Sonar Detection and Classification of Buried or Partially Buried Objects in Cluttered Environments Using UUVs

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LONG TERM GOALS

The long term goal of this program is to develop acoustic reflection methods and signal processing techniques for detecting, imaging and classifying objects buried in or resting on the seabed such that the methods can be eventually implemented on UUVs.

OBJECTIVES

- To develop acoustic and signal processing technologies for detecting and visualizing buried objects and objects lying on the seabed
- To determine the best image processing and visualization techniques for buried object imaging
- To generate databases of buried target strengths, volume and surface scattering coefficients and sediment acoustic properties over a wide frequency range that can be used for sonar prediction modeling
- To develop sonar models that predict the SNR of targets for various array geometries, sediment types, frequency bands, etc .
- To develop acoustic models of sound interacting with the seafloor to provide a theoretical basis for signal processing techniques and predicting the detection of buried objects

APPROACH

Buried Object Detection

In order to develop a UUV sonar for detecting and imaging buried objects, the phenomenon of volume and surface scattering from the sediments, fluid / porous solid boundary-interacting acoustics, and the interaction of sound with elastic objects contained with a porous solid must be understood so that the signal levels and interference can be accurately calculated when estimating sonar performance of a particular design. An experimental approach is being taken to determine those acoustic processes. Two sonars have been constructed to measure the effects of sound interacting with the seabed and to measure the characteristics of target echoes. The sonars provide a direct measurement of the target echo strength and acoustic scattering levels as a function of frequency. The first sonar uses a 3m wide by 1m long towed vehicle containing a 0.75 m long line transmitter and 16 line hydrophones covering

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an aperture of 0.75 by 3 meters. A 16 channel sonar processor was used to collect the 16 channels of reflection data. The data was sent to a topside processor via a 100 Base T link for display and storage and merging with underwater video. The data from the first sonar, covering the frequency range of 1.5 to 10 kHz, was used for testing across track focusing. Experiments over mines in sand showed that the sonar could generate images of mine-like objects to a burial depth of 2 meters, but had difficulty detecting partially buried objects because of high sediment-water interface scattering near normal incidence. The experiments showed a clear need for a steerable transmission beam which required a planar receiver that could steer the receiver beam forward and aft in addition to across track steering.

CEROS (DARPA) funded the hardware development for a compact version of the imaging sonar developed in this program. This sonar has the added features of a steerable transmit beam and a beamformer that provides across track and along track focusing. This sonar has a frequency range of 4-25 kHz. The 1 meter long by 1 meter wide towed vehicle contains a six element transmission array and eight line hydrophone arrays with 4 segments each. The sonar processor on the fish steers the transmit beam forward or aft to any selected angle of incidence and acquires 32 channels of reflection data which is sent to the topside processor via 100 Base T for display and storage. The two sonars are designed to provide integrated video and acoustic data sets for measuring the impulse response of buried targets and the scattering interference from sediments in the vicinity of the targets. The compact sonar steers the transmission beam forward thereby substantially reducing the high scattering levels from the sediment water interface at near normal incidence that make it difficult to detect objects near the interface.

Automatic Bottom Mine Detection

A 850 kHz chirp sonar was designed and constructed to provide AUVs with the capability of automatically detect mines lying on the seabed and reporting mine positions to a surface ship as the mines are detected. The operating frequency of 850 kHz was selected to ensure that the wavelength was short enough so that scattering of sloping target surfaces could be used to provide detailed target images. Automatic detection of mines is performed in real time using a 466 MHz Celeron processor and fuzzy pattern recognition procedures which analyze the acoustic shadows produced by mines resting on the seabed. The fuzzy pattern recognition procedure uses characteristics of shadows detected in acoustic returns to determine if a shadow belongs to a mine-like object. The mine-like target membership of a shadow depends on the across track and along track dimensions of the shadow, the amount that shadows overlap in adjacent pings, and the along track distance between shadow centers belonging to different acoustic returns. The length and height of the mine is measured and reported to the AUV host. An image of the mine can also be requested by the AUV for transmission via modem to shore or to a support ship.

Dr. Schock and Jim Wulf supervise the research which is conducted by graduate and undergraduate students. Jim Wulf is a retired engineer from IBM who designed and tested the electronic components of the sonar processors. Eric Bauer, a graduate student, conducts tank experiments, tests mine detection algorithms, and analyzes the performance of the mine detection system during offshore surveys.

WORK COMPLETED

The 850 kHz chirp sidescan, mounted in an OEX AUV, and executing real time mine detection algorithms, conducted missions during the FBE workup off Dania , Florida and the FBE off Panama

City, Florida. Testing and subsequent algorithm improvements substantially reduced false alarm rates while maintaining high probability of detection. Extensive sea testing is planned for the target detection system at the AUV fest in November 1999.

