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Image Processing for Analyzing Ice Floes and the Floe Size Distributions

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Abstract: Sea ice, which is defined as any form of ice that forms as a result of seawater freezing. Various types of sea ice can be found in ice-covered regions. Ice floe, which is the flat pieces of sea ice, can range from meters to kilometers in size. The floe size distribution is a basic parameter of sea ice that affects the behavior of sea-ice extent, both dynamically and thermodynamically. The sea ice features were collected using an unmanned aerial vehicle and several image processing algorithms have been applied to samples of sea-ice images to extract useful information about sea ice. The sea ice statistics were used to calculate climate and wave and structure of ice. The calculation of sea ice statistics seems to be challenging due to difficulties in ice floe identification, particularly the separation of seemingly connected ice floes. To solve this. Problem the gradient vector flow (GVF) snake algorithm is applied. To evolve the GVF snake algorithm automatically, an initialization based on the distance transform is proposed to detect individual ice floes, and the morphological cleaning is afterward applied to smoothen the shape of each identified ice floe. Based on the identification result, the image is separated into four different layers: ice floes, brash pieces, slush, and water. This makes it further possible to present a color map of the ice floes and brash pieces based on sizes, and the corresponding ice floe size distribution histogram. The proposed algorithm yields an acceptable identification result. Sea ice statistics helps in providing an early warning of an ice compaction event, which can be dangerous if the ice-structure interaction mode changes from a "slurry flow" type to a "pressured ice" type.

Keywords: Ice floe, GVF snake algorithm, brash pieces, slush, and water.

I.INTRODUCTION

The sea ice covering the Arctic Ocean is broken into distinct pieces, called floes. In the summer, these floes, which have diameters ranging up to 100 km, are separated from each other by a region of open water. In the winter, floes still exist, but they are less easily identified. An understanding of the geometry of the ice pack is of interest for a number of practical applications associated with transportation in ice-covered seas and with the design of offshore structures intended to survive in the presence of ice. The present investigation has the objective to clarify ideas about floe sizes and to propose techniques for measuring them. Measurements are presented with the primary aim to illustrate points of technique or approach. A preliminary discussion of the floe size distribution of sea ice is devoted to questions of definition and of measurement. Identification of ice floes and their outlines in satellite images is important for understanding physical processes in the polar regions, for transportation in ice-covered seas, and for the design of offshore structures intended to survive in the presence of ice. At present this is done manually, a long and tedious process that precludes full use of the great volume of relevant images now available. We describe an accurate and almost fully automatic method for identifying ice floes and their outlines. Floe outlines are modeled as closed principal curves, a flexible class of smooth nonparametric curves. We propose a robust method of estimating closed principal curves that reduces both bias and variance. Initial estimates of floe outlines come from the erosion-propagation (EP) algorithm, which combines erosion from mathematical morphology with local propagation of information about floe edges. The edge pixels from the EP algorithm are grouped into floe outlines using a new clustering algorithm. This extends existing clustering methods by allowing groups to be centered about principal curves rather than points or lines. This may open the way to efficient feature extraction using cluster analysis in images more generally. The method is implemented in an object-oriented programming environment, for which it is well suited, and is quite computationally efficient.
Observations from satellites play an important role in tracking sea ice movement. Synthetic aperture radar (SAR) images are preferred because they are neither weather nor daylight dependent. Tracking the movement of individual objects (icebergs or sea ice floes) that may threaten ships or installations is of particular interest. The Ice Tracking from SAR Images (ITSARI) algorithm was originally developed to track large icebergs in the Antarctic. An adaptation of this algorithm to identify and track the movement of sea ice floes in Arctic conditions is presented, using ENVISAT wide swath SAR images of the Fram Strait acquired at 1–3-day intervals during the month of February 2008. It is shown that the algorithm can be successfully adapted to gain a general sense of the direction of movement of the ice due to both winds and ocean currents and, significantly, to identify and track

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specific objects of interest over a series of images. Sea ice is the principal environmental factor in all of the offshore artic areas. The most abundant type of sea ice encountered offshore is less than 1 year old. This first-year ice begins to form during fall and grows to a thickness of 4 to 8 ft during the winter. Sheets of ice close to shore become landfast and remain locked in place throughout the winter. Beyond the landfast zone, the ice is kept in constant motion by wind, currents and, in some areas, the influence of the arctic polar pack. This dynamic movement causes shearing impacting between ice features that produce ridges of ice several miles in length. Ice ridges formed in this manner are called pressure ridges. Localized ridging around a grounded ice feature, the shoreline, or a structure is considered a rubble pile. In areas of extremely cold winter temperatures, the ice blocks within a ridge or rubble pile begin to refreeze into a contiguous feature. Depending on the conditions, the refrozen consolidated thickness could become several times larger than the first-year ice thickness.

