Tethered Fish Data Collection and Species Classification:

Prince William Sound Bottomfish

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***Abstract*— This paper describes the first classification results with the first broadband sonar fish identification system prototype that was built by Scientific Fishery Systems, Inc. Two species of fish and the bottom were used in a set of classifier experiments using two different sets of features – echo shape and echo spectra. We will describe where the data was collected, review the data collection methodology that was used, and provide a summary of the data that was collected. We will then define the features that were extracted and the classification results that were attained with these features. We will conclude with summary discussion of areas for future work.**

Keywords* – *Broadband, Sonar, Fish Identification, Classification

I. INTRODUCTION

This report describes the first classification results with the first broadband sonar fish identification system prototype that was built by Scientific Fishery Systems, Inc. Two species of fish and the bottom were used in a set of classifier experiments using two different sets of features – echo shape and echo spectra. Section 2 describes where the data was collected, the data collection methodology that was used, and provides a summary of the data that was collected. Section 3 describes the features that were extracted and the classification results that were attained with these features. A summary discussion outlines areas for future work. Appendices describe both the broadband sonar prototype and the fuzzy neural network that was used in these experiments.

II. DATA COLLECTION

The main strategy of the beginning phase of our project is the collection and analysis of the acoustic data during killer whale predation on the commercial longline gear.

In order to collect a comprehensive data set of acoustical signals related to the longline fishing activity we deployed two independent acoustic data recording systems on board of F/V Prowler during a fishing trip in June 2004.

A. Data Source

The F/V Lady Simpson, a 30 meter, 170 ton crabber/longliner was hired for experiments in the Prince William Sound in late October 1995. Data collection permits were granted by both the Alaska Department of Fish and Game and the International Pacific Halibut Commission to conduct these studies. All fish were retained and disposed of in the Cordova dump.

1) Location

Two species of fish were used in these experiments: Pacific Halibut and Rockfish. The halibut were caught in Zaikoff Bay on Montague Island and the Rockfish were caught in Lower Herring bay on Knights Island, both located in the Prince William Sound of South Central Alaska (**Figure 1**).

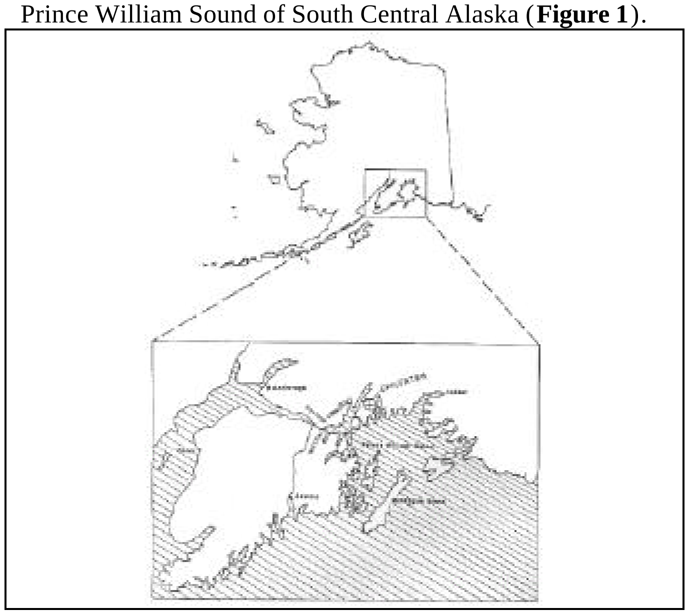


Figure 1. Prince William Sound – Location Where Data was Collected

2) Species

Two Pacific Halibut (71 cm and 114 cm) and two Rockfish (31 cm and 34 cm) were caught by jig for the data collection experiments. The fish were alive throughout the data collection process. Figure 2 below shows examples of each of these species. In addition to these two species, data was also collected on the bottom.

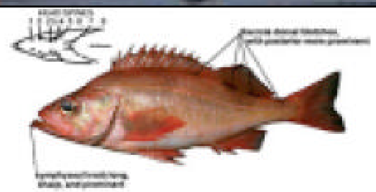
Species	Sample Picture
Halibut	
Rockfis h	

Figure 2. Sample Photos of Two Species Used During Data Collection

B. Tethered Data Collection

SciFish has developed a tethering technique that allows echo data collection from the surface to the bottom. This approach is shown below in Figure 3. A line is fastened to an anchor or a weight. The live fish is then wrapped in a small mesh net and hung along the line in the dorsal aspect. The anchored line is then dropped directly below the transceiver during slack water (when the tide action is minimal) or when the vessel is tied at the dock. The transceiver's beam is then adjusted until a strong return is received from the tethered fish. At this point data can be collected for each of the signal types (CW, FM, and Barker).

