MOSAICKING VERY-HIGH-RESOLUTION HELICOPTER-BORNE IMAGES ACQUIRED OVER DRIFTING ARCTIC SEA ICE USING COTS SENSORS

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KEY WORDS: Sea ice, Very-high-resolution, Commercial off-the-shelf, UAV, Icebreaker, Helicopter-borne

ABSTRACT:

In order to observe and record conditions of the sea ice efficiently and specifically during in-situ investigation with the support of icebreaker research vessel (IBRV), the very-high-resolution (VHR) imaging systems have been used in recent past. The VHR images are generally acquired lower altitude than cloud height, therefore, the images can be acquired even in unfavourable weather conditions for optical satellite image acquisition, and can be applied to comparison with various kinds of remote sensing datasets. However, producing mosaicked image using the VHR images have suffered from drift of sea ice. The sea ice drift interrupts simultaneous geotagging in overall study area as geographic locations of sea ice moves continuously; therefore, the mosaicked image generated from improperly geotagged individual image depicts a scene of ambiguous time. In this study, we present a case study of VHR sea ice image acquisition using a helicopter equipped with commercial off-the-shelf (COTS) geotagging and imaging sensors with a support of IBRV Araon in East Siberian Sea, Arctic Ocean. We also propose an image mosaicking strategy using the improperly geotagged VHR images acquired over drifting sea ice to decrease temporal and spatial ambiguity**.**

1. INTRODUCTION

Changes in properties of arctic sea ice, e.g., extent, concentration, thickness and melt pond coverage, reflect climate changes in arctic ocean. To investigate the former and present states and predict future condition of sea ice, low-resolution remote sensing technique with a spatial resolution of 1 km or larger pixel size, generally has been used, e.g., passive microwave satellite remote sensing (e.g., Cavalieri et al., 1996) and optical satellite remote sensing (e.g., Rösel et al., 2012), because the low-resolution satellite remote sensing has capabilities of acquiring dataset over vast polar regions within a short period of time, e.g. daily or a few days temporal resolution. Therefore, high temporal resolution sea ice products e.g., extent, concentration and thickness, over entire arctic or antarctic regions can be produced. Very-high-resolution (VHR) remote sensing with a spatial resolution of a few centimetres, on the other hand, has been less applied to sea ice studies.

In order to observe and record conditions of the sea ice more efficiently and specifically during the period of in-situ investigation with the support of icebreaker research vessel (IBRV), the VHR imaging systems attached on the IBRV have been used in recent past (e.g., Toyota et al., 2006). The shipborne imaging systems have limits on observing range from restricted height of observation position and oblique viewing geometry. More recently, unmanned aerial vehicle (UAV) or helicopter equipped with VHR imaging systems have been used (e.g., Perovich and Jones, 2014). While the UAV and helicopter imaging systems improved spatial coverage from multiple higher image acquisition positions than the shipborne imaging systems, drifting sea ice still hampers generating precisely mosaicked image.

The in-situ acquired VHR images can be used for recording detailed sea ice conditions simultaneously with field research activities, and can be applied to calibrate, validate or compare with lower resolution satellite remote sensing datasets of wide spatial coverage. The VHR images are generally acquired lower altitude than cloud height, therefore, the images can be acquired even in unfavourable weather conditions for optical satellite image acquisition, and additionally, can be applied to comparison with various kinds of remote sensing datasets, e.g., optical, passive microwave or synthetic aperture radar datasets. However, producing mosaicked image have suffered from drift of sea ice. The sea ice drift interrupts simultaneous geotagging in overall study area as geographic locations of sea ice moves continuously; therefore, the mosaicked image generated from improperly geotagged individual image depicts a scene of ambiguous time.

In this study, we present a case study of VHR sea ice image acquisition using a helicopter equipped with commercial off-the-shelf (COTS) geotagging and imaging sensors with a support of IBRV Araon of Korea Polar Research Institute in the East Siberian Sea, Arctic Ocean. We also propose an image mosaicking strategy using the improperly geotagged VHR images acquired over drifting sea ice to decrease temporal and spatial ambiguity induce from continuously drifting sea ice during image acquisition.

