# DETECTION, CLASSIFICATION AND LOCALISATION OF MARINE MAMMALS USING ACTIVE SONAR RETURNS

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## 1 INTRODUCTION

Knowledge of the presence of marine mammals (MMs) is important for the Royal Navy to allow the operation of active sonars for trials and training purposes in a way which is consistent with the MOD marine mammal mitigation policy. There is a desire to improve environmental mitigation measures to support 24 hour, all-weather operations, with the possibility of reduced visibility (night time, fog etc), and to improve MM detection, classification and localisation (DCL) in mitigation of the use of active sonar.

In the first instance, MM DCL will be conducted using passive sensors, but once active sensors are in use for operational purposes, they have the potential to detect the presence of MMs and provide more accurate localisation and at greater ranges than existing methods. This information could be used to improve the mitigation measures in place to limit the impact of active sonar on the marine environment. In particular, organic sensors (those sensors that form part of a platform's operational equipment) on the Type 23 Frigate may be used to support mitigation of active sonar operation. Other nations use adjunct systems for active MM DCL[1] (additional equipment fitted solely for this requirement); however there is no information in the public domain that organic sensors have been investigated for this purpose. There is limited knowledge surrounding MM echoes, including the target strength, aspect and frequency dependence (especially at low sonar frequencies), and the effect of the dynamical behaviour of different species.

This paper presents initial results from the application of MM detection algorithms to data from the Sonar 2050 system. Sonar 2050 is the medium-range, medium-frequency hull-mounted sonar for the Royal Navy fitted to Type 23 frigates. A system description is presented along with the manner in which active sonar MM echoes are detected, classified and localised. Examples of MM echoes are shown along with an estimate of the target strength of the mammal. Classification features are discussed along with the gain in performance from their use.

## 2 THE CLASE SYSTEM

### 2.1 System Overview

A system has been developed which re-processes the received signals from the Sonar 2050 array and examines them for the presence of mammals. This is termed CLASE (Classification and Localisation of Animal Sonar Echoes). The CLASE system is designed to provide one input into a processor that will fuse the inputs from many sensors (passive sonar, radar, observers and IR sensors). The data fusion processor will use the information provided by each sensor, such as vocalisation characterisation from the passive sonar, position and speed information from the CLASE active sonar and MM observer information, to estimate the likely presence of MM's, their species and location. This information can then be provided to the command team to allow appropriate mitigation measures to be observed.

The processing architecture of the CLASE system is shown in Figure 1. This is consistent with the granularity recommended by the MOD Open Architecture research projects. The processing is intended to allow application to all RN active sonar systems. The white boxes show processing that is determined by the shape of the array and the type of the pulse that was transmitted. It is therefore possible to provide the CLASE processor with data from the output of the in-service system. The later stages, shown in blue, are tuned for the detection of MMs.

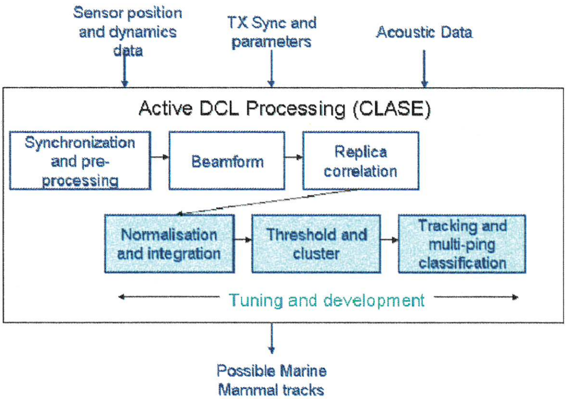



Figure 1: Active processing architecture that will be used for marine mammal DCL

## 2.2 Processing Stages

The first stage is to synchronise the received acoustic data to the transmit pulse, and to merge the parameters that describe the transmit pulse into the data stream. These parameters are then available to the down-stream processing. Non-acoustic data describing the location, speed, heading and depth of the sonar are also merged into the data stream. The data could also require pre-processing, such as filtering, bandshifting or decimation.

The receiver elements are formed into beams to provide directionality and gain against noise and reverberation. The type of array will determine whether directionality is provided in azimuth only, or also in elevation. Replica correlation is then performed. For FM pulses this increases the time resolution, which gives processing gain against reverberation and can reveal fine structure in target echoes.

A split-window normaliser is applied to calculate target signal to noise. The window sizes used are tuned to the expected echo characteristics of the target.

