Detection of Precise Time Events for Marine Mammal Clicks

Tin Ma[1], Nicole Collison[2], James Theriault[2], Joe Hood[3], Sean Pecknold[2], and Ben Bougher[3]
[1] Simon Fraser University, thm1@sfu.ca; [2] Defence R&D Canada – Atlantic: nicole.collison, james.theriault, sean.pecknold@drdc-rddc.gc.ca; [3] Akoostix Inc.: jhood, bbougher@akoostix.com

1. INTRODUCTION

Acoustic sonar users, cetacean ecologists, commercial shipping, fisheries, and tourism operators can benefit from improved marine mammal detection and localization. Marine mammals emit various sounds (such as songs, moans, and clicks) for communication, navigation, and foraging purposes. Sensors and techniques for detection, classification, and localization of marine mammal sounds are being developed by numerous institutions. The results presented in this paper benefit from the unique situation of having "truth" information on the source location by emulating marine mammal sounds.

This paper focuses on a localization technique where Time-Differences of Arrival (TDOA) for a signal on multiple receivers is estimated and used as input to a hyperbolic cross-fixing scheme [1]. The algorithm begins by using the discrete Teager-Kaiser energy operator (TKEO) on the dataset [2, 3] to remove phase information and allow event detection using a split-window moving average (SWMA). Detected events are then organized onto "click maps" based on individual animals having unique inter-click interval patterns (ICI) [4], which are then cross-correlated and interpolated to obtain precise measurements for each TDOA. By considering trends in the measurements, a likelihood function can be applied to get a better successive TDOA estimate.

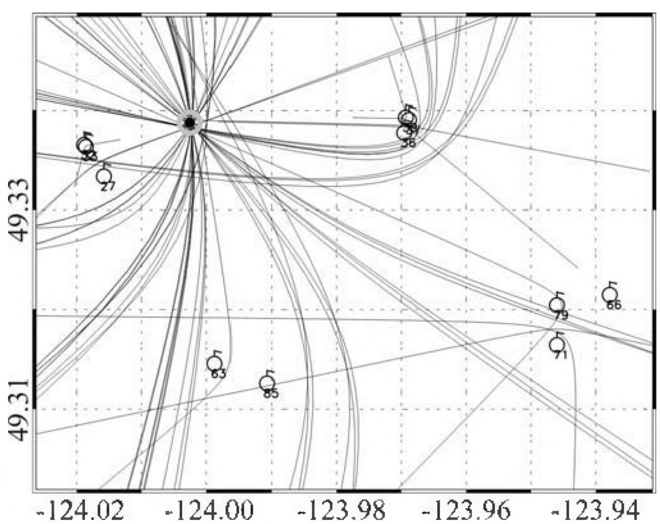

Figure 1: Tactical plot showing trial geometry and an example localization of the source at ~2301 UTC. The estimated source location is within the light grey circle and is indistinguishable from the true location at this scale.

2. SEA TRIAL DATASET

On January 28th 2010, DRDC Atlantic held several sea trials at the Canadian Forces Maritime Experimental and Test Ranges, Nanoose Bay, BC. One dataset was intended to provide clean, known click data that simulated a marine mammal click train. As a first step, frequency-modulated pulses were transmitted, based on a "standard" pulse with a frequency range of 1.0-2.5 kHz and duration of 1.0 s. One hundred pulses, slightly varied from the standard pulse (in amplitude, duration, and frequency range, but not bandwidth), were played as a quasi-periodic pulse train (where the ICI was also slightly varied). The pulse train was repeated to record fifteen minutes of data, starting at 2300 UTC. The recordings were match-filtered with the standard pulse to compress the pulses into simulated marine mammal clicks. This effectively compresses the energy in the 1-sec FM pulses into pulses of approximately 1-ms duration, mimicking the signal characteristics required to test the algorithm (i.e., quasi-periodic ICI, appropriate energy level). We refer to this as the "raw" data in this paper. The signals were received at eleven sonobuoys outfitted with a global positioning system device (GPS) drifting in grouped arrays at four different locations (see Figure 1, where the sonobuoys are denoted by open circles with flags and the source location is within the light grey circle). The speed of sound was assumed constant at 1480 m/s. Analysis of the time period from 23:00:45 to 23:01:15 UTC is presented in this paper's figures.

3. METHODOLOGY

a. Event detection

A series of events (i.e., clicks) are selected from one sonobuoy time series (master channel) for a time period of at least 30 seconds. The time series are later broken up into 15-second time frames with 50% overlap. TDOA values are determined per time frame and remaining sonobuoy time series (slave channels). For each slave channel, the length of data retrieved considers the maximum possible time difference between buoy pairs so that only necessary data is processed. The frame duration determines how many clicks will be cross-correlated at a time. By increasing this parameter, click association becomes more robust at the cost of additional computational time.

