STYRELSEN FÖR

VINTERSJÖFARTSFORSKNING

WINTER NAVIGATION RESEARCH BOARD

Research Report No 119

Robin Berglund, Manu Lahdes

MONITORING OF SHIPS UNDER ASSISTANCE

Finnish Transport and Communications Agency	Swedish Maritime Administration
Finnish Transport Infrastructure Agency	Swedish Transport Agency
Finland	Sweden

Talvimerenkulun tutkimusraportit — Winter Navigation Research Reports
ISSN 2342-4303
ISBN 978-952-311-789-1

FOREWORD

In this report no 119, the Winter Navigation Research Board presents the results of research project DistAssist - a tool to ease monitoring of ships under assistance. The feasibility of using a Frequency Modulated Continuous Wave Radar to monitor the distance to, and the relative speed of the ship that is under assistance by the icebreaker was investigated. However, the prototype could not be tested on-board an icebreaker due to COVID-19 related restrictions.

The Winter Navigation Research Board warmly thanks Robin Berglund and Manu Lahdes for this report.

Helsinki

June 2022

Lauri Kuuliala

Finnish Transport and Communications Agency

Anders Dahl

Swedish Maritime Administration

Jarkko Toivola

Finnish Transport Infrastructure Agency

Stefan Eriksson

Swedish Transport Agency

CUSTOMER REPORT

VTT-CR-00490-21 | 16.6.2021

Photo: Robin Berglund

DistAssist - a tool to ease monitoring of ships under assistance

Authors:	Robin Berglund, Manu Lahdes
Confidentiality:	Restricted

Report's title

DistAssist - a tool to ease monitoring of ships under assistance

Customer, contact person, address	**Order reference**
Lauri Kuuliala Finnish Transport and Communications Agency PO Box 320, FI-00101 Helsinki, Finland	TRAFICOM/459922/02.03.01/2020
Project name	**Project number/Short name**
DistAssist	129239/DistAssist

Summary

The aim of the winter navigation research projects, such as Dist Assist, is to produce publicly available information that can be used to improve services and technologies that influence the Baltic winter navigation system.

The aim of the DistAssist-project was to provide information about the feasibility of using a frequency modulated Continuous-wave (FMCW) radar to continuously monitor the distance to, and the relative speed of the ship that is under assistance by the icebreaker. Keeping an optimal distance to the ship that is being assisted, is of utmost importance. If the distance is too short, there is a risk of collision in case of sudden deceleration of the icebreaker. On the other hand, if the distance is too long, the channel may close before the ship, and the assisted ship runs the risk of being stuck, requiring time-consuming operations to get the ship going again. Constant monitoring of the assisted ship is just one of the duties of the icebreaker officer. Tools to aid the officer in this task, would increase efficiency and safety of the icebreaking operations, especially in bad weather conditions with low visibility, and thus contribute to the research on methods to increase effectiveness of icebreaker assistance.

In DistAssist, a trial was planned to be carried out where an FMCW radar prototype would be positioned on the superstructure of the icebreaker having free visibility backwards from the icebreaker. The user interface of the radar application would continuously show the most important measured parameters, such as the distance to the nearest valid echo and the rate of change of this distance. However, due to COVID-19, the on-board trial was not possible to realize in 2021. Instead, the prototype system was improved, and a user questionnaire directed to the icebreaker officers, about this kind of supporting device, was implemented, and the on-board trial was left to be the focus of a follow-up project next winter.

This report contains the results of the User questionnaire, the basic principles of a FMCW radar, a description of the prototype system and the results of the onshore trials.

Espoo 16.6.2021

Written by	**Reviewed by**	**Accepted by**
Robin Berglund Senior Scientist	Ilkka Perälä, Senior Scientist	Maria Tikanmäki, Research Team Leader

VTT's contact address

VTT, PL 1000, 02044 VTT

Distribution (customer and VTT)

Contents

1. Introduction

Part of the Baltic Sea freezes every winter. Icebreakers are used to keep the ports open all year around. Ships are assisted through the ice field by an icebreaker making the channel navigable for ships that cannot navigate independently. For the icebreaker it is of utmost importance to keep an optimal distance to the ship that is being assisted. If the distance is too short, there is a risk of collision in case of sudden deceleration of the icebreaker. On the other hand, if the distance is too long, the channel may close before the ship, and the assisted ship runs the risk of being stuck, requiring time-consuming operations to get the ship going again. Constant monitoring of the assisted ship is just one of the duties of the icebreaker officer. Tools to aid the officer in this task, would increase efficiency and safety of the icebreaking operations, especially in bad weather conditions with low visibility, and thus contribute to the research on methods to increase effectiveness of icebreaker assistance.

The DistAssist-project aims at providing information about the feasibility of using a frequency modulated Continuous-wave (FMCW) radar to continuously monitor the distance to, and the relative speed of the ship that is under assistance of the icebreaker.

The original idea was to finish the project with an on-board trial of the prototype radar. However, COVID-19 prevented any visits to the Finnish icebreakers in winter 2021, so the on-board trial had to be postponed to a forthcoming winter.

Instead, a more thorough user involvement was performed in the form of a questionnaire, and the results of this questionnaire are reported here in addition to the results of the trials using the radar device from shore measuring the distance to approaching merchant ships.

Although the goal of performing on-board trials, was not achieved in this project, a much better understanding of the requirements and the conditions of operation has been obtained.

The project has been performed by VTT. Senior Scientist Robin Berglund has been the project manager and performed the user enquiries. Senior Scientist Manu Lahdes has specified and built the radar system prototype including processing algorithms, data analysis and user interface.

A Steering group consisting of Jarkko Toivola from the Finnish Transport Infrastructure Agency, Lauri Kuuliala from the Finnish Transport and Communication Agency, Amund Lindberg and Anders Dahl from the Swedish Maritime Administration and Stefan Eriksson from the Swedish Transport Agency has supervised the project.

