Radar Detection of Marine Mammals

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LONG-TERM GOALS

The long term goal of this work was to develop a radar solution for the detection of marine mammals using ship-borne radar and demonstrate its performance. In particular, a solution using commercial surface search radars was desired it would provide a readily accessible technique for commercial shipping concerned about ship strike of marine mammals and/or detection for compliance with operating permits.

OBJECTIVES

The two technical objectives for this work were to first develop a near-real-time signal processor/radar combination that would be suitable for the detection of marine mammals and then assess the performance of such a combination in specific ocean conditions / species combinations in order to establish the utility of such a system.

APPROACH

The general approach has been to iterate between experimental results and processing improvements. This approach was designed to allow the work to progress in stages.

The first stage was to collect a data set from a fixed location which would allow us to test our radar capture/processing capabilities and detection algorithms in a less stressing environment than aboard a ship. The dataset should have significant diversity in look directions, range from the radar and sea conditions. The dataset should also have sufficient animals to make a statement about both the probability of detection (PD) as well as false alarm rate (FAR). Following this, the next task was to make an assessment of the radar data and the performance of the radar plus signal processing algorithm for the detection of marine mammals. The next stage was to refine the radar processing and algorithm for use aboard a ship. Collecting a data set aboard a ship using the newly refined algorithms was the next step which was again followed by further improvements to the detection algorithm. This process was to have continued towards implementing a near-real-time signal.

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WORK COMPLETED

During the period of performance two experiments were successfully completed. The first was conducted as part of the MAST08 experiment. During this experiment a radar was mounted on a cliff to observe the Gray whale migration off the coast of California. We collaborated with a team of visual observers who identified more the 200 pods. This experiment demonstrated that we were able to collect and record radar data with our system. An early offline version of the radar processing software was used to detect and track some whale pods in a semi-manual fashion on-site. The second experiment was an at-sea data collection. We accompanied the NOAA Southwest Fisheries "Ecosystem Survey of Delphinus Species" (ESDS) cruise aboard the R/V MacArthur II. Integration of the data recorder into the MacArthur II's Furuno radar was successful and over 500 hours of radar data were collected. However, for operational reasons, the radar was typically operated in M2 mode. The use of this crude-resolution mode coupled with the fact that the tracker that was developed to provide tracks for the marine mammals was unable to effectively distinguish between true marine mammal tracks and noise-related tracks led us to a two-fold approach involving an alternate tracker for the MacArthur II data and a re-examination of a previous data case from the Mediterranean. While this new approach and use of a different data set does show promise, a significant false alarm issue remains. The results of this new approach illustrating both the progress made and the remaining false alarm issue are described below.

RESULTS

Our initial evaluation of the ESDS data showed that we had a significant issue with false alarms. While it was at times possible for our algorithms to detect and track whales, in most cases it was impossible to determine whether or not whales were being detected due to the large number of false alarms. This led us to investigate both an improved new detector (ND) and an alternate tracker. In addition to this, we applied the improved detector and new tracker on an older data set (CEDAR) collected at a better resolution than was available in the ESDS data.

The previous algorithm had been designed to be easily implemented in real time, but by stepping back from real time processing, we found that we could do a better job of cleaning up the data which led to an improved detector. The ND first fits a polynomial versus range to each pulse. Removing this polynomial effectively removes the range dependence of the data. Further whitening is achieved by removing a median from each range bin. A filter is then applied using a noise model derived from the range bins furthest from the ship over several scans and a very simple signal model. Finally a 2D Gaussian is fit to the data and narrow detections are rejected to further mitigate radar interference. The second approach was to implement the BFT-BPT algorithm for use with our radar data. This track-before-detect algorithm had been effective in enhancing small but persistent signatures in another application.

Both the ND and the BFT-BPT were then applied to the ESDS data. As we had previously found, the crude-resolution combined with the limited visual observations of ESDS made it very difficult to evaluate the performance of either the improved detector or the BFT as neither were able to reduce the number of false alarms. This led us to abandon the ESDS data and turn to the CEDAR data.

The CEDAR experiment was carried out in the Mediterranean with the primary species being Fin whales, but also with one Beaked Whale sighted. The data is mostly at low sea state (3 and below) and is in the better resolution S1 radar mode (10.5 m in range vice 75 m for M2 mode). Dedicated visual observers were on hand to give multiple resights to provide good visual tracks.

