AN EXPERIMENTAL APPROACH TO EVALUATION OF ACOUSTIC MASKING OF BELUGA COMMUNICATION BY SHIP NOISE

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1 Introduction

Out of concern about the impact of industrial noise on marine mammal communication, the Canadian Coast Guard initiated a project to develop quantitative techniques for determining the degree of interference between various kinds of noise and marine mammal calls. Particular emphasis lies in the study of icebreaker noise.

During a cruise in the Arctic Ocean, vocalizations of different animals, for example seals, humpback whales, killer whales and beluga whales, were recorded as well as icebreaker related ramming noise and bubbler noise. If the icebreaker rams an ice-ridge at full speed, it might crack the ice immediately or be lifted onto the ridge and crack it due to its weight. Also the ice might withstand the ramming such that the ship is stopped with its propeller still turning at full speed. The corresponding noise is a broadband signal consisting of short bursts of high intensities. Bubbler noise is generated when a ship passes through cracked ice and uses so-called bubblers along its sides that blow air at high pressure into the water in order to push ice debris away and leave a clean passage for the boat. The corresponding noise is a loud signal of long duration but narrow bandwidth.

2 Previous Research

Preliminary interference studies were carried out in three different ways. The animal calls were digitally mixed with the noise signals in various signal-to-noise ratios. First, the spectrograms of the mixed signals were plotted and the threshold noise level at which the original animal call could not be recognized was determined by eye. Second, the mixed signals were converted to analog form and the human ear was used to detect the threshold. Third, matched filter techniques were applied in which the cross-correlation coefficient of the mixed signal and the call was evaluated and a threshold noise level was defined. Discrimination of signal from noise cannot simply be expressed in terms of the signal-to-noise ratio. The masking effect depends on both frequency and temporal properties of call and noise. The overall result was that animal calls of long duration and temporal coherence, as used by the bearded seal, are very robust to noise of short bursts like ice ramming even if the noise level far exceeds the call. This is because identification is possible from the short undistorted pieces emerging through the gaps in the noise field. Even though bubbler noise is not as loud as ice ramming noise, its masking effects are more severe due to its long duration and frequency overlap with most of the animal songs. For comparison, naturally occurring, thermal ice cracking noise was also investigated. It has the least impact on the chosen animal vocalizations. Although these three applied methods yield qualitatively similar results, they exhibit subtle differences. In order to assess their accuracy and to develop reliable models for the animals' auditory abilities, experiments with trained mammals are necessary.

3 Current Experiments

The Vancouver Aquarium houses various marine mammals, for example killer whales, beluga whales, porpoises, sea-lions and seals. As a first step, experiments are conducted only with beluga whales, because they are easily trained. Right now they are learning to identify three different beluga calls, one is a short chirp, the other two are pulsating calls. One of the latter consists of short pulses at a high repetition rate, the other consists of long pulses at a low repetition rate. The spectra of the three calls are shown in figure 1. The songs are transmitted into the pool by a J9-hydrophone. The whales have to station against a pole held into the pool by a whale trainer and whenever they hear one of the three songs they are trained to move away. Once this works reliably, noise is introduced. The different calls are mixed with different kinds of noise at different signal-to-noise ratios and played to the animals in a random sequence. Each sound has a duration of about 2 seconds. The animals are allowed a 2-second-reaction time. If they do not respond to a signal, i.e. if they do not move away from the pole, it is assumed that they were unable to identify the call. If they do move, the event is counted as a successful discrimination of call from noise and the animals are stationed again for further listening. The experiments are carried out in a small pool adjacent to the main pool. There is always only one animal in the small pool at a time. In order to make sure that the investigated animal does not respond to calls coming from the other animals in the main pool, their acoustic activity is observed continuously with a recording hydrophone. For obtaining reliable data, it is essential that no cues are passed to the animals. Therefore, neither the whale nor the whale trainer knows when to expect a signal and which one it will be. The experiment conductor sits out of view