2. User Requirements study

The preliminary requirements were gathered during discussions with icebreaker officers – the idea was in fact discussed already in spring 2020 during a trial concerning the use of drones in icebreaker operations on board the Swedish icebreaker ATLE. More detailed discussions were conducted in Helsinki during a visit to the icebreaker Polaris when the icebreaker was at the Katajanokka pier. During that visit the location possibilities were surveyed, and the icebreaker officers were asked to give their opinion of a distance measuring device and the requirements of such a system.

Based on interviews with officers on board the icebreaker Polaris (first officer Sampo Tammiala) in January 2021, the main usefulness of the planned system is to give the helmsman a real time tool for monitoring the distance to the assisted ship. The most important distance interval was argued to be from 500 m to distances closer than that. The main information would be the distance expressed in meters or cables (0.1 Nautical miles) (or both).

An interesting comment by the first officer on Polaris was that it is important that the icebreaker always controls the distance to the ship behind by adjusting the power of the icebreaker engines - the control and responsibility of keeping an optimal distance should not be given to the assisted ship. Thus, the idea of setting up a warning light (analogous to the braking light on a car) that would automatically light up when the icebreaker decelerates, would cause the assisted ship to reduce its engine power, which would very probably lead to the ship getting stuck in the ice whereby a time-consuming operation to get the ship moving again would be required.

A list of the requirements is summarized in the table below:

Table 1 Summary of preliminary requirements of a distance monitoring system

User interface		**In prototype?**
	Continuous display of distance to nearest valid echo.	x
	Continuous display of relative speed to nearest valid echo.	x
	Units in m and cables, m/s and knots	x
	Display dimmable or night mode selectable	maybe
	Position of the display on the bridge enabling the helmsman to monitor the display continuously if needed	x
	Display of trendline showing the distance as a function of time (1, 5 or 10 minutes)	x
	Indication of absence of valid radar echo	x

FMCW radar		
	Operate on license-free frequency bands	x
	max distance > 500 m	x
	Protected against interference from ship X- and S-band radars	TBD
Radar box		
	Attached low enough on the superstructure of the icebreaker to capture the echo from the bow of the ship, but not so low that the icebreaker structures would (partially) occlude the signal.	x
	Weather resistant (rain, snow, wind)	x (for shorter times)
	Operational temperature range down to - 30 degrees	Not in proto
	Equipped with own GPS	x
	Equipped with camera for documentation of special situations	TBD
Processing		
	Processing of echo to filter out erroneous spikes	Only simple processing in proto
	Combination of several radar box signals to generate more reliable distance measurements	Not in proto
	Filtering of echoes originating from ice ridges	Not in proto – this is one of the effects that must be studied in the trial
Communication		
	Communication link between radar box and user interface	x
	Remote control of system over existing communication services (Internet)	TBD

(TBD = To Be Determined)

2.1 Questionnaire

To validate the assumptions made regarding the system, a questionnaire was designed and sent to the icebreaker officers in Sweden and Finland. The questionnaire and a detailed analysis of it, is included as an attachment.

The main points in the questionnaire were to get a confirmation from the users about the situation when such a system would help. Another issue was about what information, and in which format this information should be displayed. Also, the necessity of an audible alarm was asked about. Finally, some background information of the respondents (years of experience) was requested.

3. FMCW radar technology

3.1 Operation principle

Traditionally in maritime applications a pulse type of radar has been used. In a pulse radar, short RF-pulses are transmitted and echoes reflected from targets are received (Figure 1). The range of the target is calculated from the time difference between transmitted and the received pulse. A pulse radar or pulse compression radar are well suited for long range measurements but struggle at short distances. In this project a different kind of radar is used, a frequency modulated continuous-wave (FMCW) radar. As its name implies, it transmits all time instead of short pulses, The transmitted signal is also frequency modulated forming a so called frequency ramp or chirp. When transmitted and received reflected signal are mixed together, their frequency difference is related to the time difference between them. This frequency difference, so called beat frequency, is directly related to the distance of the target. The principle is presented in. In real life the mixed received signal (IF) is digitized with analog to digital converters. Then the signal is converted to frequency domain by perfoming a FFT (fast Fourier transform) for analysis. The frequency scale is then directly related to the distance. Advantages of an FMCW radar are: good distance resolution, ability to measure short distances, simple structure, low power and low cost.

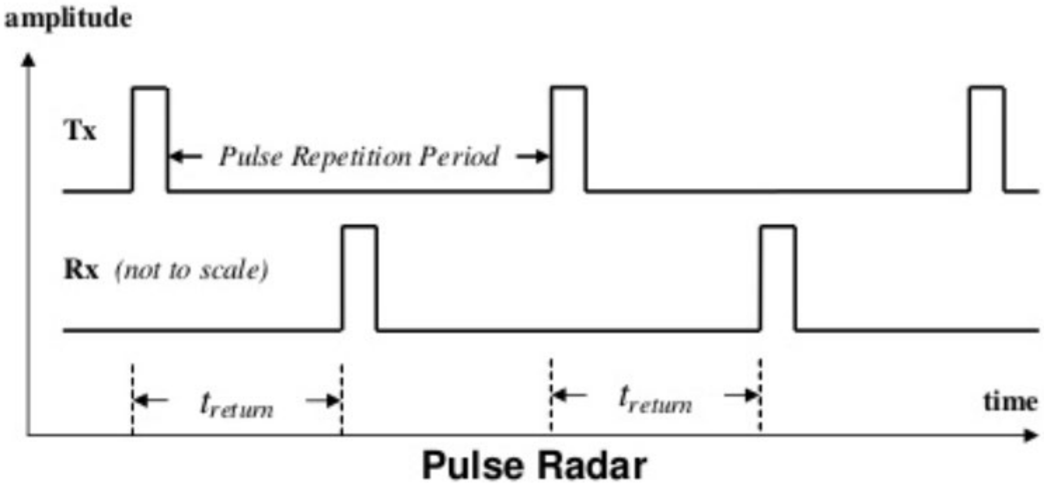


Figure 1: Operating principle of a pulse radar. The time difference between transmitted and received pulses is measured giving the distance to the target. (Source: Prof. Bill Mullarkey, dB Research Limited)

