Final Research Performance Progress Report

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Project Title: Offshore thermal imaging whale detection test in Canadian waters

PI: Dr. Daniel P. Zitterbart

1. MAJOR OBJECTIVES AND GOALS

The primary focus of this project is to test and refine our latest thermal imaging system for the automatic detection of whales. There is an immediate concern that ship-strikes can bring whale populations closer to extinction. This became particularly clear in 2017, when 17 of the ~470 remaining North Atlantic right whales died. At least six of these deaths are believed to be due to vessel collisions. Thermal imaging systems have been increasingly tested during the last decade for their capability to detect and localize whales in real time. For systems to be effective, automatic detection of the whale signatures in the video feed is crucial. To achieve reliable detection during high seas and for fast vessels, a stabilized video feed is necessary. We are currently developing a stabilized, low-cost thermal imaging camera system for marine mammal detection. We tested our system during two field experiments in 2020 and 2021.

Introduction

Growing concerns that aquatic noise produced during anthropogenic maritime activities such as shipping, construction, and seismic surveys may be harmful to marine mammals have led an increasing number of regulating agencies to request mitigation measures. Increasing concerns that ship strikes might threaten marine mammal populations (Fais et al. 2016; Dawson et al. 2018, UNCTAD 2018) have also led to an increased interest in reliable marine mammal detection technologies. This became especially clear during 2017, when 17 North Atlantic right whales of a current population of 360 (Pace et al. 2021) died, which the National Oceanic and Atmospheric Administration (NOAA) called an unusual mortality event. According to NOAA, six of the 17 are believed to have been killed by vessel collisions. This unusual mortality event clearly shows the need for technologies that allow the mitigation of ship-whale collisions (Cates et al. 2016).

High level underwater acoustic sources for marine geophysical prospecting have the potential to elicit injuries or negative physiological or behavioral responses in marine mammals (Richardson et al. 1995, Erbe et al. 2018, Southall et al. 2019). Naval mid-frequency sonar is criticized for its potentially negative effect on marine mammals and has been implicated in several whale stranding events. To minimize possible adverse impacts on individuals and their populations (e.g., D'Amico et al. 2009, Miller et al. 2012), competent authorities commonly require the implementation of mitigation measures, including vessel speed reductions and shut-down of acoustic sources if marine mammals are sighted in high-risk areas or in a pre-defined exclusion zone around the vessel (Weir and Dolman 2007, Laist et al. 2014, Constantine et al. 2015).

The most common measure is to implement a "marine mammal watch," a team of observers scanning the ship's environs for signs of marine mammal presence to trigger a shutdown of the hydroacoustic source or a change in vessel course and speed when marine mammals are entering a predefined exclusion zone (Verfuss et al. 2018). Marine mammal observers usually scan the ship's environs for whales using binoculars or the naked eye. Sightings mostly rely on spotting a whale's blow, which might rise to a height of several meters but is visible for only a few seconds. Hence, in combination with the whales' prolonged dives, sighting opportunities are rare which, in addition to the limited field of view and finite attention span of human observers, renders this method personnel-intensive and difficult, even during fair weather and daytime. During darkness it is not feasible.

With the goal of improving marine mammal detections beyond using these traditional methods, studies in recent years have evaluated the use of thermal imaging cameras to detect marine mammals at the ocean's surface (Verfuss et al. 2018) and to make such detections automatic (Santhaseelan et al. 2012, Zitterbart et al. 2013). Thermal imaging systems have been used for a few decades to detect marine mammals during night-time hours (Perryman et al. 1999, Schoonmaker et al. 2008).

Aiming at overcoming daytime constraints, observer fatigue, and berth limitations, we developed an automatic whale detection system (Zitterbart et al. 2013, Zitterbart et al. 2015, Zitterbart et al. 2020, Smith et al. 2020) that uses a machine learning algorithm to continuously detect whale blows in real-time. The whale detection system is based on a state-of-the-art, stabilized, high-resolution, 360°-scanning, cooled thermal (i.e., infrared) imager – *FIRST-Navy* by Rheinmetall Defense Electronics – that provides a 5 Hz video stream. This video stream is subsequently analyzed for whale signatures. To date, this is still the only available automated marine mammal detection system that can detect non-vocalizing surfaced marine mammals and can provide a gyroscope stabilized 360° field of view. The high cost of this system is a barrier to its widespread use, so in recent years we successfully integrated low-cost, commercial off-the-shelf cameras for whale detection.

2. ACCOMPLISHMENTS TOWARDS GOALS

Approach and Procedure

In this project we tested new thermal imaging-based whale detection prototypes specifically around North Atlantic right whales. We tested two previously developed vessel-based thermal imaging whale detection systems during dedicated cruises as well as on opportunistic platforms. Dedicated cruises were used to image large numbers of whale blow from humpback and North Atlantic right whales. Data obtained on dedicated cruises during Years 1 and 2 were used to refine the detection systems for long-term deployment on platforms of opportunity later in Year 2.

Task 1: Installation of camera systems on dedicated vessel. Operation of dedicated vessel for five days at sea.

We installed two previously developed prototypes on R/V *Auk*. R/V *Auk* is a 50 ft aluminum hydrofoil-assisted research catamaran owned and operated by the NOAA's Stellwagen Bank National Marine Sanctuary. Due to COVID-19 restrictions, the number of personnel on the vessel was reduced to an absolute minimum. We therefore changed from a team of seven where each instrument would have its own dedicated operator and two marine mammal observers, to a team of two consisting only of the principal investigator and one marine mammal observer.

Figure 1. R/V *Auk*, the Stellwagen Bank National Marine Sanctuary's research vessel.

Figure 2. Installation of two thermal imaging-based whale detection systems on R/V *Auk*. (A) is a low-cost camera system for ship-strike mitigation; (B) is a higher-end system that allows for varying payload.

We mounted two different whale detection systems as high as possible on top of the R/V *Auk's* flying bridge at an elevation of 5.5 m. The first system was very low-cost and was specifically designed for ship-strike mitigation. It included two thermal cameras and one RGB camera and provided a 25° forward field of view (Figure 2A). This system was actively stabilized using a motorized gimbal. The second system included a custom designed gimbal that allowed for larger payloads (Figure 2B) and could carry up to 10 kg. This allowed for different camera configurations. During the 2020 experiment, we operated only one TCM 2014 LWIR camera with a 30°field of view. The gimbal was designed to allow use of camera systems with up to a 180° field of view.

Due to the shortage in personnel on the research cruises, all necessary data acquisition was done using mobile computers from a single workstation.

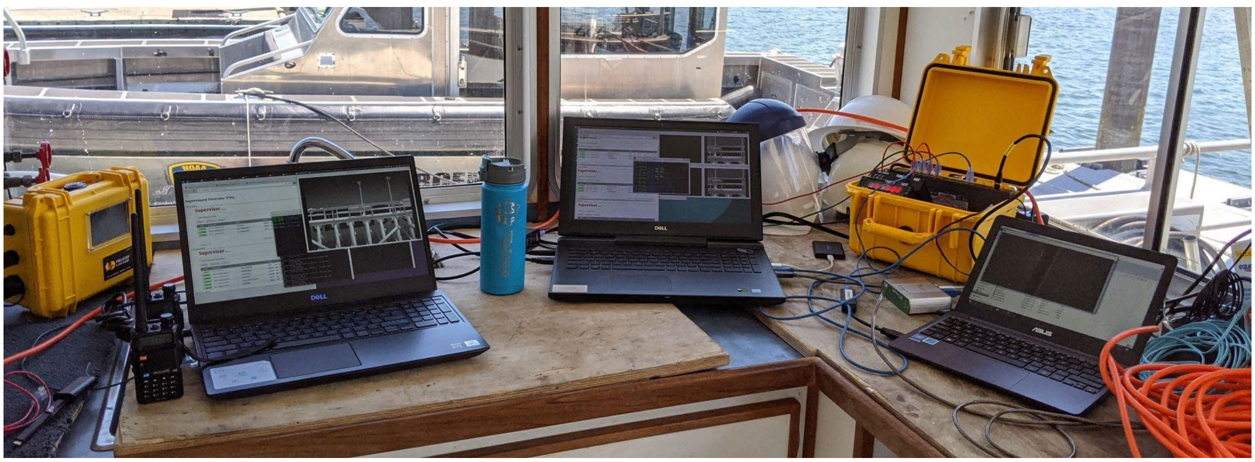


Figure 3. Data acquisition and processing on mobile computers on R/V *Auk*.

