SEA ICE THICKNESS MEASUREMENT FROM AN ICE BREAKER USING A STEREO IMAGING SYSTEM CONSISTED OF A PAIRS OF HIGH DEFINITION VIDEO CAMERAS

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ABSTRACT:

Sea ice monitoring is quite important from the global warming point of view. Sea ice thickness is one of the most important parameters for understanding the heat flux of sea ice area. Usually, sea ice thickness is measured by drilling a hole on the sea ice. However, this work does take a lot of time. In order to effectively measure sea ice thickness from an icebreaker deck, in 2000, the authors have introduced a 3D measurement system using a pair of digital cameras. When the icebreaker breaks sea ice, the cross-section of the sea ice comes above sea level, and can be captured by the cameras. The system allows users to measure sea ice thickness with the error of 1.5cm when the stereo pair images were taken from the 2.5m above the sea level in proper condition. However, since the broken sea ice is moving rapidly, catching of good timing to release the shutter was not easy. As a result, number of the good stereo pair images was always limited compared with the total number of images taken during one cruising. Recently, the authors have replaced the digital cameras with high definition video (HDV) cameras. SANYO Xacti DMX-HD 1000 was selected as the HDV video cameras. Since the video cameras can continuously take the sea ice movement, the best stereo pair images to measure the sea ice thickness can be selected after the observation. In March 2009 and 2010, the authors have performed several experiments on an icebreaker Garinko-2 around the Monbetsu Bay of Hokkaido, Japan. The total number of the good stereo pair images taken during one cruising increased two or three times compared with the previous system. The result proved the usefulness of the system for measuring sea ice thickness along the trajectory of the ice breaker without stopping the cruising.
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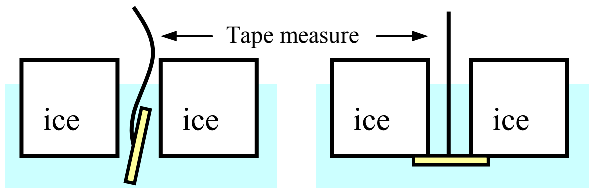
1. INTRODUCTION

In order to detect the sign of global warming, the importance of sea ice monitoring is increasing. Especially sea ice thickness is an important parameter for understanding the heat flux of sea ice area. Usually, sea ice thickness measurement is performed by drilling a hole on the sea ice as shown on Figure 1(a). Once the hole is open, the operator inserts a tape measure into the hole (see Figure 1(b)). A bar connected to the forefront of the tape measure act as a prop, and the operator can easily measure the ice thickness with the tape measure (See figure 1(c)). However, this work takes certain time and sometimes quite dangerous.

Several non-direct measurement methodologies for measuring sea ice thickness have been developed in the passed. Uto et al.(1998) used ship-borne single video camera for the measurement. When the icebreaker breaks sea ice, the cross section of the sea ice plate comes above the water and can be captured by the camera (See Figure 2). By assuming the field of view(FOV) size of the camera on the water surface, one can estimate the ice thickness from the video images. Ship-borne laser distance sensor (Shimoda et al. 1999), and mooring ice profiling sonar (Fukamachi et al., 1999) were also developed. However, the measurement accuracies of any of these methods were around 5cm or less.

(a) Drill a hole on the sea ice



(b) Insert a tape measure into the hole. (c) Measure the ice thickness with the tape measure.

Figure 1. Direct measurement of sea ice thickness

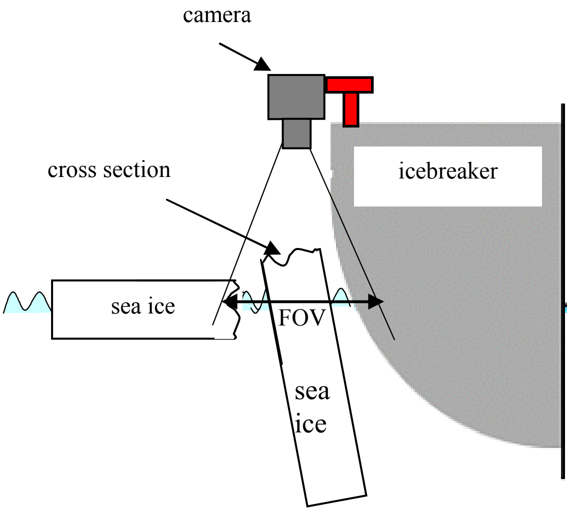


Figure 1. Taking cross section images of sea ice for ice thickness measurement.