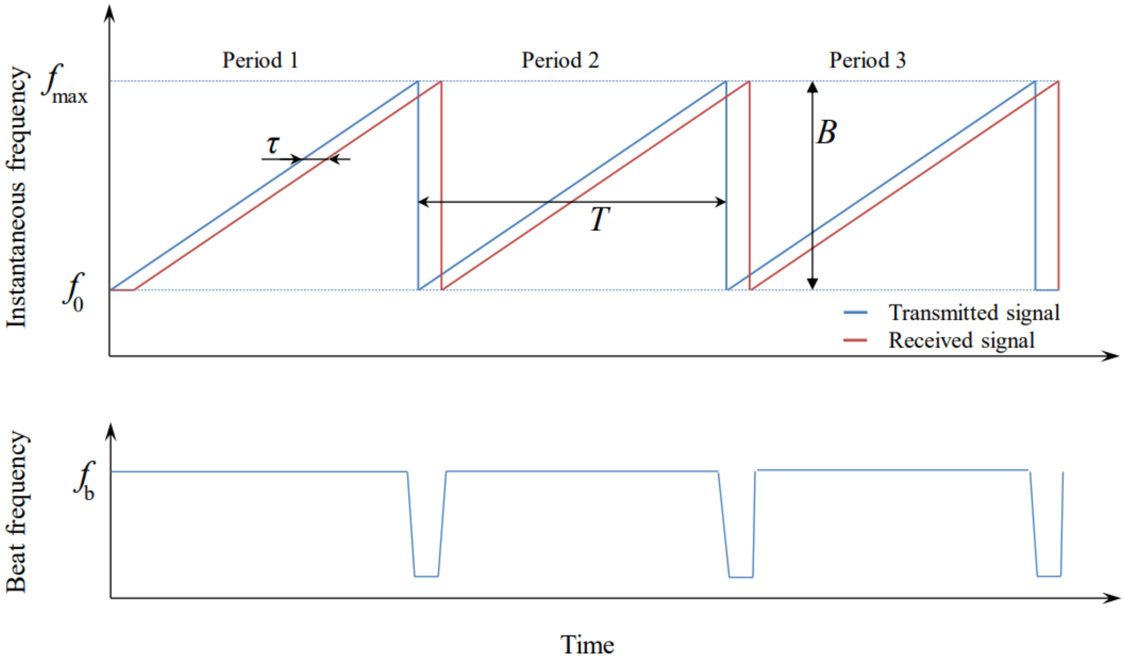


Figure 2 (Top) Instantaneous frequency of transmitted and received waves in case of a single stationary object. (Bottom) Resulting beat frequency. τ is a signal delay caused by wave travelling double distance to an object, T is a period of modulation, B is a bandwidth of modulation

3.2 Microwave characteristics

The need for a distance measurement tool is greatest during poor visibility conditions. Typical reasons for poor visibility are darkness, fog, haze, rain, and snow. There are several technologies for measuring distances. Two main methods for long range measurements are optical and microwave radars. The optical systems usually employ some kind of laser beam that can be static, or it can be scanned. Signal attenuation caused by hydrometeors is actually a quite complex phenomenon and it involves the geometry and the size of the hydrometeors as well as the wavelength of the signal and many other variables. But in general, it can be said that optical methods which employ signals close to visible light suffer when the visibility is bad, especially in dense fog and heavy snowfall. Same principles apply to microwave signals as well, but the wavelength is significantly longer. In Figure 3, the total attenuation caused by oxygen, water vapour and rain has been calculated based on the models provided by the ITU (International Telecommunication Union), [ITU838-3], [ITU676-3]. The operating frequency of the radar is 24 GHz, so it can be seen from the graph, that only a very heavy rain (> 12.5 mm/h) is starting to affect the performance. Same models predict that fog has only a neglible effect on signal propagation. Unfortunately, such models are not provided for snowfall which would be most relevant case for this application, but we could still assume that the attenuation caused by snow is less than that of heavy rain.

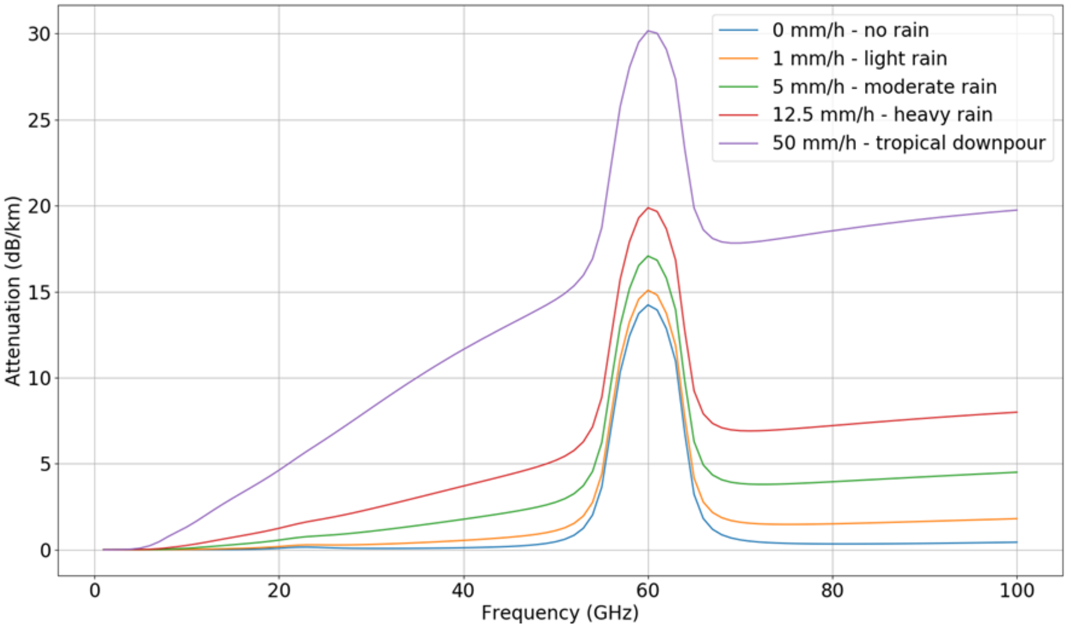


Figure 3: Total attenuation caused by oxygen, water vapour and rain as a function of frequency. has been calculated based on the models provided by ITU (International Telecommunication Union), [ITU838-3], [ITU676-3].

