360º CAMERA SYSTEM FOR MONITORING ICE CONDITIONS

Henrik Bjørklund[1], Anatoly Sinitsyn[1], Aleksey Prusakov[1]
[1]The University Centre in Svalbard, Longyearbyen, Norway

Abstract
A 360° camera system was designed and built for the Oden Arctic Technology Research Cruise 2013, with the objective of providing a comprehensive and systematic documentation of the ice environment throughout the cruise. The system consists of two 360° cameras, logging software and hardware. The cameras were installed on the deck above the bridge of ice-breaker Oden. This enabled to cover an area of 250m radius from the center of the vessel. The system was intended to be completely autonomous, and allowed adjustable timing and frequency of images along the cruise track for regions of particular interest. The pictures in each sample were afterwards stitched into panoramic views. Indoor calibration of the cameras and analysis of the finished panoramas indicate that constructed 360° flat projections of ice floes offer minimal geometric distortion, especially for distances up to 100m from the vessel. The collected data can be used for documentation of ice conditions during sailing in ice waters, for example ice concentration could be assessed by image processing. Also, the pictures collected are relevant as in situ validation data for satellite images. This paper presents the overall experience with the design and the calibration of the system, the data processing for generating the panoramic pictures, and it offers a preliminary analysis of the results.

Introduction
The 360º Camera System is intended as a support system for ice management operations, where real-time determination of ice parameters is needed for collating ice loads. Traditionally, on-board observation of ice conditions has been conducted visually by a human observer on board the ship at regular intervals. An obvious drawback of this method is that the observed ice conditions (concentration, thickness, etc.) will be subject to the individual observer's assessment, and so observations made by different observers would not be consistent, due to a lack of common reference points. Furthermore, such observations are typically coarse, in the sense that observations of changing ice conditions may be made at an hour-by-hour rate, but hardly minute-by-minute and certainly not second-by-second.

Automated video surveillance of ice conditions provides an alternative way to determine ice parameters in real-time. Such a concept has been tested by Richard J Hall et al. 2002. Digital video was used to map ice conditions along the investigation route during the Second Chinese National Arctic Research Expedition (Zhijun Li et al, 2004). Other investigations have made use of downward-facing cameras mounted at the bow of the ship to measure the thickness of sea-ice (Jones et al. 2001 , Xie et al, 2010).

In this paper we present a system designed for and tested during the OATRC2013 research cruise with Icebreaker Oden to the Fram Strait, Greenland Sea (Scibilia et al. 2014). This system consists of multiple cameras, capturing a full 360º view of the waters surrounding the ship, as well as software for combining the images into a single panoramic view in which image area is proportional to actual area. This enables direct estimation of ice concentration from individual images, in principle allowing for fully automated real-time ice concentration logging.

The 360º Camera System
The 360º Camera System is a ship mounted automatic monitoring and data logging tool intended for on-site documentation of ice conditions by producing a continuous stream of images with a 360º field of view around its host ship. The system consists of a pair of 360º panoramic surveillance camera units connected to a Network Attached Storage (NAS) unit, and a dedicated instrumental computer.

The camera units used during the OATRC2013 research cruise were of type ArecontVision AV8365DN-HB. Each camera unit contains 4 camera objectives with overlapping fields of view and a total resolution of 20 megapixels. The camera units also have nighttime capability in the infrared regime. This capability could not be tested during the OATRC2013 research cruise, as the cruise was conducted during the polar day. The objectives are contained inside of a protective housing with integrated heater and blower to allow normal camera function in cold and wet conditions. Each unit is capable of a sampling rate of up to 5 images/second. More detailed specifications for the camera units is available on the manufacturer's website. One separate 12-20V DC power source is required for each camera unit to operate the objectives as well as the heater/blower. The cameras are mounted on the ship in such a way that the camera units give a complete coverage of the waters surrounding the port and starboard side of the ship respectively, and that the ship's prow and stern are visible from both camera units. The location of the cameras onboard the icebreaker Oden during the OATRC2013 research cruise, and the corresponding areas covered are shown in figures 1 and 2 respectively.