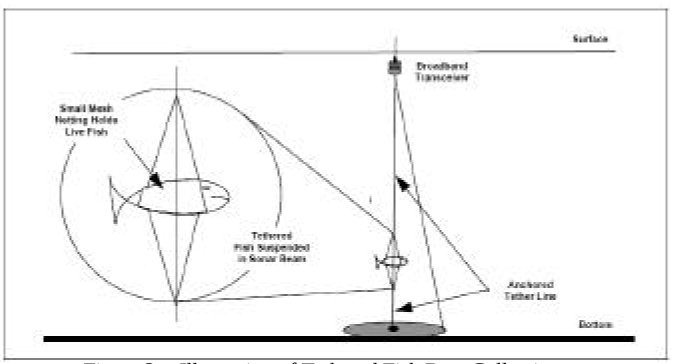


Figure 3. Illustration of Tethered Fish Data Collection

With tethered collection, the ground truth is extremely reliable. The position of the fish, its range to the bottom, its species, sex, and size, and the number of fish are completely defined prior to collection. This ground truth information is essential to the training process. The tethering approach provides the control that will be needed to capture the massive amount of data that will be used to explore the full capability of the broadband fish identification approach across a wide range of species and under varying bottom conditions.

C. Broadband Sonar Fish Identification Prototype I

In 1995, SciFish built and tested an active broadband acoustic fish identification system [4]. This instrument, called ORCA, was used to collect midwater pelagic data and the bottomfish data used on this effort (Figure 4).

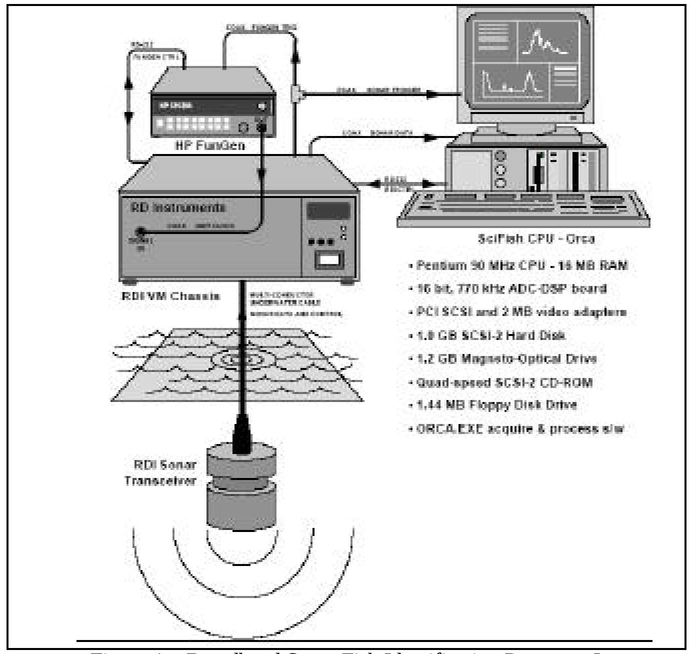


Figure 4. Broadband Sonar Fish Identification Prototype I

Three types of transmit waveforms were programmed in to the RD Instruments electronics. The available transmit waveforms include pulsed CW at any single frequency between 100 kHz and 200 kHz, linear FM sweep (chirp) over the entire range of frequencies with positive or negative frequency slope, and pseudo-noise (PN, phase coded) sequence as is used in the current profiling product application at RDI. RDI's pseudo-noise code sequence was modified so that the first 13 elements transmitted represent a Barker Code for maximal bandwidth energy.

The CW mode emulates modern echo sounder and fish finder technology and provides a simple waveform for use evaluating ambient noise and adjusting receiver gain at fixed frequencies of interest. The FM mode provides a well characterized broadband signal than can be matched filtered and whose returns are rich in spectral content. The PN mode is meant to impart maximum spectral energy into the water column for a given pulse length. These returns too can be matched filtered and, of course, are also rich in spectral content.

The transducer housing contains the analog electronics for transmit and receive, transducer tuning, and the four-stage receiver amplifier. Ping transmit waveforms travel to the transducer housing and an analog signal representing the acoustic returns travels up the underwater cable to the RD Instruments VM Chassis. The RD Instruments VM Chassis controls the sonar transmit cycle and sends the appropriate waveform signal. It also accepts serial ASCII commands from the SciFish 2000 processing platform to configure all aspects of the transmit waveform and provides trigger and raw signal to the processing platform over two coaxial lines. In the FM mode, the RD Instruments VM Chassis receives it's timing clock and waveform from the HP Function

Generator. For CW and PN modes, the function generator provides a fixed timing clock only.

