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A method for crack recognition between two connected model ice floes

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ABSTRACT

The separate ice floes recognition in images is the relevant problem. Results of the reliable and precise recognition help collecting statistics on ice coverage in natural and model conditions.

In the paper the important problem of under segmentation in broken ice images recognition is considered. Usually the contrast of the junction crack to the ice surface is much lower than the contrast of the ice surface to surrounding water. This feature leads to misrecognition of such cracks by thresholding methods. Earlier several approaches to this problem were suggested, but there is still no conventional and effective solution of it.

In the paper, the method which allows solving this problem for one or several connected ice floes is suggested. The method is based on locating, studying and tracing the narrow neck of the segment. An application of this method to the case of the model ice floes recognition in images is considered. Examples of junction crack detection are provided.

KEY WORDS: model ice; image; segmentation; local binarization.

INTRODUCTION

Aerial or satellite ice images recognition is necessary step in the modern ice management. Satellite images with resolution allowing lead patterns recognition and ice floe distribution analysis were obtained as early as 1972 with the launch of ERTS, Earth Resources Technology Satellite (Campbell et al., 1975). Separate ice floes, their boundaries, cracks in ice and places of ice floes connection became visible in images from this satellite.

Comparing to satellite images, which resolution became high enough relatively recently, the aerial photographs have provided high resolution images of ice floes and leads since long ago. An example of such an image made in the modern mission in the Beaufort Sea is provided in Figure 1. One can see that most of the floes in image have tight connections to each other. Ice floes have large variety of sizes, they are of irregular shapes and some of them obviously are not convex. Junctions of floes are visible as thin cracks with variable width along the connecting edges.

Gathering the statistics on ice floes linear sizes and areas is impossible without segmentation of ice floes and correct separation of merged ice pieces. In the beginning of 80-s the automatic methods of ice floes segmentation still were not developed, as soon as Rothrock and Thorndike (1984) reported segment separation in an image by manual contouring with help of special tracer.