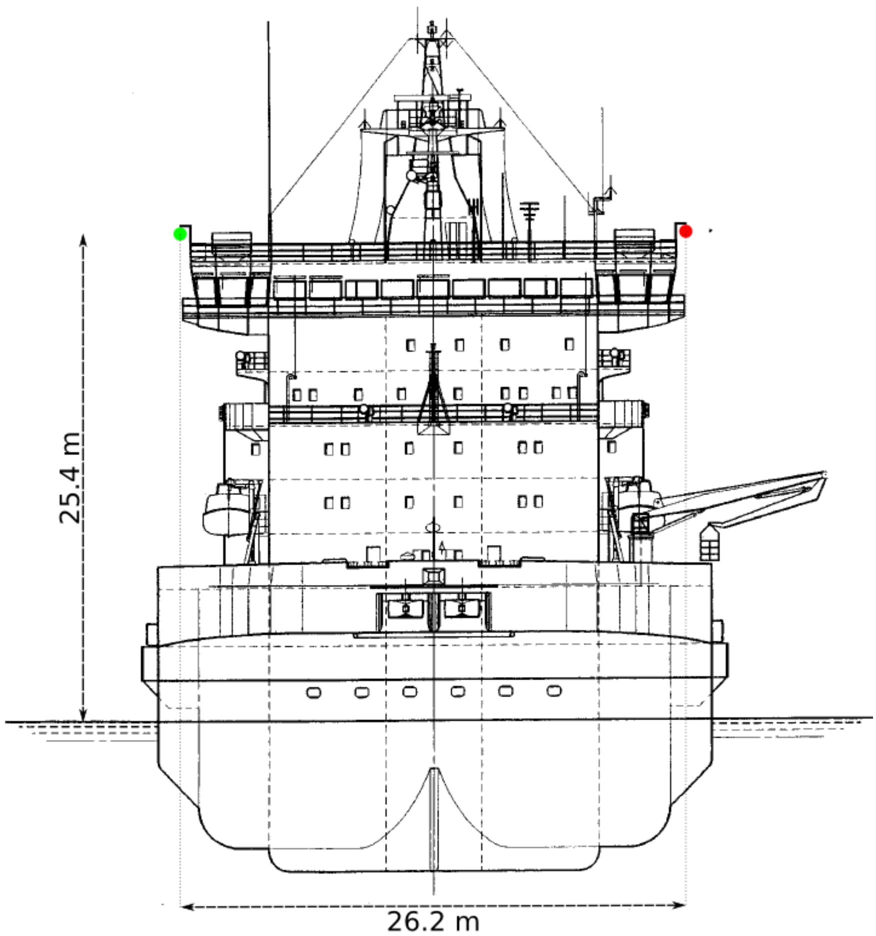

Figure 1. Mounting points for the camera units on the flying bridge of Icebreaker Oden during the OATRC2013 Research Cruise.

