Automatic image segmentation for boundary detection of apparently connected sea-ice floes

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ABSTRACT

Ice concentration, ice types, and floe size distribution are three important factors in the analysis of ice-structure interaction in a broken ice field. The use of cameras as sensors for offshore operations in ice-covered regions is relevant for identification of the ice conditions and ice parameters, as part of a sea-ice monitoring system. In particular, this can be used for estimation of ice forces that are critical to Dynamic Positioning (DP) operations in Arctic waters. For the actual ice image, the apparent connection between ice floes should be identified, as it challenges the boundary detection algorithms and seriously affects ice floe size analysis. To solve this problem, a method of connected ice floes segmentation based on the watershed transform is presented in this paper. After ice image preprocessing, all the ice floes in the image are first identified by the Otsu threshold algorithm, and the greyscale image is converted into a binary image. Then, the seed points for the individual ice floes are located, and the watershed algorithm is carried out to segment the image. Finally, a chain code is used for concave spot localization, and then over-segmentation lines are removed. Experimental results are presented and a discussion of the method is given.

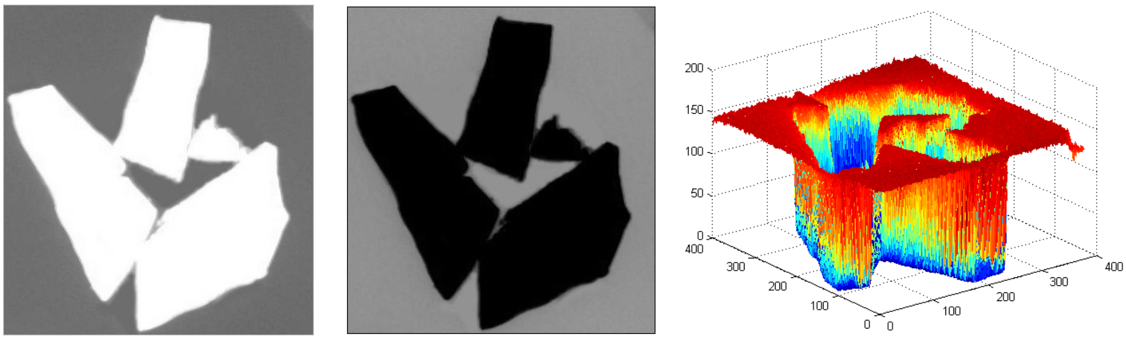
INTRODUCTION

Various types of remote sensing technologies have been developed in sea-ice observation for measurements of ice statistics and ice properties, and several image processing algorithms are adopted to analyze ice concentration, ice floe boundaries, ice floe velocity, and ice types (Ji et al., 2011; Zhang et al., 2012). A remote sensing mission of ice conditions was carried out at Ny-Ålesund in early May, 2011 and 32 GB of high resolution images of sea-ice were collected (Zhang, et al., 2012; Grøtli, E., 2011). From these images it is clear that, in the actual sea-ice covered environment, ice floes typically touch each other and possibly overlap, and the junctions are usually difficult to detect in the digital images. A remedy to this problem is to use the watershed transform to segment the connected ice floes.

The watershed transform and its improvements have been used to segment connected objects with acceptable results in several research areas, such as grain (Talukder et al., 1999) and cell nuclei (Chen et al., 2006) images. Blunt et al. (2012) adopted the watershed transform to segment sea-ice images. Due to an ineluctable over-segmentation problem, Blunt et al. removed these over-segmented lines manually. In this paper, the combination of concave detection and neighboring region merging is proposed to remove the over-segmentation automatically.

WATERSHED TRANSFORM

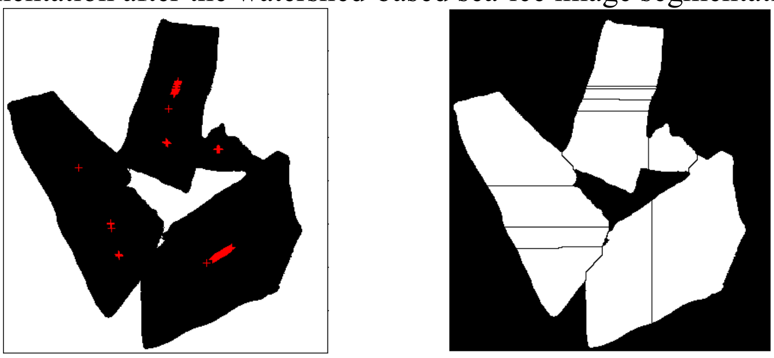
The watershed transform is a morphological-based algorithm to segment images (Gonzalez and Woods, 2002). The pixel values are interpreted as heights and a greyscale image is considered as a topological surface. Water falling on this topological surface flows towards the "nearest" minimum which lies at the end of the path of steepest descent and would collect in the areas called catchment basins. And water falling exactly on the called watershed ridge line would be equally likely to collect in either of the two catchment basins. Figure 1 shows the topological surface of a complemented grey scale ice image.



