

ACTIVE SONAR CLASSIFICATION TRAINING USING RECORDED DATA

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ABSTRACT

The improved technology for quieting submarines has placed a renewed interest in the use of active sonar in Anti-Submarine Warfare (ASW). This increases the need for training ASW operators in the effective use of active sonar, particularly in the classification of an active sonar contact as either a target (submarine) or a non-target (e.g., a sea mount or a school of fish). Current trainers using synthetically generated contacts do not provide the realism needed for classification training. Operators have very little chance to practice using actual acoustic contacts.

This paper describes two demonstration models of a trainer using recorded acoustic contacts for active sonar classification training. The demonstration models were developed by Applied Research Laboratories, The University of Texas at Austin (ARL:UT), under the sponsorship of the Naval Training Systems Center (NTSC). The first is DEC MicroVAX based and is compatible with the hardware available in the Passive Acoustic Analysis Trainers (Devices 21H14 and 14E40). The second is personnel computer (PC) based and provides a much less expensive implementation. Both models provide the CRT display and the audio signal available in the operational sonar. The result is a trainer that provides the realism needed for classification training. The low cost of these units should make them applicable to the full spectrum of operator training, from classroom training to on-board refresher training.

INTRODUCTION

The ability to distinguish submarine targets from non-submarine targets is a critical skill required by the active-sonar operator. The operator determines whether a contact is valid by indications such as track consistency, echo shape, echo consistency, and particular aural characteristics. False contact indications include erratic track motion, no track motion, inconsistent echo quality, and non-submarine aural characteristics. Operator training requires accurate representation of the echo and aural characteristics to support target classification training and practice.

Use of Recorded Acoustic Data

The use of recorded data from actual acoustic contacts for active classification offers a means of providing a high fidelity presentation of aural and visual data needed for training. Using recorded acoustic contacts for active classification training is an extension of a technique used in the Submarine Passive Acoustic Analysis Trainer (Device 21H14) and the Surface Passive Acoustic Analysis Trainer (Device 14E40)¹. These trainers provide more than 100 student stations for hands-on classroom training in passive acoustic analysis.

Preprocessed recorded sonar data provides high fidelity displays and aural cues not previously available in sonar operator training. Conventional

trainers that electronically stimulate an actual sonar set do not produce the subtle signal characteristics needed for the classification task. Realistic aural signals are more difficult to synthesize than realistic visual displays. Passive sonar displays and aural signals generated by using stored data have proven effective in training passive acoustic analysis². The same technique should be effective for teaching active sonar classification.

As a side benefit, the use of stored data produces a more affordable trainer. Preparing the actual sonar data for display in advance, using off-line signal processing, reduces the computation load on the trainer. This allows the use of a less expensive computer workstation or a personal computer. Low-cost desktop computers currently available provide the capability to replicate the operational displays, implement an instructional system, and store the processed data. The result is a trainer that offers the realism of actual sonar contacts in a portable trainer. The low cost and portability make possible wide distribution of trainers to fleet units and to reserve units.

The use of recorded data in active sonar is more complex than the application to passive sonar. In passive sonar, the entire signal processing necessary to prepare data for display can be performed off-line. In active sonar, a major part of the signal processing can be performed off-line, but some of the functions must be performed during the training exercise. The operator has choices such as range setting and filter bandwidth selection that make prestorage of every case impractical.

Capabilities Required

The following capabilities are required for an active sonar classification trainer:

- **Fidelity.** The acoustic signatures displayed must provide sufficient fidelity to support target classification proficiency training and practice.
- **Synchronized Aural Signals.** The aural signal presented to the student must provide equivalent realism to that required of the graphics display. In addition, the aural signal and graphics display must be synchronized so

that the timing of the aural signal matches the display.

- **Ease of Operation.** The system must be user friendly so that the sonar operators do not need special training to use the trainer.
- **Portability.** The system must be easily transported on and off a ship. It must be small enough to be used in compact shipboard spaces.
- **Automatic Evaluation.** The system must automatically evaluate operator skill levels and provide guidance concerning additional training or practice that is required.
- **Instructional Capability.** The system must provide appropriate additional training based upon the particular operator's skill level. The process must be automated so that instructor intervention or participation is not required.