4. The prototype system

4.1 System description

The diagram of the prototype radar system is shown in Figure 4. The radar sensor is located outside at the stern of the icebreaker. It is connected to the operator's pc which is situated inside. The computer runs a script (written in Python, a computer language) that controls the radar and gathers the data from it. The script then uses a detection algorithm that calculates the distance to the nearest point of the assisted ship and its relative speed. It then sends the data to the bridge of the ship thru a short-range radio system operating at 433 MHz frequency. The data is received and transferred to Raspberry Pie microcomputer which controls the 7" screen displaying the relevant data to the operator of the ship. The display unit can be programmed to show the data in different formats. Currently it shows the distance and the relative speed in both nautical and metric units and draws a graph of the distance as a function of time.

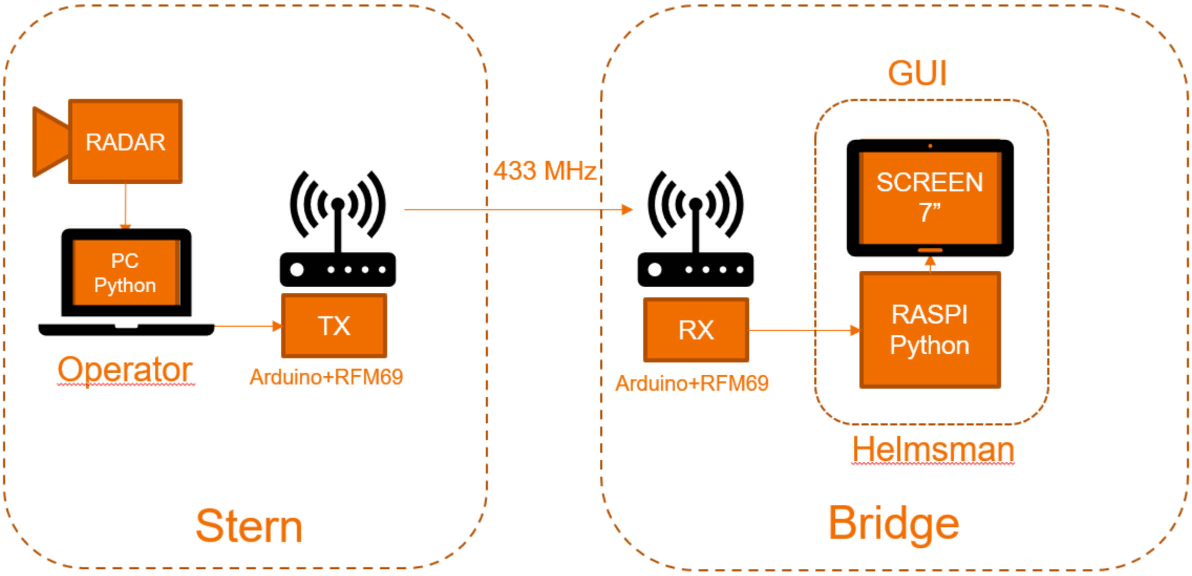


Figure 4: Diagram of the distance measuring radar prototype system.

4.2 The radar system hardware

The distance sensor used in this project is a FMCW-radar operating at 24 GHz. The radar is developed by VTT. The Radar's basic operating parameters are presented in Table 2. The radar is enclosed inside a plastic waterproof box, which is shown in the Figure 5 with the handrail fixture system. The radio communication is handled by custom made RFM69-chip based radios that are controlled by Arduino Uno processors (Figure 7). The communication utilizes a 433 MHz licence free frequency band. The intended placement of the radar and the display unit (Figure 6) on Polaris is shown in Figure 8.

Table 2 : Basic parameters of the radar.

Parameter	**Value**
Frequency	24 GHz
Frequency bandwidth	150 MHz
Transmit power	10 mW
Antenna beamwidth	14°
Distance resolution	1 m

Figure 5: Radar enclosure with handrail fixtures.

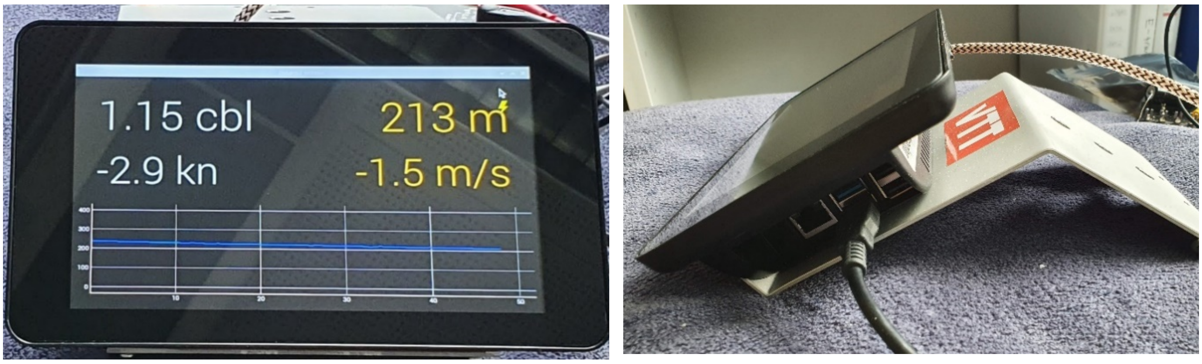


Figure 6: The display unit.