(a) (b) (c)

Figure 1. An illustration of some connected ice floes: (a) Grey scale image, (b) its complement, and (c) its topological surface.

The watershed-based segmentation could be used to solve a connected objects division problem. But over-segmentation is a major problem of this watershed, since it depends on local minima in the image. The watershed will first check the local minima in the image and then perform the transformation based on these. Usually, there are more than one minimum for each object, and this will induce over-segmentation (see e.g. Figure 2). Refinements, such as minima-combination (Ghalib and Hryciw, 1999), mark-controlled (Gonzalez and Woods, 2002; Yang et al., 2006), and H-dome transform (Malpica et al., 1997) were adopted to improve the over-segmentation. However, due to varieties of sea-ice floe shapes and sizes, it is hard to locate the correct local minima or markers for each ice floe automatically. In this paper, the greyscale sea image is first converted into a binary image (see e.g. Otsu, 1979) and the watershed algorithm is carried out to segment the image. Then a neighboring-region merging method is proposed to reduce over-segmentation after the watershed-based sea-ice image segmentation.



(a) (b)

Figure 2. An illustration of watershed-based segmentation: (a) Local minima superimposed in binary image. (b) Over-segmented image.

NEIGHBORING REGION MERGING

In this method, it is assumed that each ice floe has a convex boundary, and the junction line between two connected ice floes has at least one concave ending point. Based on this assumption, the junction lines obtained from the watershed-based segmentation are filtered by deleting those that have two convex ending points.

Figure 3 gives a flow chart of the watershed-based segmentation and the neighboring region merging algorithm:

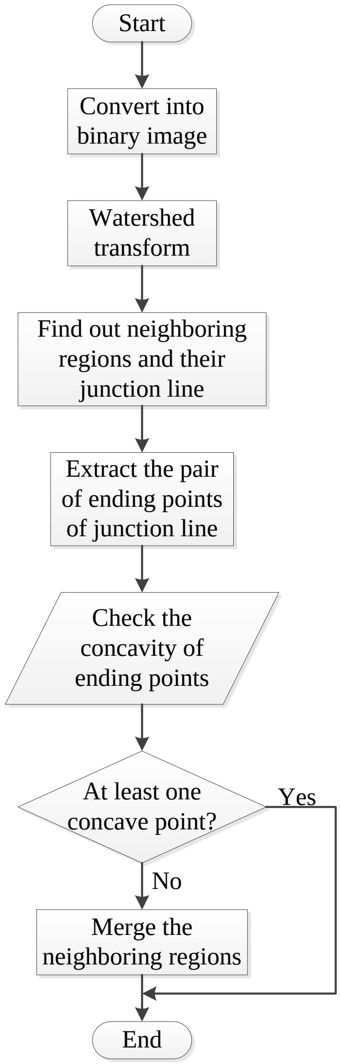


Figure 3. Flow chart of the watershed-based segmentation and neighboring region merging.

Concave detection by chain code

Chain codes are used to represent a boundary by a connected sequence of straight-line segments of specified length and direction (Freeman and Davis, 1977). Typically, this representation is based on 4- or 8-connectivity of the segments. The direction of each segment is coded by using a numbering scheme as shown in Figure 4.

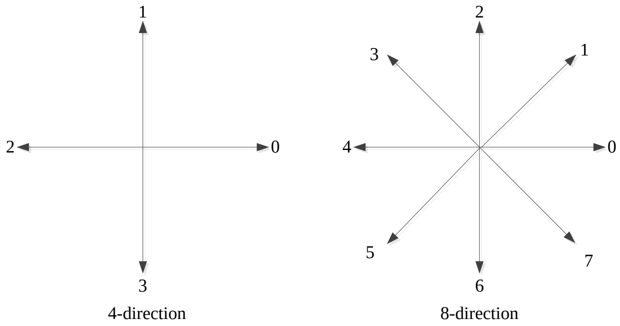


Figure 4. Numbering scheme of the chain code.

The first difference of code is obtained by counting the number of direction changes that separate two adjacent elements of the code. If the difference is less than 0, the difference should be modulo 8. Changes in the code direction indicate a corner on the boundary. By analyzing the direction changes as we travel in a clockwise direction along the boundary, we can determine and mark the convex and concave corners.