A second 850kHz sidescan sonar with automatic mine detection capability was constructed for the Morpheus mini-AUV. As of this report, the sonar has not been deployed on a Morpheus mission.

Substantial testing and analysis was conducted on data collected by the buried object imaging sonar at a test range in Hawaii. Sonar performance was established and images of many types of buried objects were generated. Focusing algorithms were improved. All processing and visualization runs in real time. Target detection algorithms that in the future will allow automatic reporting of buried targets to an AUV host were coded and tested successfully.

RESULTS

Automatic Target Detection

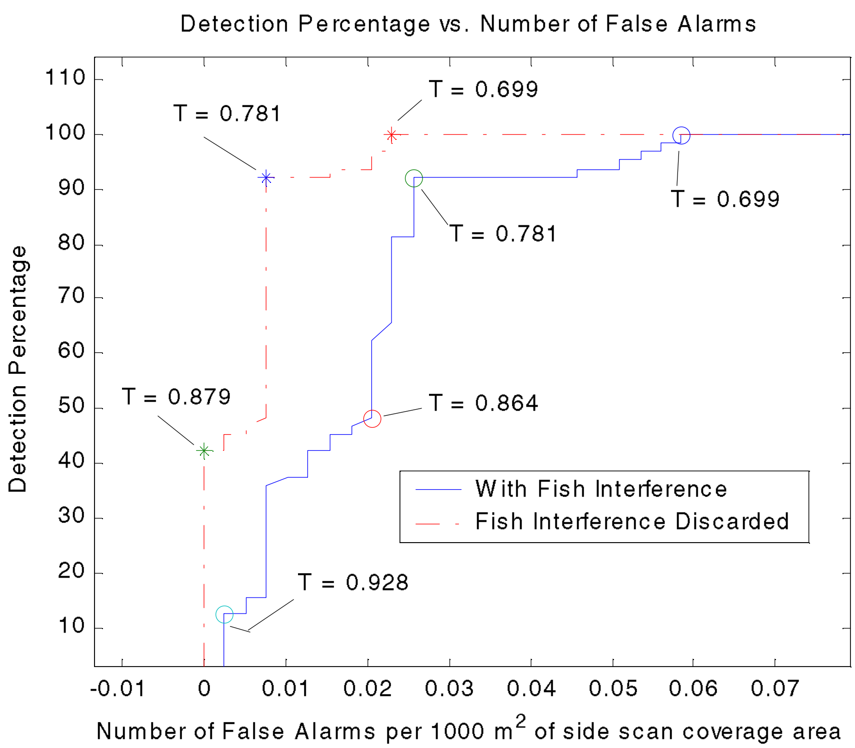
The automatic mine detection algorithm was tested in real time on three missions using the AUV OEX-Drake with a 850kHz chirp. The first mission occurred on June 9th, 2000 off the coast of Dania Beach, Florida during the FBE (Fleet Battle Experiment) workup. The sonar data set contained 150,000 m^2 of seabed imagery. The AUV maintained an altitude of approximately 3 meters and an average speed of 2.5 knots. The second and third missions occurred on August 25th, 2000 and September 5th, 2000 off the coast of Panama City, Florida during FBE. On August 25th, 40,400 m^2 was covered by the AUV with a speed of 2.5 knots and an average altitude of 5 meters. An area of 202,500 m^2 was covered on September 5th where the altitude and speed of the AUV remained at 3 meters and 2.5 knots respectively.

Table 1 summarizes the performance of the real time algorithm for detecting bottom mines for all three missions conducted during FBE and FBE workup. The detection algorithm only used data at sonar ranges where targets generated acoustic shadows; the algorithm ignored the data under the AUV that contained no shadow information. The minimum range at which the algorithm started searching was determined by the size and shape of the various bottom mines. As stated in Table 1, when the detection threshold (mine-like target membership) was set to 0.699, all mines were detected and there were 23 false alarms during the 3 hour, 19 minutes of total sonar mission time. Most of the false alarms were caused by fish swimming along side the AUV causing mine-like shadows in the imagery.

Table 1. Results for Fuzzy Auto Detection Algorithm for FBE and FBE Workup Missions

64 Target events during 3 hours and 19 min of collection time.			
Total Area of Side Scan Imagery = 393,000 square meters			
Detection Threshold, T	# of Detections	# of False Alarms	Detection %
0.699	64	23	100%
0.781	59	10	92.19%
0.864	31	8	48.44%
0.928	8	1	12.50%
Fish Interference Discarded			
0.699	64	9	100%
0.781	59	3	92.19%
0.879	27	0	42.19%

The following figure displays the detection percentage versus the number of false alarms for the three data sets. The curve was generated by reprocessing the raw sonar data and varying the detection threshold (target membership) from 0.5 to 1.0.