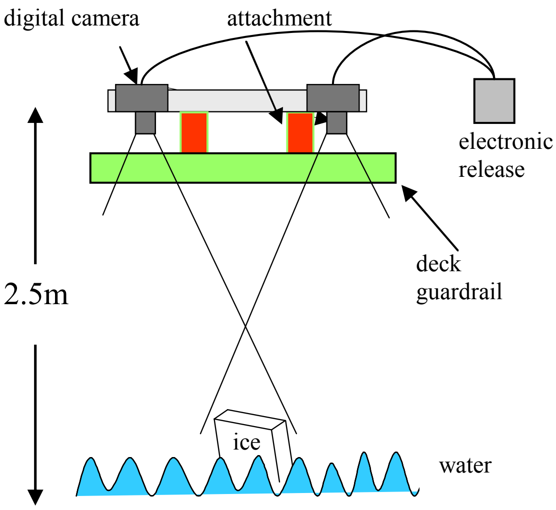


Figure 2. Stereo pair imaging system for measuring sea ice thickness.

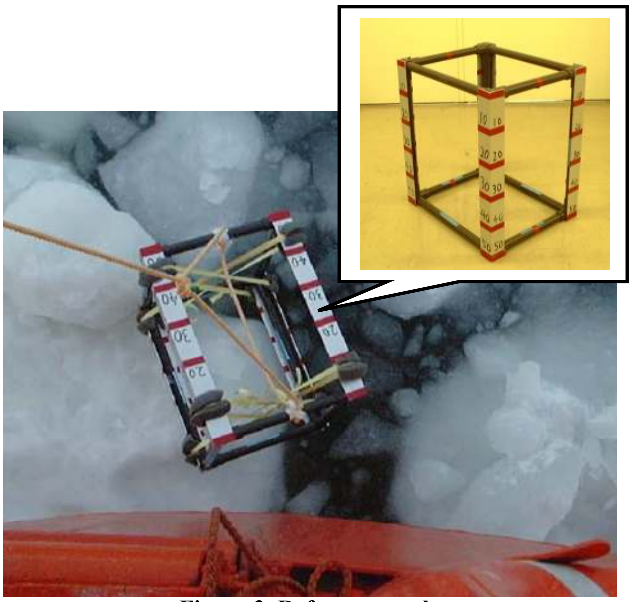


Figure 3. Reference angle

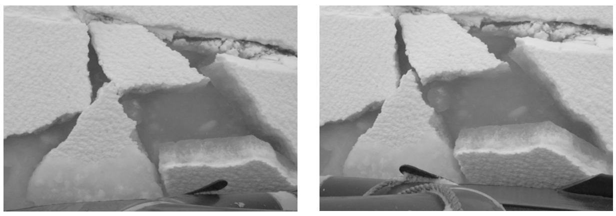
2. THE 3D MEASUREMENT SYSTEM

In order to measure sea ice thickness from an icebreaker with high accuracy, the authors have introduced a 3D measurement system using a pair of digital cameras (Cho et al. 2002). Figure 2 shows the concept of sea ice thickness measurement. Two digital cameras are attached on the deck guardrail of an icebreaker. When the icebreaker breaks sea ice, the cross section of the sea ice plate comes above the water and can be captured by the two cameras. The measurement of the ice thickness from stereo pair images were performed by For the past few years the authors have been testing the system every winter near the coast of Hokkaido, Japan by equipping a pair of 1280x1000pix resolution digital cameras on an icebreaker. In the beginning of an experiment, we take a pair photos of a rectangular parallel-piped angle of 50cm x 40cm x 45cm as a reference (see Figure 3). By using the parameters of the reference images, the ice thickness from the stereo pair images could accurately be estimated with commercial 3D measurement software such as Techno Viewer 3D. The accuracy of the system was 1cm when measures from 2.5m above the sea surface. However, since the sea ice around the icebreaker is always moving, getting good stereo pair images of the ice cross section with a pairs of digital cameras were not easy.

In order to continuously get good high resolution stereo pair images, the authors have replaced the pair of digital cameras with the pair of high definition video (HDV) cameras SANYO Xacti DMX-HD1000. This HDV camera provides non interlace 1280x720pix size images in 60 fps (frames per second). Table 1 shows the specifications of the 3D measurement system, and Figure 4 shows a stereo pair images of sea ice. Table 2 shows the measurement error evaluation result. When the target was measured from 2.5m distance, the maximum error of the measurement was 0.7cm for x(horizontal) axis, 0.6cm for y(vertical) axis, and 1.4cm for z(depth) axis.