2. MATERIALS

2.1 Description of Study Area

The sea ice field investigation was conducted around 77°36’N/179°12’E in the East Siberian Sea, Arctic Ocean with a support of IBRV Araon, during August 13-15, 2017 (Figure 1). Sea ice conditions during the field investigation period around the study area were estimated in the range of 80–90% sea ice concentration from the National Snow and Ice Data Centre (NSIDC).

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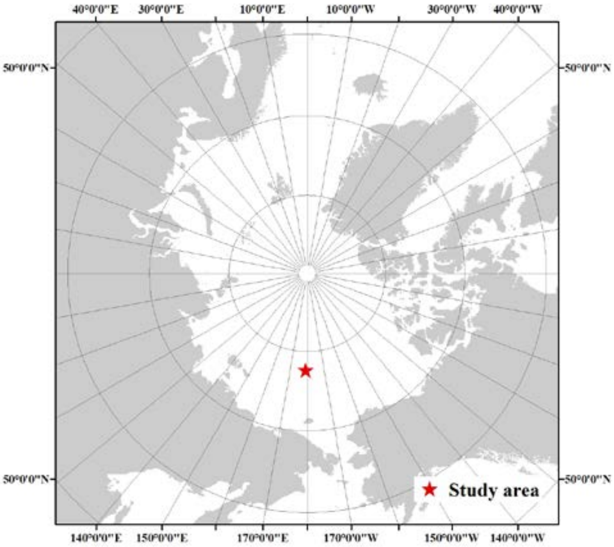

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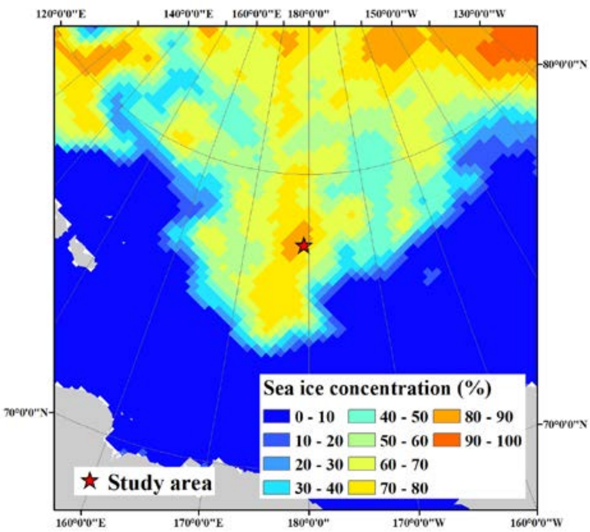

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Figure 1. Overview of study area: (a) location of the study area and (b) sea ice condition data from NSIDC around the study area on August 14, 2017.

2.2 Acquisition of Dataset

The VHR images were acquired during sea ice field investigation using helicopter-borne COTS imaging sensor. A commercial Canon M6 digital camera was attached on the bottom of helicopter and set to nadir viewing geometry (Figure 2). Imaging time interval was set to every single second. Timing of image acquisition was recorded in metadata as a temporal resolution of 0.05 second.

Figure 2. Details for installation of imaging equipment on helicopter.

To record flight path of the helicopter, a commercial potable GPS logger with a capability of 20 Hz recording frequency was carried during flight for image acquisition. In a post-processing procedure, the GPS logs of the time difference less than 0.02 second between GPS log and timing of image acquisition were selected and designated as the image acquisition positions of corresponding images.

2.3 Image Pre-processing Procedure

To decrease temporal and spatial ambiguity of the VHR images, linear time interpolation approach was adopted (Hyun and Kim, 2017). The IBRV Araon was anchored firmly in the sea ice floe where field investigation was conducted during the VHR image acquisition and the position of the IBRV Araon synchronized with drift of ice floe field was recorded in 1 Hz frequency by interior voyage logging system. The position of the IBRV Araon at the mid of timing of the VHR images selected for analysis was assigned as a reference position, and then other positions of the IBRV Araon recorded in 1 Hz, i.e., 1 second time interval, were linearly interpolated to 0.05 second interval to match with the VHR images.