1. Percentage of mines detected versus the number of false alarms per 1000 sq meters of sonar coverage area. Fish swimming adjacent to the AUV cast large mine-like shadows on the seabed causing most of the false alarms.

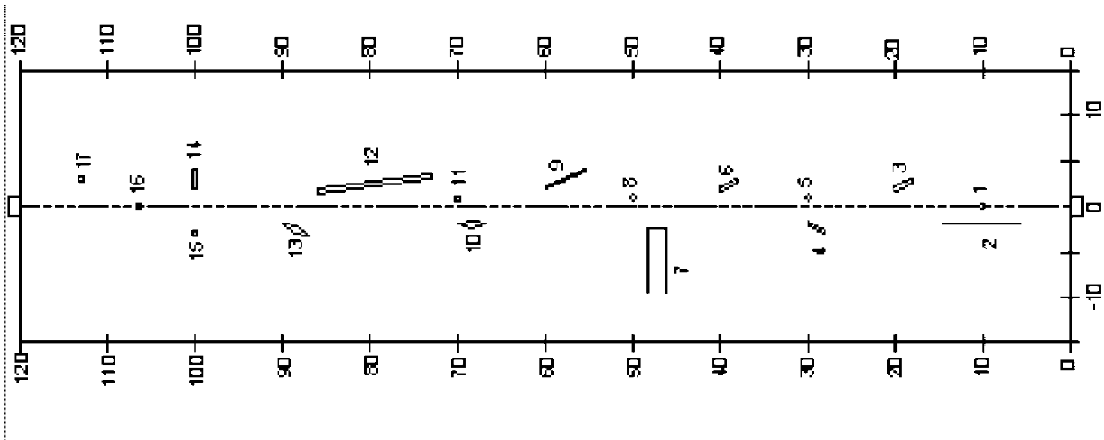
Results of Buried Object Detection Research

During the past year, a compact (1m x 1m) 32 channel buried object imaging sonar developed with funds from this program and CEROS funds was tested over a field of buried objects off Oahu, Hawaii. The field tests were conducted along a line containing buried ordnance, pipes and a cable as shown in Figure 2. A description of the targets is provided in Table 2. The 1x1 meter sonar vehicle was towed about 2 to 3 meters above the seabed. The transmission rate was 20 pings per second. The 32 data records of hydrophone data generated during each transmission are processed by a matched filter and time delay nearfield beamformer in real time. The slices of the seabed are stored in a buffer which can be viewed at any angle using maximum intensity projection. Real time 3D visualization allows the operator to view buried target shape, size and location.

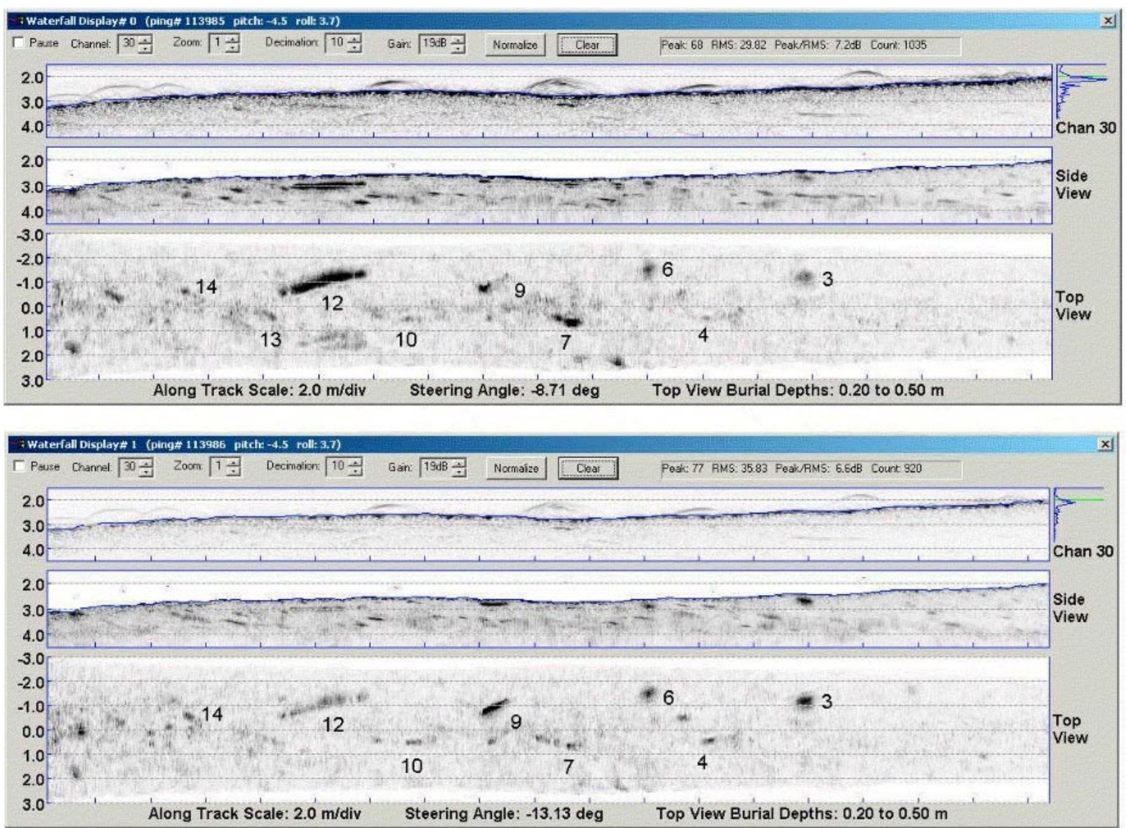
Field data showed that target echo SNR depends on the transmission beam angle and the target aspect. Figure 3 displays images of the seabed, including a single channel display and plan view and side view displays produced with the focused data. Note the large improvement in SNR due to focusing. The figure shows images produced for transmission beam steering angles of 9 and 13 degrees. Note the large change in target strength with the beam steering angle. These displays demonstrate the importance of focusing in 3D to obtain adequate SNR for imaging targets of unknown aspects.