The transmit power is fixed but the receiver gain can be adjusted in four fixed steps which are set to 18 dB, 41 dB, 64 dB, and 87 dB. For most experimental work, the gain was set to 64 or 87 dB. At any gain setting, preamp input impedance is much greater than the transducer output impedance allowing a gross estimation of the instantaneous sound pressure level from the digitized amplitude.

D. Data Summary

The number of echoes available for three classes (Rockfish, Halibut, and Bottom) is shown in Table I. Echoes were collected at 1 m range to the bottom for each fish. Data was collected with a single fish and then both fish. In all cases bottom echoes were also collected and stored at full-resolution for studies of halibut echoes mixed with the seabed backscatter and for future bottom type classification analyses. More than 500 megabytes of raw ping data were collected and stored on a magneto-optical cartridge during the four-day data collection effort.

TABLE I. SUMMARY OF ECHO SHAPE DATA

Class	Max Amp (mV)	No. Echoes
Halibut	[0,20]	124
	[20,50]	122
	[50,200]	43
Rockfish	[0,100]	18
	[100,500]	42
	[500,1100]	52
Bottom	[100,200]	150
	[200,500]	209
	[500,800]	43

III. RESULTS

In the following sections, we describe the features that were extracted for classification and we report the classification results using these features.

A. Feature Extraction

In these initial bottomfish identification experiments, two sets of features were extracted: echo shape and spectra. Examples of each are given below.

1) Echo Shape Parameters

The shape of the echo provides a great deal of information about the reflecting object. The slope of the echo's leading edge reveals how hard the reflecting surface is. The trailing edge reveals information about the absorption of the echo by the target and the target's resonant structure. Following detection, each echo is resized to a length of 40 samples and then rescaled to values that span the full range from 0 to 100. The echoes original max amplitude is retained with the echo for later processing.

The average echo shapes within each class are shown in Figure 5. As this figure shows, Halibut and Bottom shape are relatively consistent across the different amplitudes, but the

