POAC'11
Montréal, Canada

Proceedings of the 21st International Conference on
Port and Ocean Engineering under Arctic Conditions
July 10-14, 2011
Montréal, Canada

POAC11-077

DIGITAL IMAGE TECHNIQUES OF SEA ICE FIELD OBSERVATION IN THE BOHAI SEA

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ABSTRACT

In this study, digital image techniques are adopted to process the sea ice parameters based on the dynamic characteristics and distribution conditions of sea ice in the Bohai Sea. A precise algorithm and effective software system are developed to determine the ice thickness, ice velocity and ice concentration, respectively. In the winter of 2009-2010, the developed sea ice digital image collection and processing system was utilized to monitor the ice parameters in the JZ20-2 oil-gas field of the Liaodong Bay. It shows that the developed system has the advantages of convenient operation, high accuracy and reliability.

INTRODUCTION

Systematic field observations of sea ice started in early 1960s in China, and different techniques have been developed since then. The field observation techniques have been continuously developed and improved especially since the oil and gas exploitation in the Liaodong Bay from 1990s. It has the advantage of continuous measurements with high precision, and is particularly important for providing detailed localized information of sea ice to ensure the safe operations during the exploitation of oil and gas fields in ice covered regions. The JZ20-2 oil and gas field was the first to apply field observation techniques with comprehensive monitoring contents.

Ice thickness, concentration and velocity are the three most important parameters in the field observations of sea ice parameters. The measurement techniques of ice thickness include ship based radar, upward looking sonar, electromagnetic induction and digital image techniques, besides visual measurement (Haas, 1998; Hall et al., 2002). Compared with fast ice in the polar region, sea ice in the Bohai Sea has the characteristics of high flowability and low thickness, and it is not suitable to perform contact measurement on the ice surface. Digital image techniques have been the main way for sea ice thickness measurement because of its high precision, low cost and easy operation.

For ice concentration measurement, satellite remote sensing, with wide measurement area and relatively high precision, has been used to extract the ice concentration information in the polar region (Knuth and Ackley, 2006; Toyota et al., 2009). However, satellite remote sensing data are easily affected by climate and receiving interval, and cannot get continuous measurement data. In addition, big errors exist in the ice concentration monitoring of local sea area. The ice concentration data have been obtained mainly by visual measurement with strong subjectivity. Recently, digital image recognition technique has been initiated in the ice concentration monitoring in the ice breaker investigation in the polar region (Richard et al., 2002; Lu et al., 2010).

Sea ice velocities are normally monitored with marine radar, buoys and satellite remote sensing. Relatively ideal velocities have been obtained through marine radar. However, this method involves manpower, and can not get velocities continuously during the whole ice period. On the other hand, buoys and satellite remote sensing have the disadvantage of high cost or weak continuity.

Therefore, we developed a software system for sea ice field observations using OpenCV and C# language to process digitally the monitored image data in this study. We applied the system on the JZ20-2 oil and gas field in the Liaodong Bay during the winter of 2009-2010, and monitored continuously the sea ice parameters of the whole ice period. The obtained sea ice data provide timely and reliable reference for early warning and protection for ice damage.

DIGITAL IMAGE TECHNIQUES AND THE SOFTWARE DEVELOPMENT

Digital image technique of ice thickness

The measurement of ice thickness includes three parts: 1) The installation, configuration and calibration of video monitoring system; 2) The collection and digital processing of video images; 3) The extraction and analysis of ice thickness data. When sea ice interacts with the conical structure on the pile of the platform, flexural failure may happen, and the ice thickness cross section is clearly displayed with the overturn of the ice after breakage. The marginal points of sea ice are extracted after corrections to the collected images of the ice breakup process, and the corresponding pixel points of the ice thickness are predicted. The corresponding length of the pixel points can be calibrated by the characteristic length of the conical structure.