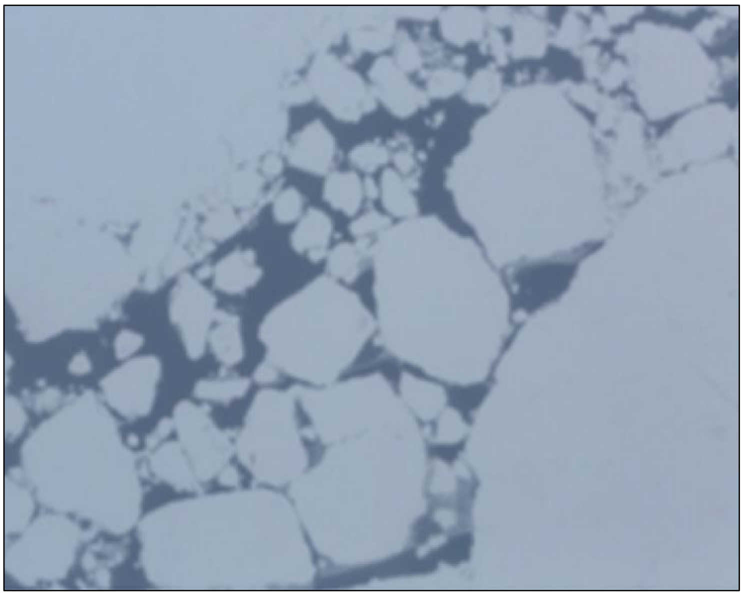


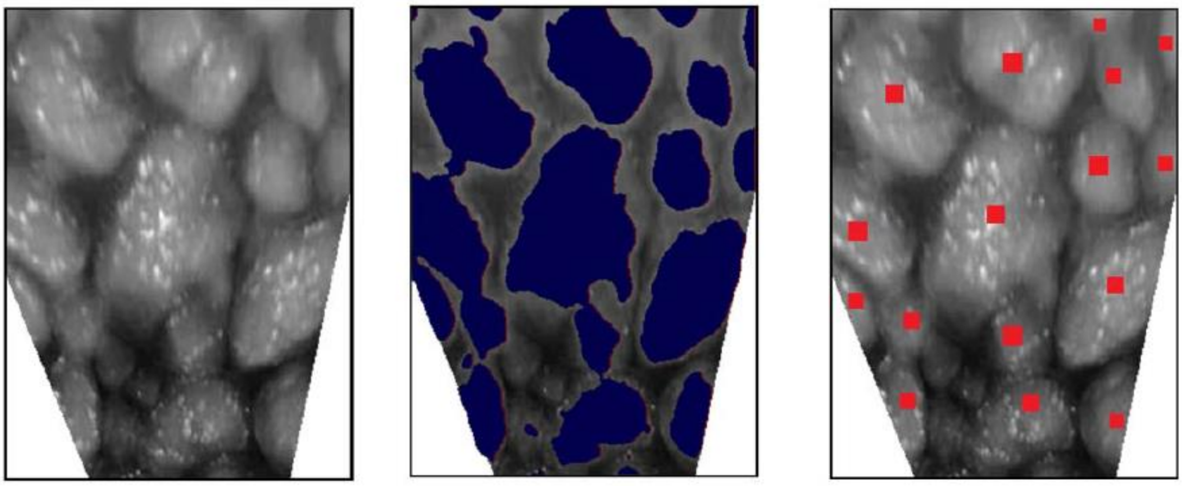
Figure 1. Surface conditions during the 2014 sea ice transition period over the Beaufort Sea photographed from the ARISE aircraft using the nadir camera 5 Sep, 80°N, 140°W (Smith et al, 2017)

Almost three decades after that, Blunt et al. (2012) performed an algorithmic segmentation of ice floes in images by means of morphological segmentation method. One of main steps in their approach was the watershed algorithm. In that algorithm a grayscale image is considered as a surface with elevations given by lighter pixels, and depressions given by darker pixels; fallen "water" fills depressions performing a segmentation of an image this way. However, Blunt et al. asserted that watershed segmentation technique applied by them has a tendency to over segment ice images. To fix this issue they permitted manual reviewing and joining over segmented floes. Hence, the problem of connected floes segmentation by completely automatic procedure was still relevant at that time.

Later, Zhang et al. studied watershed algorithm and a neighboring regions merging method in their attempt to solve the over segmentation problem for connected ice floes in image (Zhang et al, 2013). However, that problem still was manifesting in example of several joint ice floes image segmentation provided in that paper. It was concluded that the under-segmentation and ambiguous-segmentation cannot be reduced by studied methods.

In the paper published by Zhang et al. (2015) the gradient vector flow snake algorithm was used for connected ice segmentation. An ordinary active contour method algorithmically adjusts contour to the boundary in image; gradient vector flow concept improves this method making it less demanding to the quality of the initial approximation. The gradient vector flow snake algorithm was applied by Zhang et al. in couple with distance transform method for seeding of initial mask. As it follows from the paper, algorithm had provided acceptable results for ice floes of rectangular shapes, and allowed making an automatic segmentation if proper parameters of algorithm were applied. Images of model ice floes for that paper were provided by HSVA ice tank (Hamburg, Germany). However, in that paper no study was performed about applicability of the method to ice floes of irregular shape.

In the paper (Roach et al., 2018) images of pancake ice taken by drifting wave buoys, which had a camera mounted on the mast of 1 m high, were considered. Low resolution of cameras led to blurry edges of recorded ice floes (Figure 2 a). In their study authors used user-specified thresholds for segmenting separate ice pieces in image (Figure 2 c), while global thresholding did not provide correct segmentation (Figure 2 b).



a b c

Figure 2. Orthorectified image of pancake ice (a); ice area estimate from a fixed threshold (b); discrete floes found by a user-specified threshold (c) (Roach et al, 2018)

Concluding this short review we have to say, that up to now there is no conventional method for recognition of crack between two connected ice floes. In spite of the advances in ice segmentation techniques in the last decade, their wide applicability is not studied well enough. In this paper we propose the technique for searching of possible juncture place of connected ice floes.

The structure of the paper is as follows. The first section is introductive. In the second section the problem of junction recognition is stated for contacting model ice floes; algorithm of the proposed method is introduced. In the third section a way of bottleneck search based on contour rotation is given. In the fourth section the way of crack tracing in located window is provided. Last part contains the conclusion.