Research cruises originated in Scituate, MA, and the experiments were conducted in the Stellwagen Bank National Marine Sanctuary (Figure 4A). Experiments were conducted on July 29, 2020, and on August 13, 2020, for the entirety of each day. Experiments followed a simple protocol that was driven by the aim of obtaining as many whale blows in the cameras' fields of view as possible. After a group of humpback whales were localized (local whale watching tour companies notified us of the whales' location, thus localization was very easy), we slowly (vessel speed 1-5 kn) approached the group from several kilometers distance with the aim of keeping the majority of the group in the field of view up to 300 m. From this nearest point, we either turned around and repeated the experiment, or the group of whales were passed at a distance and approached again from a different angle. Different angles were chosen to provide different angles to the sun, thereby including different glare situations. The marine mammal observer marked every visually observed whale blow using a GPS. In total, over 900 whale blows were imaged within two days.

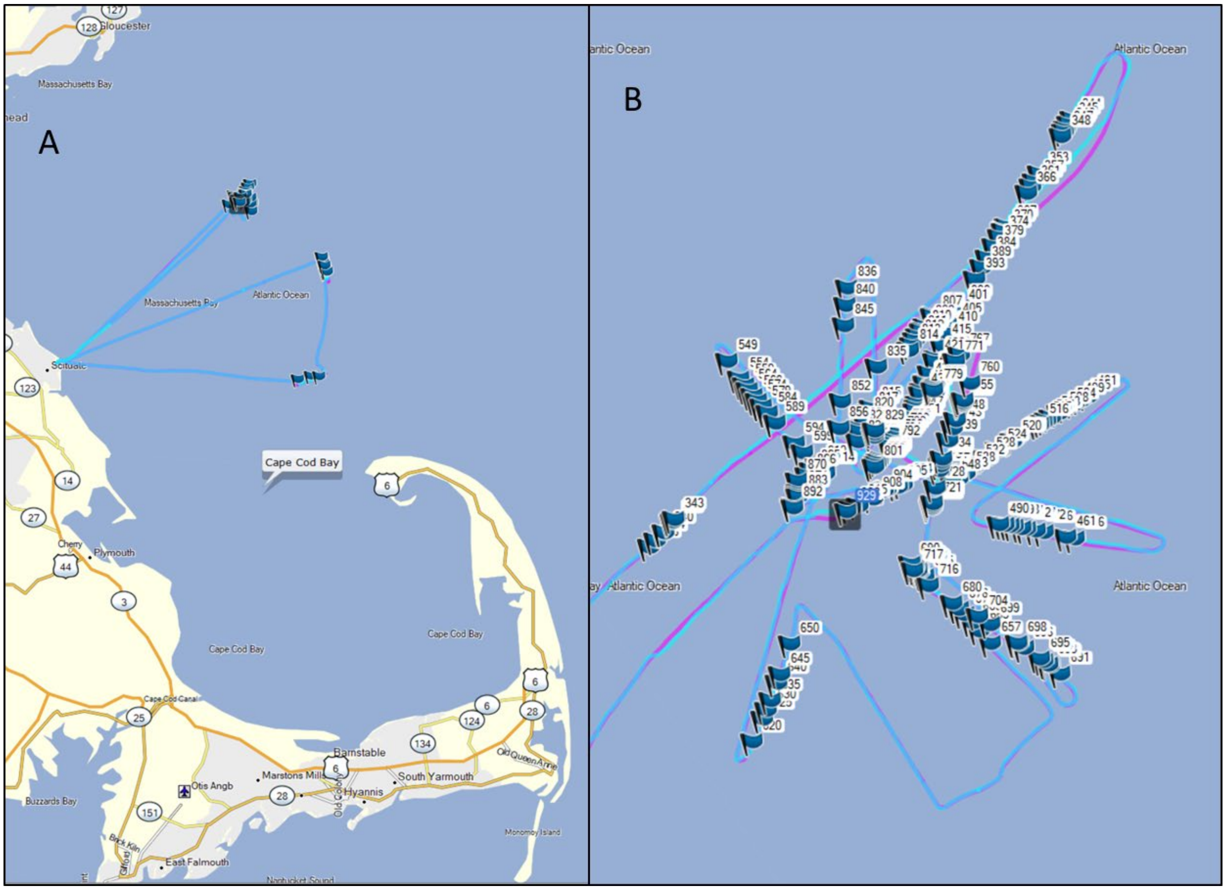


Figure 4. (A) Research cruises were conducted in Stellwagen Bank National Marine Sanctuary, and the vessel sailed from Scituate harbor. (B) After a group of humpback whales was identified, a star-like pattern was used to obtain whale blows at different distances.

Task 2: Data analysis and system refinement

The data were retrospectively analyzed at specific time points to obtain a detection function for humpback whale blows (Figure 5) from a platform like R/V *Auk*. We found that the detection function showed the expected behavior. With increasing distance from the vessel, the number of detected whale blows increased, in this case at a range of up to 1,000 m (Figure 6). After that range, the number of detected whale blows decreased again. We interpreted this to mean that beyond the range where the detection function reached its peak, the camera system started to "lose" detections. We defined this range as Reliable Detection Range (RDR), which was 1 km in this case. When we compared the RDR of this experiment with previous experiments (Figure 7), we found a strong elevation dependence of the RDR (please note the logarithmic x-axis). We expected the number of whale blows to be similar at larger ranges because we were imaging the same group of whales with the same number of animals at different ranges. It is to be noted that detections that were further than 4 km should be disregarded. Due to the low elevation of R/V *Auk*, at those ranges an individual pixel in y-position on the image could induce substantial errors. Errors were due to the horizon detection for range estimation as well as to residual movement for which the gimbal could not compensate.