Table 1. 3D measurement system specification

digital camera	SANYO Xacti DMX-HD1000
	pixel number: 1280×720
	focus length:f=49.7mm
	ISO : 50−800
appendix	adjustable arm(1m)
	electric double release
imaging spec.	shutter speed:1/250 – 1/500sec.
	Frame late : 60ftp
	base line:75cm
	distance:250cm
	pixel size:1.55 2mm/pixel
3D measuremet software	Techno Viewer 3D (Techno Vanguard)



(a) Left image (b) Right image
Figure 4. A stereo pair images of sea ice

Table 2. Measurement error evaluation

Direction	Min Error	Max Error
X	0.1cm	0.3cm
Y	0.1cm	0.3cm
Z	0.8cm	2.0cm

(* When measured from 2.5m distance)

3. SEA ICE THICKNESS MEASUREMENT EXPERIMENT

In Feburuary 2008, the authors have started the sea ice thickness measurement experiment using the HDV cameras at the Monbetsu Bay located along the coast of Hokkaido, Japan (See Figure 5). The 3D measurement system was equipped on the back side deck guardrail of the sightseeing icebreaker Garinko-2 as shown on Figure 6. Garinko-2 is a 35-meter-long icebreaker with maximum capacity of 195 passengers. Garinko-2 uses unique Archimedean screw as the driving power. The main purpose of the experiment was to establish a methodology to effectively collect sea ice thickness data of a wide area in short period of time to compare with satellite images.

On February 22 2009, the optical sensor AVNIR2 onboard ALOS satellite observed the Sea of Okhotsk around the Monbetsu Bay. Table 3 shows the specifications of AVNIR2, and Figure 7 shows the Band 4 (near infrared) image of AVNIR2. Unfortunately, the area was cloudy. However, we could slightly see the sea ice distribution under the thin clouds. On the same day, the sea ice thickness measurement using icebreaker Garinko-2 was performed. The sea ice zone was located about ten km offshore from Monbetsu Bay and was not widely distributed. Figure 8 shows the trajectory of the icebreaker and the area of sea ice thickness measurement overlaid on the AVNIR2 image. The red box in the Figure 7 corresponds to the area of Figure 8. Stereo pair images of the cross section of sea ice plates were captured during the cruising, and the ice thickness were estimated from the stereo pair images after the cruising using photogrammetric 3D measurement method. Figure 9 shows the ice thickness measurement results. The total average of the sea ice thickness measured in this area was 11.8cm.

One of the purposes of our study is to set up the ways to measure thin sea ice thicknesses to compare with optical sensor images observed from space. The experiment result proved that the sea ice thickness around 5 to 10cm could be measured with this 3D measurement system.

Figure 5. Location of Monbetsu Bay

(b) Two HDV cameras attached on the back side guardrail of the icebreaker.

Figure 6. Observation from icebreaker Garinko-2

Table 3. Specifications of ALOS AVNIR2

Band	Wavelength	IFOV	Swath
1	0.42 ～ 0.50μm	10m	70km
2	0.52 ～ 0.60μm		
3	0.61 ～ 0.69μm		
4	0.76 ～ 0.89μm		

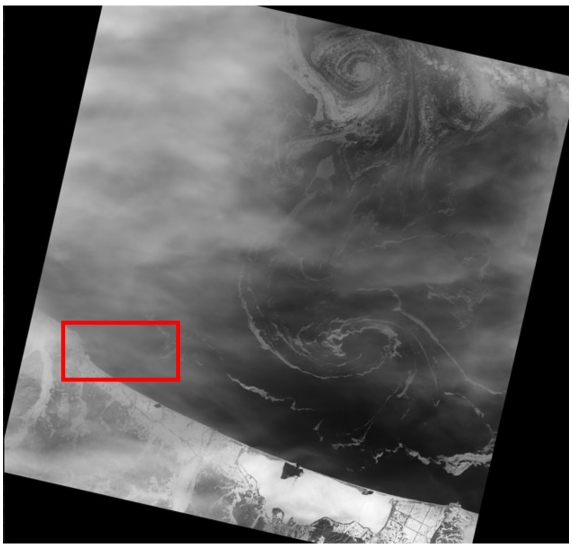


Figure 7. ALOS AVNIR2 image of the Okhotsk Sea along the coast of Hokkaido (February 22, 2008)