Echoes are picked out from the background by the application of a threshold. Threshold crossings are grouped into returns from the same physical object using a clustering algorithm. These clusters describe the range, bearing position and extent of the threshold crossings.

Single-ping classification relies typically upon a large quantity of training data, involving the collection of target echo data under controlled conditions covering different ranges, aspects, environments and target types. Due to the difficulty in applying this approach to MMs, single-ping classification within CLASE is based on applying rules to the physical size of the contacts. Thresholds are applied to the cluster extent in range and azimuth, and to the number of samples that exceed the detection threshold within a cluster.

The contacts generated on each ping are used to produce tracks over successive pings. It is at this stage that we have the greatest flexibility to tune the system to allow the discrimination of MMs. The characteristics of their movement could distinguish them from other active sonar returns. The consistency of the contact on a ping-to-ping basis may separate non-uniform objects such as sea-bed features from MMs.

The core of many tracking algorithms is the Kalman filter. The difference between trackers for different applications is the management of the filter: track initialisation, association of rules, dynamics hypotheses, the criteria for track deletion and the ranking of preferred tracks. Our algorithm starts a track on every contact. Each contact track is ranked by a weight value that is determined by the sum of the X and Y position variances within the track covariance matrix. Poor tracks are removed along with those that have not received an update on three successive pings. Currently there is a simple straight line manoeuvre model as the variety of dynamics that MMs could exhibit makes a finely tuned model impractical. Instead, the association parameters have been set sufficiently broad to cope with variations in speed and course. The output of the tracker is an error region describing the position, course and speed of the track.

Multi-ping classification follows the tracking stage to reduce further the false alarm rate. Each track update has an estimated speed, a number of times it has been updated and a weight value. Tracks with a mean speed greater than that expected from MMs, and with less than four updates are not output.

### 2.3 Expected Target Characteristics

The processing parameters have been set to allow for the expected mammal echo characteristics. One or two echo highlights are expected to arise from the lung cavity and/or the cranial region of the mammals. Due to the social nature of some species, there is the potential for multiple mammals in close proximity to be detected; the processing has been designed such that individual tracks will be formed. A range of speeds will be encountered from 0-20 knots. The Killer Whale (*Orcinus Orca*) has a maximum speed of 20 knots, however the majority of mammals rarely exceed 10 knots.

## 3 MARINE MAMMAL DETECTIONS

### 3.1 Determining Ground Truth Data

One of the most difficult aspects of using existing data for developing a system to detect MMs is the uncertainty in position, number and species of the mammals in the trials data. There may be MM Observer records with visual sightings that could be used to generate a ground truth, if the MM's are at the surface. The opportunistic nature of the data recordings used in this work has meant that MM Observer records are rarely available. The approach used has therefore been to identify MM vocalisations through passive analysis of the acoustic data. The bearing of the vocalisation is associated with mammal-like contacts generated by the active processing. These contacts are then assumed to be MMs.

## 3.2 Trials Data Description

The results presented in this paper are based on analysis of 1 hour of data recorded in the Atlantic Underwater Test and Evaluation Centre (AUTEC) in the Bahamas during May 2006. The data set consists of 189 individual Sonar 2050 transmissions. MM activity is regularly observed in and around the test area. Visual (frequency-domain) and aural examination of the data set showed approximately 40 separate MM calls occurring over a 10 minute period. Examples of these are shown in the spectrogram below (Figure 2). Regular repeated calls are observed over the 10 minute period in the 1-6kHz range.

From the type of vocalisations observed in Figure 2, it is believed that either Bottlenose Dolphins (*Tursiops Truncatus*) or Pilot Whales (*Globicephala Macrorhynchus*) are the probable source[2,3]. These mammals range in length from 1-3.5m([4]) and 2-6m([5]) respectively. Estimates of the orientation of the mammal have been derived from the track that the mammal follows relative to the position of the receiving platform.