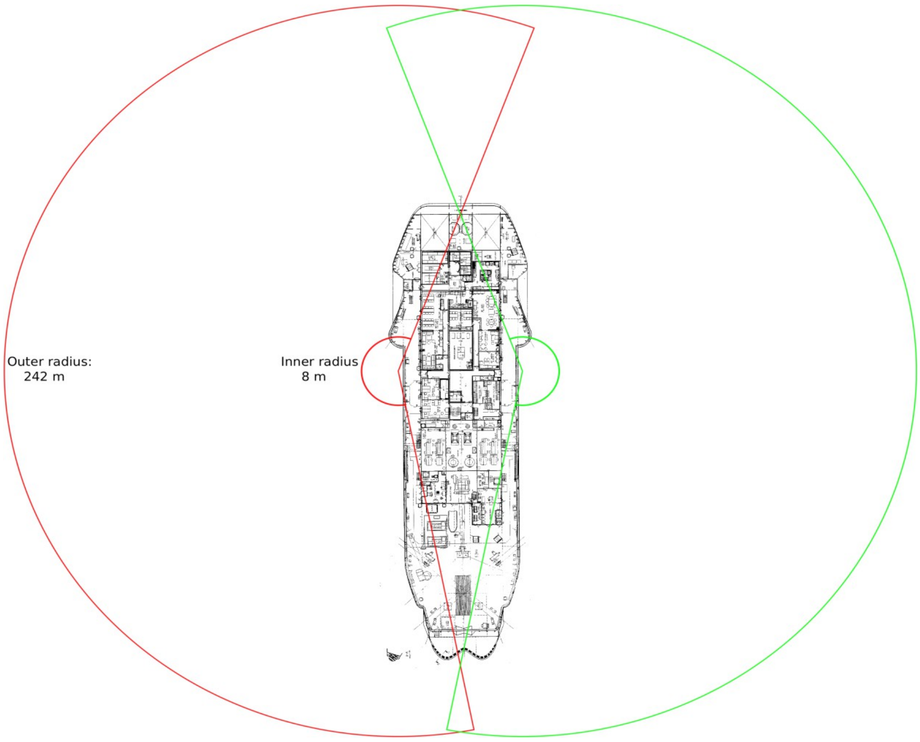

Figure 2. Approximate area of coverage for the camera units mounted onboard Icebreaker Oden.

Figure 2 gives the area covered by the cameras as from approximately 8 m and out to 242 m from the ship. In truth the area covered is larger and more rectangular, as each camera unit sees further out towards the image edges. (The numbers given in figure 2 were calculated based on measured declination angles to the middle points of the upper and lower edges of camera images.)

For the OATRC2013 research cruise the camera units were installed on specially mounted masts on the upmost deck (flying bridge) of Icebreaker Oden, as illustrated in figure 1. Figure 3 shows the actual mast with mounted camera. The masts ensured that the cameras were suspended overboard, giving an unobstructed view of the surrounding waters. The camera units were rotated so that two two objectives were parallel to the ship and one faced directly outwards. In this configuration the whole field of view from one side of the ship was covered by three camera objectives.