Assume $C(i)$ and $C(i-1)$ is the chain code of current Node i and former Node $i-1$, $R(i)$ is their relative chain code, and $A(i)$ and $A(i-1)$ is the absolute chain code of Node i and Node $i-1$. This gives

$$A(0)=0 \tag{1}$$

$$R(i)=[C(i)-C(i-1)+8]MOD8 \tag{2}$$

$$if\ (R(i)>4)\ then\ R(i)=R(i)-8 \tag{3}$$

$$A(i)=A(i-1)+R(i). \tag{4}$$

It should be noted that, when travelling along the boundary and back to the starting point, the difference of absolute chain codes is 8.

The absolute chain code sum of three sequential points is

$$S(i)=A(i)+A(i-1)+A(i-2). \tag{5}$$

When calculating the starting two nodes, the former absolute chain code should be shifted to the ends of the sequence and adjusted accordingly since the boundary is closed.
The differential chain code is the difference of the chain code sum between the three sequential ingoing and outgoing nodes, that is,

$$D(i)=S(i+3)-S(i). \tag{6}$$

Similarly, when calculating the last 3 nodes, the latter absolute chain code sum should start at the starting nodes and be adjusted accordingly.

The tangent direction (slope) of the edge points can be found by the absolute chain code sum of the three sequential nodes, and the curvature of the edges can be found by the differential chain code (Lu and Tong, 2002). Herein, the differential chain code, $D(i)$, defines the change of direction between two neighboring boundary segments:

$$\theta=D(i)\times 15°. \tag{7}$$

Therefore, Node i is identified as a concave point if the differential chain code, $D(i)$, is positive when tracing clockwise along the boundary.

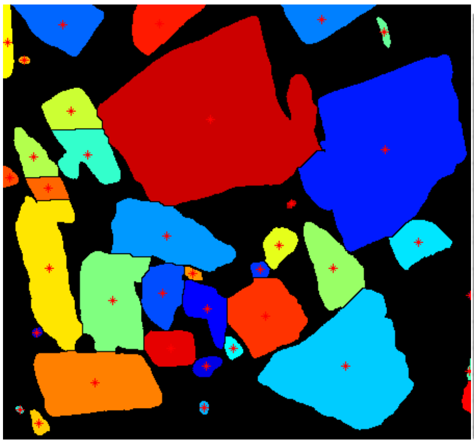
In this paper, the differential chain code method is applied to check the concavity of the two ending points of a proposed junction line between two connected ice floes, where the junction lines and the corresponding ice floes are obtained from the watershed-based segmentation.

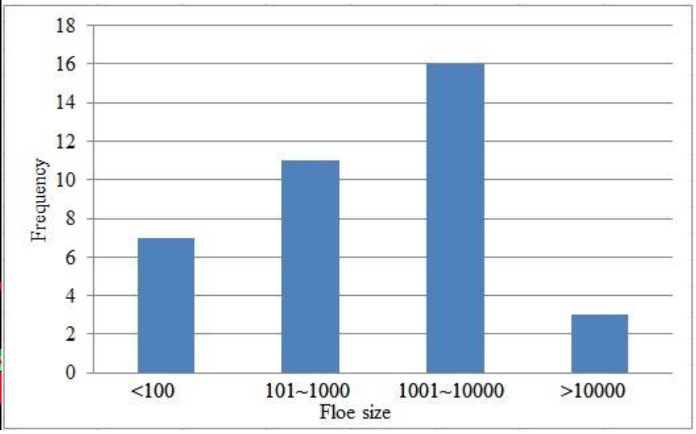
EXPERIMENTAL RESULTS

A few sea-ice images (1-4) obtained from a remote sensing mission of ice conditions carried out at Ny-Ålesund in early May, 2011 (Zhang, et al., 2012; Grøtli, E., 2011), are applied in a case study. It should be noted that the brash ice has been removed manually from the images before segmentation. Some examples of the experimental results are then shown in Figure 5.

Figure 5. Examples of experimental results: (a) Original ice images. (b) Binary images with manually identified segmented lines between connected ice floes. (c) Segmented images based on the watershed transform. (d) Segmented images after neighboring region merging.

Based on the segmented ice image, the floe size can be calculated by the amount of pixels within each ice floe. Figure 6 shows an example of the segmented ice image and the calculated floe size distribution (grouped by pixel numbers which can be scaled to real size).





(a) (b)

Figure 6. (a) Segmented image with floe center superimposed. (b) Calculated floe size distribution.

DISCUSSION

Image segmentation by using the watershed transform is powerful for connected object segmentation. However, there is a problem with over- and under-segmentation with this transform that must be overcome.