II.REMOTE SENSING

One of the best ways to observe ice conditions in the oceans is by using aerial imagery and applying digital image processing techniques to the observations. This method can reduce or suppress ambiguities, incompleteness, uncertainties, and errors regarding an object and its environment, yielding more accurate and reliable information. Cameras are typically used as sensors on mobile sensor platforms in ice-covered regions to characterize ice conditions. Cameras can collect precise spatially continuous measurements, which are particularly suitable for providing detailed localized information of sea ice. However, an important prerequisite is a clear sky and sight during missions. Remote sensing makes it possible to collect data of dangerous or inaccessible areas. Remote sensing applications include monitoring deforestation in areas such as the Amazon Basin, glacial features in Arctic and Antarctic regions, and depth sounding of coastal and ocean depths. Military collection during the Cold War made use of stand-off collection of data about dangerous border areas. Remote sensing also replaces costly and slow data collection on the ground, ensuring in the process that areas or objects are not disturbed. A remote sensing mission to determine ice conditions was performed by the Northern Research Institute (NORUT) at 78◦55_ N 11◦56_ E, Hamnerabben, Ny-Ålesund, from May 6 to 8, 2011. An unmanned aerial vehicle (UAV) was used as a mobile sensor platform because of its flexibility in coverage and in spatial and temporal resolution, which are three important sensor-platform attributes. The use of cameras as sensors on a UAV was explored to measure ice statistics and properties. The objective of the mission was to gather information about the ice conditions in the Arctic. The further goal was to develop tools based on the processed ice data that can be applied for decision support in Arctic offshore operations.


FIG 1.CRYOWING

A Cryo Wing Unmanned aerial vehicle as shown in Fig. 1, was used for the mission. This Unmanned aerial vehicle was designed for cryospheric measurements and environmental monitoring, and its technical specification is found in Table I. The basic instrumentation of the Cryo Wing is an onboard computer that controls the different payload instruments, stores data to a solid-state disk, and relays data to the ground. The onboard payload system has a GPS receiver and a three-axis orientation sensor that is independent of the avionics system. The sensor device used in this analysis is a digital visual camera with specifications found in Table II. The vehicle flew in the inner part of Kongsfjorden to collect high-resolution images of sea ice. Several image-processing algorithms have then been applied to these images to extract useful information of the sea ice, such as ice concentration, ice floe boundaries, and ice types

III.ICE IMAGE PROCESSING METHODS

A digital image is a numeric representation of a two dimensional picture, and it is composed of pixels which are the smallest individual elements in the image. A pixel holds quantized values that represent the color or gray level of the image at a particular point. To identify sea ice from open water is crucial to this research. Based on that sea ice is whiter than open water, the pixel values are different between sea ice and open water in normal conditions. In this research, we applied several image processing algorithms to these real sea ice images. The objective was to analyze the sea ice features: ice concentration, ice floe boundaries, and ice types. As we will see, obtaining accurate results are significantly more difficult with real sea ice images than for the deterministic model basin images.

Due to the fact that sea ice is whiter than open water, the pixel values differ under normal conditions. Ice pixels have higher intensity values than those belonging to water in a uniform illumination ice image. Therefore, ice pixels can be extracted by using the thresholding method. Most of the ice can then be identified, as shown in Fig. 2based on Fig3. Of the ice pixels identified, however, only "light ice" has larger pixel intensity values than the threshold.

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"Dark ice," with pixel intensity values between the threshold and water, such as ice pieces under the water surface, may not be identified and thus considered to be water, according to the thresholding method. Both "light ice" and "dark ice" pixels are required for an accurate analysis. To distinguish "dark ice" from open water, the k-means clustering algorithm can be applied. This minimizes the within-cluster summed distance to partition a set of data into k clusters. The image is then divided into three or more clusters, using the k-means algorithm. The cluster with the lowest average intensity value is considered to be water, while the other clusters are considered ice, as shown in Fig. 3. The "dark ice" is then obtained by comparing the difference between Figs. 2 and 3, as shown in Fig. 4.