Figure 1 shows the schematic of ice thickness measurement. A characteristic length *AB*, here the diameter of the cone *D*, is chosen and calibrated, and the thickness t_i is measured after ice break-up. The real thickness of sea ice can be calculated based on the proportional relationship between the diameter of the cone and the ice thickness,

$$t_{\mathrm{i}} = D\frac{r_{\mathrm{i}}}{r_{\mathrm{D}}} \tag{1}$$

where *D* is the diameter of the cone, r_i is the pixel length of ice thickness and r_D is the pixel length of the cone diameter. Usually, three different ice thicknesses are chosen to reduce the measurement error. For example, the thicknesses are 13.2cm, 13.7cm and 13.9cm, respectively, of the three different cross sections of the sea ice shown in Fig. 1. In fact, the ice thickness measurement is the measurement of distance, and has the advantage of high stability and strong operability.

The ice thickness measurement error is attributed to the image resolution and analytical technique. However, the sunlight, climate and measurement angle in the field observations will also produce some measurement error. In order to improve the reliability of the monitored data, the observation was performed perpendicularly to the conical structure and the ice thickness cross section. This was considered when installing CCD, and statistic analysis were carried out to multiple sets of measurement data.

Figure 1 The schematic of ice thickness measurement.

Digital image technique of sea ice concentration

Sea ice concentration can be determined through the processing of sea ice digital images, which includes image correction and parameter identification. Image distortion exists to some extent due to the shooting angle when shooting or videoing from the platform, and needs to be corrected. Image recognition is mainly to determine the proportion of sea water and sea ice through image segmentation.

We used the maximum between-class variance (Otsu method) to segment sea water and sea ice. The key point is to identify and extract the object (sea ice) from the background (sea water). Global threshold segmentation algorithm was used to segment the image. The image was first enhanced with Homo-morphic filtering method and then inpainted with morphological method after image edge detection. After obtaining the binary image and multiplying the image correction matrix, the proportion of the white pixels in all the pixels is calculated and the ice concentration is obtained.

However, the simple global threshold segmentation algorithm cannot meet the precision requirement when the demarcation line is not so clear between ice and water due to the effect of sunlight, shadow and climate. Thus, the adaptive threshold segmentation algorithm was adopted with the following three improvements: 1) Compress the image to reduce the computational complexity; 2) Enhance the image contrast by equalizing the grey scale; 3) Evaluate the optimum threshold value to simplify the segmentation algorithm.

This used image processing method has the advantages of simple calculation and high stability. It is suitable for 90% and above images, and can be programmed to realize batch image processing. For example, Fig.2-a is the image collected at 13:30 on Jan. 1, 2010 on the JZ20-2 sea area. Fig.2-b is the segmentation of ice and water on the binary image, and the ice concentration is 86.1%. In addition, considering the interference of the sea level in the digital image (as in Fig.3), a function to extract the sea level is added in the concentration identification. With the definition of the sea horizon, the sky on the upper image is deleted and only the image under the sea horizon is processed. By this way, the problem of taking the sky as sea ice is effectively solved. The sea ice concentration identification results reflect the real condition of sea ice objectively.

On the sea ice concentration parameter extraction during the digital image processing, the resolution, the choice of threshold value and computational precision will induce the measurement error unavoidably. Besides, the position and gesture of the video camera is another main factor inducing measurement error. Only when the CCD of the video camera is perpendicular to the measured surface, the error induced by image distortion can be reduced to the minimum. However, a certain degree of shooting angle exists in the field observation when shooting the sea ice far from the observation point. Reasonable planar rectification is an important issue in the digital image recognition.

Figure 2 Ice image and the binary image (concentration measured at 86.1%).