SONAR SYSTEM DESCRIPTION

The AN/SQS-53A³ sonar set was selected for the Active Acoustic Analysis Demonstration Unit (AAADU). The AN/SQS-53A is the Navy's primary surface ship sonar and will remain so through the 1990s. Further, recorded sonar data are available for this unit.

Figure 1 shows a functional diagram of the AN/SQS-53A. The single time-shared transducer is used for both transmitting and receiving acoustic signals. The transducer transmits both continuous wave (cw) and coded pulse (CP) signals. There are separate beamformers for the variable depth receiver (VDR) and the surface duct receiver (SDR). The VDR processes both signal types, and the SDR processes only cw signals.

Displays

The receivers provide input to three consoles which have active sonar displays. The VDR detection (A-scan) console presents a display of range versus amplitude for 12 CP and 12 cw beams from the VDR. This display is used primarily for target detection with the VDR receiver. The SDR detection (B-scan) console presents data received on the 72 SDR beams on

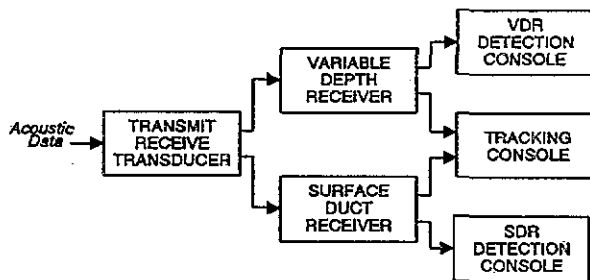


Figure 1. AN/SQS-53A Sonar Functional Diagram.

the plan position indicator (VDR) display and a B-scan display. The VDR display shows a polar presentation with the center representing own ship. The B-scan display shows range versus true or relative bearing.

The target tracking console can be used with an SDR or a VDR target. The console presents two displays: (1) the sector scan indicator (SSI) and (2) the target Doppler indicator (TDI), along with an aural signal. Figures 2 and 3 show these displays for cw and CP signals.

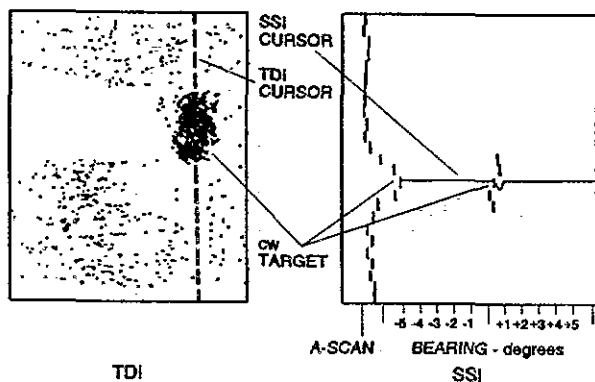


Figure 2. cw Target Tracking Console Display.

The SSI display provides two presentations. The A-scan on the left side shows processed signal amplitude in the horizontal direction versus range in the vertical direction. The SSI shows fine target bearing and target range values. The SSI cursor allows the operator to select a target by placing the

range line with its movable notch over the return of interest.

The TDI display provides information from which an operator determines target Doppler and target Doppler consistency. The presentation shows target Doppler along the horizontal versus target range along the vertical axis. The range axis for the TDI and SSI displays is the same.

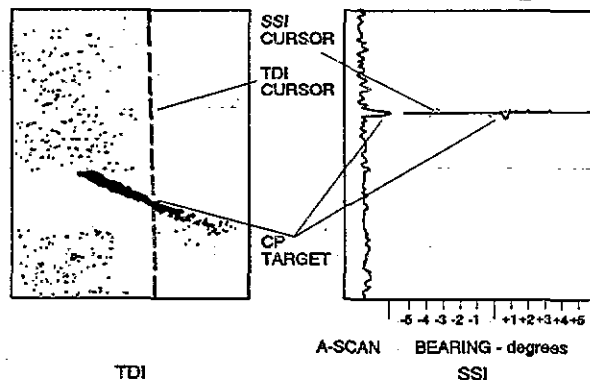


Figure 3. CP Target Tracking Console Display.