An energy-based amplitude envelope is calculated using the TKEO on all selected and retrieved time series data. Figure 2 shows details of the raw data for a single click with the TKEO envelope. The SWMA is used on the TKEO envelope to detect significant events. The SWMA consists of five windows: two noise windows outside of two gap windows, all of which symmetrically enclose a signal window. The averages of the energies in the signal and noise windows are compared to give a signal-to-noise ratio. Ideally, the signal windows should encompass the majority of the signal energy; the gap windows should be set to prevent the signal tails from being included in the noise estimate. A threshold is set so that significant events are detected and their times listed. Because of the limited sampling resolution, the precise timing for each event is estimated by parabolic interpolation [5] of the TKEO envelope.

b. Event association

After obtaining a list of event times, an event map is generated for each channel. To increase robustness in association, each event is represented by a Gaussian distribution function of unit amplitude centered precisely at each event time. The width of the Gaussian function is set to compensate for small variations in the received click pattern. The resulting event map represents when clicks were detected, whether they are direct- or multi-path, as shown in Figure 2.

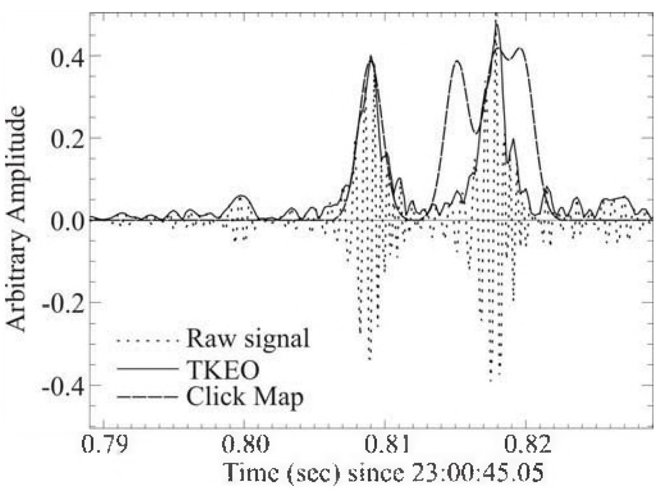

Figure 2: Details of a click. The click map shows spurious peaks because it is triggering on noise peaks.

For each time frame and sensor, event maps are extracted. The event maps from slave channels are cross-correlated with the event maps from the master channel where the output amplitude provides a measure of the match quality. The correlation is subject to noise resulting from partial matches, so candidate TDOA values are found using the SWMA with interpolation on the correlation function.

Candidate TDOA values are then analyzed to select one TDOA estimate for each time frame/sensor combination. The most-likely (i.e., highest-correlated) time is picked for the first time frame. Per subsequent time frame, a Gaussian error model is constructed from prior (selected) TDOA values and used to weigh the correlation of candidate values, so as to find the most consistent (assumed best) delay. This is valid because arrival time will be constrained for a moving source; thus TDOA changes over time will also be limited.

4. RESULTS AND DISCUSSION

The primary result for this paper is shown in Figure 1, where the estimated source location is defined by a black dot within a computed area of probability (denoted by the light grey circle). The drawn hyperbolas are defined by TDOA measurements, and the localization algorithm defines statistically the estimated source location and associated area of probability by clustering the crossing points. The estimated location was 55 m from the source GPS position at a bearing of 200° True. The localization error radius was 115 meters, containing the source.

In Figure 1, the hyperbolas associated with 10 of the 11 sonobuoys provided reasonable inputs to the localization; however, all hyperbolas associated with buoy 71 were found to be inaccurate, possibly due to position error.

In the future, we hope to improve our detection algorithm by implementing an adaptive estimation approach [3]. Different algorithms could be tried such as using a stochastic matched filter [6]. These can all be compared to a ground-truth dataset as we have done here. In addition, this dataset could be used to explore the effect of using a subset of sonobuoys to investigate how the algorithm would react to closely-space buoys. Since this dataset does not include multiple sound-emitting sources, a new dataset would have to be obtained to test this algorithm against this particular case. Testing should also be performed using vocalizing animals to fully test robustness of the algorithm.

REFERENCES

[1] Informal communication, Joe Maksym, DRDC Atlantic.
[2] H. Glotin, F. Caudal, and P. Giraudet, "Whale cocktail party: real-time multiple tracking and signal analyses," *Canadian Acoustics*, vol. 36, no. 1, pp. 141-147, 2008.
[3] V. Kandia, Y. Stylianou, and T. Dutoit, "Improve the accuracy of TDOA measurement using the Teager-Kaiser Energy operator," in *Proceedings of the International Workshop on New Trends for Environmental Monitoring Using Passive Systems (PASSIVE '08)*, IEEE Xplore, Hyeres, France, October 2008.
[4] R.P. Morrissey, J. Ward, N. DiMarzio, S. Jarvis, and D.J. Moretti, "Passive acoustic detection and localization of sperm whales (Physeter macrocephalus) in the tongue of the ocean," *Applied Acoustics*, vol. 67, no. 11-12, pp. 1091-1105, 2006.
[5] W. Press, B. Flannery, S. Teukolsky, and W. Vetterling, *Numerical Recipes: The Art of Scientific Computing*, Cambridge University Press, 1986, Chapter 10.2.
[6] F. Caudal and H. Glotin, "Stochastic Matched Filter outperforms Teager-Kaiser-Mallat for tracking a plurality of sperm whales," in *Proceedings of the International Workshop on New Trends for Environmental Monitoring Using Passive Systems (PASSIVE '08)*, IEEE Xplore, Hyeres, France, October 2008.