Using a subset of over 250 visual observations, the fraction of observations with a radar detection was calculated as a function of range. For comparison the fraction for a similar set of “random” visual observation was also computed. This allowed us to calculate an adjusted detection fraction. This adjusted fraction is a measure of how effective the algorithm is at actually finding marine mammal as it removes the detections expected from random correlations. Overall, the ND showed promise with the CEDAR data. About 46% of the observations have a correlated radar detection while only 8% of the random have an associated radar detection. When the adjusted fraction is plotted as a function of range (Figure 1) we can see that the new detector greatly improves the number of positive detections at both the near range and mid range (0-2 km and 2-4 km) as compared to the old method. We now find roughly 60% of the whales at less than 2 km and 25% of those between 2 km and 4 km. It should be noted that there is still a false alarm issue, but it is not nearly as severe.

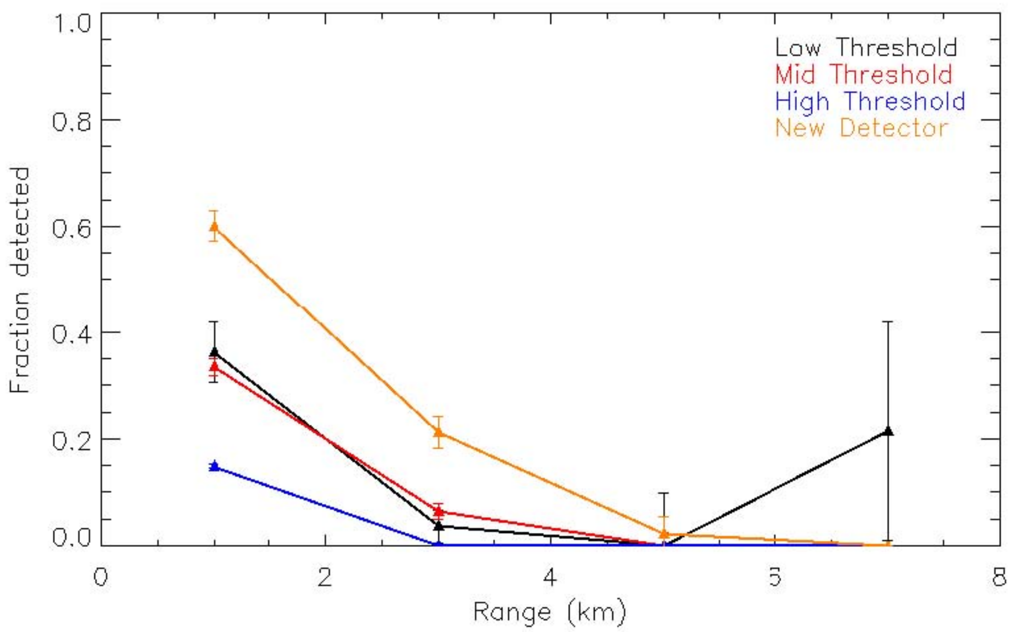

Figure 1: Fraction of the visual observations that were detected in the radar after adjusting for random correlation. The black, red and blue lines represent three different threshold levels of the old detector while orange represents the new detector results.

There are still many places where the new detector could be improved. There are indications that we could further exploit the shape of the whale signal as opposed to the shape of signals due to false alarms. Including the temporal behavior of the signal in the filtering could lead to reduced false alarms (particularly close to the ship where clutter dominates). Also, stepping back from real time might allow for similar improvements in the tracker. Ultimately, these improvements would reduce false alarms and improve delectability in high clutter areas but there will still exist situations (e.g. at long range) where no detections will be possible with the detect before track algorithm.

We next evaluated the track before detect algorithm, the BFT-BPT, on the CEDAR data. The BFT-BPT utilizes a likelihood field to attempt to build up tracks over time. This posed some difficulty as a true likelihood ratio was difficult to generate without a real whale signal model. However, the ideas and methods adopted for the new detector allowed an approximate likelihood field to be created from the radar data which could then be used in the BFT-BPT. We then assessed its performance using the same method as was used for the new detector with the exception that the long range observations were omitted due to processing time limitations.

The initial results showed some promise with about 27% of the visual observations at all ranges having a radar detection while only 8% of the random have a match.   The BFTBPT does better than random for both near range and mid-range and is just at the maximum expected from random at the far range. However, even though the false alarm rate is fairly low, the fraction detected is also relatively low. The BFT-BPT results are comparable to the previous detect before track results. The new detector out performs the BFT-BPT at short ranges, but the two are equal in the mid range (see Figure 2).