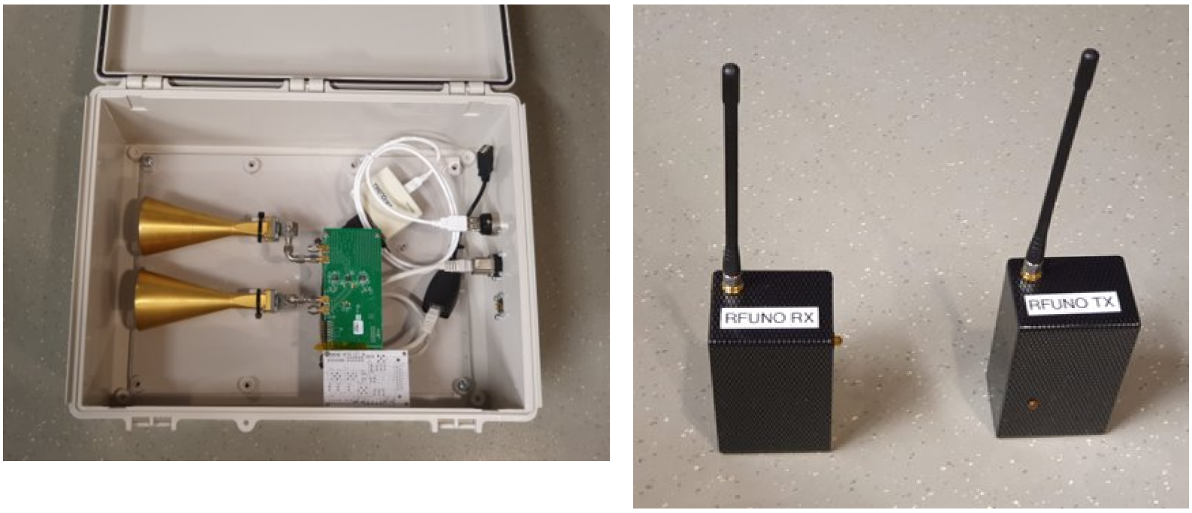


Figure 7: Inside of the radar enclosure and the radio units.

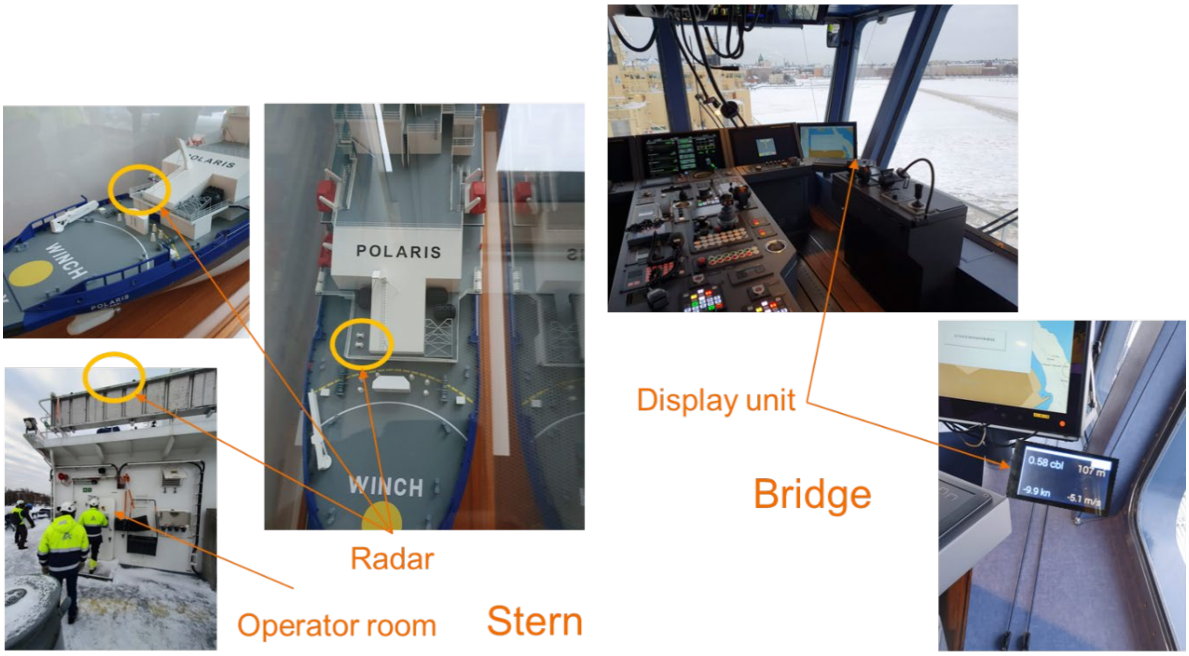


Figure 8: Locations on ib Polaris.

5. On shore trials

The purpose of the measurements from shore were to test the system and to obtain measurement data for improving the detection algorithms.

5.1 Trial 1

The first trial was conducted on Saturday 6.3.2021 when M/S Pasila was approaching the Kellosaari pier, Helsinki. The weather conditions were as follows: - 2 °C, quite strong wind, 12 m/s SW (measured at the Harmaja station). Ice on the water (as can be seen in the pictures below, Figure 9 and Figure 10).

Figure 9: Overview of the trials. The radar box is positioned on shore facing the fairway.

Figure 10: M/S Pasila approaching pier 6th March 2021.

5.2 Trial 2

The second trial was conducted on Sunday 28.3.2021 when M/S Alppila was approaching the Kellosaari pier, Helsinki. The weather conditions were as follows: + 2 °C, light breeze 5 m/s wind from South (measured at the Harmaja station). Open water, no ice. (Figure 11)