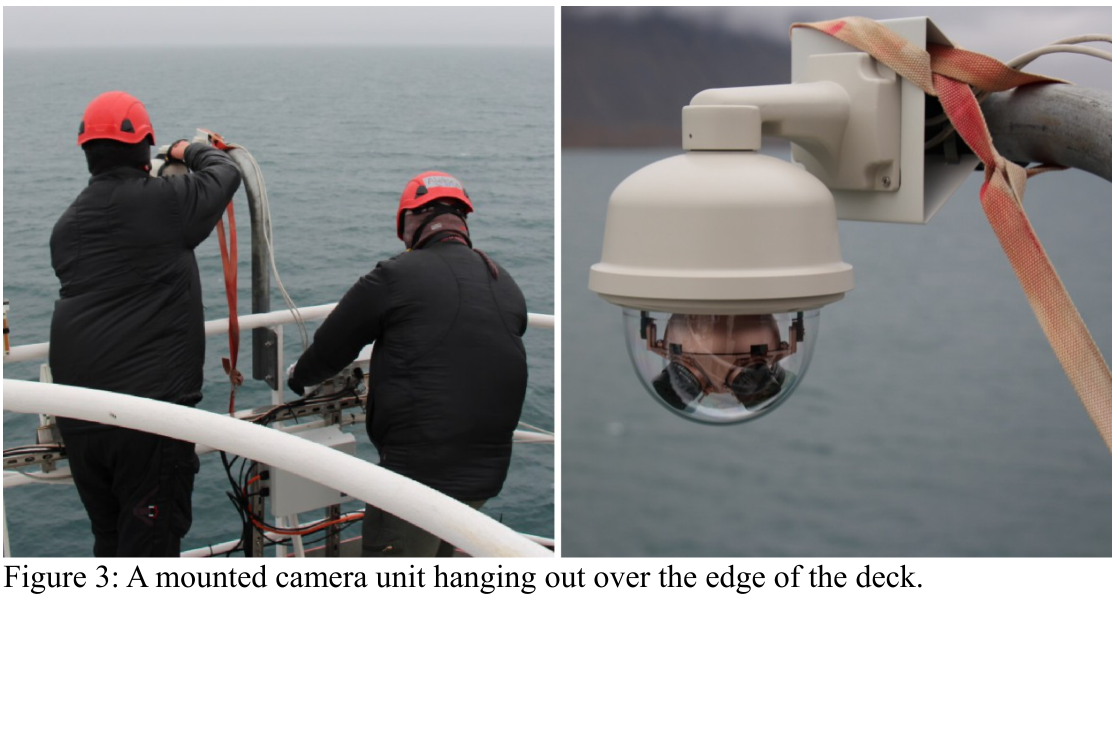

Figure 3: A mounted camera unit hanging out over the edge of the deck.

During the OATRC2013 research cruise it was convenient to connect the camera units, NAS and intrumental computer together through the ship's internal network. GPS coordinates and the ship's pitch/roll were also available over the ship's network, and could be associated with the images. Though the presence of such a ship's network was convenient, system components could also have been connected directly, without the need for an external network. In either case, with the cameras operational and connected, images were requested from the cameras from the instrumental computer and stored to the NAS. Images were stored in sets of six (three simultaneous images from either side of the ship), and were sampled at rates from 0.1 images/second to 1 image/second. This image collection process could be automated with a simple shell script. Once stored to disk, a set of six images could be combined together to a single panorama view of the waters surrounding the ship. This process is described in the next section.

Data Processing

As described in the previous section, the data obtained from the 360° camera system constists of sets of 6 simultaneous images giving a complete overview of the ice conditions around the vessel at a particular time. By using commercially available photo stitching software PTGui, these individual images could be stitched together to form a single panoramic view of the ice around the vessel. Using a particular set of 6 images as a reference set, a panoramic view could be produced by identifying common control points between images. The resulting stitching could then be used as a template, allowing for automatic batch processing of any number of images with identical camera positioning.

The resulting panoramic view may be presented in several different projections; a particularily useful projection for ice monitoring purposes is the rectilinear (flat) projection, which projects the panoramic view onto a plane. Insofar as the iceflow can be considered a planar surface, the image area in this projection is proportional to the actual area of the iceflow. Thus, ice concentration can be estimated directly from the image by simply counting pixels (Zhang and Skjetne, 2014).

During the operation of the 360° camera system during the OATRC2013 research cruise, a number of technical issues were identified:

- Occasional icing/fogging on the camera dome due to insufficient heating.
- Stitching mismatches in the panoramic image introduced by the viewpoint correction.
- Aberrations introduced in the panorama view due to engine vibrations transferred to the cameras, giving stitching mismatches towards the edges of the panoramic view.
- Influence of the pitch and roll of the icebreaker during maneuvers (see next section).

Out of these, the last three are remediable in post-processing.

Image Post Processing

Due to the large separation between the two camera units (approx. 26.2 m), a significant parallax problem when comparing images from the different camera units would occur. However, for flat surfaces it is possible to compensate for this by performing a transform on the image corresponding to virtually moving the camera position, mapping every pixel in the original image to the position it would have if the image were taken from the virtual viewpoint. Again assuming the ice field a planar surface, it is then possible to combine images from the different camera units into a single panoramic image. The stitching software used for this system was selected in part for its ability to perform this transform automatically.

