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Classification of Aspect-Dependent Targets by a Biomimetic Neural Network

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EXECUTIVE SUMMARY

A biomimetic neural network was used to model a bottlenose dolphin's ability to recognize aspect-dependent targets. Researchers used echo trains recorded during the dolphin trials to train an Integrator Gateway Network (IGN) to discriminate among the targets using echo spectra. The IGN classifies targets using an average-like sum of the spectra from successive echoes. However, combining echoes may reduce classification accuracy if the spectra vary from echo to echo. The dolphin and the IGN learned to recognize the geometric targets, even though orientation could vary. The process of recognition using cumulated echoes was robust for nonstationary raw input. The results support the notion that ensonified mines with complex shapes and echoes may be reliably classified using neural network architectures that are motivated through understanding of Marine Mammal System echolocation signals and performance.

CONTENTS

INTRODUCTION

Evolution of bottlenose dolphin echolocation has resulted in signal design and cognitive signal processing tolerant of the very poor ambient sound conditions typical of navigation and target detection in shallow-water and very-shallow-water (SW/VSW) habitats. Dolphins' native echolocation abilities have prompted their use in Navy Marine Mammal Systems (MMS) for Mine Countermeasures (MCM) that are extremely effective in searching out and classifying various SW and VSW mine threats (e.g., MMS Mk-7) (Moore, 1997; Moore & Bivens, 1995). Most SW/VSW mines have aspect-dependent shapes that return different echoes depending on the orientation of the target relative to the incident echolocation signal. The acoustic structure of echoes does not necessarily map onto the 3-D structure of the targets isomorphically, that is, target shape and orientation cannot necessarily be inferred directly from the acoustic structure of target echoes (Neubauer, 1986).

Figure 1 illustrates the variable nature of echoes from rotating aspect-dependent targets. Echoes from the cube are presented on the left panels; from the pyramid in the middle; and the rectangle on the right. The echo waveforms are presented on the top on a time scale that extends to 250 μsec. The echo spectra are presented on the bottom on a frequency scale from 2 to 180 kHz. The planar face of each stimulus was perpendicular to the incident click in the top sample (0 degrees), and then rotated 0, 5, 10, 20, 30, 40, 45, 50, 60, 70, 80, and 90 degrees in each successive waveform. Notice how the echoes changed, lengthening and increasing in complexity as the target rotated from having the planar face normal to the ensonifying click to 45° ("edge on") to the ensonifying click.