From the time interpolated drift records of the IBRV Araon, differences in locations between the reference position and linearly time interpolated positions corresponding to each VHR image acquisition position were calculated. As a final step, the VHR image acquisition positions except for the image at the reference position were adjusted using the differences of locations to compensate temporal and spatial ambiguity from the sea ice drifts.

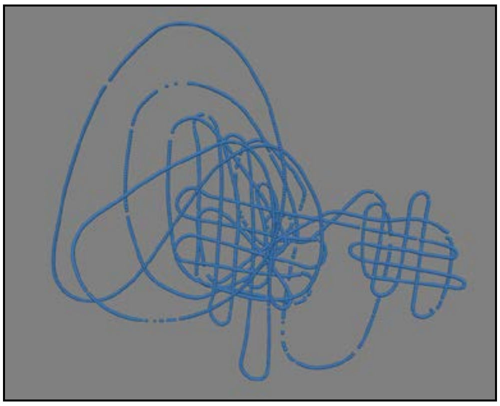
2.4 Image Mosaicking and Error Assessment

After the compensation of the effects from sea ice drifts in the VHR images acquisition positions, structure-from-motion (SfM) technique was applied to mosaic the pre-processed VHR images. To assess improvement of errors of camera locations after pre-processing, photogrammetric inference and accuracy assessment of camera locations were conducted during image mosaicking procedure with Agisoft Photoscan software.

3. RESULTS AND DISCUSSION

3.1 Specifications of Image Acquisition

Totally, about 4,000 VHR images were acquired during sea ice field investigation in a single flight using helicopter-borne COTS imaging sensor (Figure 3). Although the flight path was not designed as a systematic flight plan for conventional terrain mapping considering uniform overlaps between images and terrestrial elevation changes, rather a flight for opportunistic acquisition of images, the images were acquired with sufficient overlaps.



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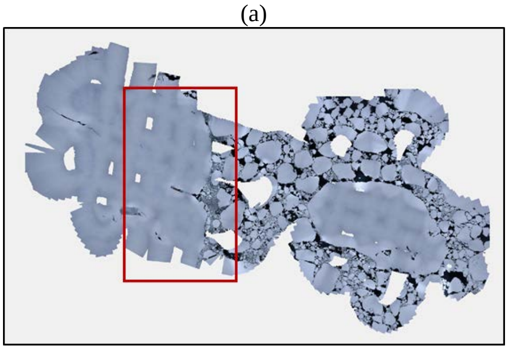

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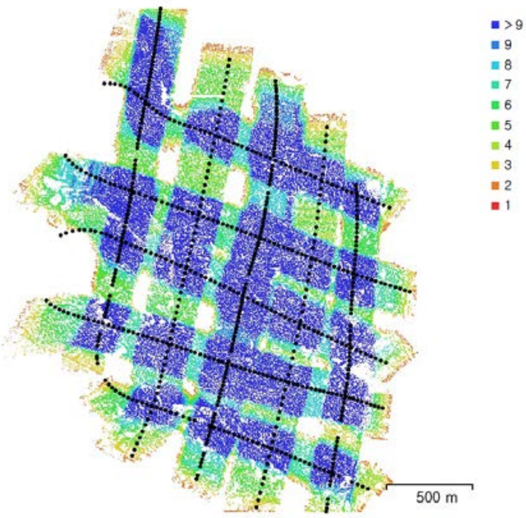