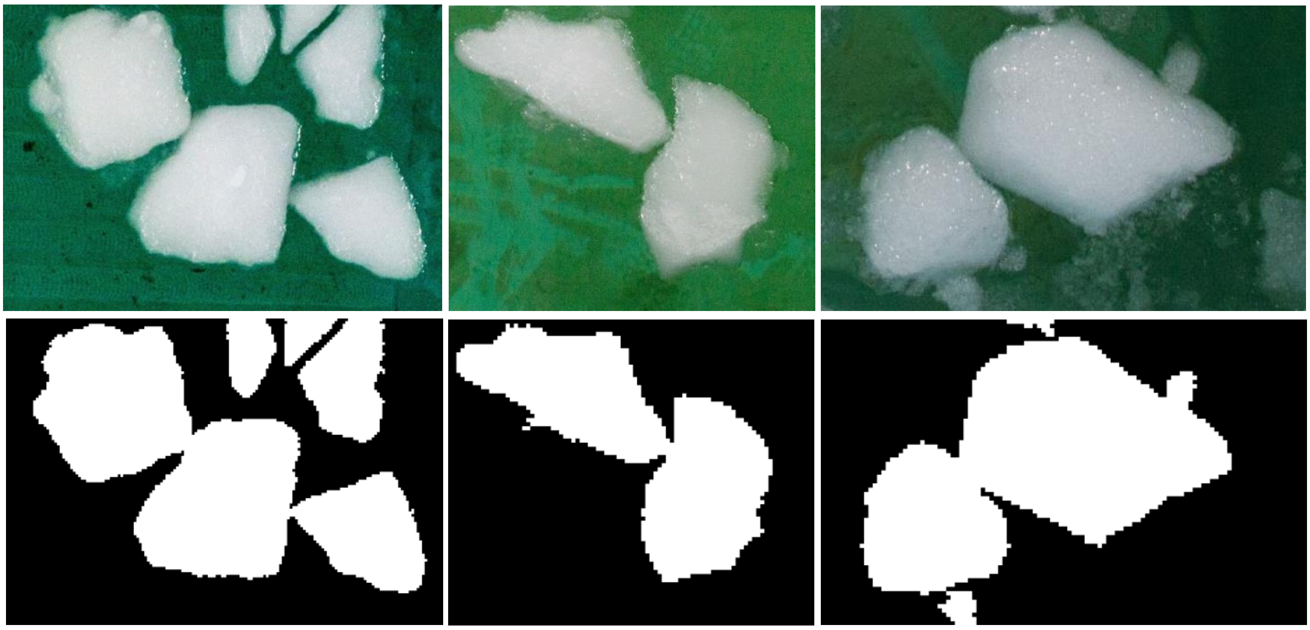
CONTACTING MODEL ICE FLOES

Broken model ice pieces usually congregate together on the surface of the ice tank. Separate pieces usually have places of contact, which can be visually recognized. Some examples of such ice floes contact are provided in Figure 3. In Figure 3 b two non-convex ice floes are connected with each other, while in Figure 3 a and c we can see a “chain” of connected floes. Images of contacting floes were obtained in the ice tank of Krylov State Research Centre (St. Petersburg).

Performing the recognition of images with model ice, the first step is the segmentation of objects in these images. We made the segmentation by the automatic segmentation tool developed by us in St. Petersburg Polytechnic University. Results are presented in the lower row of Figure 3. Close connection of objects in images led to the situation, when two or three ice pieces were recognized as one. This way, we need a method for automatic partitioning of two or more mistakenly united ice segments.

Having an automatic segmentation result, like shown in Figure 3, we are not sure, if some of obtained ice segments actually correspond to connection of two or more ice pieces. In general, possible options are described in Figure 4.