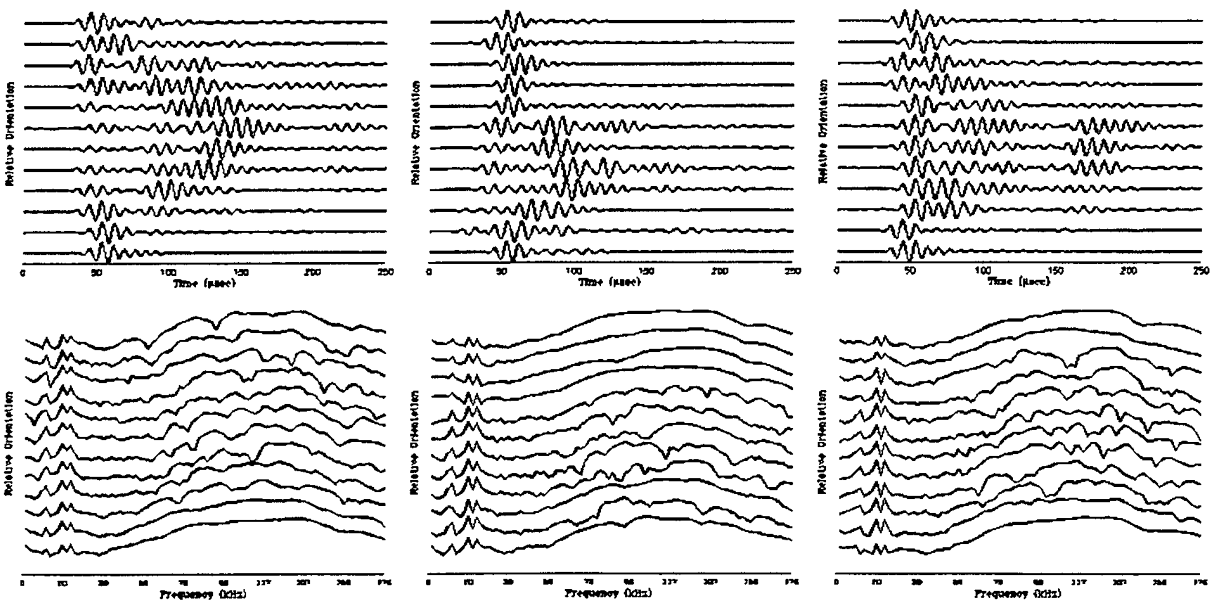

Figure 1. Changes in echoes as the targets were rotated.

An optimal sonar target classifier should be capable of identifying complex targets independent of the encounter angle. By this definition, dolphins' performance in MCM tasks demonstrates that they are without doubt optimal sonar target classifiers. Dolphins can readily discriminate among aspect-*independent* targets such as spheres and cones (e.g., Busnel & Fish, 1980; Nachtigall & Moore, 1986).

They can also discriminate among aspect-*dependent* targets (Au & Turl, Nachtigall et al., 1980), but discrimination performance may suffer if the animal does not gain experience with the targets at multiple orientations (Nachtigall et al., 1980). As part of the current study, researchers taught a dolphin to recognize a set of aspect-dependent targets (foam cubes, rectangles, and pyramids; see figure 1) even though their orientation was not controlled (Helweg et al., 1996). Target orientation was unfixed and changes in orientation were induced by water movement of the floating apparatus during trials. The dolphin clearly could recognize the stimuli, regardless of random rotations that could have occurred both during and between inspection of the sample and comparison stimuli (Helweg et al., 1996).

This document addresses the question of whether stable target classification can be achieved by a neural network using the highly variable echo trains generated by ensonified aspect-dependent targets. To address this issue, the dolphin's discrimination performance was compared to that of a biomimetic neural network model of dolphin echolocation target discrimination. It is well established that neural networks can be used to classify ensonified targets (see references). In a process of reverse engineering, dolphin echolocation abilities have been used to motivate the development of neural networks, termed "biomimetic networks." The Integrator Gateway Network (IGN) was created as an explicit model of information processing by an echolocating dolphin (Moore et al., 1990; Roitblat et al., 1991). The high classification accuracy of the IGN relative to other neural networks indicates that cumulation of echoes increases reliability of target classification (Moore et al., 1990; Moore et al., 1991; Roitblat et al., 1991).

The IGN forms a running average of the incoming target spectra with no "history," that is, the information used by the network to perform classification has no record of changes in spectra from echo to echo. The process of combining echoes from aspect-dependent targets may actually reduce the amount of information if the target can be identified only by dynamic changes in echoes across an echo train. Thus, testing an IGN with echoes from aspect-dependent targets is a rigorous test of the ability of the IGN to classify targets with variable echoic properties.

METHODS

TARGETS

The targets were regular solids made of closed cell foam internally weighted with lead and sealed with polyester sanding resin. One target was an elongated rectangular prism (henceforth, rectangle), 3.75 X 3.75 X 15 cm. The second target was a square-based equilateral pyramid with a side length of 11.25 cm. The third target was a cube 7.5 cm on the side. The air contained in the foam eliminated sound penetration into the target, thus the echoes contained information about external shape only. The targets were presented to the dolphin via monofilament lines using snap swivels. It is crucial to note that the swivels allowed the targets to rotate freely while being ensonified by the dolphin.

