MATCHED-FIELD PROCESSING OF HUMPBACK WHALE SONG OFF EASTERN AUSTRALIA

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Abstract

Matched-field processing (MFP) is a technique for tracking an acoustic source in range and depth by comparing the output of an ocean acoustic propagation model with measured acoustic data collected across multiple hydrophones. In October 2003 a MFP experiment was conducted using humpback whale sounds recorded during the spring migration off the Sunshine Coast in Queensland, in conjunction with a larger experiment conducted by the Humpback Acoustic Research Collaboration (HARC). Humpback whale sounds with frequency content between 50 Hz to 1 kHz were recorded on a five-hydrophone vertical array deployed in 24 m deep water near Noosa, Queensland. The vertical array consisted of a set of flash-memory autonomous recorders attached to rope with an anchor at one end, and a subsurface float at the other. Acoustic data were simultaneously collected and monitored on five sonobuoys deployed over approximately 2 km range. The azimuth and range of the whale could be estimated via relative time-of-arrival measurements on the buoys. Using the range estimates as bounds on the matched-field processing, a inversion using the calls was performed on the vertical array data using a genetic algorithm. Inversion parameters included animal range, depth, and array geometry. Preliminary results of the inversion and resultant 3-D position fixes are presented. [Work supported by the US Office of Naval Research, Ocean Acoustic and Marine Mammal Programs].

Introduction

The annual spring migration of humpback whales off eastern Australia has been monitored visually and acoustically off the Sunshine Coast in Queensland for several years[1-3]. The 2003 field season was the first year of an expanded two-year research program called the Humpback Acoustic Research Collaboration (HARC). The organization and goals of HARC are presented elsewhere in this conference. Songs from singing whales are acoustically tracked by cross-correlating sounds from an animal across 3-5 hydrophones distributed over a 3 km aperture. The derived differences in a sound's arrival times are then used to generate a set of hyperbolas whose intersection yields an animal's range and azimuth from the array center.

In 2003 a six-hydrophone vertical array was deployed to determine whether matched-field processing (MFP) tracking methods could be applied to humpback whale song in shallow water, thus providing information about the depth of the singing animal. The term MFP is a general description of any tracking technique that involves a comparison between a measured acoustic field

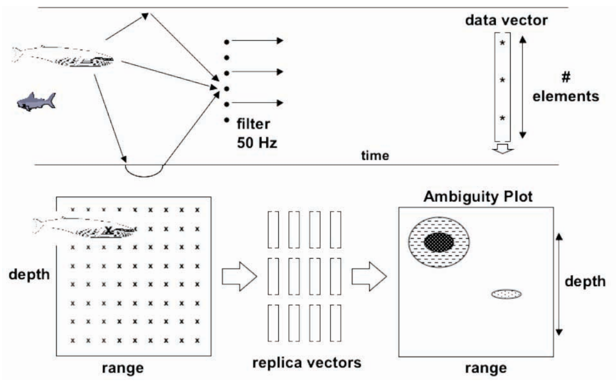

Figure 1: Concept of MFP on a vertical array.

and a set off modeled fields computed with a propagation model[4 ,5]. While MFP can take place with any array geometry, a vertical array provides a convenient and compact deployment for performing the technique[6]. Figure 1 illustrates how sound from an acoustic source is received on several hydrophones of a vertical array. Due to the effect of multipath from the ocean surface and bottom, the relative amplitude and phase of a given frequency component will vary between each hydrophone. To determine the range and depth of the source, a numerical model is run that simulates the acoustic field produced by a hypothetical source over a grid of ranges and depths. For each location the relative amplitude and phase of the chosen frequency component across the array is computed. The modeled fields are then correlated with the measured data, and the location that yields the highest correlation is selected as the true source range and depth. Thus this procedure, when combined with the azimuthal information provided by the distributed sonobuoy array, should provide a 3-D fix of the whale position.

In practice the ocean environment, including the sound speed profile and sediment properties, is not sufficiently characterised to enable an accurate numerical simulation. Thus a "focalization" technique can be used that treats the ocean bottom properties, array geometry, and water column sound speed profile as additional parameters to solve[7,8]. As searching over this wide parameter space yields many local suboptimal matches, a global inversion technique such as a genetic algorithm[9] or simulated annealing[10] is typically used.