Display Selected for Training

The target tracking console displays were selected for implementation for the AAADU for the following reasons.

- The fine target bearing and range information provides the best resolution available for classifying active targets.
- The SSI display can be used to classify shortrange submarine targets by "linelikeness." That is, the echoes from individual scatterers along the submarine map out a line on the range-bearing display. This mode of classification is not available on the VDR or SDR display consoles, because only very low resolution target bearing information is available on those displays.
- The TDI display provides target speed information that is useful in classifying targets with significant opening or closing Doppler.

Operator Controls

The following controls are available to the operator at the tracking console.

Range Window. The range scale on the SSI display is operator selectable in three range increments: 2000, 1000, and 500 yards.

Pulse Mode. The transducer is capable of transmitting cw signals of varying lengths from 30 milliseconds to 1 second for SDR processing. For the VDR the sonar can transmit both a cw signal and a CP signal. The duration of the cw signal is variable from 10 milliseconds to 0.5 seconds. The CP signal is fixed at 0.5 seconds. The operator may also select various transmit sequences.

The transmit mode for the VDR is selected by the operator at the VDR detection console (or A-scan console). The transmit mode for the SDR is selected by the operator at the SDR console (or B-scan console). The tracking console operator options are limited to the selection of one of the available signals.

Doppler Filtering. The operator may select two optional narrow bandwidth filters (equivalent to ± 2 knots and ± 6 knots) to be applied to the TDI data before it is displayed.

Threshold. Nine threshold values are available to filter what data will be shown on the SSI display. The threshold values are operator selectable, but not from the front panel.

SIGNAL PROCESSING

The signal processing emulates the processing in the AN/SQS-53A sonar set⁴. Figure 4 shows a simplified block diagram of the target tracking receiver. The data from recorded contacts are stored after the beamformer. The signal processing functions are (1) signal conditioning, (2) target tracking signal processing, (3) display generation, and (4) audio generation. The data for each acoustic contact was recorded using whatever pulse mode was chosen by the operator during the exercises. The data selected for implementing the AAADU was limited to single pulse sequences consisting of both CP and cw signals.

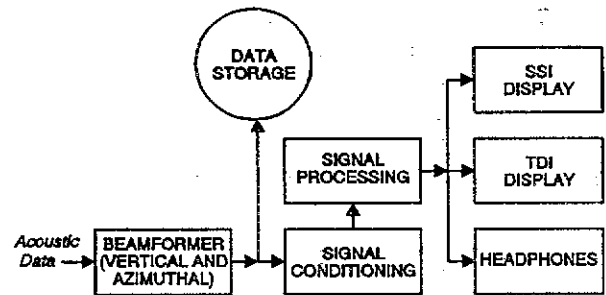


Figure 4. Target Tracking Receiver.

Signal Conditioning

Figure 5 shows the processes performed in signal conditioning for the AAADU. The processing converts the recorded data to complex data samples used by the VDR and SDR.

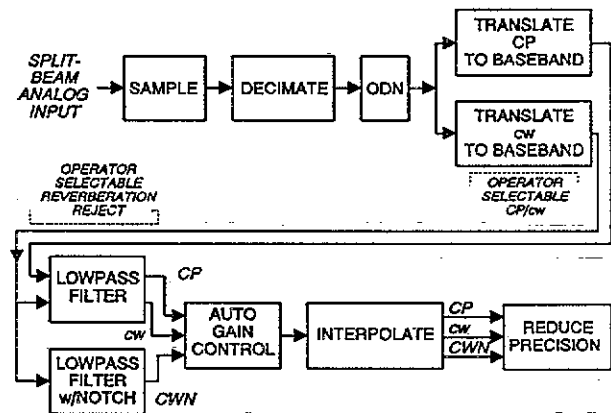


Figure 5. Signal Conditioning Implementation.