Since over the course of a cruise thousands of images are created with identical camera positioning, it is advantageous to create a single template from which all image sets may be combined automatically into panoramic images. This greatly expedites the image processing and ensures that each combined panoramic is created by the same process. However, images produced in this way suffer from an additional defect due to vibration in the camera units: the vibration causes the objectives to shift slightly relative to each other, with the result that the template stitches du not match up ideally.

The transform necessary to account for parallax when combining images from taken from opposite sides of the ship also tended to increase the mismatch between the stitching edges. Clearly, the best way to remedy this error is to minimize the distance between the camera units, while maximizing the distance to the target ice flow around the ship, thereby reducing the amount of viewpoint correction needed. For the OATRC2013 cruise, however, with a camera unit separation fo 26.2 m and a minimum distance to the ice of 25.4 m, it was possible to produce usable panoramic images with reasonably small distortion resulting from viewpoint correction.

The flat projection, though desirable because of its property of making image area proportional to actual area, has a few disadvantages. Firstly, it stretches the image, resulting in pixels being distorted and stitching mismatches becoming more pronounced towards the image edges. The uncertainty of the apparent ice distribution is therefore expected to be greater towards the image edges.

The rolling of the ship during operation introduces another problem: as the ship pitches and rolls, the "plane" of the ice flow is tilted relative to the projection plane of the panoramic images. When this happens, image area is no longer proportional to actual area. In principle, this can be corrected for if the pitch and roll of the ship at a given time is known, though no such correction was attempted during the OATRC2013 cruise.

Use of Data

In the following a simple way of extracting ice concentration data from panoramic views produced from the 360^{o} camera system is briefly illustrated. Figure 4 shows 2 out of 6 sample images used to construct a panoramic view. Figure 5 shows the full set of images stitched into a single panoramic view with the rectilinear (flat) projection. Figure 6 shows a similar panoramic view, to which a very basic algorithm for determining ice concentration has been applied: the area of the image obscured by the vessel is masked out, and for the remainder a threshold value is used to determine whether a given pixel is ice or not. Since image area is proportional to actual area, the ice concentration can then be given for a given area of the image by giving the ratio of ice pixels to total pixels in that area. This algorithm is illustrated in figure 7. Here the total ice concentration is estimated to 0.519, whereas the concentration in the green zone is estimated to 0.643.

As can be seen in figures 6 and 7, the algorithm used here does not differentiate between meltwater ponds on ice and open water, identifying both as "not ice". Furthermore, the assumption that the ice field is flat neglects to take into account above-water shapes such as ice sails. Given that the cameras are at a height of 25.4 m, the presence of an 5m high above-water shape at a distance of 242 m (right at the edge of the image) would obscure ice features (flat, i.e. at a height of 0m) in an area stretching out approximately 59.3 m behind it. The same shape at a distance of 100 m from the cameras would cast such a "shadow" with a length of 24.5 m. This is illustrated in figure 8. For a 1 m high above-water shape, the corresponding shadows would be 11.9 m and 4.9 m respectively. Such features will be projected down into the plane in the panoramic views, incorrectly giving the impression that the shadow of an ice sail is in fact filled with ice. Since this effect is greater the greater the distance to the ice feature, it will cause the largest discrepancy near the image edges, even before accounting for image distortion. These are concerns that would need to be addressed when designing a more accurate image analysis algorithm; the basic algorithm used in this paper is only intended to demonstrate the concept.

Future Work

It is at present not known how well the panoramic views produced in this manner correspond to the actual ice distribution surrounding the vessel as it has not been possible to compare it directly with other sources. A possibility would be to compare panoramic views with simultaneous high-resolution satellite images of the area surrounding the vessel and with results obtained by an ice observer.