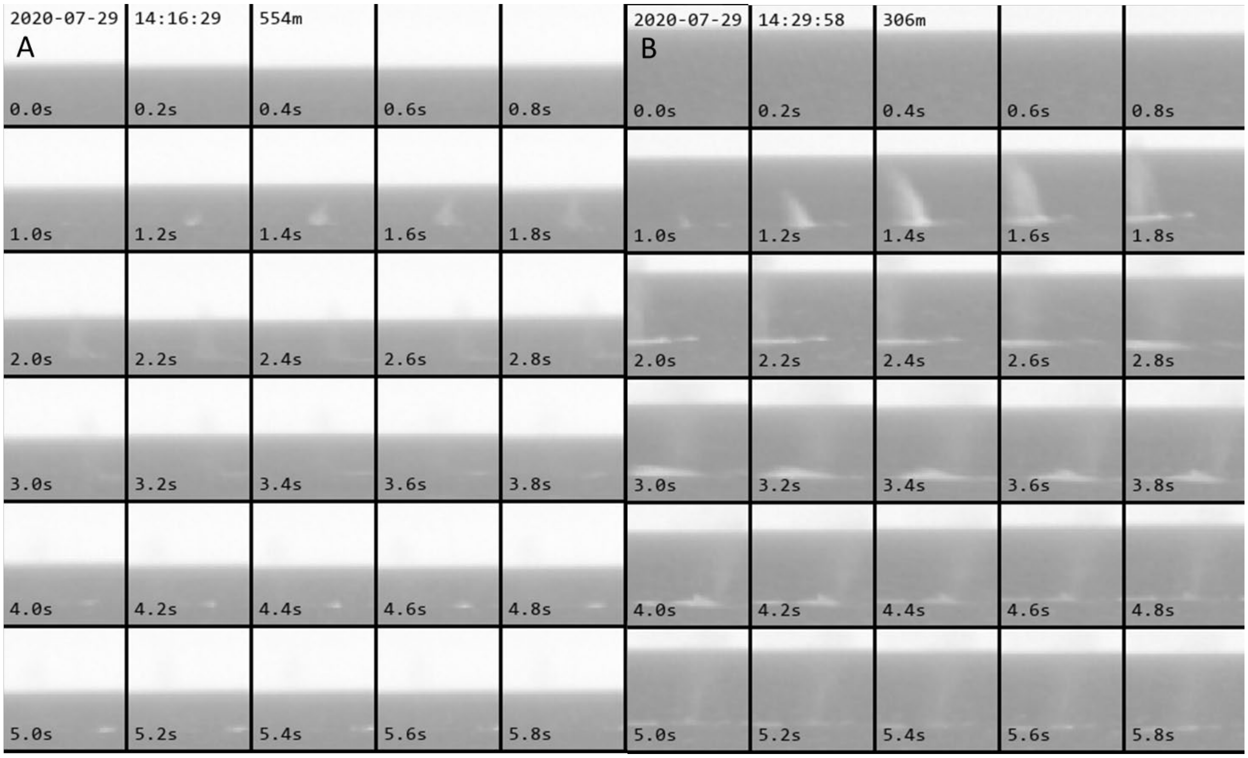


Figure 5. Example humpback whale detection at distances of 554 m (A) and 306 m (B), respectively.

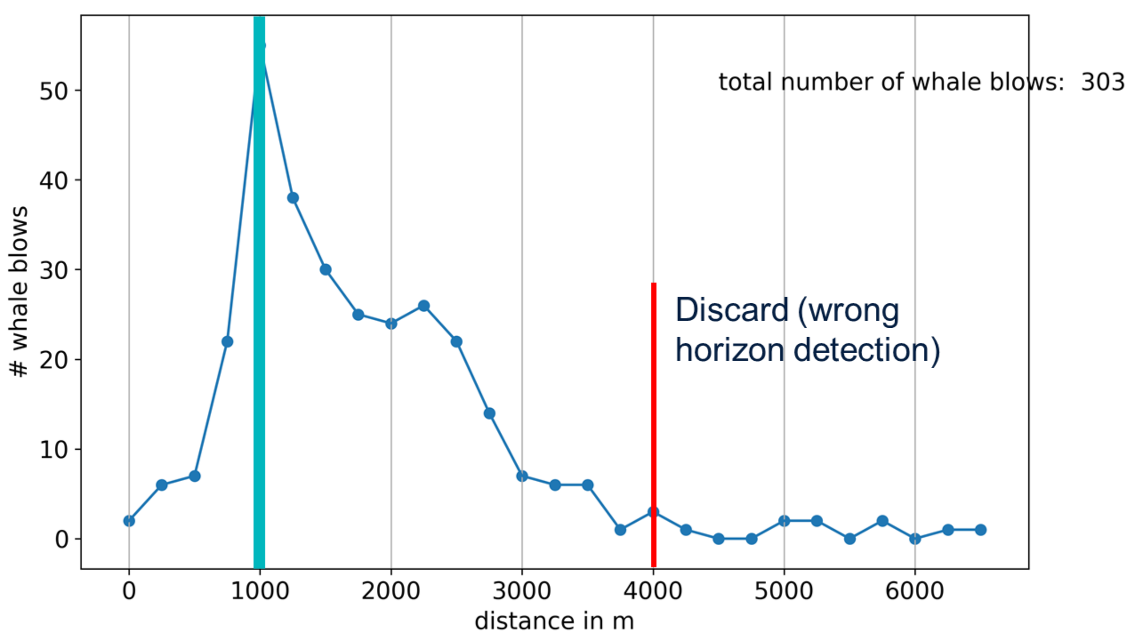


Figure 6. Detection function for humpback whales from R/V *Auk* using thermal imaging-based whale detection.

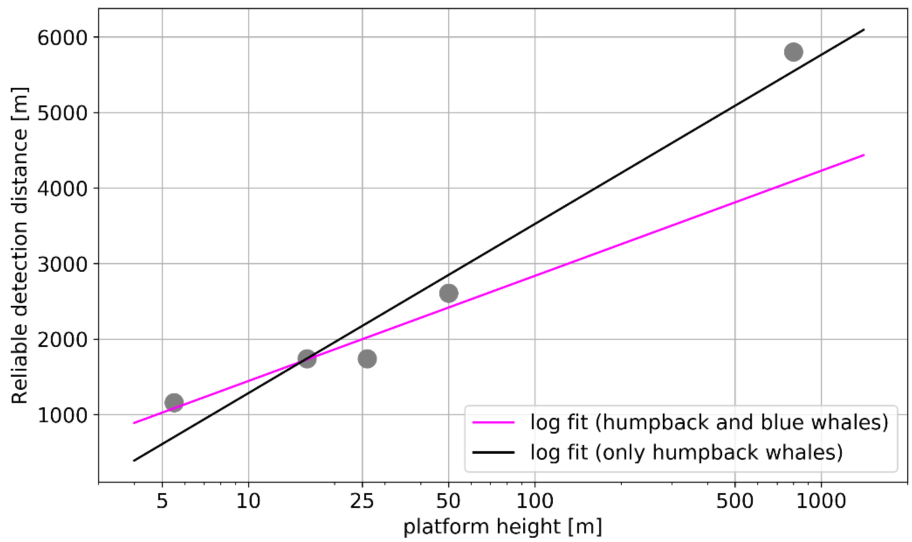


Figure 7. RDR depends on the elevation at which the detection system is mounted.

We analyzed the gimbal residual motion using horizon tracking. The gimbal was able to correct roll and pitch to <0.2° and <0.1°, respectively (Figure 8). Further refinement will include a predictive Kalman filter model do drive the motor servos with anticipation of well predictable ships' motions. It is to be noted that R/V *Auk* is a small catamaran with a very low draft, making it very susceptible to short wave motion. While roll and pitch are well stabilized with the respective gimbals, we found that R/V *Auk* shows significant yaw motion (~1°), again based on the vessel design. The gimbals we designed were not able to compensate for yaw, therefore during system refinement we designed a way to electronically compensate for yaw drift using the yaw measurement of the internal motion unit (IMU). In contrast to roll and pitch, yaw can be compensated without the loss of usable vertical field of view because correction is solely in the horizontal direction. We anticipate that larger vessels will track better and show less yaw motion in most cases.

