Marine Radar for Improved Ice Detection

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ABSTRACT

A high-speed marine radar combined with advanced digital processing can produce high resolution images that allow the user to identify hazardous ice features and small icebergs which are nearly impossible to see with a conventional radar. The Canadian Coast Guard (CCG) is working in partnership with Transport Canada's Transportation Development Centre (TDC) to develop an "Ice Hazard Radar". The system was evaluated in three dedicated trials on board the icebreaker CCGS *Henry Larsen* to fully demonstrate the capability of the radar in a variety of operating environments and ice conditions. This paper presents the results of the trials.

KEY WORDS: High-speed scanner; radar; detection; navigation; multi-year ice.

INTRODUCTION

One of the problems facing shipping in ice-infested waters is the inability of a conventional marine radar to detect small floes of multiyear ice or dangerous glacial ice such as bergy bits or growlers early enough to avoid a collision. This is particularly true in heavy sea conditions where they may be lost in the "sea clutter". Bergy bits are pieces of icebergs showing 1 to 5 m. above sea level. Growlers are pieces of icebergs showing less than 1 m. above sea level. Detection on radar or visually can be as little as a half mile from a vessel, if at all. (CCG 1999) There is a high risk for hull damage due to collision with multi-year and glacial ice, even for ice strengthened vessels. Fuel consumption is also higher for vessels transiting heavy ice conditions so it is more efficient to avoid multi-year or thick first-year ice.

In 2004, the Climate Change Technology and Innovation Initiative (CCTII) funded a scoping study to identify research areas for improved year-round transportation in the Arctic. Fifteen Captains who regularly operate vessels in the Arctic unanimously picked the detection of multiyear (MY) ice as the key research area. (Timco et al. 2005) Based on these results, a four year comprehensive research program was proposed to improve ice information in this area (Timco et al. 2008). As Task 3 of the CCTII Arctic Transportation Project, the CCG chose to develop an enhanced marine radar that could detect dangerous ice earlier and more accurately than conventional marine radars, to be evaluated aboard a CCG icebreaker.

For this project, various advanced radar technologies that were developed over the years by TDC are being integrated into a single system optimized for ice detection, including:

- A modular radar interface (MRI) that captures high resolution radar imagery onto a computer for advanced processing and display. The radar software uses digital signal filtering techniques, including scan-to-scan averaging, to enhance and detect weak targets and improve the image display. (Sigma 2003)
- A high-speed scanner which rotates at 120 rpm, four times the rate of conventional radars, to improve the detection of small targets in heavy seas. (Rutter 2005)
- A cross-polarized system, which transmits radar pulses horizontally and receives them vertically and horizontally, will be able to discriminate between multi-year ice in first-year ice fields. (Sicom 1998)

The "Ice Hazard Radar" project was divided into two phases to ensure that Arctic field trials could be conducted in collaboration with other CCTII Arctic Transportation Project Tasks in 2006 and 2007. Phase one was the development, installation and evaluation of a high-speed radar, beginning in August 2005 and concluding in March 2008. Phase two will include the development of a vertically-polarized receive-only scanner, synchronized (in rotation, frequency and pulse timing) to the main high-speed radar, which is horizontally polarized; the development of a dual-channel MRI; and real-time processing capability for the two systems.

ARCTIC TRIAL AUGUST 2006

The Ice Hazard Radar display system was installed in the navigation consol of the CCGS *Henry Larsen* in June 2006. It consists of a monitor, computer, the "sigma S6" MRI and software produced by Rutter Technologies Inc, St. John's, NL, Canada. Figure 1 shows the radar configuration. The Ice Hazard Radar display was connected to the vessel's Bridgemaster II x-band radar in slave mode for the 2006 trial.



Figure 1 - Radar Configuration

The first trial was conducted between August 9 and 19, 2006, from Thule, Greenland to Nares Strait, to Alexandra Fiord, finishing at Pond Inlet, Nunavut, Canada (see Figure 2). Ice conditions varied during the trial, from bergy waters to a heavy mixture of multi-year and thick firstyear ice. Weather conditions ranged from bright sunlight, to overcast conditions and fog. At times the winds gusted over 35 knots.



