significant variations on the appearance of images, causing poor separation of tone or texture features. In addition, it is known that SAR images are heavily contaminated by speckle noise. These problems constitute the major obstacles to the segmentation task.

A number of methods have been proposed to deal with the segmentation of SAR sea ice images, which can be divided into histogram-based approach [1,9,10], Markov random field (MRF)-based approach [1-3], edge-based approach [1,5] and hybrid approach [1,5]. Specifically, in the hybrid approach, an image is first partitioned into a set of primitive regions in terms of local image properties, a region merging or growing algorithm is then employed to generate the final segmentation result. Since the advantages of both region-based and edge-based methods are potentially combined, hybrid approach is considered to be the most promising direction, and has been adopted by recent research work on sea ice image segmentation [1,5]. Watershed algorithm has been proven to be a powerful means to image segmentation and boundary detection [6], and is deemed to be the most appropriate technique for the initial segmentation of sea ice regions in hybrid approach. It is also noted that, however, the current watershed algorithm suffers the following two drawbacks:

- *Oversegmentation*. Oversegmentation is a well known difficulty with watershed algorithm caused by noise and irrelevant contour elements in images. For SAR images, the problem becomes worse due to the heavy speckle noise. In hybrid approach, a large initial oversegmentation normally increases the probability of false region merging and incurs a heavy computational burden on subsequent merging. In addition, it makes filament structures difficult to survive the merging process.
- *Imprecise location of boundaries*. This problem is partly due to the false merging, and partly caused by smoothing operation. Although overlooked by most watershed algorithms, an imprecise location of boundaries may result in a poor estimation of boundary strength, which is an important local characteristic of image guiding the subsequent merging.

To deal with these problems, a new watershed algorithm is proposed for the segmentation of SAR sea ice images. Bilateral filtering [11] is first introduced to remove the speckle noise. Unlike the traditional Gaussian filters, both spatial distance and intensity dissimilarity between image pixels are taken into account in deriving the bilateral filter, which is hence capable of preserving major image edges. To further remove the disturbance from irrelevant boundaries, bilateral smoothing is applied to the SAR image iteratively such that oversegmentation is significantly reduced in the watershed algorithm. Finally, a region merging algorithm which incorporates the boundary strength and average intensity difference between regions are used to iteratively merge neighboring regions.

In the next section, bilateral filtering-based watershed algorithm is first presented. Hybrid segmentation combining watersheds with region merging is then described in Section 3, followed by the evaluations on the performance of proposed method in Section 4. This paper is concluded in Section 5.

2. Bilateral filtering-based watersheds

Watershed algorithm has been successfully applied to the segmentation of various types of images. It normally adopts a drainage pattern of simulated rainfall to partition an image into regions. Each watershed region consists of a set of pixels draining to the same local minima by following the image gradient direction. Watershed algorithm is able to reveal important structure information in images. Based on a gradient magnitude image, boundaries of watershed regions are closely related to edges of objects in the image, which facilitates the extraction of object boundaries.

Noise and irrelevant image details are two difficulties with watershed algorithm, which cause oversegmented result. There generally exist two approaches to overcoming the problem. One approach is to select a set of markers as regional minima to guide the generation of watershed regions. Prior knowledge on the images under study or even manual intervention is required for the selection of markers, which however are unfavorable for unsupervised segmentation task or in the case the characteristics of objects of interest are still unclear. The other approach is to remove the noise and disturbing details in images, for which a natural solution is smoothing the image or its gradients. Traditional smoothing filters, such as Gaussian filter, are not desirable candidates since they would blur or even remove object boundaries. For this reason, edge-preserving filtering becomes a major concern in this approach [6,7].

Bilateral filtering was first proposed by Tomasi and Manduchi in 1998. Due to its excellent performance on edge-preserving smoothing, this filtering method is considered to be a better alternative to traditional smoothing filters for various image edge- or gradient-based algorithms [12,13].