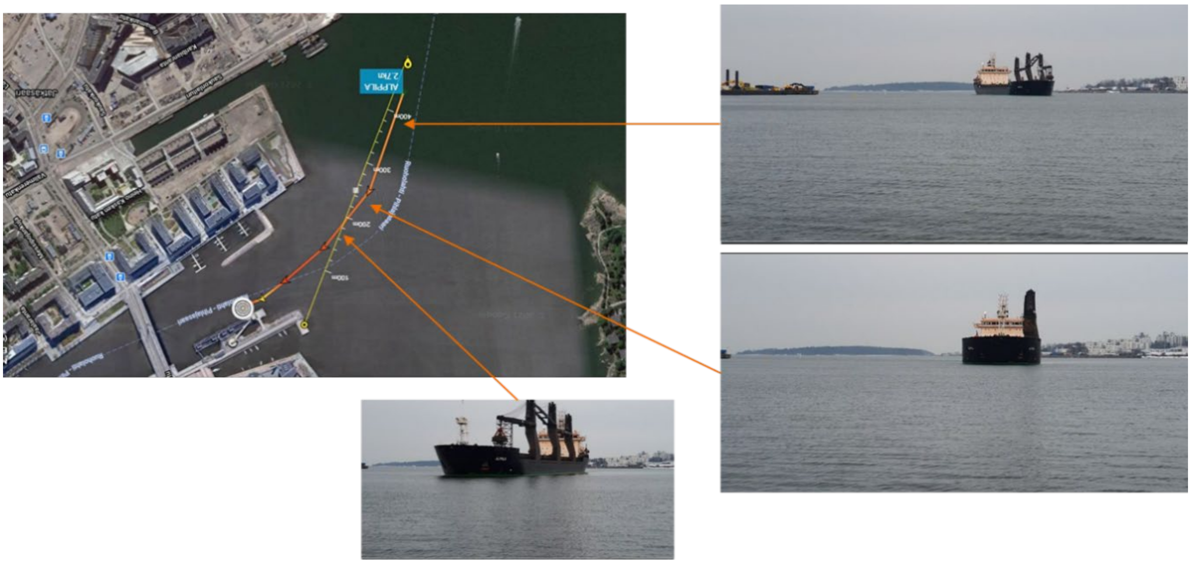
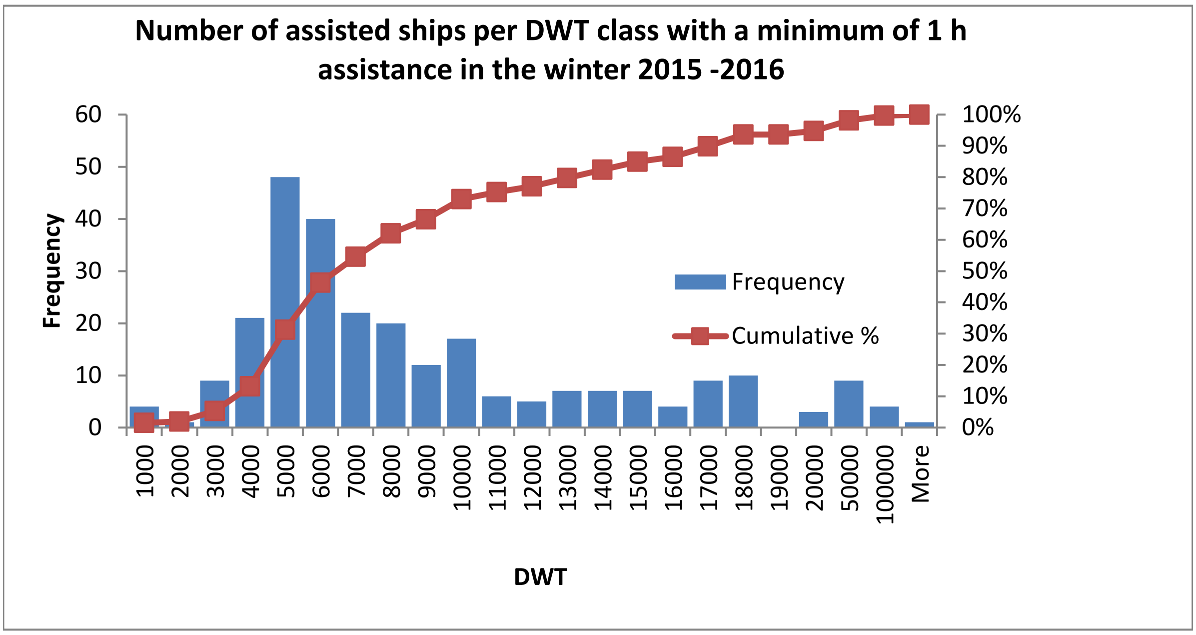


Figure 11: M/S Alppila approaching the pier 28th March 2021.

A discussion of the representativeness of the ships M/S Alppila and M/S Pasila:

M/S Pasila has a deadweight of (DWT) of 13 367 tons, M/S Alppila 20 499 tons. Compared to ships being assisted these ships are quite large. A histogram showing DWT distribution of assisted ships in the Baltic Sea in a typical winter (here 2015-2016) looks like this (data from the IBNet system):



A weighted average $sum(DWT * ha)/sum(ha)$, where *ha* is the total assistance time per ship that winter and *DWT* is the DWT of the ship, gives a value of 7888 tons. This is an indication of the average size of an assisted ship. Compared to these, both Alppila and Pasila can be considered to be large ships.

6. Results

The on shore trials were conducted as described in the previous chapter. The target ships are quite similar to each other both in size (137 m – 155 m) and shape and they both have large on-board cranes. Their radar signatures were also quite similar. The range of the radar was limited to 500m (a parameter in the signal processing software). The position and the orientation of the ships was useful from 350 m to about 175 m. From distance of 200m to 250 m the target was on a direct head-on course towards the radar, which is close to the real life ship assistance case (Figure 12, middle row).