Figure 2 – Map showing route of first trial.

The analog signal from the x-band radar is processed by the sigma S6 and displayed as a 12-bit digital video image (1024x1024). Figure 3 is a photo of the standard x-band radar. Figure 4 is an image taken of the ice radar. The CCGS *Henry Larsen* (shown in Figure 5) is at the centre of the radar screen. The comparison between these two images is striking. With the Ice Hazard Radar, the coastline is more clearly defined; icebergs are visible at greater distances, as are the smaller bergy bits and growlers. Shadows are visible behind icebergs on the Ice Hazard Radar, caused by the lack of radar returns behind a high target.



Figure 3 – Standard x-band radar image of Thule Harbour, Greenland.



Figure 4 - Ice Hazard Radar image of Thule Harbour, Greenland.



Figure 5 – CCGS *Henry Larsen* in multi-year ice in Kennedy Channel off the coast of Greenland.

The shapes of ice floes, the ridges and rafted ice and open water leads are also more distinct in the Ice Hazard Radar, particularly when using the short radar pulse length (see Figures 6 and 7).

The Captain, Ship Officers and team evaluated the capability of the radar processing system for displaying ice imagery. Captain Vanthiel stated "The radar is proving to be a very useful tool for tactical ice information. It allows the bridge watchkeeper to differentiate the different ice features and easily discern the water leads."



Figure 6 - X-band radar image of multi-year ice in Kennedy Channel off Greenland.



Figure 7 – Ice Hazard Radar image of multi-year ice off Greenland.

ARCTIC TRIAL JULY 2007

Conventional marine radars were developed as target detectors (for other ships, coastlines and hazards) with a typical scanner rotating at 25 to 30 rpm. They may not detect small floes of multi-year ice, bergy bits or growlers (fragments of icebergs) in the sea clutter early enough to avoid a collision. A higher speed radar combined with a digital radar processor greatly increases the probability of the detection of small targets (Rutter 2005).

In 2006, TDC, hired a contractor to develop a conversion package for an off-the-shelf marine radar to be used as a high-speed scanner in a low-cost, advanced radar system. A Bridgemaster E x-band radar scanner was modified to rotate at speeds of 30, 60 and 120 rpm and then validated in continuous operation and in winds up to 180 km/h (Massicotte 2008). The high-speed scanner was installed on CCGS *Henry Larsen* in June 2007 and connected to the Ice Hazard Radar display.

The system was evaluated in dedicated trials on board the icebreaker between July 4 and 12, 2007, between St. John's, NL and Iqaluit, NU (see Figure 8). On the voyage north, the icebreaker encountered a few icebergs, growlers and bergy bits. In Hudson Bay and Frobisher Bay, the ice was 3 to $5/10^{ths}$ thick first year with patches of MY ice. There was shore fast ice from Pike Resor Channel inbound to Iqaluit.



Figure 8 – Map showing route of second trial

The high-speed radar, together with the advanced radar processing techniques such as scan-to-scan averaging (up to 128 consecutive radar scans), was able to detect large targets such as vessels and icebergs at longer ranges than the conventional radar. When rotating at 120 rpm, it was also able to detect bergy bits and growlers from decaying icebergs at more than three nautical miles (seen as smaller spots in figure 9). The growlers were not detected by the standard radar until about a half mile away.



Figure 9 – Image of two icebergs, bergy bit and growlers. The nearest iceberg is 3.6 n.m. The bergy bit (centre) is 2.75 n.m. The cluster of growlers range between 2 and 1.5 n.m. from the vessel. Wind 10 kts.

Ice floes are more distinct with the Ice Hazard Radar than with the conventional x-band radar, particularly when using the short radar pulse length (compare Figures 10 and 11). Captain Broderick commented "The Ice Radar proved a great advantage while navigating through the icebergs in reduced visibility. Consistently we were able to detect the bergs at a greater range with the Ice Radar. This allowed us more time to determine the best route through high concentrations. Additionally we were able to differentiate between the size of bergs and bergy-bits. Our navigational radars could not give us the long range detection nor the resolution and definition. I will give this year's version of the Radar Project an excellent review and I hope we can continue to improve on the present set-up."