Sampling and Decimation. The first step is to convert the analog data to digital form. The data are sampled at four times the center frequency of the recorded signal, then the number of samples is reduced by taking only two adjacent samples out of every 24.

Correction for Own Ship Doppler. The Own (ship) Doppler Nullification (ODN) correction factor is obtained for the ship's trajectory and servo information recorded on the analog instrumentation tapes. The frequency shift due to the sensed own ship motion is computed, and

frequency shift due to this motion is eliminated by translating each complex data sample by the appropriate value.

CP/cw Separation and Notch Filtering. The CP and cw bands are converted to baseband frequency and separated by two low-pass filters into two data streams. A third data stream is produced by applying a notch filter equivalent to ± 6 knots to the cw data.

Automatic Gain Control (AGC). The AGC function is implemented by computing a gain value that makes the average input signal equal to a constant. The number of samples considered in setting the gain corresponds to the time constant selected for the pulse length being transmitted. The sampling interval is 0.15 seconds for pulses of 0.1 second or less, and 0.5 second for longer pulses.

Interpolation. The data for each data stream are interpolated to give the same output sampling rate as the complex sampler in the AN/SQS-53A. This introduces an error of less than 1 dB. in amplitude and less than 0.2 degrees in bearing. These errors are negligible compared to the resolution of the displays. After interpolation, the results are reduced to 8-bit samples to match the precision of the complex sampler in the AN/SQS-53A.

SSI Display Signal Processing

Figure 6 shows the signal processing to convert the conditioned CP, cw, and notched cw signals into an SSI display. The dotted line separates those processes that can be performed off-line from those that must be performed in the trainer.

Replica Correlator. Replica correlation is the matching of the received data to stored replicas of the transmitted signal. For CP signals, the correlation uses a single replica of either the up-swept or down-swept FM transmitted signal. For the cw band, the reference signal is read out at various rates to produce shifted replicas to produce the effect of Doppler shift. The comparison of the replica with the signal is performed by a set of matched filters.

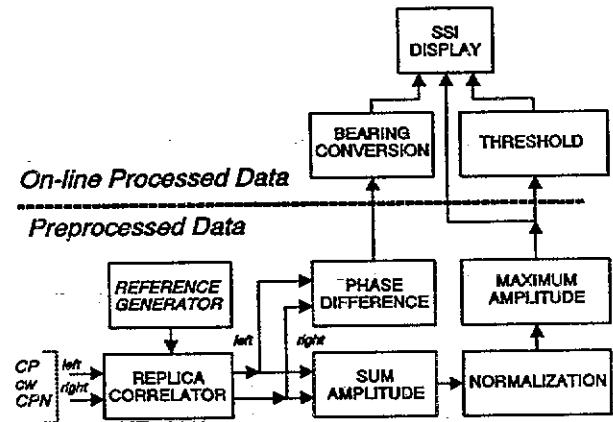


Figure 6. SSI Simulation.

Amplitude, Bearing, and Normalization. Left and right beam correlator output data are summed to form sum beam data. These data are normalized and the maximum amplitude over the matched filter outputs is found and reduced to a 6-bit representation. The left and right matched filter outputs, corresponding to the maximum amplitude, are used to compute a phase difference. This phase difference is reduced to a 10-bit bearing angle. This 16-bit representation of an amplitude and bearing for each range increment forms the data base for the AAADU.

Display Generation. The A-scan part of the SSI display presents amplitude of the return signal on the horizontal axis versus range on the vertical axis. The SSI display shows maximum signal return at each range at a vertical position corresponding to range and a horizontal position corresponding to bearing. The amplitude value determines the brightness of the point displayed. Those points whose amplitudes are less than the threshold set by the operator are not displayed.

TDI Signal Processing

Figure 7 shows the signal processing necessary to convert the conditioned CP, cw, and notched cw signals into a TDI display. The dotted line separates those processes that can be performed off-line from those that must be performed in the trainer.