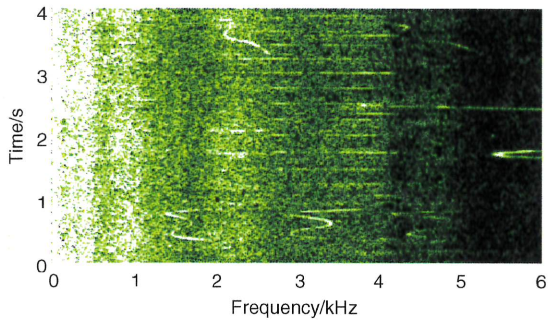



Figure 2: Example of marine mammal vocalisations

Figure 3 shows a range-ping history plot displaying a track believed to be produced by a MM. The track occurs at the same time and in the same direction as a number of vocalisations. A range of beams are shown for each ping, where a change in the coloured block on the left hand-side denotes the next ping, e.g. the lower red block denotes ping 1, the orange: ping 2 and so on. The MM is detected at a range of 480 to 825m over 12 transmission periods. Note for most of the contacts that there appears to be two contacts separated in azimuth. The second, weaker contact is a detection in one of the first beam pattern side lobes.

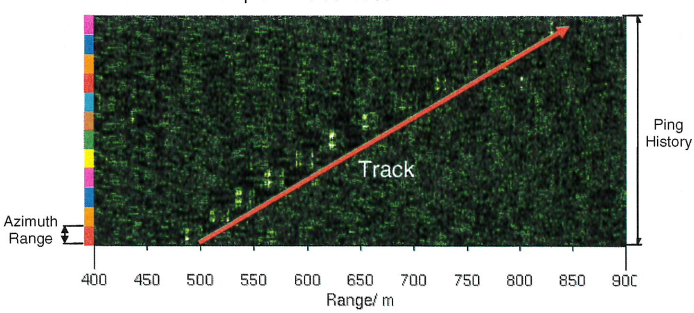
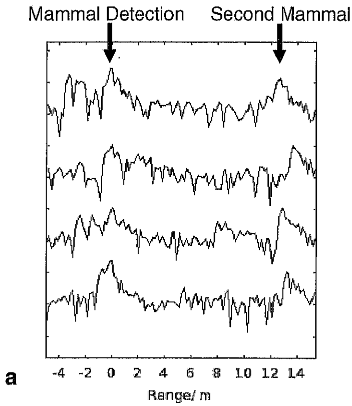



Figure 3: Marine mammal track

Figure 4a shows four A-scans of the MM detections. The range scale has been centred upon the main detection to highlight the spread of the echo. A second echo is observed at a separation range of ~13m from the first. Due to the shallow depth of the acoustic source, this separation is greater than that expected from a multipath echo; a possible source of the echo is a second mammal. The separation range varies which is consistent from dynamical contacts such as MMs. The mammals have an echo extent of approximately 1 and 0.5m respectively.



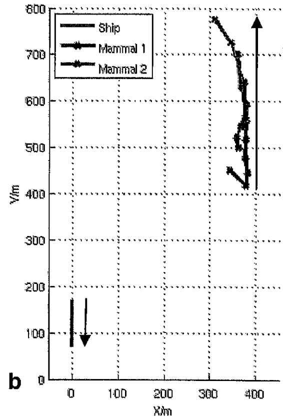




Figure 4: **a.** Example A-Scans of MM Detections. Amplitude scale tick marks at 20dB divisions **b.** Figure showing the two marine mammal tracks with respect to the platform position

Figure 4b shows the two MM tracks with respect to the receiving platform position. The mammals are transiting in a south-north direction, opposite to that of the platform. As the aspect is predominantly from a broadside-tail area, the echoes are occurring from the lung cavity of the mammal. The mean speed of the mammals has been estimated at between 6.5 and 8ms$^{-1}$. Bottlenose Dolphins have been observed travelling at maximum speeds of 8ms$^{-1}$([6]). It is therefore believed that Bottlenose Dolphins are the source of vocalisations.

## 3.3 Target Strength Estimation

The measured target strength of the MM detections has been estimated using:

$$TS_{measured} = (EL + Cal) - SL + 2PL$$

Equation 1

where *EL* is the measured echo level of the MM detection, *Cal* is the array calibration factor, *SL* is the source level of the active transmission and *PL* is the propagation loss (spherical spreading has been assumed). All the values are measured in dB re 1μPa. The combined error on this estimate is 12dB re 1μPa. This large error is dominated by an uncertainty in the calibration figure for the sonar. The target strength measurements use the peak of the echo.