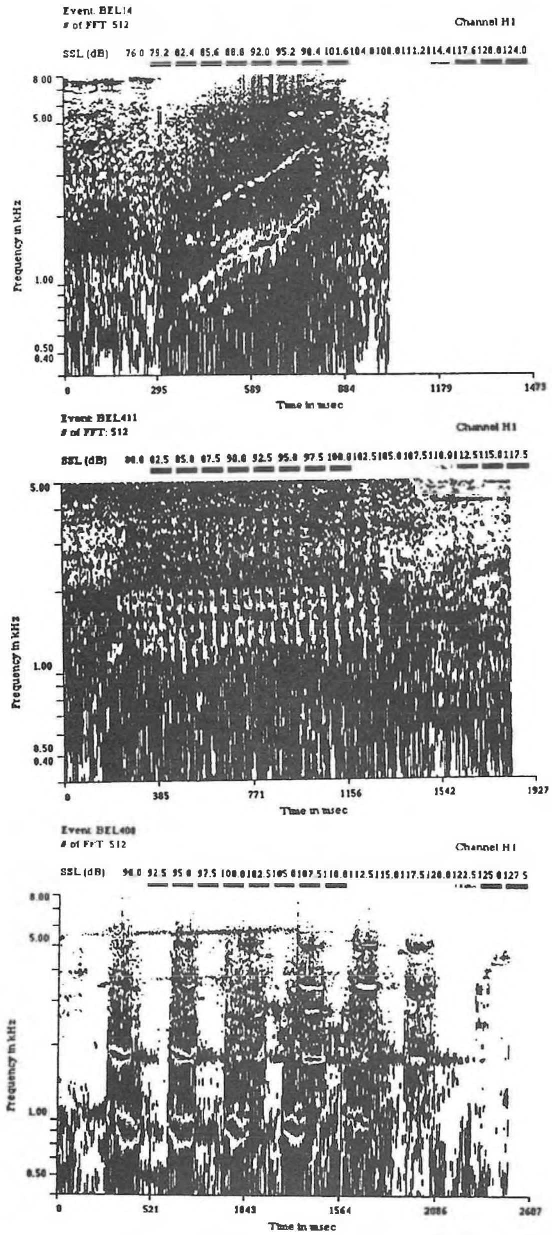

Figure 1: Spectra of Beluga Calls

of the whale at the side of the pool. He controls the transmission of the signals with a portable notebook computer and observes the response of the recording hydrophone. He can only see the whale trainer who reports the movement of the whale. A sketch of the pool is shown in figure 2.

4 Resonance Frequencies of the Pool

During any acoustic experiments, the resonance frequencies of the pool have to be taken into account. As a closed chamber, the pool has an infinite number of distinct eigenfrequencies. It acts as a filter on any incoming signal by amplifying these frequencies and damping the others. By solving the three-dimensional wave equation under specified boundary conditions for the dimensions of the pool,

$$\Delta P = \frac{1}{c^2} \cdot \frac{\partial P}{\partial t^2} \quad ,$$

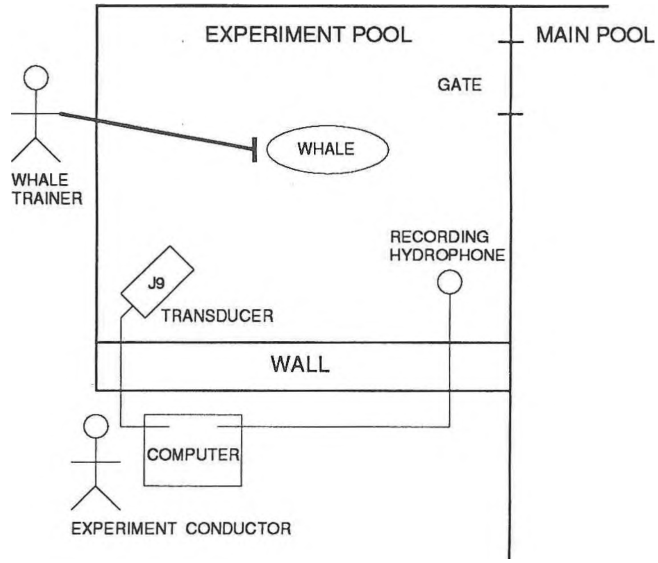

Figure 2: Experiment Set-up

where $P = P(x, y, z, t)$ denotes the pressure, Δ represents the Laplacian operator and c stands for the sound speed, the theoretical resonances were calculated. With one transmitting and one receiving hydrophone, these frequencies were experimentally verified. The presence of the whale alters the acoustic response of the pool such that the resonance frequencies are shifted and the spatial characteristics of the modes are changed. This was also measured and led to a proper positioning of the whale and transducer.

5 Neural Network Modeling

Neural networks as a fourth method for modeling discrimination of signal from noise have recently been introduced. A two-layer back-propagation network was trained with four different seal calls [1] by applying the pure calls and varying the weights and biases such that it gives a desired output. Then the net was tested with calls mixed with icebreaker noise and thermal ice cracking noise. It successfully identified the calls even for high signal-to-noise ratios.

This technique will also be applied to the beluga calls. The call recognition of the neural net will then be compared to that of the trained animals. This provides a reliable assessment of the accuracy of the neural net model. The long term goal is to use the aquarium tests to develop increased confidence in such models so that they may be used to determine the impact of any noise on marine mammal communication for situations where direct experiments are impossible.

References

[1] I. J. Booth and K. H. V. Booth, Using Neural Nets to Identify Marine Mammals. *Oceans 93* (1993), 112-115