ECHO COLLECTION PROCEDURE

A Bruel & Kjaer 8103 hydrophone mounted 2 m from the subject and 1 m underwater was used to detect and record the dolphin's echolocation clicks. A second directional hydrophone mounted adjacent to the subject 1 m underwater was used to record target echoes. Detection of a click to the center target triggered the echo hydrophone to record the returning echo after an appropriate delay. Echolocation clicks were amplified 20 dB, and echoes were amplified by 50 dB and bandpass filtered from 6.3 to

200 kHz. The clicks and echoes were digitized at 500 kHz with 12-bit resolution using an RC Electronics ICS-16 ComputerScope and stored to computer files.

INTEGRATOR GATEWAY NETWORK PROCEDURE

An IGN was trained to classify the geometric targets using 30 bins of spectral information as the input, 3.91 kHz/bin, spanning the range of 31.25 to 148.4 kHz. Amplitude was expressed in relative log units with a range of 0 to 1. The IGN was constructed with 30 input bins and 30 units in the summation layer. The summation layer was fully interconnected to 15 units in the feature layer, which converged onto three output bins (one each for the rectangle, pyramid, and cube).

The network was trained with the first 10 echoes from 12 trials of each target type (36 trials, a total of 360 echoes). Training trials were selected randomly from the set of all trials and were presented in random order with regard to trial and target identity. The IGN was trained until root-mean-square (RMS) error was reduced to a criterion of 0.05.

The IGN was then tested with the set of all echo trains, a total of 5,329 echoes from 108 trials. Each trial was represented by one echo train. The "choice" made by the IGN was determined by comparing confidence ratios for each target class, defined as the activation value of a given output element (target class) divided by the sum of all activation values. For every echo in a trial, confidence ratios were computed for each output element and compared. If the confidence ratio for any output element reached 0.96, that element was taken as the classification of the target and the next trial started (Moore et al., 1990).

RESULTS

The dolphin clearly could recognize the stimuli, regardless of random rotations that could have occurred both during and between inspection of the sample and comparison stimuli. Recordings of up to 100 clicks and echoes were collected on every trial of three sessions. The IGN correctly classified all three targets on the majority (65%) of trials (table 1). The performance of the Integrator Gateway and dolphin were compared using a chi-square test, with the dolphin's responses as the expected distribubution. Importantly, the IGN correctly classified the cube more often than did the dolphin, which resulted in a significantly different pattern of responses (χ^2 (4) = 71.73, p < .01). When the dolphin's matching bias towards the cube was controlled statistically without changing the value of the discrimination sensitivity index (Swets & Sewall, 1964), no significant differences in classification performance remained (χ^2 (4) = 5.54, p > .05).

Table 1. Classification by the IGN.

		Sample		
		Rectangle	Pyramid	Cube
Choice	Rectangle	24(29)	7(0)	5 (7)
	Pyramid	2(4)	24 (26)	10 (6)
	Cube	7(22)	7 (8)	22 (6)

Note: Numbers in parenthesis represent dolphin's classifications.

DISCUSSION

The dolphin and the neural network recognized the aspect-dependent targets even though orientation varied both within and across trials, good evidence that stable classification of aspect-dependent targets can be derived regardless of orientation.

In previous applications, the IGN performed as well as the dolphin, with classification performance for both near perfect (Moore et al., 1990; Moore et al., 1991; Roitblat et al., 1991). Classification of the aspect-dependent targets used in this study was harder to learn, evident in the number of units in the feature layer required for accurate classification. We required 15 feature layer units to achieve good classification of the aspect-dependent targets, whereas 12 units were sufficient for excellent classification of aspect-independent targets. One reason for the degradation in performance may be the nonstationary nature of the echoes from the targets used in this study.

In conclusion, the results of this investigation provide evidence that dolphins and the Integrator Gateway network can learn to classify aspect-dependent targets at haphazard orientations. The echolocation processing assumptions built into the IGN architecture produced stable classification of targets characterized by variable echo spectra. The process of sequential sampling instantiated in the IGN, i.e., target recognition using echoes cumulated within echo trains, is robust with respect to nonstationary raw input. These results support the notion that the complex task of SW/VSW MCM may be complemented by binding broadband sonars with adaptive biomimetic nonlinear classifier systems with architectures and/or processing structures that are motivated by an understanding of dolphin echolocation in comparable scenarios.

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