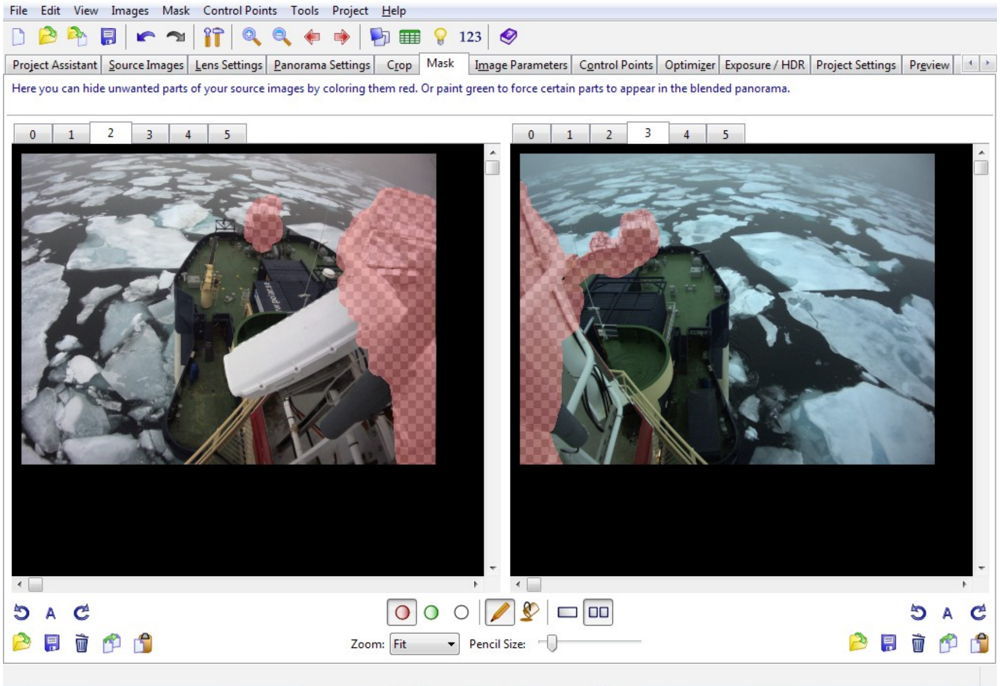

Figure 4: Pre-stitching sample view from front cameras.

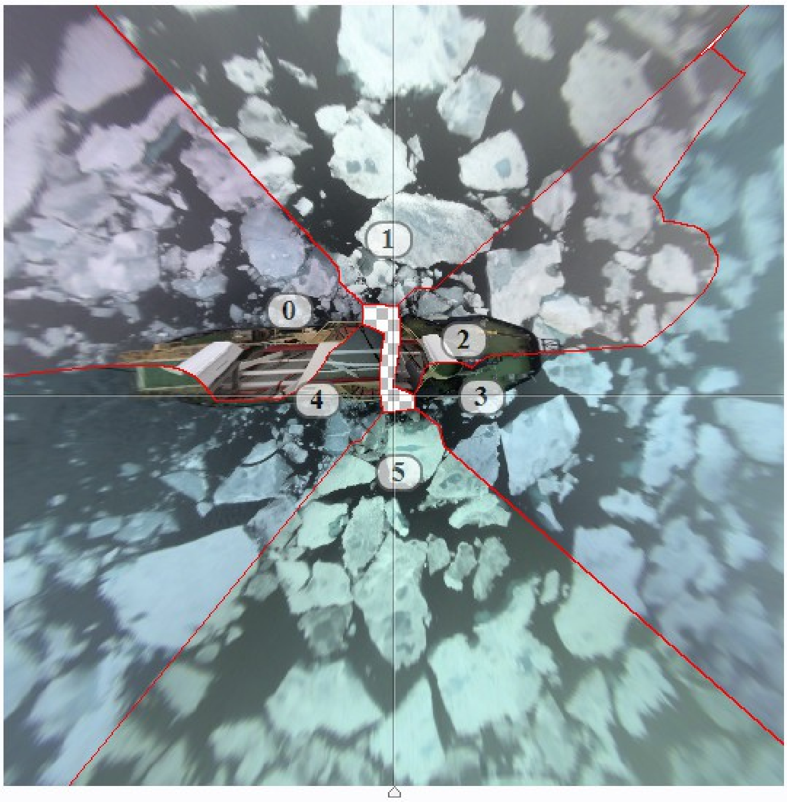

Figure 5: Example panoramic view with rectilinear projection, combining six individual images. The parts corresponding to separate images are delineated with red lines.