The predicted broadside target strength of a MM has been assumed to follow the distribution as defined by Love[1,7]:

$$TS_{predicted} = 22.8 \cdot Log(L) - 2.8 \cdot Log\left(\frac{1500}{f}\right) - 22.1$$

Equation 2

where $L$ is the length of the MM in metres, $f$ is the (centre) frequency of the active transmission in Hz and where $1<L/\lambda<130$ ($\lambda$ is the wavelength of the active transmission in metres). This equation has been used as a comparison against the measured target strength values of the MM contacts. Target Strength measurements in the literature[1,7-13] have shown good agreement to Love's formula. The target strength of the mammal changes with its orientation with respect to the sonar array[1,8-13]. From the research carried out by Love[6], it is proposed that the target strength reduces by up to 6dB when moving from a broadside to end-fire aspect[1].

Figure 5 shows the broadside-corrected measured target strengths of the two MMs averaged over the track. The values are shown in relation to a theoretical curve produced from Equation 2. The error boxes indicate the estimation error and the typical spread in lengths of calf to adult Bottlenose Dolphins. The target strength estimates from the two MMs are generally in agreement with that expected from Love's equation. The uncertainty in the size of the mammal, coupled with the large measurement error limits the contribution made by these estimates. With better calibration information, a more accurate target strength estimate could be used to infer the range of lengths of the MM, which could in turn aid species identification.

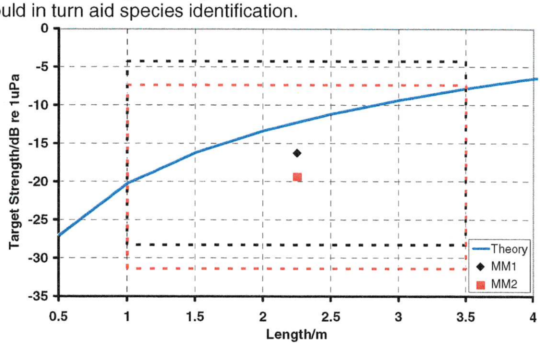



Figure 5: Figure showing the mean aspect-corrected measured target strengths of the two marine mammals assuming a size of a Bottlenose Dolphin compared to the theoretical values.

## 3.4 Detection and Classification Performance

The 1 hour of data has been used to assess the false alarm rate through the processing chain. We have assumed that the two tracks shown above are the only mammal contacts present in the data and all other contacts are false alarms. The following table shows the remaining percentage of the original number of false alarms per ping at three stages of the CLASE processing chain; clustering, single ping classification and tracking. The CLASE processing has reduced the number of contacts by a factor of 4 with only 24.5% of the above threshold echoes producing MM-like tracks. Initial estimates suggest that the multi-ping classification should reduce the false alarm rate by an order of magnitude.

| Processing Stage | Percentage of false alarms per ping |
|---|---|
| Clustering | 100% |
| Single Ping Classification | 83.5% |
| Tracking | 24.5% |

Table 1: Table showing how the number of false alarms per ping reduces at three stages of the CLASE processing chain

## 3.5 Localisation

Our passive analysis used a simple loudest beam estimate of the bearing of the vocalisations. This bearing has an accuracy of approximately 15°. Unce rtainties in the range of contacts at the cluster stage of the CLASE processing are estimated to be 10m. The tracking stage uses information from each contact in a track to reduce these errors. Figure 6 shows the two MM tracks and the associated error regions (one standard deviation) for each contact. The error regions decrease in size as the track consistency builds up over successive pings; variation in velocity cause the regions to increase in size.

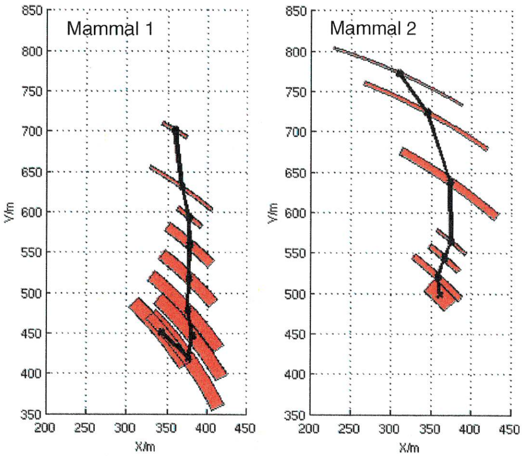



Figure 6: Figures showing the two MM tracks and the associated error regions for each contact

Figure 7 shows the change in azimuth and range uncertainties of the two MM tracks over pings, compared to the uncertainties at the passive stage and cluster stage respectively. The tracking stage reduces significantly the uncertainty in position of each contact, with azimuth uncertainties reducing to 2° and range errors to 2m.