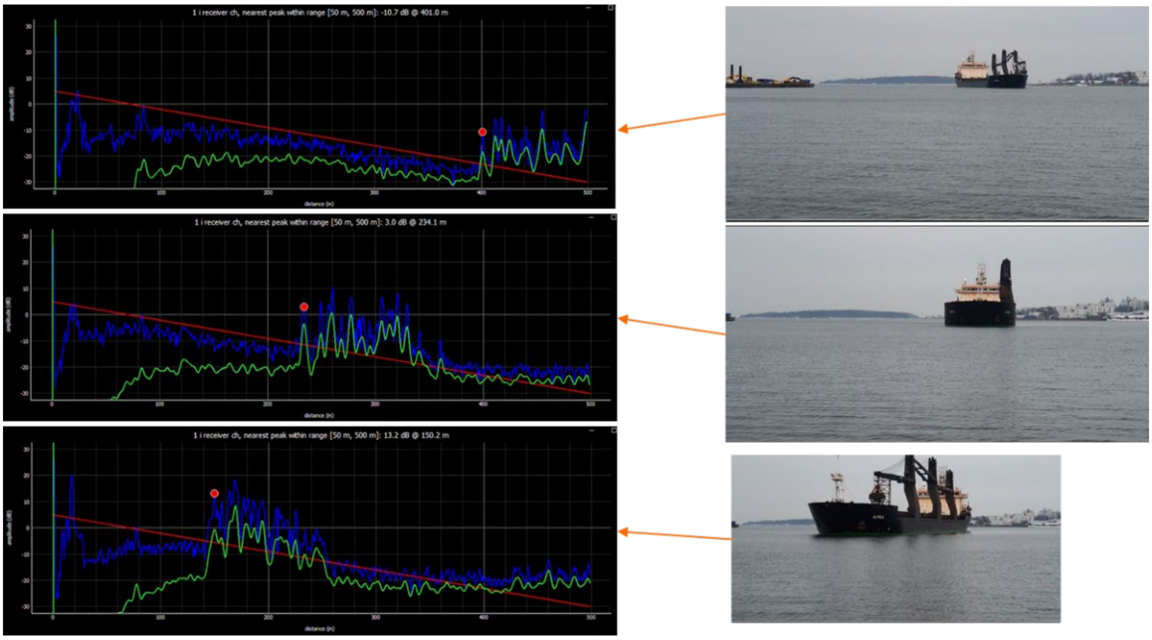


Figure 12: Processed signal from the approach of M/S Alppila. The blue graph is the uncompensated amplitude of the backscattered signal. The green graph shows the signal after applying a compensating filter. The red line is a threshold that is linearly dependent on the distance (in log-scale). And the red dot shows the detected first echo. Note the multiple peaks from the cranes and other superstructure elements on the ship.

The main objective of the radar system is to accurately determine the closest point of the target ship to the ice breaker. This becomes more important the closer the target comes. In some cases this nearest part does not have the sufficient radar cross section to be detected by the radar but is (erroneously) replaced by another stronger reflection. This causes some fluctuation in the distance measurement results, which was also noticed in the trial measurements. The fluctuation was a few meters in range. But the measurement was stable when the relative orientation of the target ship was constant towards the radar (distance range 200-250m in trials). Due to the fluctuations in distance measurement, some averaging is applied to the measurements. The distance data from the M/S Pasila approach is shown in Figure 13. The radar produces 2-4 measurements per second (blue curve). The figure also shows a moving average trendline based on a 3 second time period. The display unit shows the distance measurement history curve, so the user (the helmsman) can easily spot any sudden jumps in the measurements and disregard them. The (relative) speed was calculated from changes in distance as function of time. Since the method is based on the distance measurements, the relative speed is subject to the same fluctuations. Again, some avenging and curve fitting was applied to smooth the result. This is not the most accurate way to measure speed. A better way would be to use so called range-doppler (or 2D-FFT) measurement. In this method multiple frequency ramps are transmitted and the phase change of the each distance bin is observed over time. Unfortunatetly the radar device used in this project does not support this (more sophisticated) method.

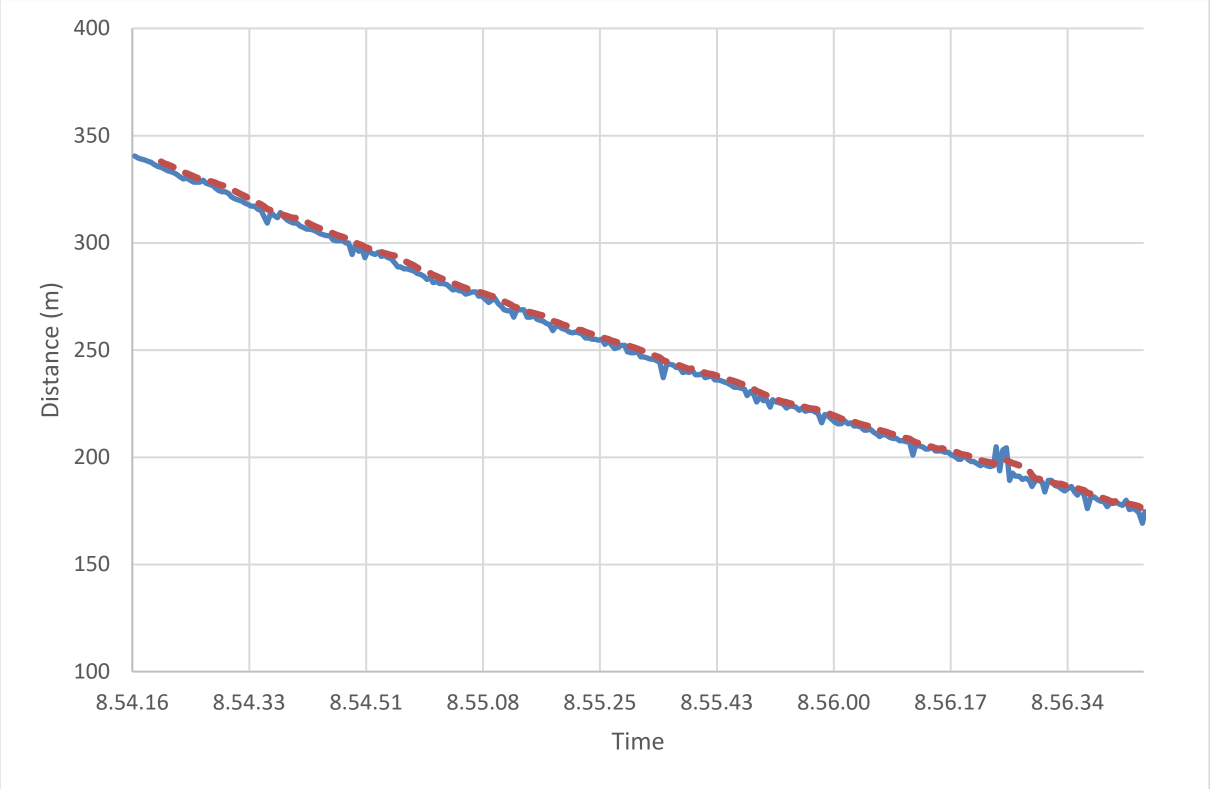


Figure 13: Distance measurement of the M/S Pasila approach. The solid blue line is the measured data and dashed red line is a 3 second average of the data.