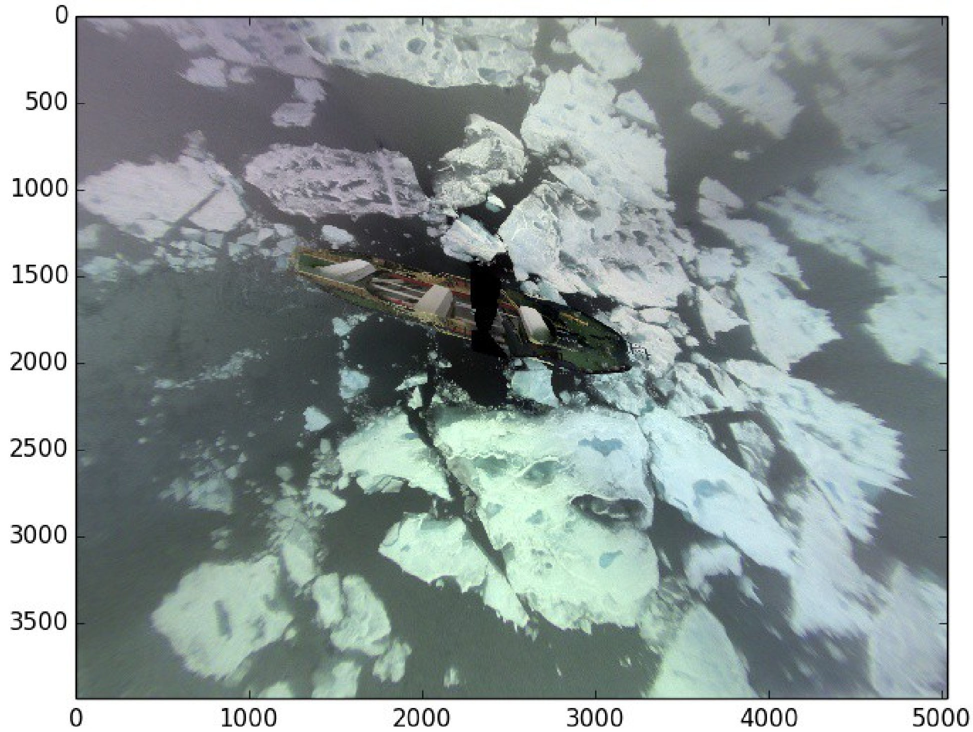

Figure 6: Panoramic view used for estimating ice concentration.