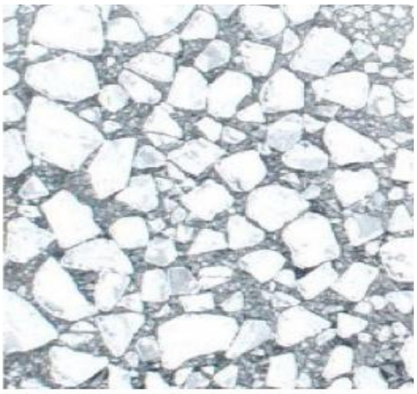

Fig. 2. Original sea-ice image.

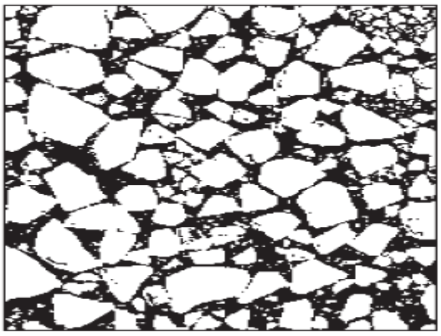

Fig. 3. "Light ice" extracted by the thresholding method.

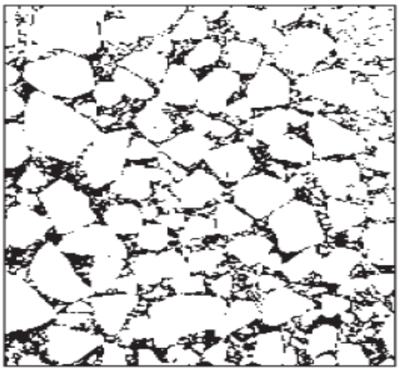

Fig. 4. Ice extraction using the *k*-means method.

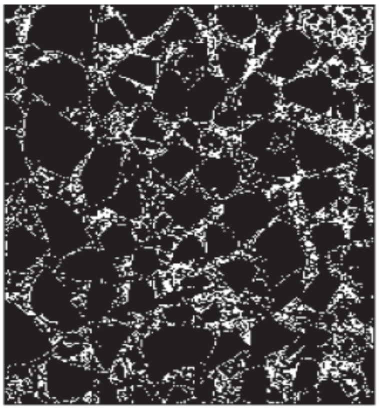

Fig. 5. "Dark ice" found by subtracting Fig. 3 from Fig. 4.

k-means is one of the simplest unsupervised learning algorithms that solve the well known clustering problem. The procedure follows a simple and easy way to classify a given data set through a certain number of clusters (assume k clusters) fixed apriori. The main idea is to define k centers, one for each cluster. These centers should be placed in a cunning way because of different location causes different result. So, the better choice is to place them as much as possible far away from each other. The next step is to take each point belonging to a given data set and associate it to the nearest center. When no point is pending, the first step is completed and an early group age is done. At this point we need to re-calculate k new centroids as barycenter of the clusters resulting from the previous step. After we have these k new centroids, a new binding has to be done between the same data set points and the nearest new center. A loop has been generated. As a result of this loop we may notice that the k centers change their location step by step until no more changes are done or in other words centers do not move any more. Finally, this algorithm aims at minimizing an objective function know as squared error function given by:

$$J(V) = \sum_{i=1}^{c} \sum_{j=1}^{c_i} \left(\|x_i - v_j\| \right)^2$$

where,
'$\|x_i - v_j\|$' is the Euclidean distance between x_i and v_j.
'c_i' is the number of data points in i^{th} cluster.
'c' is the number of cluster centers.

In order to identify different types of ice, the K-means clustering method can be applied to divide the image into three or more clusters. In this research, we divided the image into three groups, which we roughly interpret as ice floes in red regions, open water in blue regions, and others (e.g. brash ice) in yellow regions. The coverage of each cluster was also calculated. The results are presented below