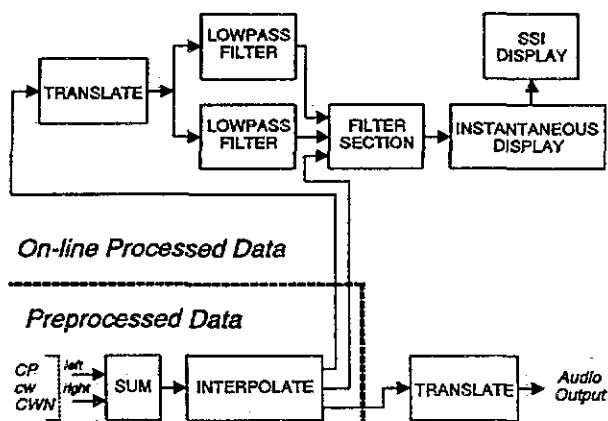


Figure 7. TDI Simulation.

Sum and Interpolate. Left and right split-beam data from the signal conditioner are summed and interpolated to produce a 800 Hz. sampling rate. The result is provided to the AAADU for use in generating the aural signal and the TDI display.

Filtering. Data for the TDI display are filtered to eliminate out-of-band signals according to the mode selected by the operator. One of three filters is applied to reduce the Doppler range of the target that may be displayed.

Instantaneous Frequency. The instantaneous frequency is computed from the rate of phase change over time. The frequency variation is then converted to target speed variation in knots.

Audio Signal Generation.

During display generation, the aural output is formed by translating the stored audio baseband data to a center frequency of 800 Hz. and converting the data to an analog signal. The 800 Hz. quadrature samples are converted to a 3,200 Hz. sampling rate and used to drive the headphones.

HARDWARE IMPLEMENTATION

Three sets of hardware are used in the demonstration of the active sonar classification trainer. The off-line signal processing hardware consists of analog-to-digital conversion equipment and a general-purpose computer. This hardware is used to process the AN/SQS-53A analog

instrumentation tapes obtained from the Naval Underwater Systems Center, New London Laboratory (NUSC/NL).

AAADU Implementation.

The hardware selected for the AAADU is a MicroVAX II workstation with a high-resolution (1024 x 1280) graphic system. The MicroVAX II was chosen to make the AAADU hardware compatible with the 14E40 and 21H14 series of passive acoustic analysis trainers developed for the surface and subsurface communities.

Special equipment was added to implement the aural portion of the trainer. In the passive trainers, only one audio channel is required. A stereo audio cassette tape provides the aural signal on one channel and a timing track for synchronization on the other channel. The active sonar trainer requires two aural tracks, one for cw signals and one for CP signals.

The aural signal generation was solved by storing the data in digital form and converting the data to analog form to drive a speaker. After conversion to analog form, the aural data is filtered and played through the DECTalk speaker. The filtering is performed by the Q-bus interface board, designed by ARL:UT. The DECTalk voice printer was modified to allow the audio signal from the filter to be played through the DECTalk speaker. This configuration allows the audio signal to be mixed with text output to the voice printer. Headphones connected to the voice printer provide the aural signal for active classification.

Personal Computer (PC) Implementation

A PC demonstration unit was developed to take advantage of the PC's low cost, small size, light weight. The PC implementation provides essentially the same graphics display as the AAADU, even though the resolution is approximately one-half that of the high-resolution monitor used with the workstation. The PC version uses audio cassette tape to provide the aural signals.

The aural signals generated by the AAADU are recorded on one of the stereo channels of an audio cassette tape, and a timing track is recorded

on the other track. The timing track is used by the software program to synchronize the display with the recorded audio signal. Because only one channel is available for audio, it is not possible to change the audio as the operator switches between cw and CP signals.

DATABASE

The data currently available for use in the AAADU consist of analog recordings of sonar contacts from the AN/SQS-53A AN/SQS-26 VDR. The data sets are shown in Table I. The data consist of dedicated submarine operations, false targets of opportunity, biologics, wrecks, bathymetric features, and surface contacts.

Table I. Data Sources.