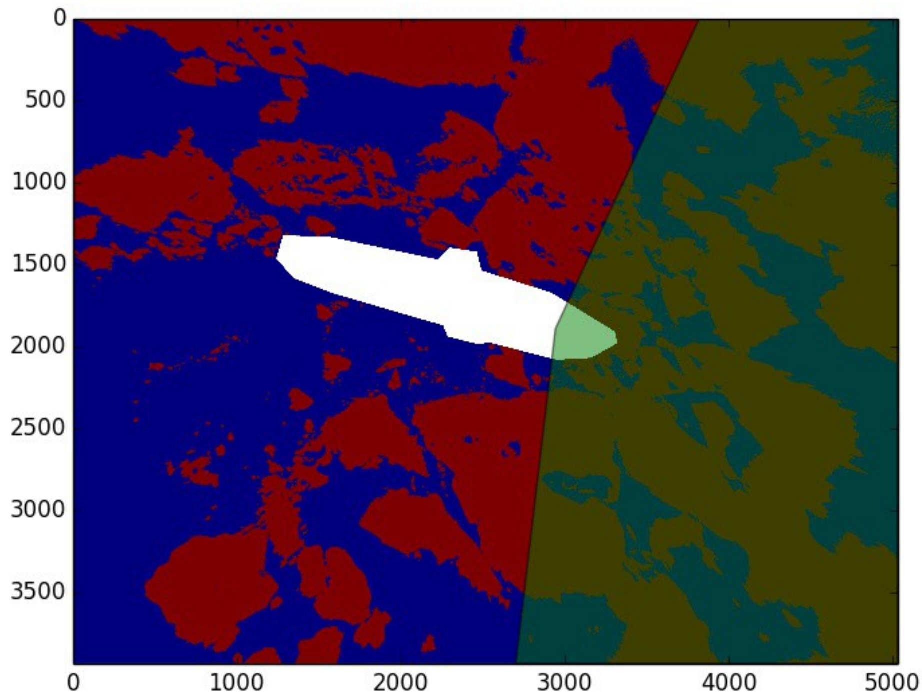

Figure 7: A very basic algorithm has been applied to the finished image to estimate ice concentration. The algorithm used here makes no attempt at distinguishing features such as melt ponds on top of ice, which consequently are misinterpreted here as open water.

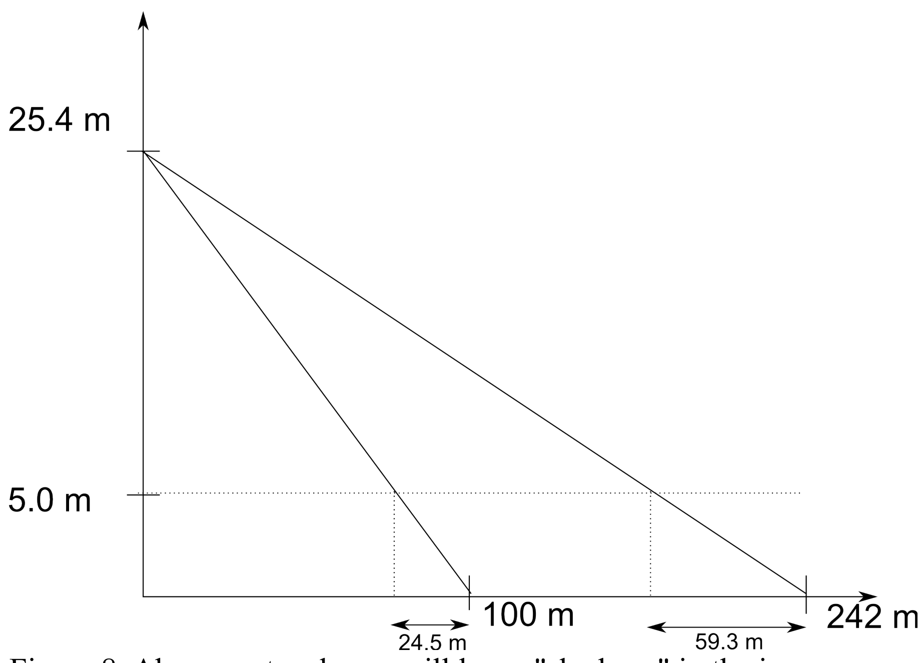

Figure 8: Above-water shapes will leave "shadows" in the image, obscuring features behind them. This figure shows the extent of shadows left by 5 m high object at distances of 100 m and 242 m from a camera located at a height of 25.4 m, the camera height at the OATRC2013 cruise.

Conclusion

The 360° camera system developed for the 2013 SAMCoT/Oden scientific cruise has been able to produce good quality panoramic images of the ice flows surrounding the icebreaker during operation. The system is fairly easy to set up and, once up, requires little intervention. The post-processing of the raw data was accomplished using commercially available software, and the problem imposed by the large distance between the port and starboard side cameras and resulting parallax was revealed to be surmountable. It remains to compare the panoramic images obtained from the 360 degree camera system with satellite images to evaluate their accuracy

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