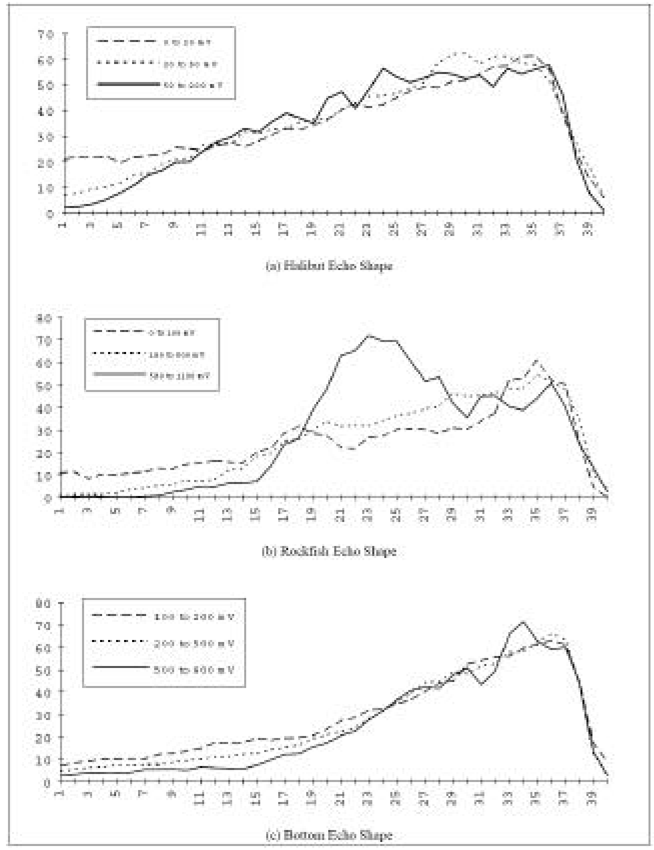


Figure 5. Averaged Max Amplitude Echo Shape Data

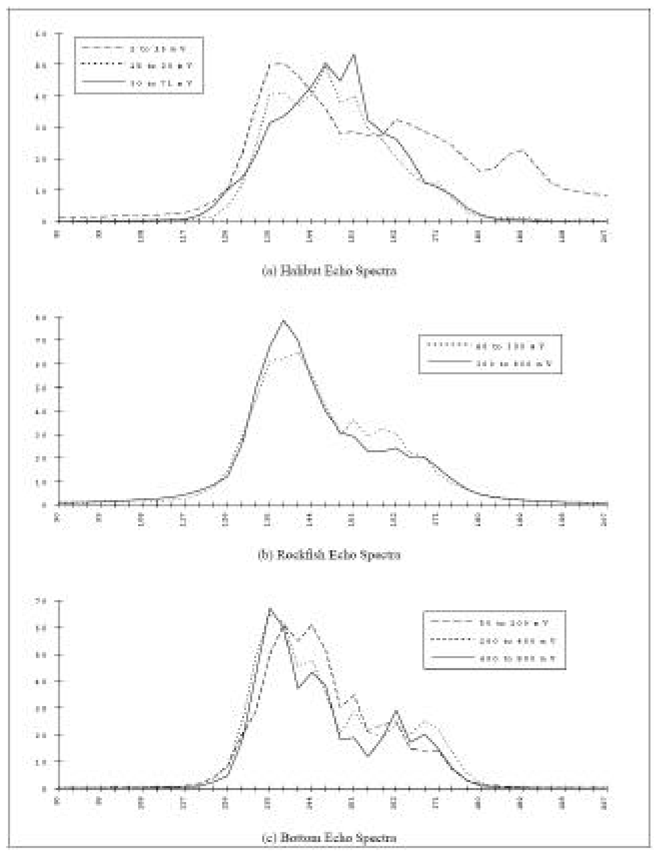


Figure 6. Averaged Echo Spectra Data

rockfish amplitude varies significantly. This is somewhat expected as the rockfish has a swimbladder and the halibut does not.

2) Echo Spectra Parameters

A 40-bin FFT power spectrum estimate covering frequencies from 90 to 210 kHz in 3 kHz bins was extracted. The number of echoes available for three classes (Rockfish, Halibut, and Bottom) is shown in Table II. Again, the echoes within each class are organized by max amplitude.

TABLE II. SUMMARY OF ECHO SPECTRA DATA

Class	Max Amp (mV)	No. Echoes
Halibut	[2,15]	85
	[15,30]	96
	[30,71]	68
Rockfish	[40,300]	32
	[300,1100]	29
Bottom	[50,200]	43
	[200,400]	246
	[400,800]	113

Plots of the average spectra show differences across the band between species (Figure 6). As this figure shows, the Rockfish forms a peak at 138 kHz. The Halibut spectra have a larger envelope, with significant spectral energy between 150 and 160 kHz. The spectra from the bottom is broader than the Rockfish, but not as broad as the Halibut, and it tends to have a dominant peak near 135 kHz with a secondary peak at 162 kHz.

B. Classification Results

The two feature sets described above, echo shape and echo spectra, were used as training and testing data for a fuzzy neural network classifier [3].

1) Echo Shape Classification

For training and testing with the echo shape data, the following data sets were created. For training, the average echo shape within each max amplitude grouping (shown in the plots in Figure 5) were used. With traditional neural network training techniques, this would not be a reasonable approach, but SciFish has developed an evolutionary programming approach to training that excels in this situation. The training data consisted of all the echo shape parameters from each of the two max amplitude groups with the largest values. A summary of the training and testing set sizes are shown in Table III.

TABLE III. SUMMARY OF SHAPE TRAINING AND TESTING DATA

Class	No. Train	No. Test
Halibut	2	165
Rockfish	2	94
Bottom	2	252

The classification experiments with the echo shape data were conducted in pair-wise comparisons, then with all three classes together. The results are shown in the set of confusion matrices shown below (Table IV), where BOT = bottom, ROK = Rockfish, and HAL = Halibut.

TABLE IV. SUMMARY OF TWO-CLASS ECHO SHAPE RESULTS

	BOT	HAL
BOT	84%	16%
HAL	24%	76%

	BOT	ROK
BOT	81%	19%
ROK	22%	78%

	HAL	ROK
HAL	79%	21%
ROK	12%	88%

TABLE V. SUMMARY OF THREE-CLASS ECHO SHAPE RESULTS

	HAL	ROK	BOT
HAL	68%	11%	21%
ROK	10%	68%	22%
BOT	8%	24%	69%

As these confusion matrices show, the echo shape parameters provide excellent separation between the classes. The classification experiments that attempt to separate bottom echoes from fish are used here to illustrate that fish near the bottom boundary layer can be identified. Often, the echoes near the bottom are all attributed to the bottom bounce, but this is not the case. As fish move up off the bottom to eat and move, they can be detected as separate echoes. Those echoes can, in turn, be identified. Clearly, the comparisons with the bottom are not intended to represent this as a method of bottom localization. The difference in echo amplitude is sufficient for this operation.

