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Annual Report
15 September 1996 - 14 September 1997

Grant: N00014-95-1-1211
Title: Sediment Penetration of Underwater Mammalian Sonar Signals
Program: ONR/ARPA Research to Replicate Biological Sonars
Principal Investigator: Nicholas P. Chotiros
Institution: Applied Research Laboratories, The University of Texas at Austin

1. Overview of scientific progress

The adopted approach for characterization of buried target detection by underwater mammalian sonars, as represented by the sonar of tursiops truncatus, has three components: (1) direct measurement and analysis of acoustic signals incident on buried targets; (2) construction of acoustic penetration and target scattering model; and (3) deduction of detection and classification methods through reproduction of target insonification processes. It has been two years since the start of the project, but progress has not kept up with the original milestone chart due to a drastic rearrangement of the funding profile. At present, tasks (1) and (2) are in progress. Under task (1), although the completion of the full measurement system has been delayed by funding problems, signals have been recorded with a reduced system in collaboration with Naval Control, Command & Ocean Surveillance Center (NCCOSC), San Diego. Under task (2), a model for wide band acoustic penetration of ocean sediments has been developed to compute the penetration of dolphin sonar pulses, based on Biot's theory[1,2] of acoustic propagation in water-saturated porous media. This approach is general enough to model a wide variety of sediments, and has been found particularly suitable for sandy sediments[3].

2. Most Exciting Accomplishments

2.1 Signal characteristics

A simple comparison of bio- and man-made sonars provides a useful point of reference. With reference to Fig. 1, the characteristic parameters of classes of man-made sonars are shown on the left, and on the right the corresponding biosonar parameters. Man made sonars cover a wide range of frequencies, from ASW sonars at around 1 kHz, through minehunting sonars in the tens and hundreds of kHz, to medical ultrasound at the tens of MHz. The biosonar is represented by the sonar of tursiops truncatus, the bottle nose dolphin. The comparison shows that the operating frequency of the dolphin sonar is in the same decade as the mine detection sonar but the band width is comparable to that of the classify or imaging sonar. (On a log scale, a 100% band width in the 10–100 kHz band, shows up as a 10% bandwidth in the 100–1000 kHz band.) The difference in pulse repetition rate is even more interesting. Detection sonars typically ping less than once per second, and the classification/imaging sonars about 10 times per second. The dolphin pings at hundreds of times per second - very similar to medical ultrasound. In summary, the dolphin has the center frequency of the mine detection sonar, the band width of the mine classification/imaging sonar and the ping rate of medical ultrasound. Although the similarities may only be superficial, these comparisons provide useful links to man-made systems.

The bottom-right graph in Fig. 1 is from a recording of the signals incident upon a buried target in a detection and classification exercise. It shows a pulse train containing hundreds of pulses with controlled variations in amplitude. This is a common technique for detection of nonlinearities in man-made sonar signals and it strongly suggests that the dolphin may also be searching for nonlinearities. Dolphins also use sonar to search for fish in sediments, and a fish swim bladder is known to have a strong nonlinear response. It is likely that acoustic nonlinearity is an important classification feature. There is a parallel in medical ultrasound in which second harmonic imaging, a nonlinear process, is emerging as a way of discriminating between different types of tissue.

The dolphin appears to be capable of independently controlling pulse frequency and amplitude as shown in the data in Fig. 2. Episodes of constant amplitude with varying pulse frequency suggest that the pulse is tunable to some degree. The changes in the power spectrum are very subtle. It appears to be part of a target classification strategy that is not yet understood.