In this paper we shall consider the case when two or more merged ice floes were percept as one by the recognition algorithm. In spite of recognition algorithm made a mistake, visually we still can partition merged ice floes. The usual reason of misrecognition of the ice connection place is low contrast of this juncture comparing to surrounding water. This problem can be solved locally, if we have a way to localize the place of the juncture.



a b c

Figure 3. Images of connected model ice floes

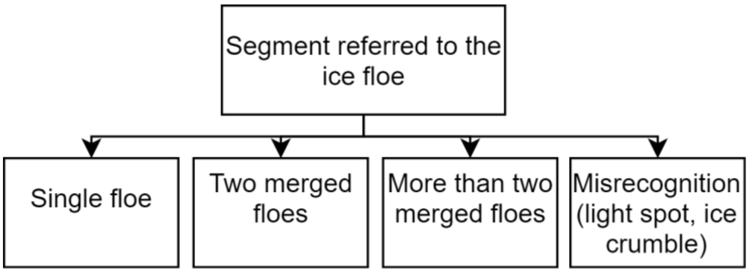


Figure 4. Cases of ice floe segmentation

We shall provide a solution for this problem for the class of merged floes, where the length of the tight juncture is significantly smaller, than linear sizes of connected pieces. In other words, junction forms so-called “bottleneck” of the segment. For example, all segments of two or more connected ice pieces in Figure 3 have such “bottlenecks”.

The algorithm of segment partitioning proposed by us in this paper consists of the following steps:

1) search for the “bottleneck” of the obtained continuous segment in binary image;
2) locally increase contrast inside the window covering found “bottleneck”;
3) try to trace the continuous path by water from the one side of window to another across the found “bottleneck”;
4) If 3 is successful, then split initial segment into two parts using path built in 3.

All of listed steps can be automated.

BOTTLENECK SEARCH

Let us consider a closed continuous contour obtained after an image segmentation and referred to the ice piece. To look for narrow neck we shall rotate the contour around its mass center with coordinates (x_c, y_c) by the angle α using formulas:

$$\begin{cases} x_{new} = x_c + (x - x_c)cos(\alpha) + (y - y_c)sin(\alpha) \\ y_{new} = y_c + (y - y_c)cos(\alpha) - (x - x_c)sin(\alpha) \end{cases}$$

Here (x, y) is an old position of the point of the contour, and (x_{new}, y_{new}) is its new position after the rotation. An example of such rotation for the segment of two connected ice floes from Figure 3 b is presented in Figure 5.

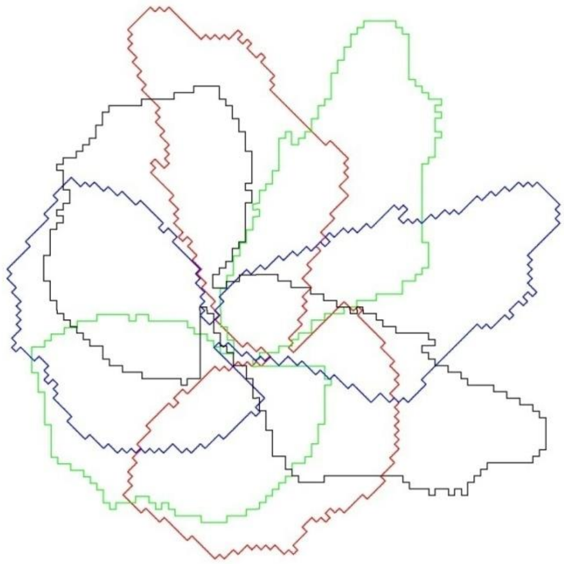


Figure 5. Rotation of the ice floe segment around its mass center

To find the "bottleneck" of the contour we shall introduce pointwise function $S(i)$, which takes on values of number of pixels in the raw i of the segment, divided by overall segment cardinality. This way, the "narrower" segment is in horizontal direction on the level of i-th row, the smaller the value of $S(i)$ is. If we have a set of k values of angle α taken from 0 to π with step $\Delta\alpha$, then we get the set of k corresponding pointwise functions $\{S_k(i)\}$.

We operated with unsmooth contours, so in order to reduce scatter we applied moving average smoothing for each $S_k(i)$. Let us denote smoothed pointwise functions $S_k(i)$ with $\tilde{S}_k(i)$. An example of $\{\tilde{S}_k(i)\}$ for contour provided in Figure 3 b is presented by curves in Figure 6. Here step $\Delta\alpha$ was taken as $\pi/12$.