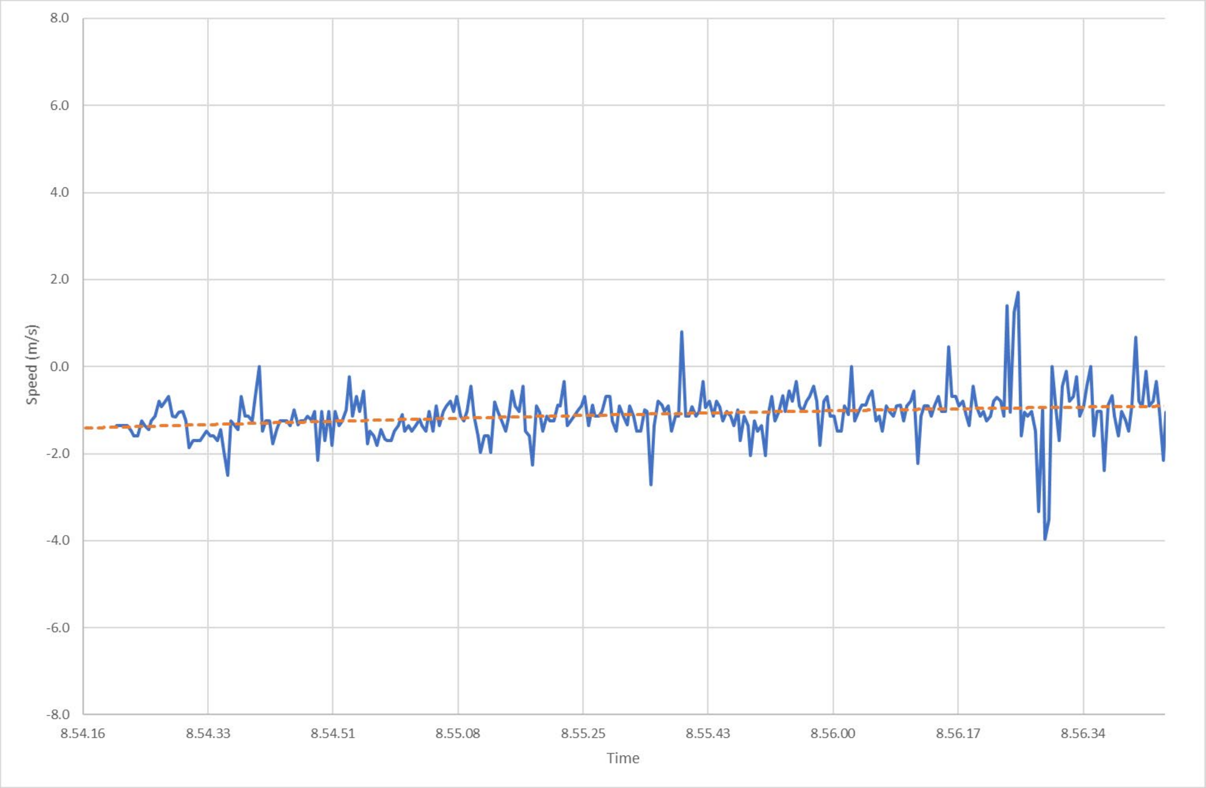


Figure 14: Speed measurement of the M/S Pasila approach. The solid blue line is the measured data and dashed red line is a polynomial trendline.

7. Conclusions and summary

The conclusions of the User questionnaire were that trials are needed for the users to be able to evaluate the usefulness of such a system. An important aspect is that the system should be reliable enough so that the users can trust the readings. As the signal may vary depending on the conditions, an indicator of the reliability of the reading, would be useful. One way of showing this, is by means of a trendline showing the distance value as a function of time. If this graph is not smooth, the reading is not reliable either.

Technically the measuring method seems to work quite well. Since the exact location of closest radar reflection point of the is not known, this method is not suitable for applications where very accurate measurement is needed (< 5 m). For example, this would be the case where the assisted ship is very close (< 50m). On the other hand, the radar is well suited for observing the assisted ships in distances between 50-500 m, especially during bad visibility conditions. The speed measurement method used by current radar device is not optimal, but this is caused by the limitations caused by current radar hardware and not the radar method in general. Better speed measurement can be achieved with different (or modified) radar hardware. From technical point of view, the current system is still accurate enough to determine, with the help of onboard trials, if the radar method is feasible for this use case in general. It is also clear, that substantial amount of effort is still needed if this idea would be further developed into an end-user product.

What remains to be tested, is the influence of backscattering from ridged ice around the ice channel, which may disturb the detection of the echo from the bow of the ship, and the variation of backscattered signal depending on the relative attitude of the ship and the shape of the ship’s hull.

A question regarding the onboard trial is whether the system can be operated by the onboard personnel or if a capability for remote monitoring and remote updates should be implemented. The decision on how advanced system is possible to develop for the trial, very much depend on the amount of funding for doing the onboard trial and preparations for these.

The aim is to apply for funding for the trial and if the trials confirm the usefulness of such a system, then proceed with discussions regarding alternatives to obtain such a system for all the icebreakers in Finland and Sweden.

References

[ITU676-3] RECOMMENDATION ITU-R P.676-3 – Attenuation by atmospheric gases

[ITU838-3] RECOMMENDATION ITU-R P.838-3 - Specific attenuation model for rain for use in prediction methods

Appendices

[1] User questionnaire summary