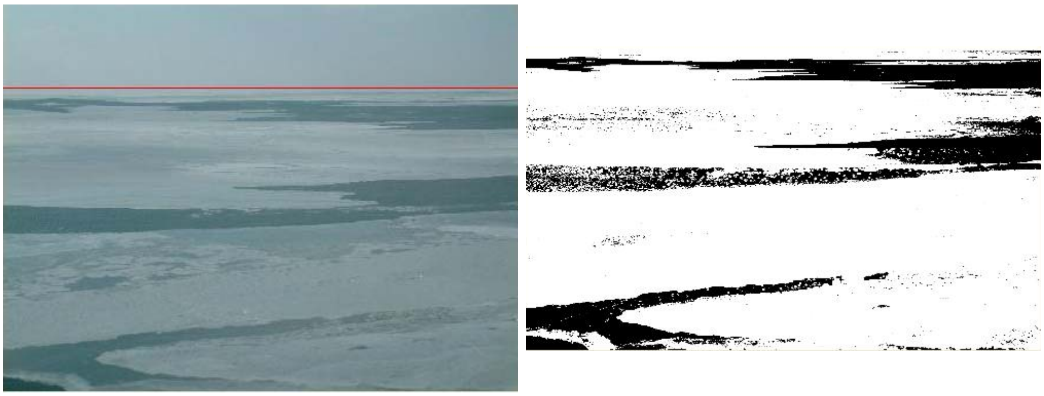


Figure 3 Ice images and the binary images of different concentrations.

Digital image technique of sea ice velocity

The calculation of speed and direction of sea ice velocity can be realized through the extraction and matching of feature points at different times in the digital images. Multiple image sequences of the same time interval are extracted, and the ice speed is determined by the comparison of the feature points of the neighbouring sequences. Feature points are the pixel points on the border of different heights in the image, and corner feature is considered to reduce the computational complexity and increase the matching speed. Harris algorithm was used here to extract feature points.

Harris corner is based on the grey scale of the image. It is the point with acute change of grey scale, and can be determined by the calculation of the gradient and curvature of the corner. Fig. 4 shows the feature points and their movements at different times monitored starting at 09:20 on Feb 15, 2010.

With the Harris operator, the feature point extraction is reasonable and uniform, and can be extracted quantitatively according to the real circumstances. In addition, it can keep robustly when images are under such conditions as rotation, change of grey scale, noise influence and change of viewing points. Based on the above method, ice velocities at three different times in

Fig. 4 are determined as (76.79cm/s,278.19°), (77.96cm/s,278.86°) and (79.26cm/s, 279.11°), and the average value is (78.00cm/s,278.72°). Here the upward direction is defined as 0°, and clockwise downward is defined as 180°. The angles in the collected images need to be calibrated to determine the ice direction in geographic coordinates in field observations.