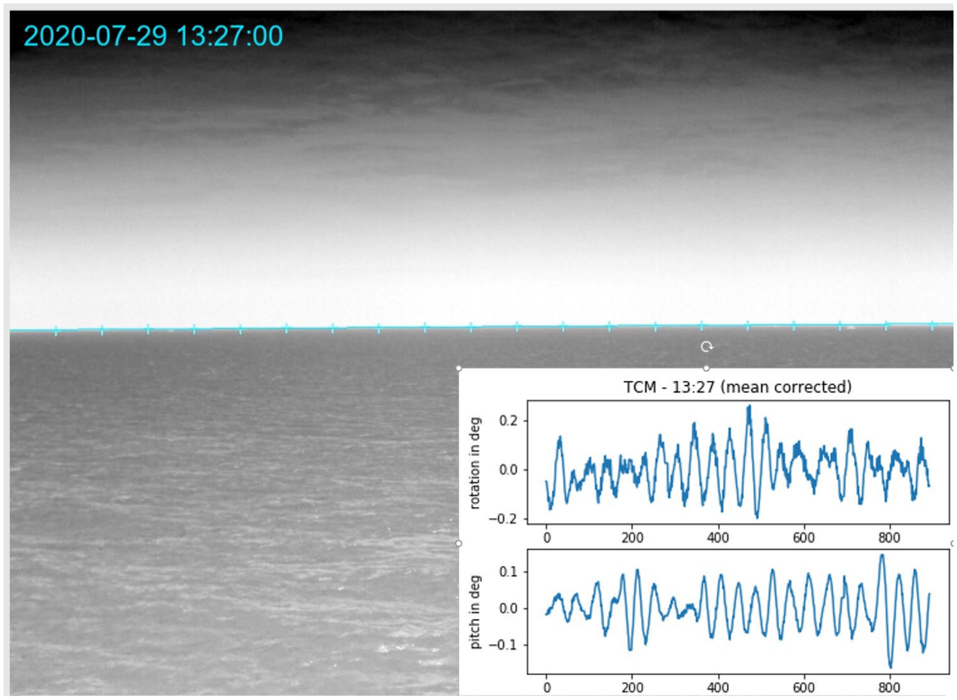


Figure 8. Residual roll and pitch motion measured using horizon tracking.

We refined both detection systems for the 2021 field season. The low-cost system (Figure 9A) was redesigned to fit into an enclosure into which the roll and pitch compensating gimbal was built (Figure 9B and C). The weight of the detection system was reduced from ~6kg to 3kg. The new design also made it very easy to waterproof. Also during the refinement process, we updated the wide field of view camera system to include four 30° thermal cameras to increase the total field of view to 120° (Figure 10). These design changes were made to simplify system installation by non-experts whenever necessary, as we believe a low-effort installation process is paramount for successful use of the systems.

Due to the ongoing COVID-19 pandemic, we anticipated that we would not be able to travel to Canada during the summer of 2021 to install the camera systems on M/S *Bella Desgagnés*. Thus, we planned for installation to be completed by the vessel's personnel. Both updated systems were used during spring and summer 2021field excursions.

Figure 9. Evolution of the low-cost whale detection system: (A) version used in 2020 research cruises; (B) new miniaturized gimbal with two thermal cameras that can now be entirely mounted into an enclosure (C).

Figure 10. Refined version of the wide field of view thermal whale detection system using four cameras and providing a total of 120° field of view.

Task 3: Installation of camera systems on the opportunistic vessel platform M/S Bella Desgagnés

After last year's installation on R/V *Auk*, this year our low-cost vessel strike mitigation system was installed on M/V *Bella Desgagnés* (Figure 11), a passenger ferry and local supply vessel operated by Relais Nordik, Inc., that travels along the northern shore of the Gulf of St. Lawrence. The main objective was to test how well the system, which includes two thermal and one RGB camera and provides a 25° forward field of view (Figure 12), would work without attention. This system is actively stabilized using a motorized gimbal.

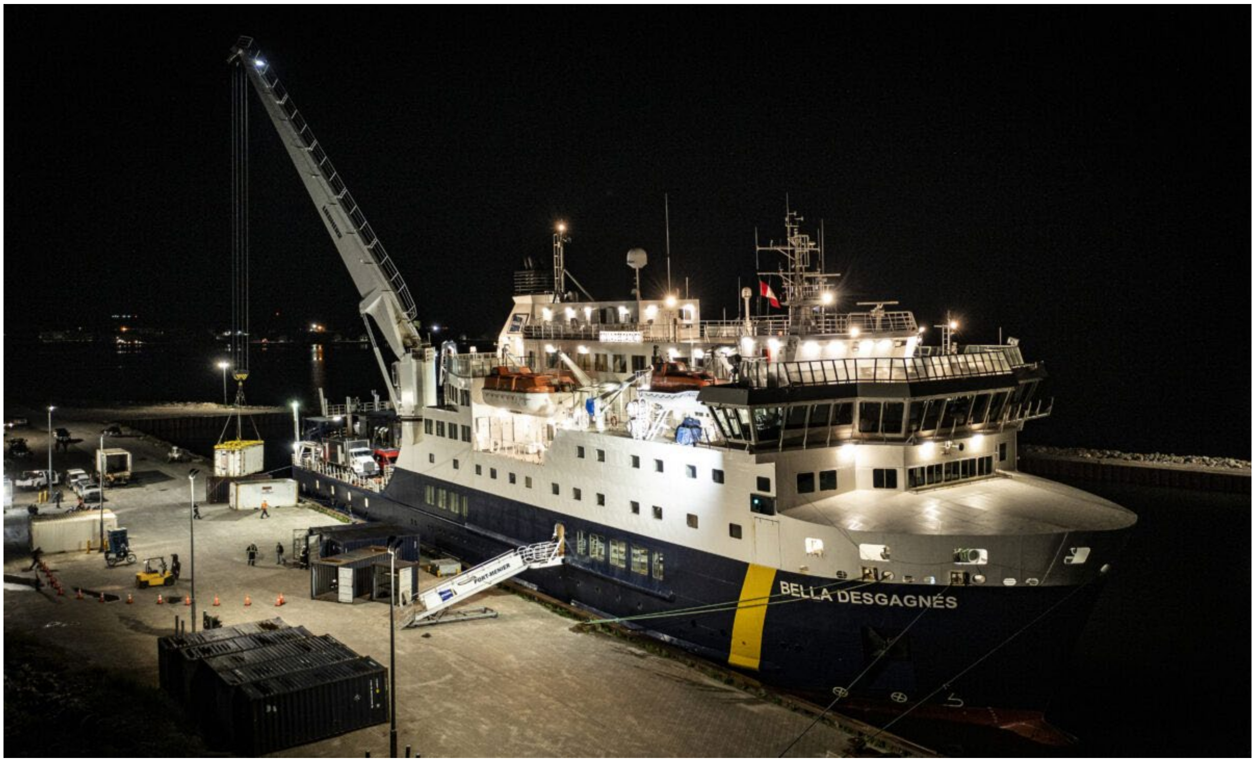
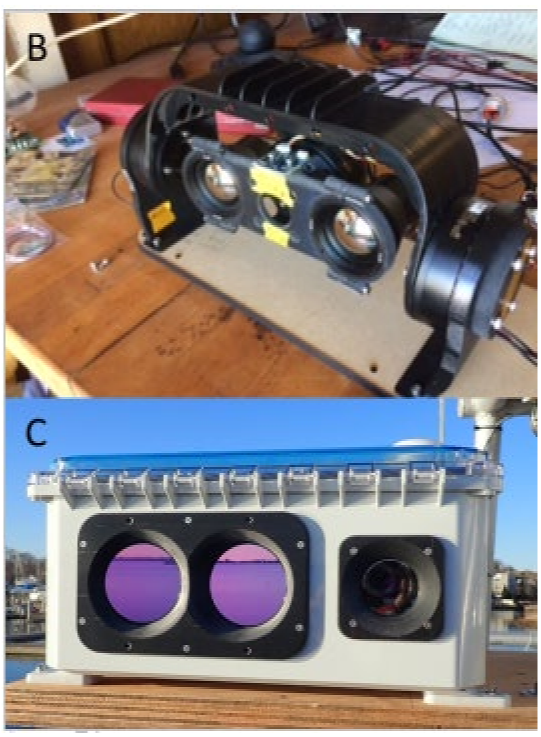


Figure 11: M/V *Bella Desgagnés*



Initially, we had planned to conduct the installation ourselves and provide an introduction to the vessel's crew. Due to COVID-19 travel restrictions, we still could not travel to Canada during the summer of 2021. The installation was therefore conducted by the vessel's crew.