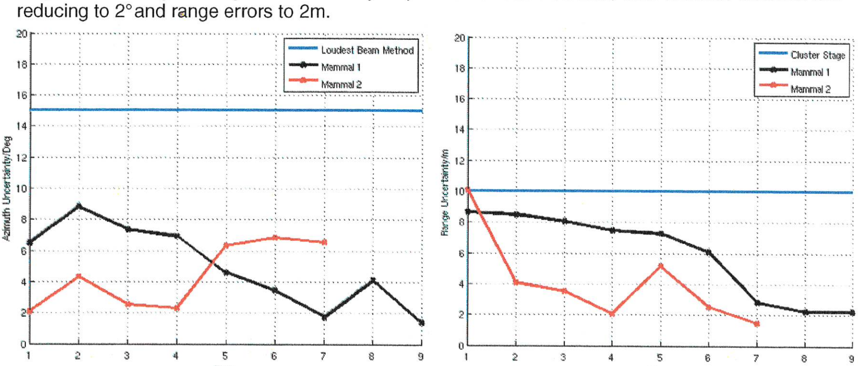



Figure 7: Figures showing the change in azimuth and range uncertainties from the tracker for the two marine mammal tracks compared to the uncertainties prior to the tracking stage

# 4 CONCLUSIONS AND RECOMMENDATIONS

We have demonstrated that the S2050 organic active sonar can be used to aid marine mammal mitigation for active systems such as S2087. The CLASE system provides estimates of position, target strength (corrected for aspect), number of mammals, speed and consistency. This adds significantly to the information available to existing monitoring systems, and when combined within a data fusion processor with other inputs such as passive, IR and observations, may offer significant benefits to MM mitigation in all-weather, 24 hour operations. The multi-stage approach to false alarm reduction within CLASE promises to provide good detection performance whilst limiting the false alerts generated by the system.

Although at an early stage, this research has increased confidence in CLASE. Within the current project we will perform a controlled experiment using a target sphere, investigate tuning of multi-ping rules with a wider data set, and provide an at-sea demonstration of the CLASE system. Better information on target strength and behavioural dynamics could provide improved species identification. The CLASE approach should be applied to other organic sensors such as S2087 itself, S2089, S2193 and Sonobuoy systems to support the continued improvement in mitigation measures in place for Royal Navy active sonars.

# 5 REFERENCES


1. W.T. Ellison and P.J. Stein, 'SURTASS LFA HIGH FREQUENCY MARINE MAMMAL MONITORING (HF/M3) SONAR: System Description and Test & Evaluation', http://www.surtass-lfa-eis.com/docs/HF-M3%20Ellison%20Report%202-4a.pdf (2001)
2. http://solmar.nurc.nato.int/solmar/education/Tursiope.htm
3. http://www.dosits.org/gallery/marinemm/11.htm
4 http://www.nsrl.ttu.edu/tmot1/turstrun.htm
5. http://www.acsonline.org/factpack/PilotWhale.htm
6. http://www.coastalguide.to/bottlenosedolphin/main.html
7. R.H. Love, 'Dorsal aspect target strength of individual fish', J. Acoust. Soc. Am. 49, 816-823 (1971)
8. R.H. Love, 'Target strengths of humpback whales *Megaptera novaeangliae',* J. Acoust. Soc. Am. 54 (5), 1312-1316 (1973)
9. J.L. Dunn, 'Airborne Measurements of the Acoustic Characteristics of a Sperm Whale', J. Acoust. Soc. Am. 46 (4), 1052-1054 (1969)
10. I. Lucifredi and P.J. Stein, 'Integrated Maine Mammal Monitoring and Protection System (IMAPS): Gray Whale Target Strength Measurements and the Analysis of the Back-Scattered Response', ISBN: 1-4244-0155-1 (2006)
11. C. Levenson, 'Source level and bistatic target strength of the sperm whale (*Physeter catoden*) measured from an oceanographic aircraft', J. Acoust. Soc. Am. 55 (5), 1100-1103 (1974)
12. W.L. Whitlow, 'Acoustic reflectivity of a dolphin', J. Acoust. Soc. Am. 99 (6), 3844-3848 (1995)
13. J.H. Miller and D.C. Potter, 'Active High Frequency Phased-Array Sonar for Whale Shipstrike Avoidance: Target Strength Measurements', Oceans 2001, Vol 4, 2104-2107 (2001)