Figure 10 – X-band radar image of Pike Resor Channel.



Figure 11 - Ice Hazard Radar image of ice in Pike Resor Channel.

WINTER TRIAL MARCH 2008

A third field trial took place from March 20 to 26, 2008, off the Northeast Coast of Newfoundland, to assess the system in winter ice conditions (see Figure 12). The trial was conducted in a variety of ice regimes, from shore-fast ice to a 9+/10ths mixture of medium and thick first year ice under considerable pressure.



Figure 12 - Map showing route of third trial.

After a year and a half using the system, it was clearly evident that the Ice Hazard Radar had become an integral tool for the bridge navigation team. The users were able to operate the system with ease and confidence. They also found it useful to compare the radar image with satellite images of the area to look for open water leads beyond the range of the radar. This is helpful when escorting vessels of various sizes and capability, particularly in poor visibility.

The following images and photographs illustrate the usefulness of the radar in escort operations. CCGS *Henry Larsen* (Figures 13 and 14) is breaking a track through 4 nautical miles (n.m.) of consolidated ice to access the shore fast ice within the channel leading to Botwood. The helicopter conducted an ice reconnaissance to assess the situation.



Figure 13 - Consolidated ice off the entrance to Botwood.



Figure 14 – Icebreaker clearing a wide track through rubble ice off the entrance to Botwood. The vessel under escort is at the top of the image. Debris from the track is seen drifting away with the current.

As one cargo vessel was escorted into Botwood, another was ready to depart. Offshore the ice was under pressure so the Ice Hazard Radar was key to finding the leads of open water in the ice. (Figure 15)



Figure 15 – First Officer and Captain searching for leads with the radar.

Figures 16 and 17 compare the images of the enhanced radar and conventional radar.







Figure 17 – Escort of cargo vessel (in the square) on the x-band radar.

Night navigation can be difficult in ice under pressure with searchlights and the use of radars. (Figures 18 and 19) Two small fishing vessels became trapped in the ice after following the track of a larger vessel. The icebreaker was able to proceed without any problems to the boats and then escorted then one at a time to the ice edge.



Figure 18 - Image of the two small fishing vessels requiring escort.



Figure 19 – Beset fishing vessel illuminated in the searchlight of the icebreaker, whose bow is visible in the foreground right; the second vessel a mere glow in the distance.

CONCLUSION

The trials helped to evaluate the performance and robustness of the software and hardware in actual operating environments. Feedback from the users on the functionality and operability of the system was provided during several stages in the development and trials. The feedback has identified some functions and technical issues that could be improved.

The Ice Hazard Radar system provides highly detailed images of sea ice conditions in the vicinity of the vessel, enabling it to manoeuvre around difficult areas, saving both time and fuel while minimizing the potential for ice damage.

The high-speed radar scanner also has the ability to detect small ice objects in various sea states far earlier than with conventional radar systems and visual detection. There are 24 hours of daylight in the Arctic during the summer months; however periods of fog, snow and poor visibility are quite common. The risk of ice damage to vessels will be reduced if they can detect dangerous ice in sufficient time to avoid it. Figure 20 shows numerous icebergs and bergy bits off the Greenland coast.



Figure 20 – An image of "Iceberg Alley" on the 3 mile range.

The following table (Figure 21) indicates the size of ice detected and the distance visible on the standard and enhanced radars, in winds of 10-15 knots. During the high-speed radar scanner trials the vessel did not experience rough sea conditions.

Ice Type	Size (Height	Distance	Distance Visible
	above sea level)	Visible on Ice	on x-band radar
		Hazard Radar	
Bergy Bit	1 to 5 m.	> 4 n.m.	1 to 0.5 n.m.
Growler	< 1 m.	> 2 n.m.	< 0.5 n.m.
Figure 21 Comparison of hazardous ice detection canability			

Figure 21 – Comparison of hazardous ice detection capability.

This technology has proven itself to be a significant improvement over the conventional marine radar.

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