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On-site helicopter-borne high-resolution image acquisition and mosaicking for investigation of drifting Arctic sea ice

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ABSTRACT

On-site high-resolution sea ice images from the imaging instruments on airplane, helicopter, ship and unmanned aerial vehicle (UAV) platforms have been used as the reference datasets for validation of the sea ice properties. Among the low altitude remote sensing platforms, helicopters usually carried onboard icebreakers for scientific research activities and logistics have been recognized as a reliable remote sensing platform from enhanced endurance and verified stability, and have flexibility for the attachment of multiple sensors. Although areal reference datasets, e.g., helicopter-borne high-resolution images, can be used to validate lower resolution sea ice information from the characteristics of enough coverage and fine spatial resolution, continuous drift of sea ice causes distorted locations of image acquisition along the drift; thus, becomes an obstacle for precise image mosaicking and matching with the sea ice information extracted from lower-resolution remote sensing imagery. This study presents methods for the cost-effective acquisition of helicopter-borne high-resolution images over drifting Arctic sea ice using a simple configuration of imaging sensor and GPS logger, and for the compensation of the effect from sea ice drift from each imaging location using the drift trajectory of sea ice. After mosaicking the sea ice drift compensated high-resolution helicopter-borne images with structure-from-motion technique, the applicability of the mosaicked image was assessed by comparing with lower resolution satellite synthetic aperture radar image. The results suggest that the proposed methods can be applicable to the high-resolution images from other low altitude remote sensing platforms, e.g., UAVs, and can be used for precise comparison with various sea ice products from satellite remote sensing.

Keywords: sea ice, helicopter-borne imaging, very high-resolution, structure-from-motion

1. INTRODUCTION

Observing the state of Arctic sea ice by remote sensing technique is important for understanding the effects of climate change. Various satellite remote sensing techniques have been applied to investigate physical properties of sea ice, for example, concentration, thickness, surface roughness, surface composition, etc.

On-site very high-resolution (VHR) sea ice images from imaging instruments on various platforms, such as airplane, helicopter, ship and unmanned aerial vehicle (UAV), have been used as the reference datasets for calibration and validation of the sea ice properties, and these low-altitude remote sensing platforms have enabled image acquisition of less affected by clouds. The VHR images are also useful for assisting fieldwork by recording the locations of experimental measurements during the fieldwork

Among the low-altitude remote sensing platforms, helicopters usually carried onboard icebreakers for scientific research activities and logistics have been recognized as a reliable platform from enhanced endurance and verified stability, and have flexibility for the attachment of multiple remote sensing sensors.

To calibrate and validate the sea ice information such as surface topography, floe size, ridge distribution and melt pond fraction, mosaicked VHR images acquired from the low-altitude remote sensing platforms can be used as ground truth data because the mosaicked images have enough coverage with fine spatial resolution which is sufficient for the calibration and validation purposes. However, continuous sea ice drift occurring during image acquisition hampers precise image mosaicking and accurate geographic matching with other remote sensing products.

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This study presents strategies for the cost-effective acquisition of helicopter-borne high-resolution images over drifting Arctic sea ice using a simple configuration of imaging sensor (i.e. a commercial digital camera) and GPS logger, and for the compensation of the effect from sea ice drift from each imaging location using the drift trajectory of sea ice.

2. STUDY AREA

The study area was in northwest of the Chukchi Sea, Arctic Ocean around 77°36′N/179°20′E. In the study area a field investigation was fulfilled on ice floes with the support of the Korean icebreaking research vessel (IBRV) Araon during 13–15 August 2017. Sea ice conditions in the field investigation period were identified as 80–90% sea ice concentration from the daily data of the National Snow and Ice Data Center (NSIDC) [1]. The IBRV Araon was tightly anchored to a conglomerate of ice floes during the field investigation on sea ice.

3. METHODS

Procedures of the VHR image acquisition, mosaicking, and accuracy assessment consist of helicopter-borne image acquisition with GPS logging, correction of the effect from continuous sea ice drift using a time-interpolated trajectory of the IBRV Araon, mosaicking the VHR images, and testing the feasibility of the mosaicked VHR image as illustrated in Figure 1. Detailed processes in each step are described in following sections.