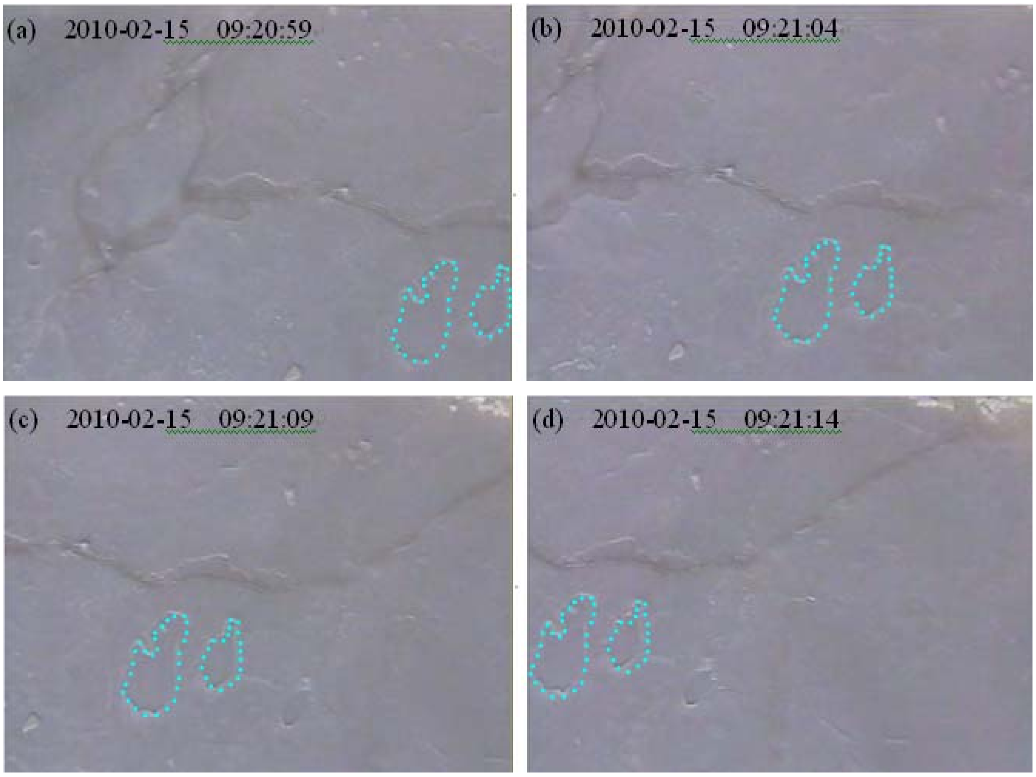


Figure 4 Sketch of the extraction of feature points in the monitoring of sea ice velocity

The measurement errors of ice velocities are from the precision of the ice velocity calibration parameters and the computational precision of the extraction and matching of the feature points. In addition, the platform will vibrate under the ice load, and this will produce the instability of the marking of corner points. Thus, to reduce the measurement error, it is necessary to determine precisely the calibration parameters and perform statistical analysis on multiple sets of measurement data of ice velocities.

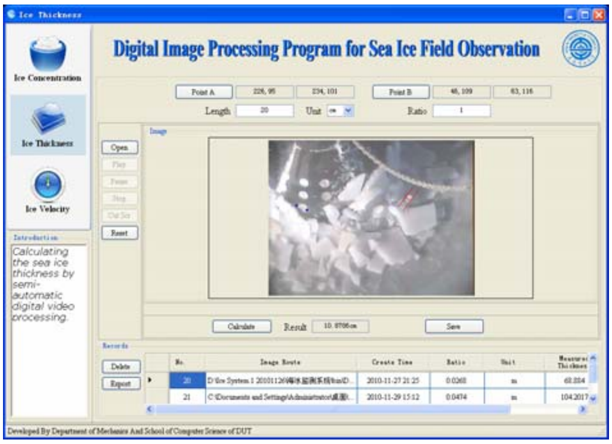
Software system for digital image techniques of sea ice

We developed a data collection and processing system of sea ice digital images using OpenCV and C# language. It consists of ice thickness, concentration and velocity module with the transferability between modules, and also has the function of simultaneous storage of multiple sets of measurement results.

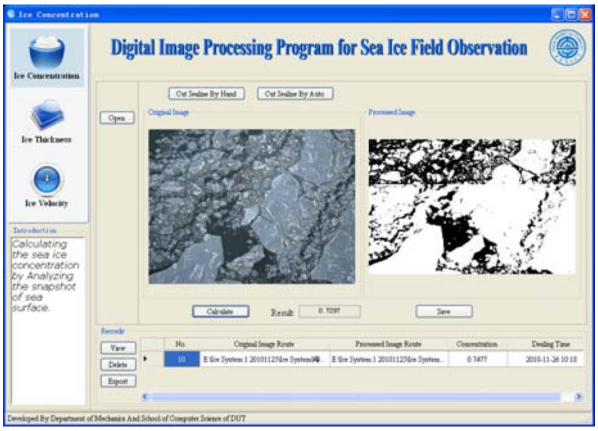
In the ice thickness measurement module, the collected digital images or video are imported to the measurement interface. For videos, the playing speed can be set and the specified interface can be saved as image format. Through the setting and calibration function of the reference on the interface, the corresponding physical length of every pixel can be obtained. In addition, in order to enhance the resolution at the edge, this module has enlargement function to precisely determine the needed references and pixels at the edge. Fig. 5(a) gives the measurement interface of ice thickness module.

In the ice concentration measurement module, the collected digital images are transferred to the concentration measurement interface. After pre-processing on the image edges, binary images are created with image correction. The Otsu method is then used to segment sea water and sea ice in the binary image, and the proportion of sea ice in the total area is determined, that is, the ice concentration. Fig. 5(b) gives the measurement interface of ice concentration module.