2) Echo Spectra Classification

For training and testing with the spectral data, the following data sets were created. For training, the average echo spectra within each max amplitude grouping (shown in the plots in Figure 4) were used. The training data consisted of all the echo spectra parameters from each of the two max amplitude groups with the largest values. A summary of the training and testing set sizes are shown in Table VI.

TABLE VI. SUMMARY OF SPECTRA TRAINING AND TESTING DATA

Class	No. Train	No. Test
Halibut	2	184
Rockfish	2	29
Bottom	2	359

The classification experiments with the echo spectra data were conducted in pair-wise comparisons, then with all three classes together. The results are shown in the set of confusion matrices shown below (Table VII).

TABLE VII. SUMMARY OF TWO-CLASS ECHO SPECTRA RESULTS

	BOT	HAL
BOT	70%	30%
HAL	29%	71%

	BOT	ROK
BOT	75%	25%
ROK	23%	77%

	HAL	ROK
HAL	72%	28%
ROK	27%	73%

The confusion matrix for all three classes being considered together is shown below (Table VIII). Although the individual class performance decreases from the two-class case to the three-class case, the separation between classes is still very good.

TABLE VIII. SUMMARY OF THREE-CLASS ECHO SPECTRA RESULTS

	HAL	ROK	BOT
HAL	61%	18%	21%
ROK	17%	66%	17%
BOT	25%	14%	61%

As these confusion matrices show, the echo spectra can provide separation between the classes, but the performance is not equal to the echo shape parameters. The next step in the classification process would be to combine both echo shape and spectra parameters together. In previous experiments, this has further improved the performance. This is a processing alternative that is left for future consideration.

IV. DISCUSSION

Extracting spectral and temporal signal parameters that are used by a fuzzy neural network for classification attained the results presented in this report. One aspect of the next stage of product development will be to determine the extent to which species classification functions may be used outside the range of data from which they were derived. Fish aggregation characteristics are not constant within species. However, the key to these approaches is that many species do have characteristic and quantifiable aggregation properties, which do not vary as much within as among species. For example, within specific systems, discriminant functions derived in one year have been shown to be good classifiers (greater than 90%) in other years [2]. Discriminant functions may also be transferable to systems having similar ecological conditions. For example, functions developed for Gulf of St. Lawrence shoals of cod and capelin classified shoals of these species off Northeast Newfoundland with high reliability [1].

In summary, there are several observations that can be drawn from the initial broadband bottomf ish identification experiments:

1. *Data Quantity*. As noted by Simmonds, et al. (1995) in their experiments with wide-band fish identification using neural networks, the greater the data, the better the overall performance. This is the result of the aspect dependence that fish have with sonar. The larger the number of "looks" at various fish over different size aggregations, the better the overall system performance will be. Our experiments tend to agree with this observation, but more extensive data collection and exhaustive data processing will be needed to fully characterize this aspect of the identification process.

2. *Feature Extraction*. The type of features extracted can significantly affect performance. In these experiments, the echo shape parameters provided better performance than the spectral parameters. In the prior experiments SciFish conducted with wideband data (SciFish, 1994), performance tended to be better with the spectral data. Further experimentation needs to be conducted to determine which combination of features provides the greatest generalization with the best classification accuracy. These experiments should also include additional feature extraction approaches such as wavelets and higher-order spectra.

3. *Echo Averaging*. An experiment was conducted with the echo shape data wherein each of the classification experiments were repeated, only instead of using an average set of parameters for the training set and all of the data for testing, the training and testing data sets were split in half. The performance did not improve. In fact, in some instances it decreased. Echo averaging improves performance. This characteristic of fish identification was also noted in the experiments described by Simmonds, et al. [5]. In the next stage of development, further experimentation will be conducted to determine the affect of echo averaging across a large ensemble of data. The goal of this work will be to characterize the number of echoes averaged versus classification performance.

4. *Performance Improvement*. Currently the classification performance ranges between the 68% and 88% correct. Although this is adequate, it would be desirable to have classification performance within the range of 85% to 95% correct.

5. *Generalization*. The ability of this fish identification approach to work in several areas and at several different times of the year needs to be explored.

6. *Mixed Species*. Data collection with multiple fish species must be conducted and the classification performance in this situation needs to be quantified.

7. *Bottom Boundary Layer*. These experiments demonstrated that two types of bottom fish are significantly different than the bottom, leading one to think that if there was a way to overcome, or suppress, the bottom echo and then retrieve from this the remaining portion of the signal, it might be possible to perform reliable fish identification when fish are at or near the bottom. Even if this is not feasible, bottomfish do move up off the bottom (and out of the deadzone) frequently during feeding and traveling, making identification possible.

ACKNOWLEDGMENT

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