Table 2.
Description of targets and burial depths verified by divers. The best target SNR and associated transmission beam angle are also reported for each target. The plan view of the field of targets is shown in Fig. 2.

Target Number	Description	Thickness of sand over target + above seafloor, - below seafloor (feet)	Beamsteering angle for best target SNR (target # : degrees)	Target SNR (Peak echo to rms noise ratio) (dB)
5, 8, 11	Air filled floats – various shapes	1	NA	
2	Double-armored cable, 1.5 inch diameter x 9 ft long Target aspect angle = 0 deg	-0.5 ft	#2: 0 deg	15 dB
3, 4, 6, 14	Steel scuba tanks filled with concrete, 2 ft long x 7 inch diameter	-0.8 to –1.0	#3: -13 #4: 9 #6: -13 #14: -9	18 16 17 12
7	Thin walled pipe, 2 ft diameter, 1-3 ft above seafloor	1 to 3	NA	
9	PVC pipe, air filled, 3.5 inch diameter x 5 ft long	-0.5	#9: -13	22
10, 13	155mm ordinance, 0.5 ft diameter x 3 ft long	-0.8 to –1.0	#10: -22 #13: -22	18 16
12	Ductile iron pipe, water filled, 6 inch diameter x 13 ft long, 0.35 inch wall	-0.8 to –1.0	#12: -9	20
1, 15, 16, 17	Air filled rubber balls, 8 inch diameter	1	NA	



2. Plan view drawing of test field



3. Images of seabed showing effect of transmission angle on target echo level. In the top three views of the seabed, the sonar transmission beam is steered 8.7 degrees aft of vertical. The lower views the beam is steered 13.1 degrees aft of vertical. The transmission beam must be steered over a range of angle to detect buried targets with unknown aspects.

IMPACT/APPLICATIONS

The imaging sonars developed under this program can be used for finding mines and ordnance which are buried or lying on the seabed. A buried object imaging sonar, developed by cost sharing between this grant and a CEROS/DARPA contract, can be incorporated into UUVs. Scattering and target strength measurements can be used to predict sonar performance and to aid in the development of other buried object sonars by the Navy. Real time target detection has been implemented in real time in an AUV mounted 850 kHz chirp sidescan which can detect and report mines lying on the seabed.

TRANSITIONS

The general purpose sonar technology has been transitioned to industry, academia and the Navy. The general purpose sonar was licensed to Edgetech. The technology is contained in sonars used by Naval Facilities Engineering Service Center and Woods Hole Oceanographic Institute who will be using the sonars to measure the impulse response of the seabed over the range of 1 to 14 kHz for the purposes of classifying ocean sediments.

The buried object imaging technology developed under this grant was modified for a DARPA sponsored program, administered by CEROS to detect and classify buried ordnance. The system has the additional capability of fore/aft beamsteering in addition to across track beamsteering and is much more compact so it is suitable for UUV applications. The sonar transmits over the range of 5 to 24 kHz.

The chirp sidescan sonar developed under this project was used on OEX AUVs during FBE to detect and report bottom mines to the support ship in real time.

RELATED PROJECTS

CEROS/DARPA contract "Development of a 3-D, Forward/Aft Sweeping, High Resolution Buried Object Imaging System"

PUBLICATIONS

Schock, S., et al, “ Buried Object Imaging Sonar,” IEEE J. of Oceanic Engineering (submitted)

Tellier, Arnaud, “Visualization of Buried Objects in 3D Acoustic Data Acquired By a Buried Object Scanning Sonar” Masters of Science Thesis, Florida Atlantic University, August 1999.