The commonly used Gaussian filtering can be expressed as follows:

$$I(\theta) = \int f(\alpha) \cdot \exp\left\{-\frac{(\theta-\alpha)^2}{2\sigma^2}\right\} d\alpha\,, \tag{1}$$

where f and I indicate the original image and the filtering result respectively. θ and α denote spatial indices, and σ is the standard deviation. As shown in the formula, Gaussian filtering performs an averaging over neighboring image pixels weighted by their spatial closeness. Such a spatial domain filtering ignores local image variations and therefore blurs edge points. In contrast, both spatial closeness and intensity similarity over neighboring image pixels are combined in the bilateral filtering as follows:

$$I(\theta) = \int f(\alpha) \cdot \exp\left\{\frac{(\theta-\alpha)^2}{-2\sigma^2}\right\} \exp\left\{\frac{(f(\theta)-f(\alpha))^2}{-2\sigma^2}\right\} d\alpha \tag{2}$$

where σ_d and σ_r denote the standard deviation of Gaussian filters in spatial domain and intensity range respectively. In this way, local intensity variations are taken into account in the smoothing process for preserving edge points.

In this work, watershed algorithm based on bilateral filtering is studied for the segmentation of SAR images. Bilateral filtering is first applied to the SAR image for removing speckle noise. Then it is further used iteratively to construct a multiscale representation of the SAR image. In comparison to the traditional Gaussian filtering-based multiscale representation, our representation is featured with edge-preserving capability. Along with the increase of scale, edges of important image structures are not blurred while small image details are gradually removed. Such a multiscale analysis of the SAR image provides an efficient approach to alleviating oversegmentation of watershed algorithm. After the bilateral filtering, canny edge detector [14], which is the first derivative of a 2-D Gaussian, is used to calculate gradient magnitude of the image.

Based on the gradient magnitude image, an initial segmentation of the SAR image, which consists of a set of watershed regions, is generated as follows. Local minima are first identified by comparing each pixel with its eight neighbors. Next, in the gradient magnitude image, the steepest downhill direction at each pixel is determined by searching its eight neighbors. Following the direction map, each pixel in the image can reach a local minimum, and is then assigned a unique region label associated with the local minimum.

3. Hybrid segmentation with region merging

The proposed edge-preserving watershed algorithm is combined with a subsequent region merging algorithm to form a hybrid method for SAR sea ice segmentation.

In region merging, a merging criterion is used to measure the similarity or dissimilarity between neighboring regions, which should take into account their relationships both locally, and globally or in a large extent in terms of probability distributions. In this work, since precise locations of object boundaries can be obtained from the watershed segmentation, boundary strength is adopted to measure the local difference between neighboring regions. Further, average intensity difference between regions is employed to approximate the difference between distributions of region intensity in a large extent. The criterion for region merging is a combination of both boundary strength and average intensity difference.

Based on the watershed regions, region merging is carried out in an iterative fashion. At each iteration, merging criterion value for all the boundaries are calculated and sorted. Boundaries with criterion value lower than a given threshold are removed and the corresponding neighboring regions are merged. At the end of each iteration, boundaries are updated to be consistent with the changed regions.

4. Method evaluations

4.1. SAR images

Two SAR images, as shown in Figure 1 (a) and Figure 2 (a), were used to evaluate the performance of our proposed segmentation method. The two images cover regions in Gulf of Saint Lawrence and Beaufort sea respectively, and contain various types of sea ice. They were captured by Radarsat-1 in ScanSAR C-band mode on Feb 20, 1998 and Oct 13, 1997, respectively, at the resolution of 100m (2×2 block average of original images at 50m resolution).

4.2. Evaluation results

Bilateral filters, whose parameters σ_d and σ_r were selected to be 2 and 20 respectively, was iteratively applied to SAR image Figure 1(a). The filtering result after five iterations is shown in Figure 1(b). It can be seen from the result that speckle noise in the original SAR image was significantly reduced, and irrelevant image details were also suppressed, while edges of leads were still well clearly preserved. Based on this filtering result, the gradient watershed algorithm followed by the region merge algorithm was then used to generate the final segments. As shown in Figure 1(d), a good segmentation of the SAR image was obtained, especially most of the leads regions were precisely picked out. Compared with the Gaussian filtering-based watersheds shown in Figure 1(c), substantial improvements on the segmentation was achieved by our method.

The performance of our proposed segmentation method was also evaluated on the SAR image containing other different types of sea ice. The results provided in Figure 2 clearly demonstrate the advantages of our proposed method on sea ice segmentation.