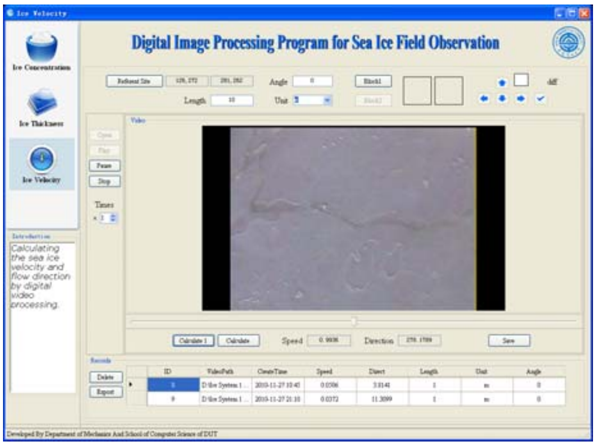
In the ice velocity measurement module, the monitored videos are imported to the velocity measurement interface, and continuous measurements of ice velocity at different times can be determined. This is done by the extraction of feature points in the video image, the matching of feature points in different image sequences, and the elimination of the mismatching points. The calibration function is integrated in the velocity module and used to determine the corresponding physical length of the pixels and the corresponding angles between the image and geographic orientation. The real-time computing function is to perform real-time computation on the current display of the video and give the corresponding real ice speed and direction. Moreover, quick browsing function is also added in the module and the needed clips can be quickly selected from the video. Fig. 5(c) gives the measurement interface of ice concentration module.



(a) Ice thickness measurement interface.



(b) Ice concentration measurement interface.



(c) Ice velocity measurement interface

Figure 5 The data collection and processing system interfaces.

THE APPLICATION IN THE BOHAI SEA OF THE DEVELOPED DIGITAL IMAGE TECHNIQUES OF SEA ICE

The Bohai Sea JZ20-2 oil and gas field (40°31′,121°21′) is located at north Liaodong Bay as shown in Fig.6. In the winter of 2009-2010, the developed digital image technique system was applied in the field observations of ice thickness, concentration and velocity.

Figure 6 The location of JZ20-2 platform in the Bohai Sea.

The ice thickness and velocity were collected by the two CCDs installed at different positions on the middle layer of deck. The CCD for thickness is perpendicular to the upper surface of the conical structure on the platform pile to collect the cross section data after ice breakage; The CCD for ice velocity is perpendicular to the ice surface to collect video as ice drifts. The two CCDs switch automatically every 30 sec, and a set of 2-min images were collected every 20min. The ice concentration images were collected by the digital camera installed at the upper deck, shooting every hour during the day.

Fig.7 and Fig.8 show the ice thickness and ice concentration obtained by the developed digital image techniques during the winter of 2009-2010 on the JZ20-2 platform, in which all values are daily average values. Fig.9 plots the ice velocity vector measured continuously between 00:00 Feb 2, 2010 and 00:00 Feb 6, 2010. The tidal component calculated through 2-D shallow water wave equation is also included in Fig.9. It shows that the ice flow is controlled by the tide during this period. In addition, the speeds in x direction at the 60th and 94th hour are obviously higher due to the effect of wind drag.

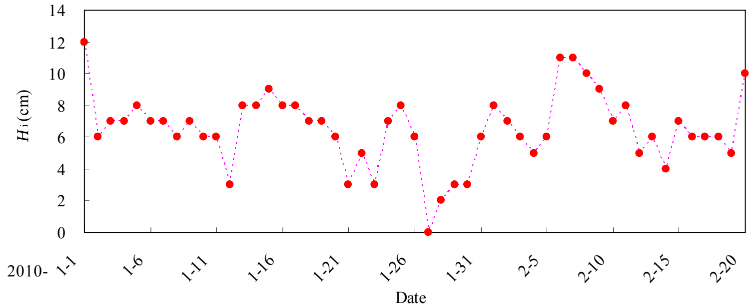


Figure 7. The daily average ice thickness of the winter of 2009-2010 on the JZ20-2 sea area.