Unfortunately, part of the gimbal was damaged during shipping (Figure 13). Thanks to the heroic efforts of one of the *Bella Desgagnés*'s electricians, a replacement part was 3D printed, and the gimbal was repaired and installed. This resulted in a small tilt of one of the cameras because the electrician did not have the opportunity to recalibrate the rotation of the cameras. However, this had no impact on detection performance as the horizon in the image could be rectified on the software (image) level (Figure 16).

Figure 12: Low-cost whale detection system to be installed on M/V *Bella Desgagnés*.

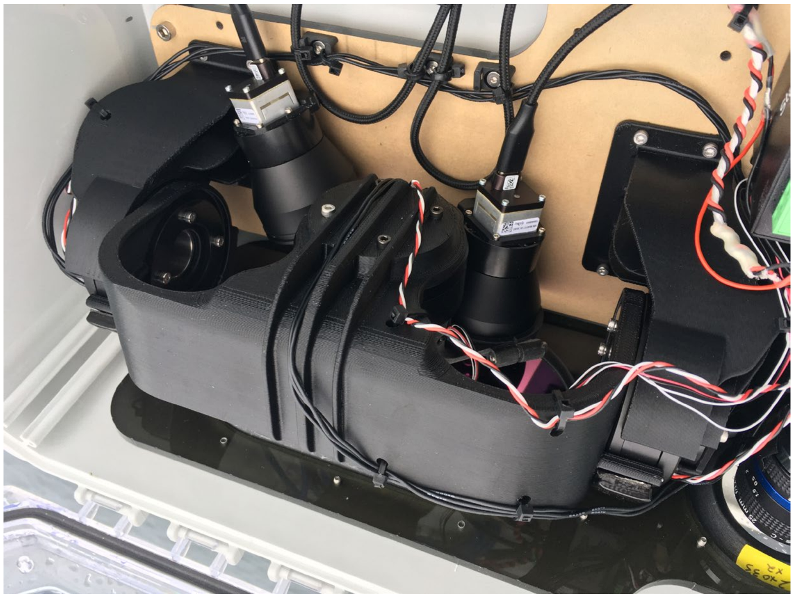


Figure 13: Damaged gimbal after shipping to M/V *Bella Desgagnés*.

Installation was conducted on the flying bridge at 19m elevation with an unobstructed view to the horizon (Figures 14 and 15).

Figure 14: Whale detection system installed on M/V *Bella Desgagnés*.

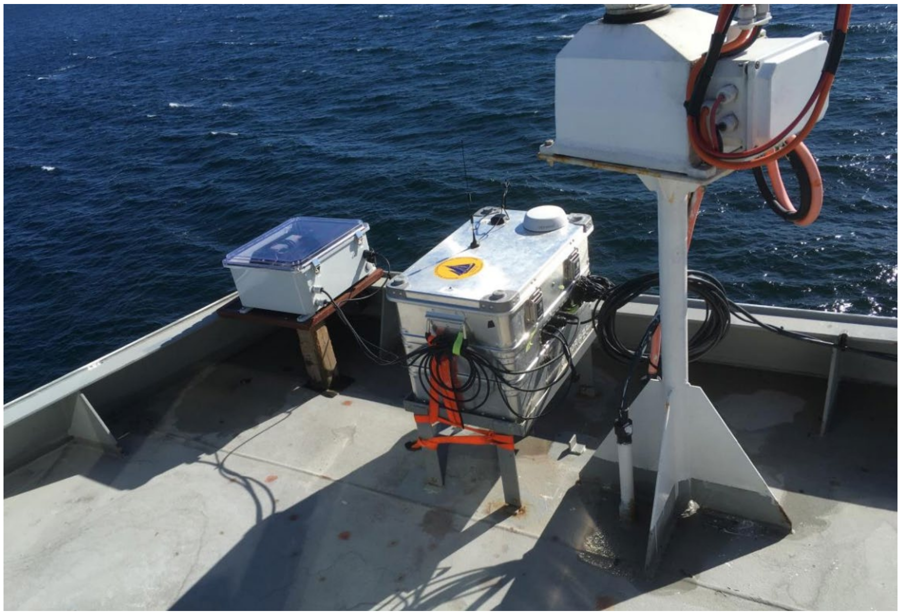


Figure 15: Whale detection system installed on M/V *Bella Desgagnés*.

On 9 Sept. 2021, the installation was completed, and the system was turned on so that we could access it through the cell network internet connection.

After installation, the gimbal needed to be calibrated. Gimbal calibration always needs to be done on the vessel to account for both the vessel's and the installation point's vibrations. Ideally, calibration is conducted during a low sea-state level at sea to account for vibrations during travel. Initial gimbal calibration was difficult due to spotty internet connection at sea, which could be fixed with a firmware update of the cell modem and a custom watchdog software. A good calibration was finally accomplished on October 21, 2021.