DATA SET	ESTIMATE D TOTAL PINGS	DATA TYPE
SPRUANCE	555	SUBMARINES FALSE TARGETS
McCANDLESS	1273	FALSE TARGETS
CUSHING/O'BRIEN	850	DD963 DESTROYERS
CUSHING/HOUSTON	2300	DEEP WATER 688 CLASS SUBMARINES
COMPTUEX 1-87	474	SHALLOW WATER SUBMARINES SURFACE SHIPS
GLOVER ASW 1987	2890	CONVERGENCE ZONE SURFACE DUCT SUBMARINES NON- SUBMARINES
I-SHAREM 1-87	2800	DEEP WATER SUBMARINES
ASWEX 86-2	400 +	SHALLOW WATER SURFACE SHIPS
ASWEX 86-4	400 +	SURFACE SHIPS FALSE TARGETS

Data Requirements

Training requires two sets of data: a teaching set and a testing set. The teaching set must show clear examples of both true and false targets in a low-level noise background. The false targets should include surface ships, wakes, kelp beds, and biologics. Examples of false alarms from reverberation, ambient or self noise, and slamming or quenching of the sonar dome should be included in the training set. The trainee should be taught to distinguish between submarine targets and commonly occurring returns that represent false alarms.

The teaching set and the test set should each contain approximately 100 examples of submarine targets and 100 examples of false targets. Each example should provide 15-30 pings on a particular contact. Assuming an average ping length of 0.5 seconds, 50-100 hours of active data are required for training and evaluation.

Noise Background

The ambient noise and/or background level has a significant effect upon the difficulty of classification. Testing of a trainee's skills before and after training requires a data set which various signal-to-noise (S/N) ratios. The different S/N ratios are necessary to provide graded test conditions to bracket the trainee's abilities. The test set must provide a high S/N to provide success, decreasing to a low S/N to provide challenge. It should be noted that a S/N ratio low enough to cause marginal trainee performance may be below the detection capability with either the SDR or the VDR.

Sea data with controlled S/N is difficult, if not impossible, to obtain. However, suitable data can be created artificially without destroying the realism of the data. This is accomplished by summing target returns with ambient/self noise or reverberation. The S/N is controlled by changing the level of the interference before combining the two sets of data. The summation of data requires the following conditions.

- Each input must be sampled at the same rate and decimated by the same factor.

- Each set of data must be translated to baseband (if not already there) and individually corrected for own ship Doppler.
- The data must be summed before the AGC.

It is advisable, but not required, to combine data before the low-pass filter to assure that the same filter is applied to each set of data. Note, however, that the power level of the individual sets of data must be determined after the low-pass filter. Also, the sonar transmit and receive configurations must be the same for each of the data sets combined. For example, cw echoes should not be combined with CP reverberations.

SUMMARY

The primary objectives of this project were (1) to develop a more effective trainer for active sonar classification by using preprocessed recorded sonar data to produce realistic displays and aural cues, and (2) to develop a more affordable trainer by using relatively inexpensive microcomputer technology.

The displays from the target tracking console of the AN/SQS-53A were selected as the most appropriate displays for training sonar operators in the task of classification. This selection is based upon the higher resolution presentation resulting from the fine target bearing and range information obtained from the split-beam processing.

Implementation of the AAADU included (1) preprocessing and storing data recorded from the VDR of the AN/SQS-53A sonar, (2) development of hardware and software to play back the preprocessed data in realtime on simulated displays of the target tracking console. The presentation includes visual displays like those of the tracking console and audio played through headphones or a speaker. Operator input is provided by a trackball.

Approximately 2,000 pings of recorded data were preprocessed. The scenarios available include submarine targets as well as false targets such as sea mounts, wrecks, and whales. The data base available is sufficient to evaluate the training

capability of this device. A larger database is needed for actual training.

This development has demonstrated that the use of preprocessed data and a relatively inexpensive microcomputer can provide an effective and affordable active classification training capability. The realistic displays and aural cues provided by use of prestored data can improve an operator's ability to discriminate between submarine and non-submarine signal returns.

The low cost of these microcomputer based trainers should make them applicable to the full spectrum of operator training. High fidelity active classification training can be added to the present classroom training. Refresher training can be moved from the schoolhouse to shipboard. Continuous refresher training should yield a significant improvement operator performance.

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