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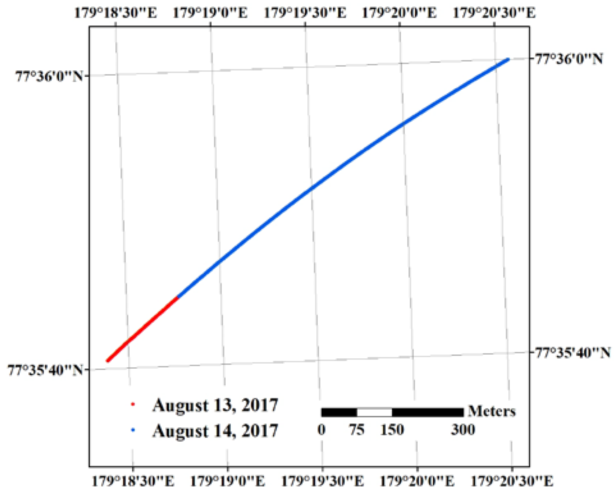
Figure 3. Helicopter-borne image acquisition results: (a) positions of image acquisition, (b) preliminarily mosaicked image using whole acquired images with a target area (red box) and (c) number of overlap images of the selected images for further sea ice drift compensation analysis.

3.2 Compensation of sea ice drift

Among the acquired VHR images, about 700 images acquired around IBRV Araon were selected for the compensation of the effects from sea ice drifts. Trajectory of sea ice drift recorded from IBRV Araon anchored to ice floe was nearly linear (Figure 4). The speed of sea ice drift was about 550 m/h during the period of the selected image acquisition.



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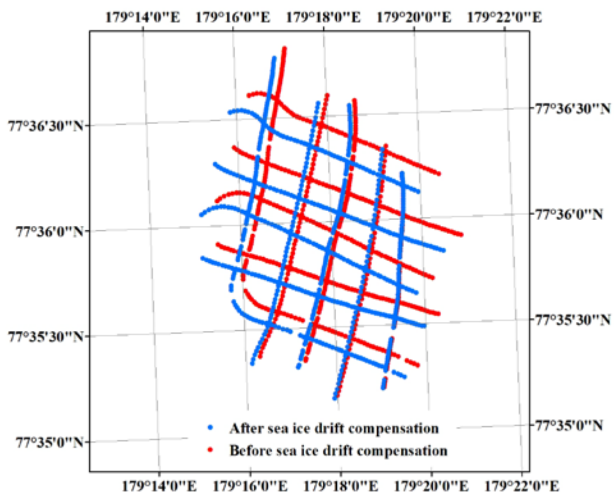

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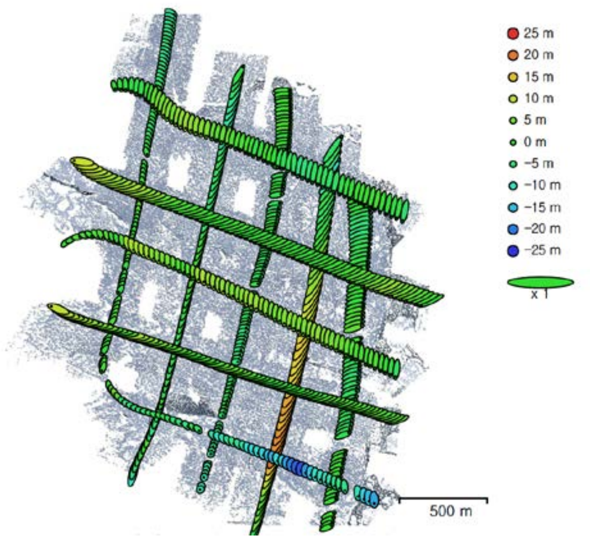
Figure 4. Compensation of sea ice drift in the VHR images: (a) trajectory of sea ice drift recorded from August 13, 2017 23:44:00 (UTC) to August 14, 2017 01:03:00 (UTC) recorded in IBRV Araon anchored to ice floe and (b) the image acquisition positions before and after compensation of sea ice drift.

Errors assessed from camera location inference results using structure-from-motion (SfM) technique were significantly decreased after the compensation of the effects from the sea ice drifts in the helicopter-borne VHR images (Figure 5). The total error of camera location was decreased about 62% after the compensation of the effects from sea ice drifts (Table 1).