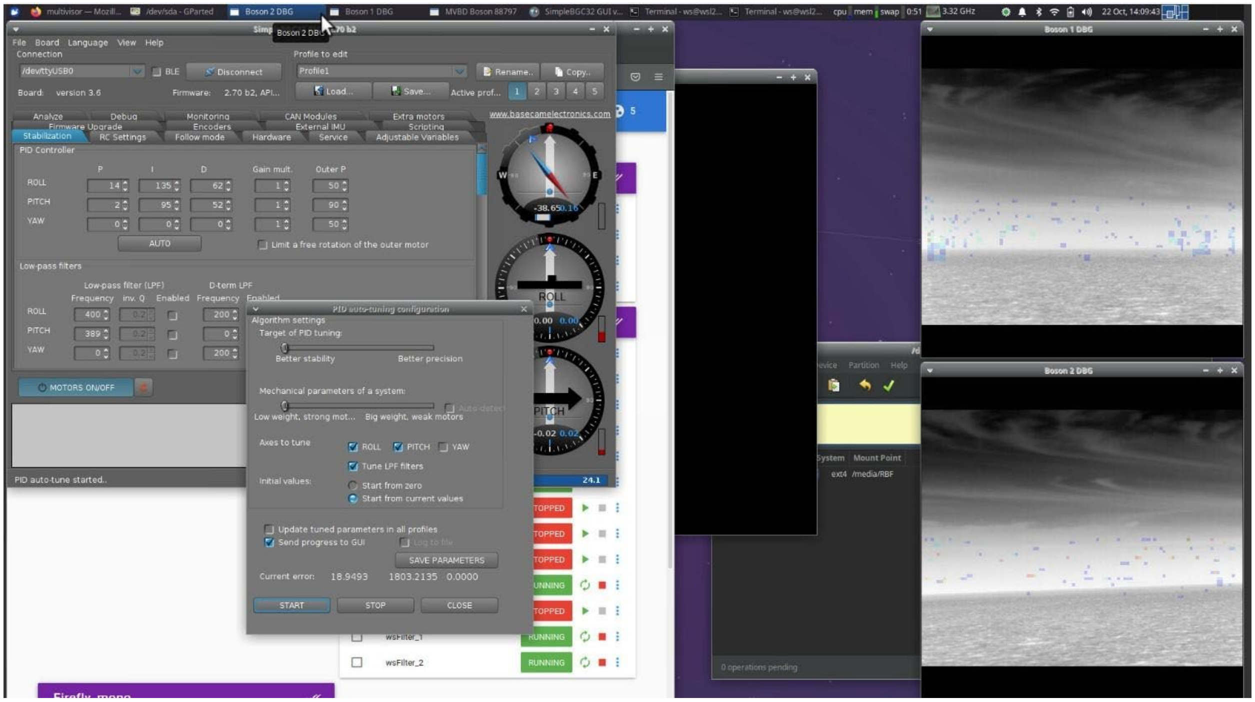


Figure 16: Remote gimbal calibration using the calibration software through the cell network. Please note the slight tilt in the lower camera image. This was due to the vessel's crew installing the camera without the ability to first align it in the office.

Task 4: Operation of the whale detection system on M/V Bella Desgagnés

The whale detection system was operated continuously from 9 Sept. 2021 until 2 Aug. 2022 except for a period from Feb. through Apr. 2022 during which the M/V *Bella Desgagnés* was in dry dock (this period is not included in this report). No major problems occurred during system operation, but we did initially experience a spotty internet connection that required the vessel's crew to complete manual power cycles. Those problems were corrected with a firmware update of the cell modem and a software watchdog that automatically reboots the cell modem. After this fix, no manual power cycle was necessary.

Over the course of months, we experienced a slow drift of the IMU. We were able to counter this by remotely changing the gimbal's offset, but it still required our intervention. Adding a better IMU will solve this problem in the next iteration of the system.

Throughout the duration of the experiment, we detected a total of 101 whales along the route of M/V *Bella Desgagnés* (Figures 17 and 18), distributed over 12 days (Figure 19). We want to note that those whale detections (Figure 20) were conducted without an AI (artificial intelligence) optimized for the vessel and area, but with the standard AI that we shipped with the camera system.

We quantified the performance of the whale detection system with a range-dependent detection function (Figure 21). The range-dependent detection function describes the probability of detecting a whale at a given distance from the vessel, assuming whales are equally distributed in the ocean (following a point-transect distance sampling scheme). The range of the peak of the detection function can be interpreted at the reliable detection distance up to which "all" cues can be detected. We find that the reliable detection range on M/V *Bella Desgagnés* is at 2 km, with detections to 6 km range. Those ranges are by far enough to allow for evasive actions of a vessel such as M/V *Bella Desgagnés* (Baille and Zitterbart 2022).

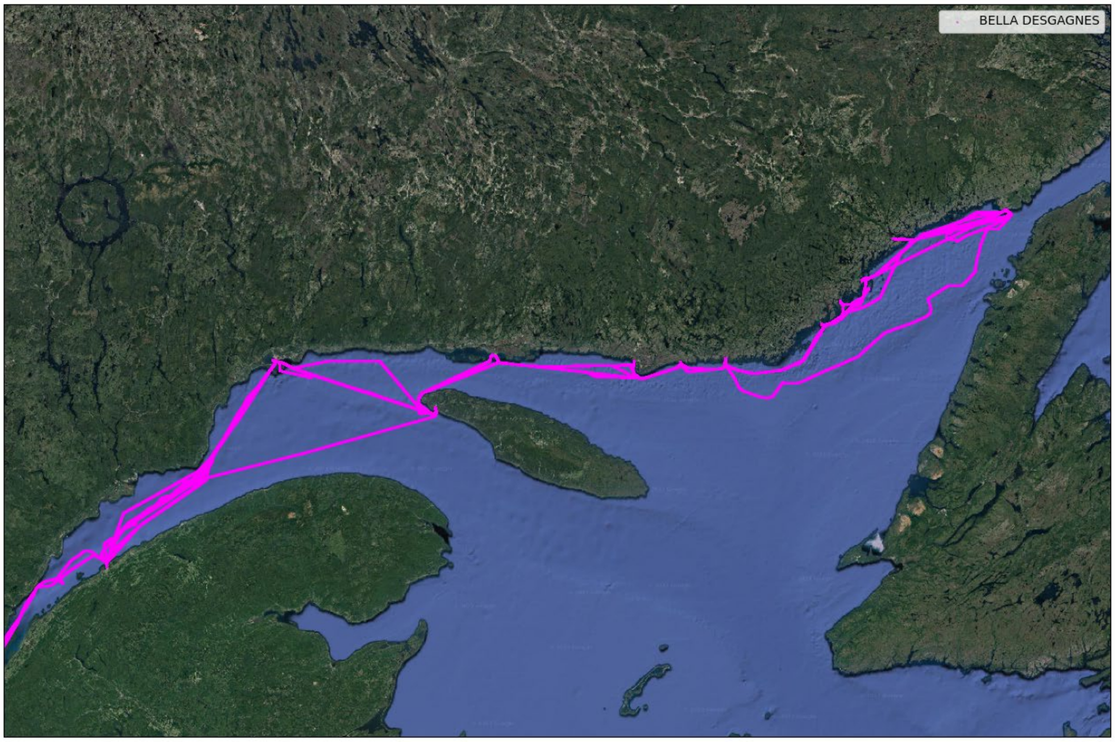


Figure 17: M/V *Bella Desgagnés* route as recorded by the whale detections system's GPS.