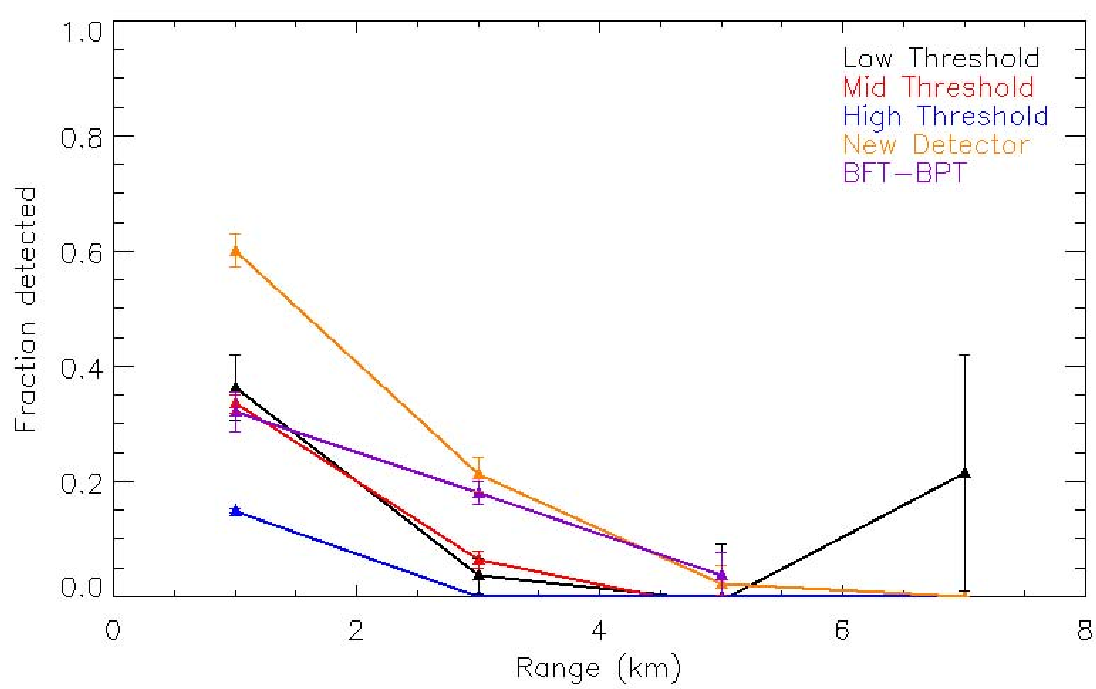

Figure 2: Adjusted Fraction of visual observations with a radar detection showing the addition of the BFT-BPT results

We have really only begun to explore the possibilities of the BFT-BPT and as such there is much room for improvement. The BFT as we are implementing it now has not been optimized for the unique aspects of whale detection. The BFT thrives on persistent low signal to noise ratio signals whereas the whales are sometimes low, sometimes high intermittent signals. Currently we are using the BFT "as is" without many specific modifications for the unique marine mammal problem. We have also not explored the full power of the BFT-BPT. The BFT-BPT is a complicated algorithm with many options and possible configurations. An improved likelihood ratio field that relies on many of the concepts of the new detector could provide better results. The BFT (as well as the original αβ-tracker) would also greatly benefit from a radar with a higher revisit rate than is possible with the Furuno's currently used.

IMPACT/APPLICATIONS

The project can provide a significant new capability for operations in and around marine mammals. If the commercial radar approach is successful, a relatively low-cost solution will be available to detect and track marine mammals. This capability can be used to extend operations into low visibility conditions (e.g. night and fog) for both ship strike avoidance applications as well as area clearance operations around active sources. If the capability can be configured to use existing radars, there would be relatively low impact on commercial ships use of the technology. Other applications that were not investigated but could be simpler to implement include using fixed mount radars for the monitoring of estuaries, harbors, etc. Similar approaches can also be developed for military-grade radars if desired.

Unfortunately at the present time there still exists significant difficulties in differentiating actual whale tracks from other noise sources. Currently, shipborne commercial radars have some limited capabilities with our new algorithms. This is mostly at less than 3 km range (~60% detect), however, false alarms need to be worked harder. While it is clear that the false alarm issue will not be easily resolved, it is possible that further progress could be made with increased detector/tracker study as well as investigating the potential of alternate radars with better resolution and revisit rate.

RELATED PROJECTS

None.