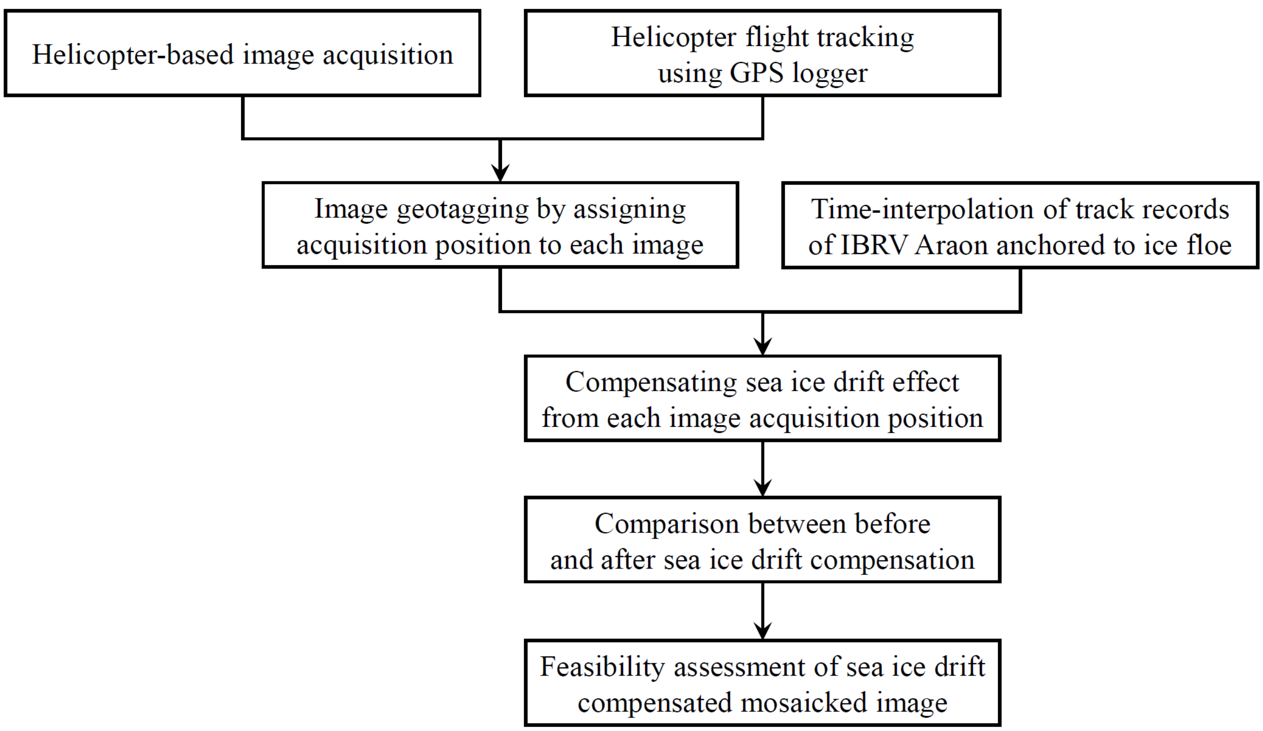


Figure 1. Working processes for acquiring and mosaicking helicopter-borne very high-resolution (VHR) sea ice images and testing the feasibility of the mosaicked VHR image.

3.1 Acquisition of helicopter-borne images

For acquisition of VHR images, a commercial digital camera was attached to the bottom of a helicopter with nadir viewing direction (Figure 2). A GPS logger was placed inside the helicopter during flight to record imaging locations. The images were acquired every second using an automatic trigger.

Figure 2. Details of the installation of the imaging equipment and GPS logger on the helicopter carried on board the IBRV Araon.

3.2 Compensation of the drift effect of sea ice in imaging locations

Two subsets were chosen from altitudes of 200–400 m and from altitudes higher than 1000 m among the acquired images. First images in the subsets were defined as reference images for the sea ice drift correction process. The drift trajectory of the target sea ice was recorded from the IBRV Araon and a sea ice buoy. Time interpolation technique was applied to the trajectory data of sea ice to match the time of image acquisition with the trajectory records. Differences between geographic locations of the target ice floe at the acquisition time of the first image and at the acquisition time of the other images were calculated, and then subtracted from each image. From this correction of the sea ice drift, the imaging locations were moved to be located as to be acquired at the same time of the first image acquisition.