5. Conclusions

In this paper, a hybrid segmentation method for SAR sea ice images is proposed, which combines watershed segmentation with region merging. In various hybrid methods for image segmentation, watershed algorithm is considered to be an appropriate tool for generating initial segments, while its performance is limited by oversegmentation and imprecise location of object boundaries. These difficulties can be significantly alleviated by the proposed iterative bilateral filtering-based watershed algorithm, which is able to reduce speckle noise and suppress irrelevant image details, while clearly preserve edges of objects. The efficiency of the proposed method has been demonstrated on the segmentation of SAR sea ice images, especially the advantages on identifying filament structures such as leads.

6. Acknowledgements

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7. References

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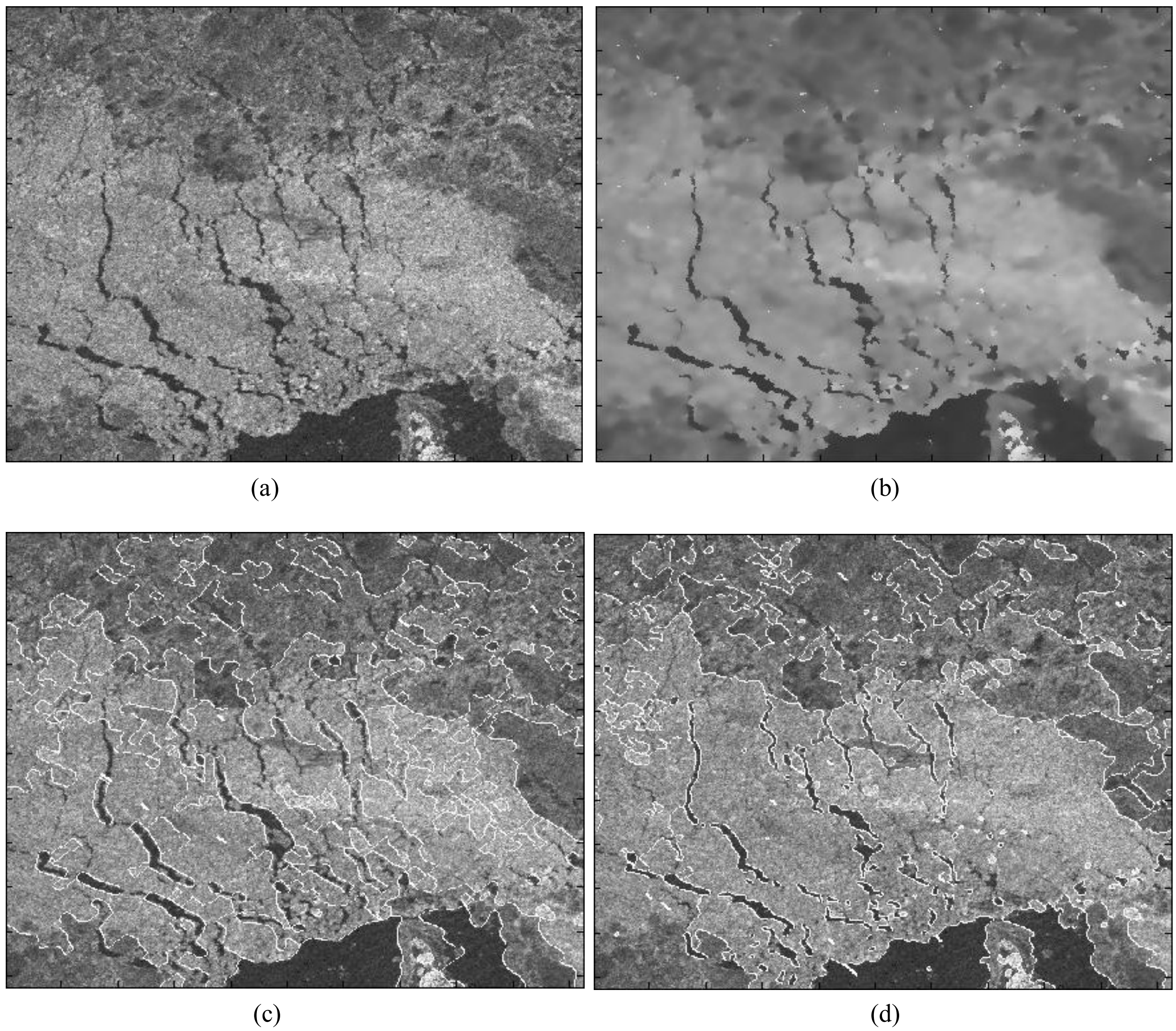
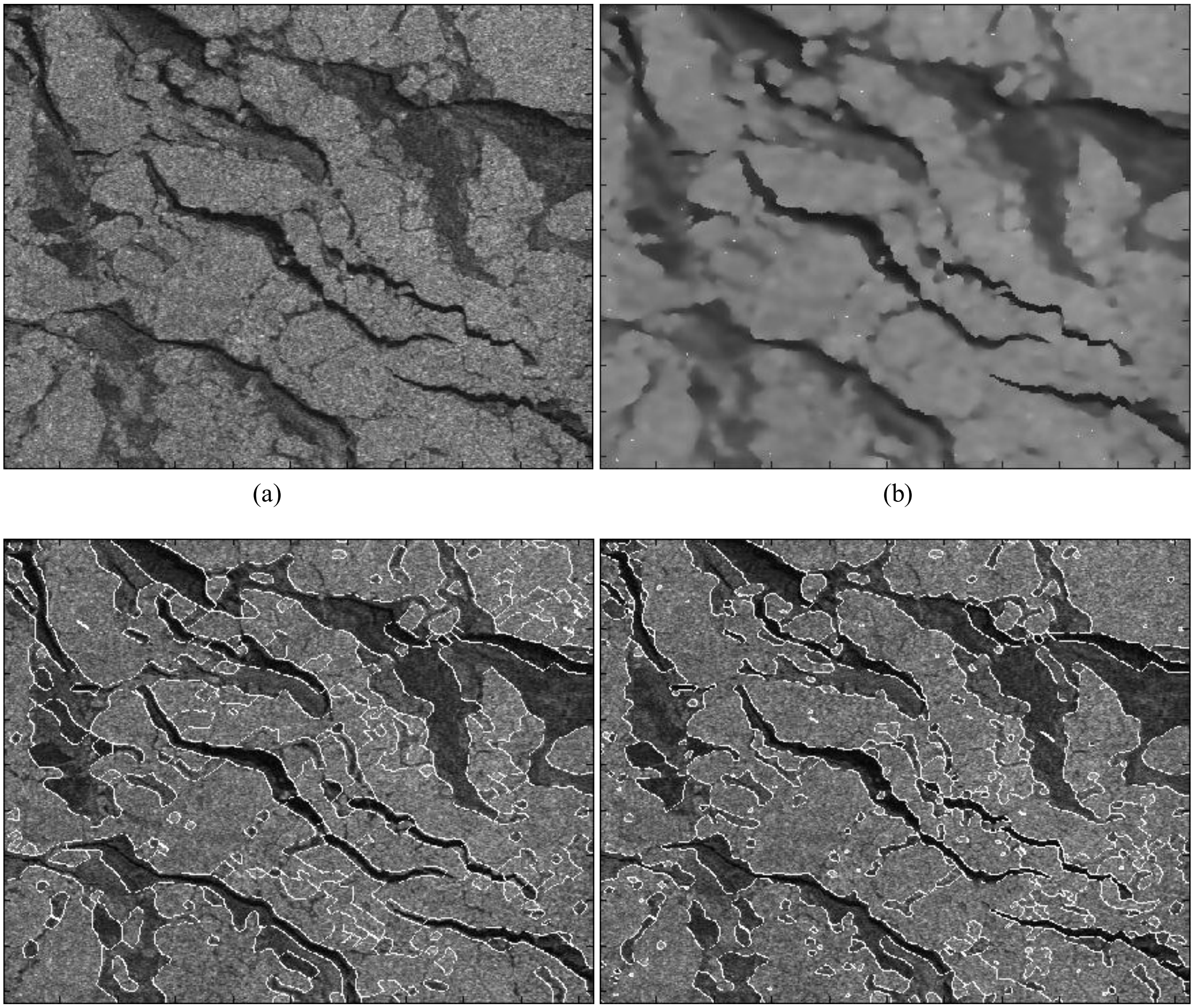


Figure 1. Segmentation of a SAR image captured over Gulf of Saint Lawrence (a) original image; (b) bilateral filtering result; (c) Gaussian filtering-based method; (d) proposed method



(a) (b)

(c) (d)

Figure 2. Segmentation of a SAR image captured over the Beaufort sea. (a) original image; (b) bilateral filtering result; (c) Gaussian filtering-based method; (d) proposed method