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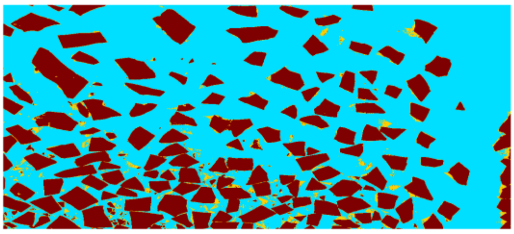
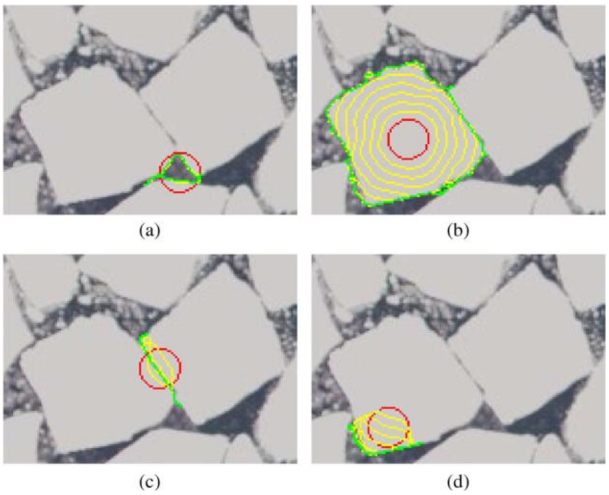


FIG 6

The most challenging task is to identify individual ice floes in the sea-ice image, in particular separating the floes that are very close or connected to each other. The boundaries between apparently connected floes have a similar brightness to the floes themselves. The boundaries are too weak to be detected directly, which significantly affects the ice floe statistical result. Therefore, the GVF snake algorithm is proposed to solve this problem.



The GVF snake algorithm is able to detect the weak connections between floes and ensure that the detected boundary is closed. As an example, shown in Fig. 6(b), given an initial contour (red curve), the snake finds the floe boundary (green curve) after a few iterations (yellow curves). The GVF snake algorithm relaxes the requirements of the initial contour.

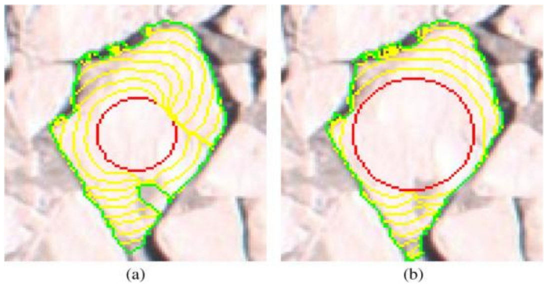
However, a proper initial contour for an object is still necessary, particularly to identify the mass of ice floes in an ice image. Many initial contours are required when performing the GVF snake algorithm to identify all individual ice floes, and these should have proper locations and shapes.

An automatic contour installation algorithm is therefore devised to increase the efficiency of the ice floe segmentation method based on the GVF snake algorithm. Fig. 6 illustrates the floe boundary detection results affected by initializing the contour at different locations. In Fig. 6(a), the initial contour is located at the water, close to the ice boundaries. The snake rapidly detects the boundaries, however, not the ice but the boundaries of the water region. When initializing the contour at the center of an ice floe, as shown in Fig. 6(b), the snake accurately finds the boundary after a few iterations.

A weak connection will also be detected if the initial contour is located on it, as shown in Fig. 6(c). However, when the initial contour is located near the floe boundary inside the floe, as shown in Fig. 6(d), the snake may only find a part of the floe boundary near the initial contour.

It should be noted that the curve is always closed, regardless of how it deforms, even in the cases of Fig8(c) and (d), which appear to be non closed curves. This behavior occurs because the area bounded by the closed curve tends toward zero.

Fig. 6 illustrates that, with proper parameters, the snake will find a boundary, regardless of where the initial contour is located. This fact is beneficial for connected floe segmentation. As shown in Fig. 6, the initial contours should be located inside the floes and centered as close to the ice floe center as possible.



To accomplish the requirements of the initial contour, an automatic contour initialization algorithm based on the distance transform and its local maxima is proposed.

Given a binary image, whose elements only have values of "0" or "1," the pixels with a value of "0" indicate the background, whereas the pixel with a value "1" indicates the object. The distance transform of a binary image is the minimum distance from every pixel in an object to the background.

IV. CONCLUSION

A remote sensing mission yielded experience in data acquisition using a UAV. Various image processing methods were applied to a few samples of the collected sea-ice image data for analysis to retrieve important sea-ice information. Focusing on identifying the nonridged ice floe in the marginal ice zone, and the managed ice resulting from offshore operations in sea ice, we proposed an algorithm to identify the individual ice floes in a sea-ice image using the GVF snake algorithm. To evolve the GVF snake automatically, "light ice" and "dark ice" were first obtained using the thresholding and k-means algorithms.

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