For "bottleneck" localization we shall use local minimum search, excepting of terminal i values. Let U is the set of all local minimums of $\{\tilde{S}_k(i)\}$. Then $min\{U\}$ provides us i_{min}, which is row number, and angle α_{min}, which corresponds to curve number k.

Having parameters α_{min} and i_{min}, we can place rectangular mask on location of plausible crack in the segment or juncture of two segments for the following segmentation.

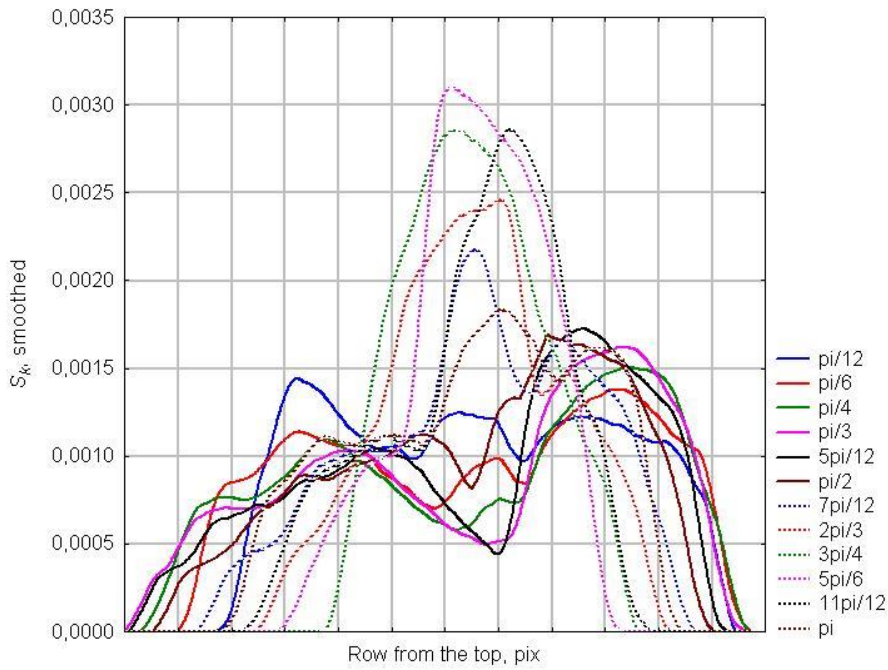


Figure 6. Curves of $\tilde{S}_k(i)$ in bottleneck search algorithm

PARTITIONING OF TWO MERGED SEGMENTS BY THE PATH

Under local binarization we understand the threshold binarization of selected local area in image. This way, we shall surround juncture by rectangular window, and then process the selected area as a separate image.

In the extracted local part of the image we shall cyclically perform attempts of getting from the one side of the image to another along the possible crack between two floes. The area selection is illustrated in Figure 7. Rectangular window is placed on the juncture of two ice floes with the angle found in “bottleneck search” algorithm described in previous section. For further image processing we convert it to untilted rectangular image.

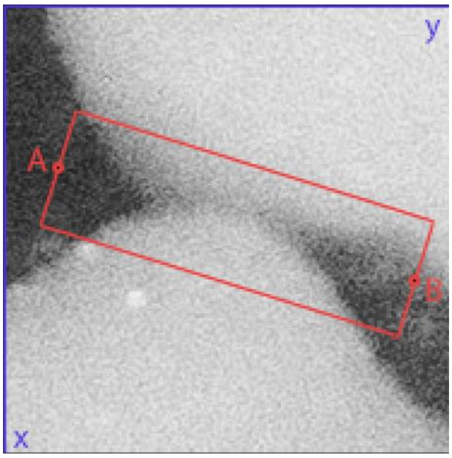


Figure 7. An area selection for local binarization

After image crop we shall try to find a path from the start point A to the finish point B from one side of the area to another following the suppositional crack. As soon as we expect the narrowest part of the crack somewhere in the middle, we shall place start and finish point on the water area at opposite borders of the image. Our aim here is separation of the image onto two parts by the path.

Trying to build a path from A to B we binarize the grayscale image by some threshold, then define the graph on the image where pixels of the black color correspond to nodes. In the defined graph two neighboring black pixels are connected by an edge, while white pixels are considered as impassable: the similar concept of the graph definition is used in (Zvyagin and Voitkunskaia, 2016).