3.3 Mosaicking VHR images and accuracy assessment

The images with uncorrected and drift corrected geographic coordinates were mosaicked using a commercial software, Agisoft PhotoScan, based on the structure-from-motion (SfM) technique [2]. Image mosaicking processes consisted of image alignment, sparse point detection and optimization, dense point cloud construction, digital elevation model generation, and mosaicking orthorectified images [3]. Accuracy was assessed by comparing estimated locations of image acquisition before and after correction of the sea ice drift for the two image subsets.

The mosaicked image was compared with the satellite SAR image for a feasibility test. To test the feasibility of the mosaicked VHR image for the calibration and validation of lower-resolution remote sensing data, geographic matching of the target ice floe included in the mosaicked VHR image and the satellite SAR image was assessed using similarity transformation [4]. For applying the similarity transformation, control points were manually selected from clear surface features on sea ice image.

4. RESULTS

4.1 Results of helicopter-borne VHR image acquisition

About 4000 helicopter-borne VHR images were acquired by a single flight (Table 1) with the low-cost digital camera and GPS logger. During the flight, the VHR images covering several kilometers were efficiently acquired, and mosaicked using the SfM technique. From this result, the helicopter carried onboard the icebreaker and the cost-effective sensors equipped on the helicopter were shown to be a simple and practical strategy for acquiring on-site VHR images.

Table 1. Specifications and results of helicopter-borne VHR image acquisition.

Helicopter-borne image acquisition results	Specifications
Image acquisition interval	1 sec
Imaging mode	Aperture priority
Aperture	F11
Shutter speed	Between 1/1000 and 1/3200
ISO	400
Number of acquired images	4041
Altitude of imaging locations	Up to 2407 m above sea level

As mentioned in the methods, Two image subsets were selected in the relatively lower altitude range of 200–400 m and from altitudes higher than 1000 m. The subset I contained images within a smaller area than the subset II, however the imaging duration was longer than the subset II.

4.2 Results of the sea ice drift compensation in imaging locations

Among the images in the subsets I and II, the first acquired images of each subset were selected as the reference images for correction of the effect from sea ice drift. Location differences between of the target ice floe at the acquisition time of the reference image and at the acquisition time of the other images were measured based on the trajectory of sea ice drift. The location differences were then subtracted from the geographic coordinates of each imaging location, so that the imaging locations were moved after the correction of the sea ice drift. During the image acquisition, the target ice floe maintained a heading direction with a low variation and translation was shown to be near linear.

After correction of the effect of sea ice drift, the imaging locations were adjusted as the locations at the acquisition time of the first image in each subset. This correction can reduce the uncertainty in the geographic coordinates of images without using ground control points [5, 6] which are not available in condition of drifting sea ice.