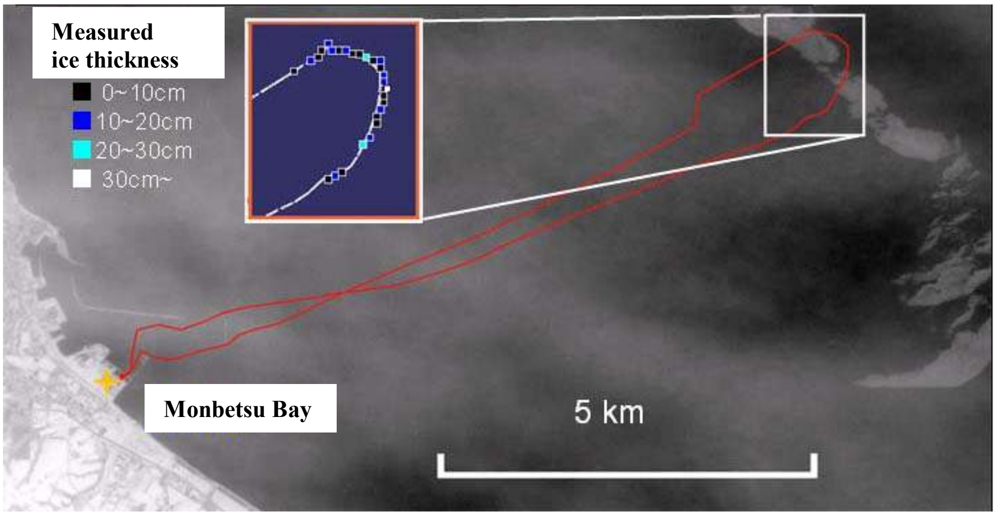


Figure 8. Trajectories and area of sea ice thickness measurement overlaid on AVNIR2 image. (Feb.22, 2008)

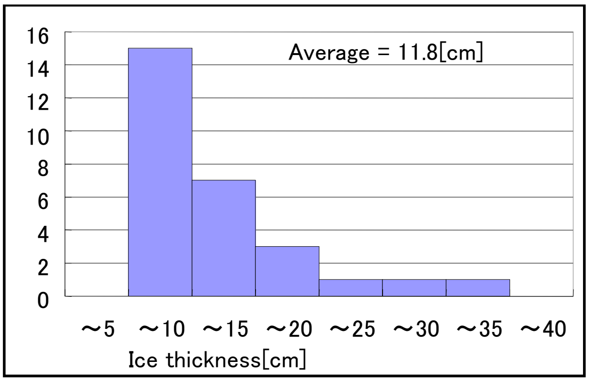
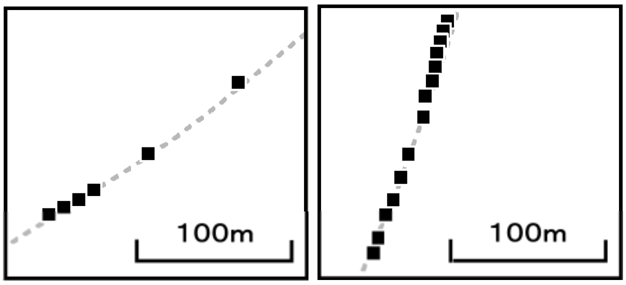


Figure 9. Ice thickness measurement result.



(a) Digital Camera **(b) HDV Camera**

Figure 10. Comparison of ice thickness measured points along the trajectory of the icebreaker.

Figure 10 shows the ice thickness measured points along the 200m trajectory of the icebreaker. Figure 10(a) shows the result of digital camera and Figure 10(b) shows the result of HDV camera. In the case of digital camera, only six good pair images were acquired. However, in the case of HDV Camera, 14 good pair images were acquired in almost constant interval. Since the both measurements were done in different sea ice area, we cannot simply compare the result. But, the result strongly suggests the advantage of using HDV camera for measuring sea ice thickness with the proposed 3D measurement system.

As for the relationship of sea ice thickness and AVNIR2 data, because of the thin cloud cover, we could not get particular relationship between the measured sea ice thickness and the AVNIR2 data.

4. CONCLUSIONS

The authors have developed a sea ice thickness measurement system by equipping a pair of digital cameras on the deck guardrail of an icebreaker. The system allows users to measure sea ice thickness with accuracy of 1.5 cm when the cameras were equipped 2.5m above the sea level under proper conditions. The experiment proved that the sea ice thickness could be measured effectively along the trajectories of the icebreaker without stopping the cruising. Especially, the use of HDV camera was useful for constantly acquiring good stereo pair images for measuring sea ice thickness. The authors are planning to perform an observation experiment by synchronizing the sea ice thickness measurement with airplane and satellites observation in February 2011 to verify the possibility of estimating sea ice thickness with remote sensing.

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