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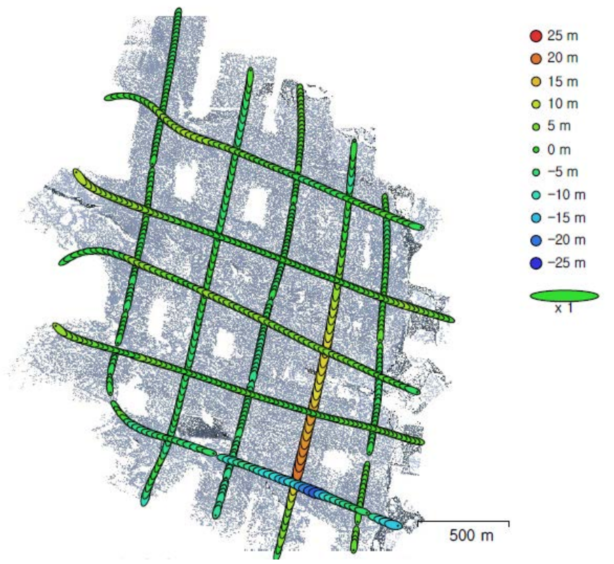

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Figure 5. Quality assessment of locations of photos taken during mosaicking: (a) errors from camera location estimation before sea ice drift compensation and (b) errors from camera location estimation after sea ice drift compensation.

Table 1. Quality assessment of camera locations before and after sea ice drift compensation.

Camera location	X error (m)	Y error (m)	Z error (m)	Total error (m)
Before sea ice drift compensation	61.1	59.0	5.4	85.1
After sea ice drift compensation	34.7	39.9	5.1	53.1

3.3 Image mosaicking using drift compensated sea ice images

Mosaicked image using sea ice drift compensated helicopter-borne images was generated with a spatial resolution of about 5 cm (Figure 6). The procedure to generate mosaicked image can be applicable to producing VHR mosaicked image at a specific time by selecting suitable reference position or time instead of the mid of timing of the VHR images selected for analysis for linear time interpolation.

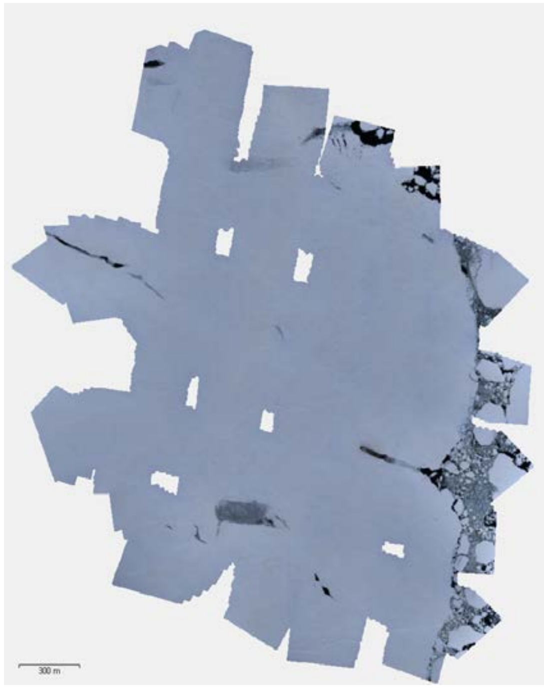

Figure 6. Mosaicked image generated from sea ice drift compensated images.

4. CONCLUSIONS

This study showed effective in-situ VHR sea ice image acquisition strategy using COTS sensors during in-situ arctic research activity. After the compensation of the effects from the sea ice drifts in the helicopter-borne images, errors assessed from camera location inference results using structure-from-motion technique (SfM) were significantly decreased.

The results are applicable to producing VHR mosaicked images at a specific time by selecting suitable reference position or time for linear time interpolation, and this enables more precise calibration, validation or comparison with lower resolution satellite images for further sea ice studies.

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