There are several pathfinding graph-based algorithms exist, which can be applied:

- The Breadth-First Search (Moore, 1959) is a basic algorithm, which uses graph traversal by its “layers”. This algorithm is stepwise, on each step it checks a set of “unvisited” nodes, which are neighboring to already visited nodes;
- Dijkstra algorithm (Dijkstra, 1959) finds shortest route from the start node to the finish node using greedy strategy;
- A* algorithm (Hart et al, 1968) uses heuristics with distance to the finish on each step, which decreases calculation time of this algorithm;
- Best-First Search algorithm (Dechter and Pearl, 1985), which relies only on heuristic function of the distance from the current point of the path to the destination point.

An important part of the method is obtaining the binary image on which pathfinding will be performed. The threshold binarization of grayscale intensity image implies that there is a threshold value exists, which is applied as follows: pixels with intensity less than this threshold are attributed to black color (water), while pixels with intensity equal or larger than this threshold are attributed to white color (ice). Cyclically turning the threshold values we shall perform local threshold binarization of selected area with trials of getting from left water segment to the right, as it is shown in Figure 8.

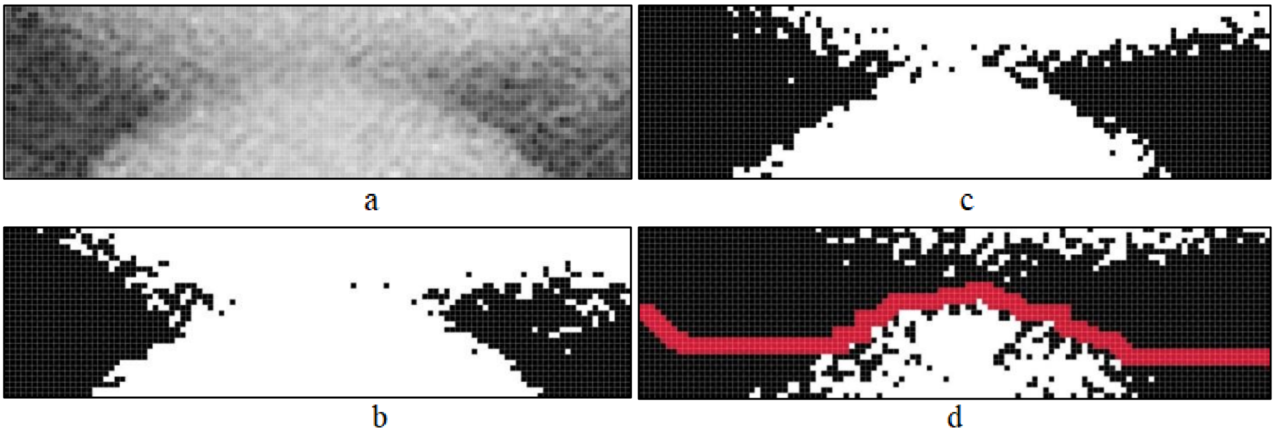


Figure 8. Steps of partitioning by the path with successive increasing of threshold: a – located area of the ice floes connection; b, c – binarization with no path available from the left to the right water segments; d – binarization with the path traced by the Best First Search algorithm.

If path from the start point to the finish point is found or if the limit value is met, the cycle stops. We took a "modal ice pixel intensity" as the limit value: this intensity value was found as the modal value of the right part of the grayscale image intensity histogram. If algorithm comes to limit threshold value without successful building of a crossing path, then there is apparently no connection of two separate floes in the considered image area.

CONCLUSIONS

Under and over segmentation are regular problems in broken ice image recognition. Under segmentation, which results in merging two or more connected ice pieces into one segment by means of the "bottleneck" (narrow junction), can be solved by the method proposed in the paper. The algorithm of the proposed method allows an automatic detection of under segmented ice pieces.

Ice segment contour rotation and local threshold adjusting for automatic tracing of crack between two ice pieces have shown good results for images of model ice floes. The method works with non-convex ice pieces of complicated shapes. However, method of "bottleneck search" can be not effective having deal with ice floes, which have very tight and/or long connection. Further study is needed on method applicability to natural ice images.

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