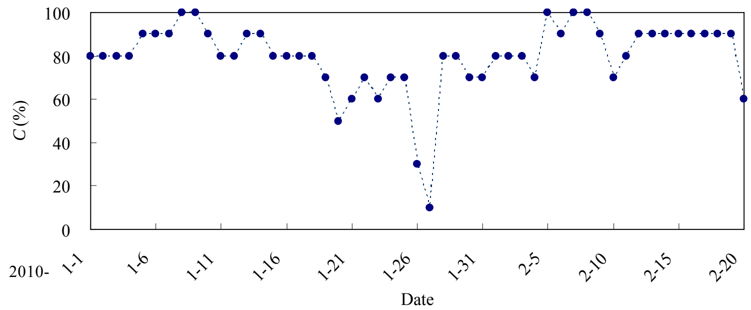


Figure 8. The daily average ice concentration of the winter of 2009-2010 on the JZ20-2 sea area.

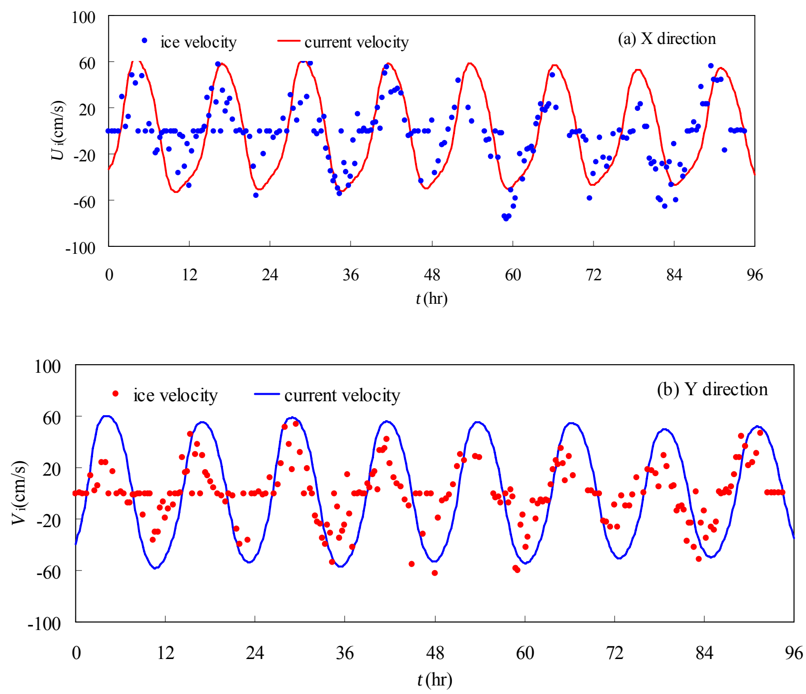


Figure 9. Measured and calculated ice velocity (From 00:00 Feb 2, 2010 to 00:00 Feb 6, 2010).

CONCLUSIONS

In the sea ice management of oil and gas field in the Liaodong Bay, much attention has been paid to the precision, continuity and completeness of the field monitoring of sea ice parameters. Considering the advantages of easy operation, low cost and high precision of digital image techniques, we developed the field monitoring techniques of ice thickness, concentration and velocity. We developed a software system with easy operation, high precision and user-friendly interface using OpenCV and C# language. We applied the developed system to JZ20-2 platform and obtained detailed ice data of the 2009-2010 winter.

In order to better apply the developed digital image techniques and software system in the oil and gas exploitation area, it is necessary to make the following improvements: 1) Adopt infrared ray image monitoring technique and collect continuously and extract ice parameters 24 hours a day. 2) Connect the monitoring system with video image collection instrument, and realize the real-time field monitoring and data extraction. 3) Apply the developed digital image techniques and software system further to other oil and gas platforms, and form fixed point field observation network and get complete ice information in the Liaodong Bay. With the above improvements, the developed digital image techniques and software system can be extended and applied to the field observation of oil and gas fields in the Bohai Sea, and provide reliable technical support for the ice management.

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