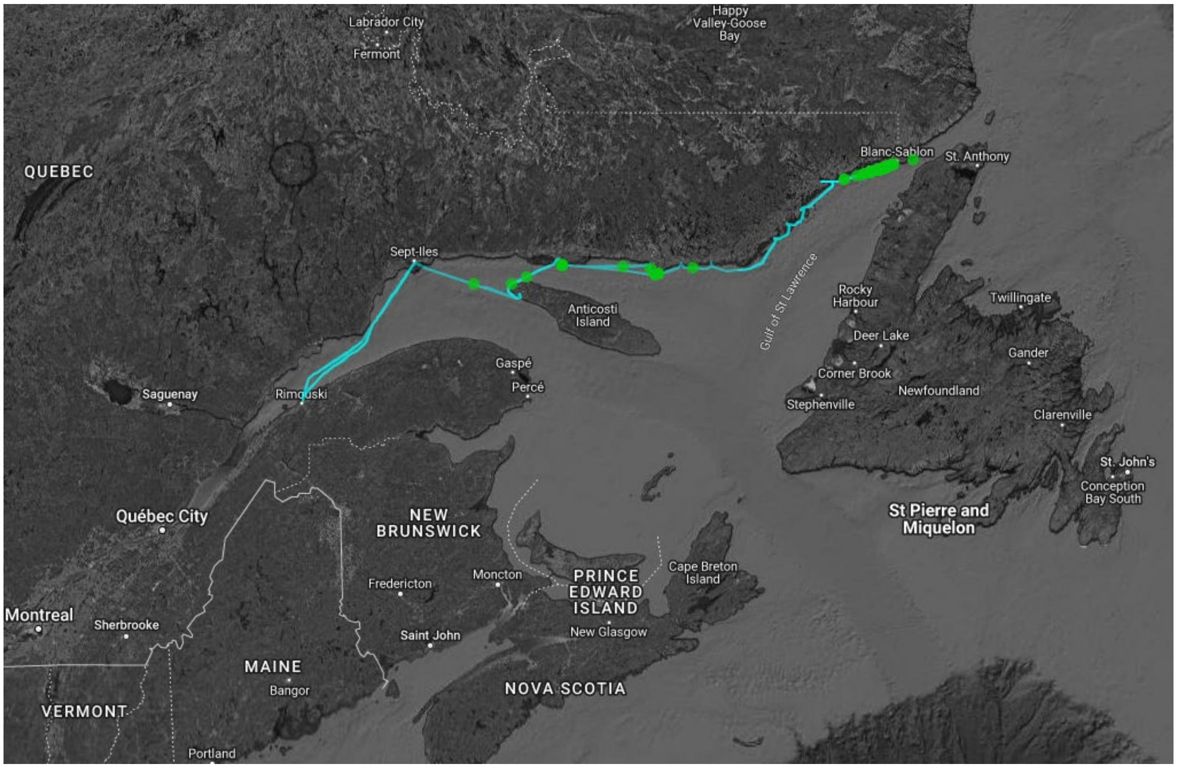


Figure 18: Localized whale detections along M/V *Bella Desgagnés* route.

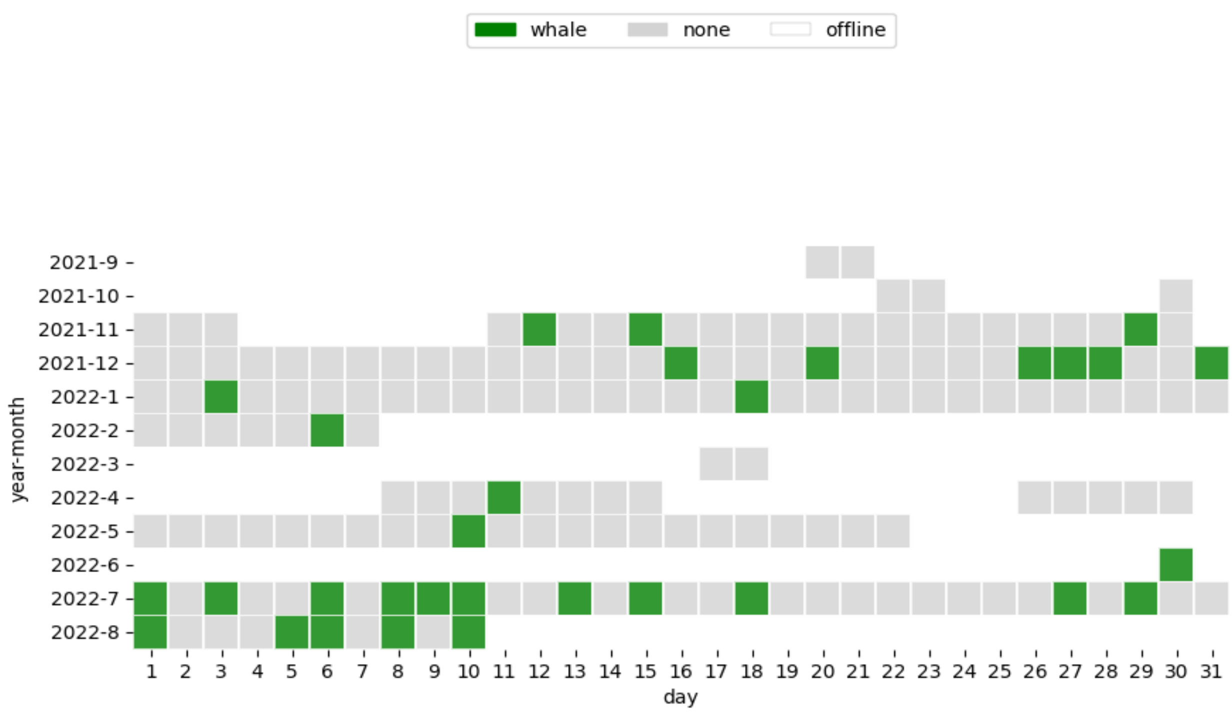


Figure 19: Detection overview for detections between Oct. 2021 and Feb. 2022. M/V *Bella Desgagnés* went into dry dock in early Feb. 2022.

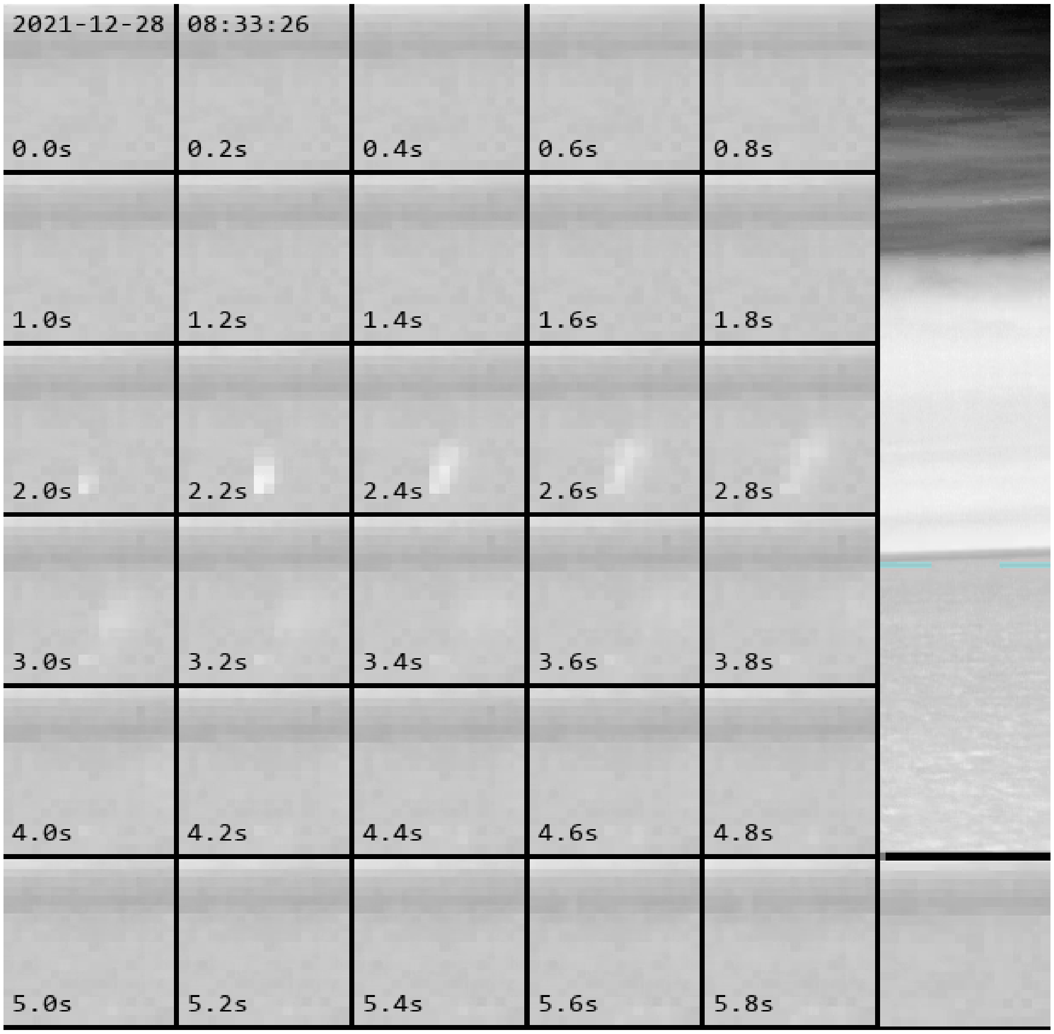


Figure 20: Example whale detection 3.5 km from M/V *Bella Desgagnés*.