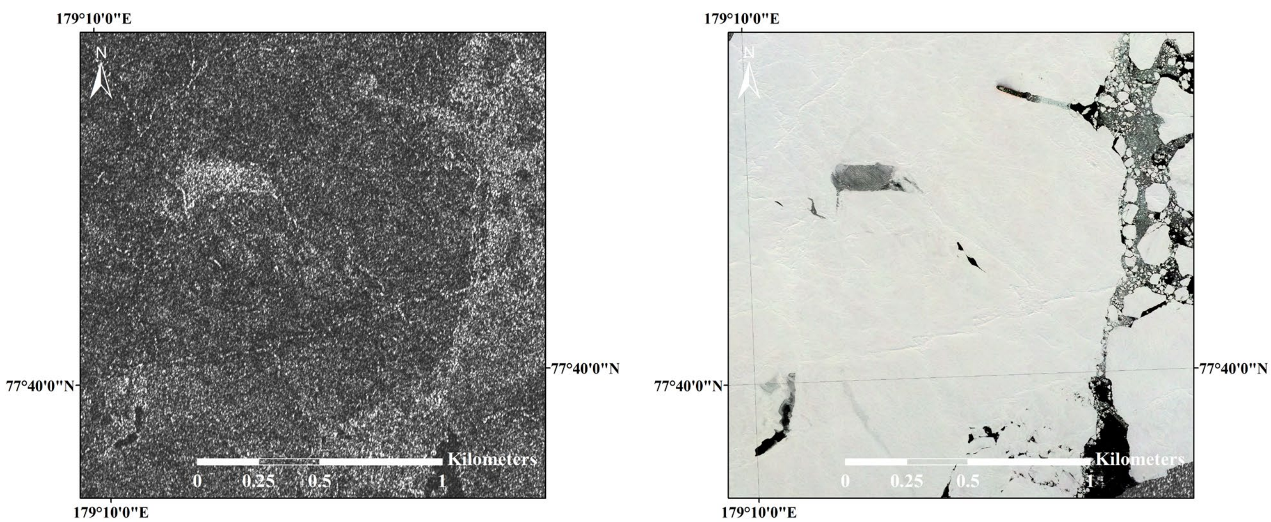
4.3 Results of image mosaicking and accuracy assessment

Mosaicked VHR images from the two image subsets were generated using the images after correction of the effect of sea ice drift. After correction of the effect of sea ice drift, the differences between the initial imaging locations and the estimated imaging locations were decreased for the both subsets. The amount of error reductions for the subset I of longer imaging duration than the subset II was larger than for the subset II.

For practical uses including the calibration and validation of lower-resolution satellite data or sea ice products retrieved from the lower-resolution remote sensing data, the mosaicked VHR image needs to be compared with the lower-resolution data. To test the feasibility of the helicopter-borne mosaicked VHR image for calibration and validation of lower-resolution remote sensing data, geographic matching with the satellite SAR image were assessed using the similarity transform. Control points were carefully selected from the prominent surface features in the mosaicked image from the image subset II, covering wider area than the subset I. The control points were located inside the ice floe to avoid areas weak for surface melting and deformation from collisions with other ice floes. As a result, the target ice floe in the mosaicked VHR image was precisely registered on the SAR image. During the registration process, the scale and rotation were evaluated as about 1 and 7 degrees. Slight rotation of the target ice flow occurred after the VHR image acquisition from continuous drift of the ice floe. Although the rotation of the ice floe after the imaging period was not considered during the drift correction, precise registration was conducted using a few control points and the similarity transformation. The distribution of ice floes adjacent to the target ice floe was changed in the SAR image compared with the mosaicked VHR image because the time passage of more than two days caused different drifts to the adjacent sea ice.

Although the mosaicking processes using the sea ice drift corrected images were carried out by using popular commercial SfM software, other SfM technique implemented software can be easily applied for generating mosaicked VHR image with the image mosaicking processes as used in this study.

In the area around the IBRV Araon, detailed sea ice surface structures such as flat ice and pressure ridge, and surface constituents such as ice, snow and water, which can be observed in the mosaicked VHR image were directly comparable with the satellite SAR image (Figure 3). The surface characteristics of sea ice can be further investigated by comparing both images and can be applied into the calibration and validation of satellite data and satellites remote sensing-based sea ice products.



(a) (b)

Figure 3. Comparison of the mosaicked helicopter-borne VHR image with the satellite SAR image: (a) The satellite SAR image around the IBRV Araon and (b) the mosaicked VHR image around the IBRV Araon.

5. CONCLUSIONS

This study presented the practical and efficient approaches for acquisition of VHR images over drifting Arctic sea ice using low-cost digital camera attaching to a helicopter, and for correcting the effect of sea ice drift. After the correcting the sea ice drift, the errors of the imaging locations were reduced, and the improvements on the geographic coordinates were depended on the imaging duration. From the feasibility test of the mosaicked VHR image by comparison with the satellite SAR image, the proposed techniques were considered to be applicable for direct comparison between lower-resolution remote sensing data and the precisely geolocated VHR images. Although helicopter-borne VHR images were acquired and utilized in this study, the proposed techniques can be used to mosaic sea ice images obtained from other low altitude remote sensing platforms such as airplane or UAV.

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