As mentioned in Gonzalez and Woods (2002), the over-segmentation problem can be serious enough to render the segmented result useless. Therefore, a neighboring region merging algorithm is applied in this paper to improve the ice image segmentation. As seen from Figure 5, most of the over-segmented lines have been removed, but some lines still exist. This is because the applied neighboring region merging algorithm is based on a very simple assumption, namely that the watershed-segmented line is taken as a correct junction line if it has one or two concave ending points, an assumption that is not always correct since a real ice floe is typically not a perfect convex shape. As shown in Figure 7(b), the segmented line highlighted by red has a concave ending point, which is just a concave corner of the floe boundary, but it is not a real junction concave corner between two floes. Even if one or both of its ending points are real junction concave corners, the segmented line obtained by using the watershed transform is still probably not a correct junction line (see e.g. the segmented line highlighted by green in Figure 7(b)).

(a) (b)

Figure 7. Examples of over- and under-segmentation: (a) Manually identified segmentation. (b) Segmentation by the established algorithm.

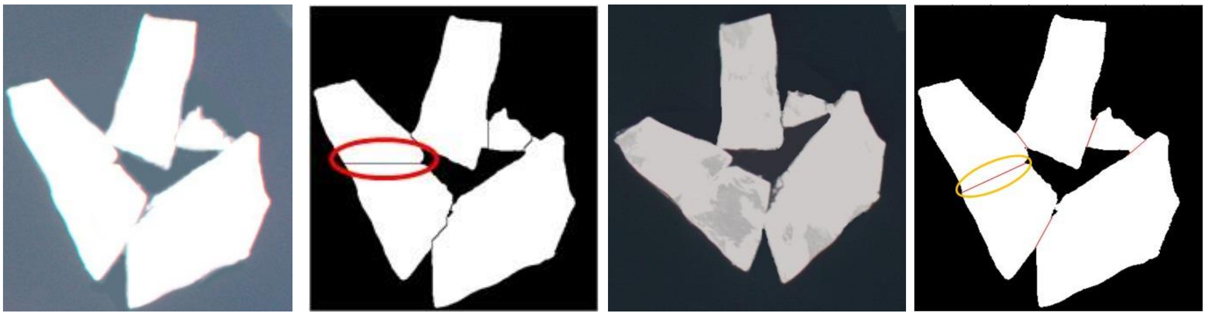
Under-segmentation is another problem of the watershed-based segmentation, and this cannot be improved by the neighboring region merging algorithm. As shown in Figure 7(a), there should be a segmented line in the region highlighted by yellow, but it is not detected by the watershed transform.

Table 1 lists the number of over- and under-segmented lines when compared to segmentation by manual inspection in Figure 5. It is found that the over-segmented lines are significantly reduced by the neighboring region merging algorithm, while the under-segmentation is still a problem. Note however, that when we apply the estimated floe size distribution in ice-structure interaction analysis, the under-segmentation of ice floes will typically lead to an overestimation of ice forces, meaning a conservative estimate.

Table 1. Number of over- and under-segmented lines compared with manual inspection.

Image	Manual inspection	Watershed-based segmentation			Watershed-based segmentation and neighboring region merging		
	No. of floes	No. of floes	Over segment	Under segment	No. of floes	Over segment	Under segment
1	5	12	7	0	5	0	0
2	12	16	5	1	11	0	1
3	20	25	7	2	17	0	3
4	38	60	26	5	37	4	6

Besides the over- and under-segmentation problems, ambiguously segmented lines are another problem. Figure 8 shows an example of this problem. By looking at Figure 8(b) it is difficult to say whether the segmented line highlighted in Figure 8(b) exists or not. Figure 8(c) shows original image taken under a different reflection condition, featuring the same ice floes with more details. By looking at this image it seems as if there is a boundary in the highlighted region, but it is still difficult to identify the exact location of this segmented line. Therefore, high resolution images may would definitely and more accurate ice floe segmentation.



(a) (b) (c) (d)

Figure 8. An example of the ambiguously segmented lines: (a) Original ice image. (b) Segmentation by the proposed algorithm. (c) Original ice image with more details. (d) Manually identified segmentation.

CONCLUSION

The watershed transform is applied in this paper for the image segmentation of connected sea-ice floes. A neighboring region merging algorithm is also proposed to reduce over-segmentation. The experimental results show the efficiency of the improvement for over-segmentation, though the over-segmentation problem still exists due to the simplified definition of the junction line between two connected ice floes. Besides, the under-segmentation and ambiguous-segmentation cannot be reduced by the current method. These issues remain for further studies.

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