The MFP technique was successfully tested on blue whales in 1996 off the California coast, over frequency ranges between 17 and 112 Hz[11]. It was not clear, however, whether the technique would work at the higher frequencies characteristic of humpback whale song, an example of which is shown in Figure 2.

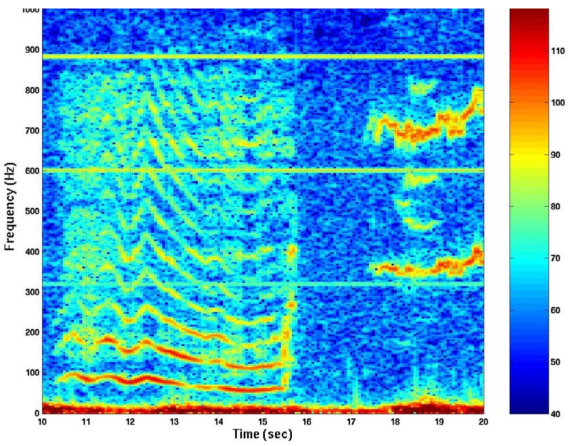

Figure 2. Spectrogram of humpback whale call used in MFP inversion. Note broadband energy content between 50-800 Hz.

Experimental Setup

The vertical array was deployed over a period of two weeks in late October 2003 in 23 to 25 m deep water near Noosa, Queensland, about half a kilometer beyond the deepest hydrophone of the distributed array. The array consisted of six autonomous recorders taped to a rope. The system was anchored to the bottom with a plow anchor, and two subsurface floats kept the assembly straight. The entire system was light enough to be deployed and retrieved by hand from a small vessel.

The acoustic recorders are derived from a marine mammal tag designed by Bill Burgess of Greeneridge Sciences, Inc[12]. Each recorder uses 4 AAA batteries to sample sound at 16 bit resolution, and pressure, temperature, and two-way tilt at 1 Hz. The data are stored on a 1 Gb flash-memory chip, and the data are downloaded via IR port after the instruments are recovered. At a 2 kHz sampling rate the instruments can be deployed for around three days before they need to be recovered. An example of what the instrument looks like is shown in Figure 3.

Figure 3. Autonomous recorder used in vertical array deployment.

During the observation period in question up to 40 pods a day passed by both array systems, of which at least five animals were singing close enough to the distributed array so that the range and azimuth of the singer could be estimated. On October 23, 2003 one animal was estimated to pass within 300 m of the vertical array, so this track was selected as a promising data set to apply the MFP technique, even though only four recorders were working at the time. The inversion software package SAGA[13] was used to perform the processing, using a normal-mode propagation code.

Results

Figure 4 shows an ambiguity surface conducted on one call at 11:53, using 12 frequency components incoherently averaged using a Bartlett processor, which is simply the normalized correlation between the measured and modeled fields. A value of 0 indicates no matched between data and model, while a value of 1 indicates a perfect match. The animal seems to be located at 20 m depth at 633 m range. Contemporary hyperbolic fixing placed the animal at 510 m range. The animal seems to be only a few meters above the ocean bottom when making this call. Note that caution must be exercised when using relatively few hydrophones because one can obtain false locations with relatively high correlations, as seen in the figure.

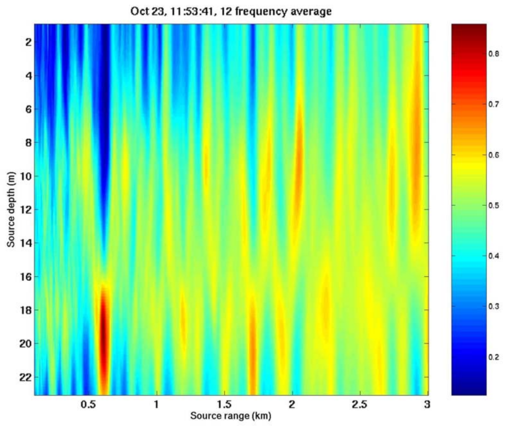

Figure 4. Plot of correlation between measured data and modeled acoustic field, as a function of range and depth, using 12 frequencies spaced between 100 and 1000 Hz.

Conclusions

Matched-field processing of humpback whale song has been demonstrated using a set of autonomous acoustic recorders attached to fishing gear. Future work will example other close approaches during times when more hydrophones were working, and in 2004 an eight-hydrophone array is planned to be deployed as part of the second year of HARC.

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