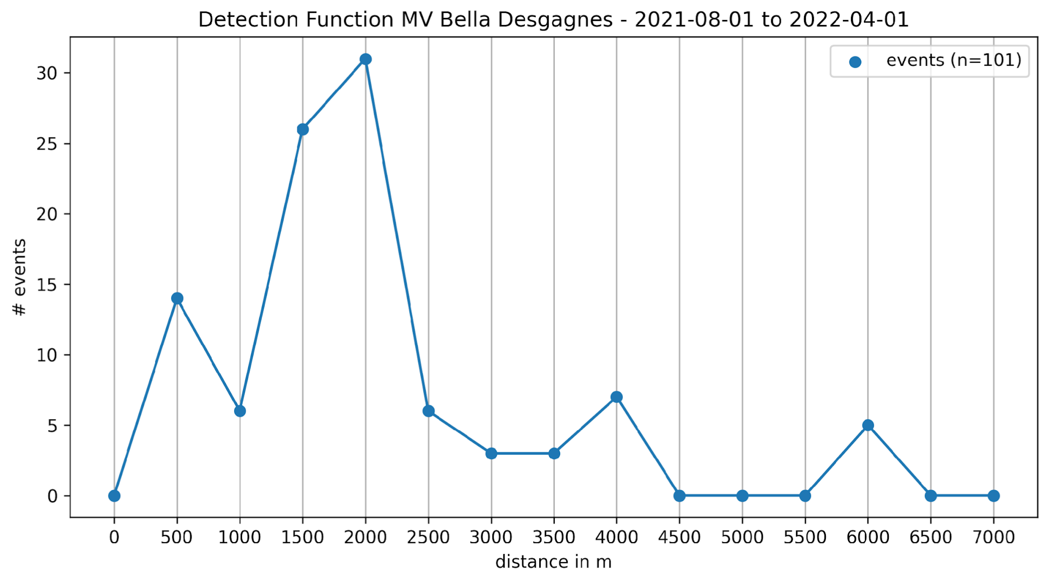


Figure 21: Range-dependent detection function of whale detections from M/V *Bella Desgagnés*.

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3. OPPORTUNITIES FOR TRAINING AND PROFESSIONAL DEVELOPMENT

Nothing to report.

4. DISSEMINATION OF RESULTS

The following presentations of our results were made:

Baille, L.M.R. and D.P. Zitterbart (2021) "Evaluation of surface-based detection performance for vessel strike mitigation of North Atlantic right whales." 2021 North Atlantic Right Whale Consortium Annual Meeting, 26-27 Oct., virtual

Baille, L.M.R. and D.P. Zitterbart (2022) "Effectiveness of surface-based detection methods for vessel strike mitigation of North Atlantic right whales." 2022 State of the Science Workshop on Wildlife and Offshore Wind Energy, 26-28 July, Tarrytown, NY.

Zitterbart D.P., S. Richter, A. Bocconcelli, L. Baille, D. Gomez-Ibanez, F. Thwaites, R. Petitt, M. Baumgartner, and D. Wiley (2020) "Automatic whale detection from vessels for real-time ship-strike mitigation – current developments and applicability." 2020 North Atlantic Right Whale Consortium Annual Meeting, 27-28 Oct., virtual.

Zitterbart, D.P., S. Richter, L. Baille, A. Winterl, A. Vanderlaan, and H. Yurk (2022) "Automatic whale detection from vessels for real-time vessel-strike and noise impact mitigation – current developments and applicability." 2022 State of the Science Workshop on Wildlife and Offshore Wind Energy, 26-28 July, Tarrytown, NY.

5. HONORS DURING REPORTING PERIOD

Nothing to report.

6. TECHNOLOGY TRANSFER

Provisional patent application (U.S. Patent and Trademark Office):

Serial number 63/453,527; "System and Method for Marine Mammal Detection"; Daniel Zitterbart and Daniel Gomez-Ibanez; submitted 21 March 2023; currently under review

License application (SeaRobotics):

"Joint Development Agreement, Infrared-Based Marine Mammal Detection Systems"; submitted in 2023; currently under final review and execution

7. PARTICIPANTS

The following individuals worked one (1) person-month or more during the project reporting period:

Dr. Daniel P. Zitterbart, Principal Investigator (Associate Scientist)
one (1) person-month worked

not a National Academy Member

Daniel Gomez-Ibanez, Other Professional (Senior Engineer)

one (1) person-month worked

not a National Academy Member

Dr. Fredrik T. Thwaites, Other Professional (Research Engineer)

one (1) person-month worked

not a National Academy Member

8. STUDENTS

A total of three (3) undergraduate STEM students participated in this project. Two (2) received a degree in mechanical engineering, and one (1) received a degree in electrical engineering.

9. PRODUCTS

"Automatic whale detection from vessels for real-time ship-strike mitigation – current developments and applicability"; Daniel Zitterbart, Sebastian Richter, Alessandro Bocconcelli, Loicka Baille, Daniel Gomez-Ibanez, Fredrik Thwaites, Robert Petitt, Mark Baumgartner, David Wiley; 2020 North Atlantic Right Whale Consortium Annual Meeting; 27-28 Oct. 2020; virtual; Federal support was acknowledged.

"Evaluation of surface-based detection performance for vessel strike mitigation of North Atlantic right whales"; Loicka Baille and Daniel Zitterbart; 2021 North Atlantic Right Whale Consortium Annual Meeting; 26-27 Oct. 2021; virtual; Federal support was acknowledged.

"Automatic whale detection from vessels for real-time vessel-strike and noise impact mitigation – current developments and applicability"; Daniel Zitterbart, Sebastian Richter, Loicka Baille, Alexander Winterl, Angelia Vanderlaan, Harald Yurk; 2022 State of the Science Workshop on Wildlife and Offshore Wind Energy; 26-28 July 2022; Tarrytown, NY; Federal support was acknowledged.

"Effectiveness of surface-based detection methods for vessel strike mitigation of North Atlantic right whales"; Loicka Baille, Daniel Zitterbart; 2022 State of the Science Workshop on Wildlife and Offshore Wind Energy; 26-28 July 2022, Tarrytown, NY; Federal support was acknowledged.

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Offshore thermal imaging whale detection test in Canadian waters

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6. AUTHOR(S)
Zitterbart, Daniel P.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Woods Hole Oceanographic Institution
266 Woods Hole Road
Woods Hole, MA 02536-1536

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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13. SUPPLEMENTARY NOTES

14. ABSTRACT
Thermal imaging systems have been increasingly tested during the last decade for their capability to detect and localize whales in real time. For thermal imaging systems to be effective, automatic detection of the whale signatures in the video feed is crucial. To achieve reliable detection during high seas and for fast vessels, a stabilized video feed is necessary. We are currently developing a stabilized, low-cost thermal imaging camera system for marine mammal detection. Here we propose to test and refine our latest system development, especially the stabilization performance, during two field experiments in 2020 and 2021.

15. SUBJECT TERMS
Thermal imaging, marine mammal, detection, vessel collision

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