2.2 Buried target detection: sediment acoustic signal characteristics

The ocean sediment consists essentially of water saturated solid particles, therefore, acoustic penetration modeling should be based on a theory of acoustic propagation in a fluid-saturated porous medium. The base line model for sand is described by Chotiros[3]. An extension of the model[4] for a broader range of sediment types was used to compute acoustic penetration into the silty sediment at an NCCOSC site that was used in a buried target detection exercise. The model was used to compute a transfer function between the incident signal in water and the acoustic pressure in the sediment. Using a sample pulse recorded during the exercise, the acoustic pulses at various depths in the sediment were computed, as shown in Fig. 3. The configuration was that of a dolphin at a range of 20 m and swimming at an altitude of 7 m above the sediment, which gives a grazing angle of 20° at the sediment directly above the target. The transfer function from water to points in the sediment at various depths were convolved with the incident sound pulse to obtain in-sediment signal pressure estimates. There is a slight amplification of the pulse amplitude at the sediment interface due to constructive interference involving incident and reflected pulses. Pulse amplitude decreased monotonically with depth. In this case, the signal amplitude was reduced by over 20 dB at a depth of 0.6 m. The energy spectral density shows that the higher frequencies are attenuated faster, giving a reduction in bandwidth. Since a certain minimum bandwidth is necessary for target classification, the depth dependent bandwidth suggests that the ability to classify must decrease with depth. On the positive side, the reduction in bandwidth may be used as an indication of the depth of burial. Unlike the detection of targets in water, where signal-to-noise ratio is the most important independent parameter, with buried targets, there are now two independent parameters, i.e. signal-to-noise ratio and bandwidth. The interaction between these parameters will determine target detection and classification performance.

The findings to date may be summarized as follows: The dolphin sonar uses the same frequency band as mine detection sonars, the bandwidth of imaging sonars and the pulse repetition rate of medical ultrasound devices. Dolphin sonar pulses collected so far show amplitude variations indicating that acoustic nonlinearity may be a classification feature. The variations in pulse frequency were also observed and may be part of a signal processing strategy for target classification. With regard to the buried target problem, a model is under construction. Modeling results indicate that detection is mainly limited by reduction in signal amplitude. Signal bandwidth is also reduced and may be used as an indicator of burial depth. It is also a limitation for target classification. These are not isolated findings and work in progress is directed towards unraveling their significance and interconnections to produce a comprehensive characterization that will be directly useful for buried minehunting applications.

3. Productivity Report

3.1 Publications

Nicholas P. Chotiros, Kenneth L. Krueger, Nathan S. Crow, Robert A. Altenburg, “Observation of buried object detection by a dolphin,” presented at the Aerosense Conference, 20-25 April 1997, Orlando, FL,
and published in SPIE Proceedings Vol. 3079, 1997.

3.2 Transitions:

A dolphin training aid

The monitoring and recording of dolphin clicks incident on a buried target attracted the attention of the dolphin trainers at NCCOSC. It was apparent from the data that the dolphins were occasionally not pinging but were reporting on the presence of the target from memory. On other occasions, it was evident that as a dolphin was moved from one test site to the next in a systematic progression in the course of its training, it was not only pinging on targets in the assigned test site but also those in adjacent test sites and beyond. The trainers expressed an interest in the monitoring capability as a training aid and we obliged by lending them a spare unit for evaluation.om backscattering model, called BOGGART, currently undergoing tests.

3.3 Trainee data:

Matthew B. Evans, undergraduate student in Electronic and Computer Engineering, assembled and tested amplifiers, digitizers and the communication link.

3.4 Honors to PI or members of PI's research group:

Nicholas P. Chotiros was elected to Fellow of the Acoustical Society of America, 3 July 1997.

3.5 Number, cost and description of equipment items costing more than $1000 that were purchased on your ONR grant:

None purchased in this reporting period.

References

[1] M. A. Biot, "Theory of Propagation of Elastic Waves in a Fluid-Saturated Porous Solid -- I. Low Frequency Range," J. Acoust. Soc. Am. 28, 168-178 (1956).

[2] M. A. Biot, "Theory of Propagation of Elastic Waves in a Fluid-Saturated Porous Solid -- II. Higher Frequency Range," J. Acoust. Soc. Am. 28, 179-191 (1956).

[3] N. P. Chotiros, "Biot model of sound propagation in water-saturated sand," J. Acoust. Soc. Am. 97(1), 199-214, (January 1995).

[4] F. A. Boyle, N. P. Chotiros, "Bottom Grain Gas and Roughness Technique (BOGGART) Version 3.0: Bottom Backscatter Model User's Guide," Technical Report No. (TR-96-10), Applied Research Laboratories, The University of Texas at Austin (June 1996).

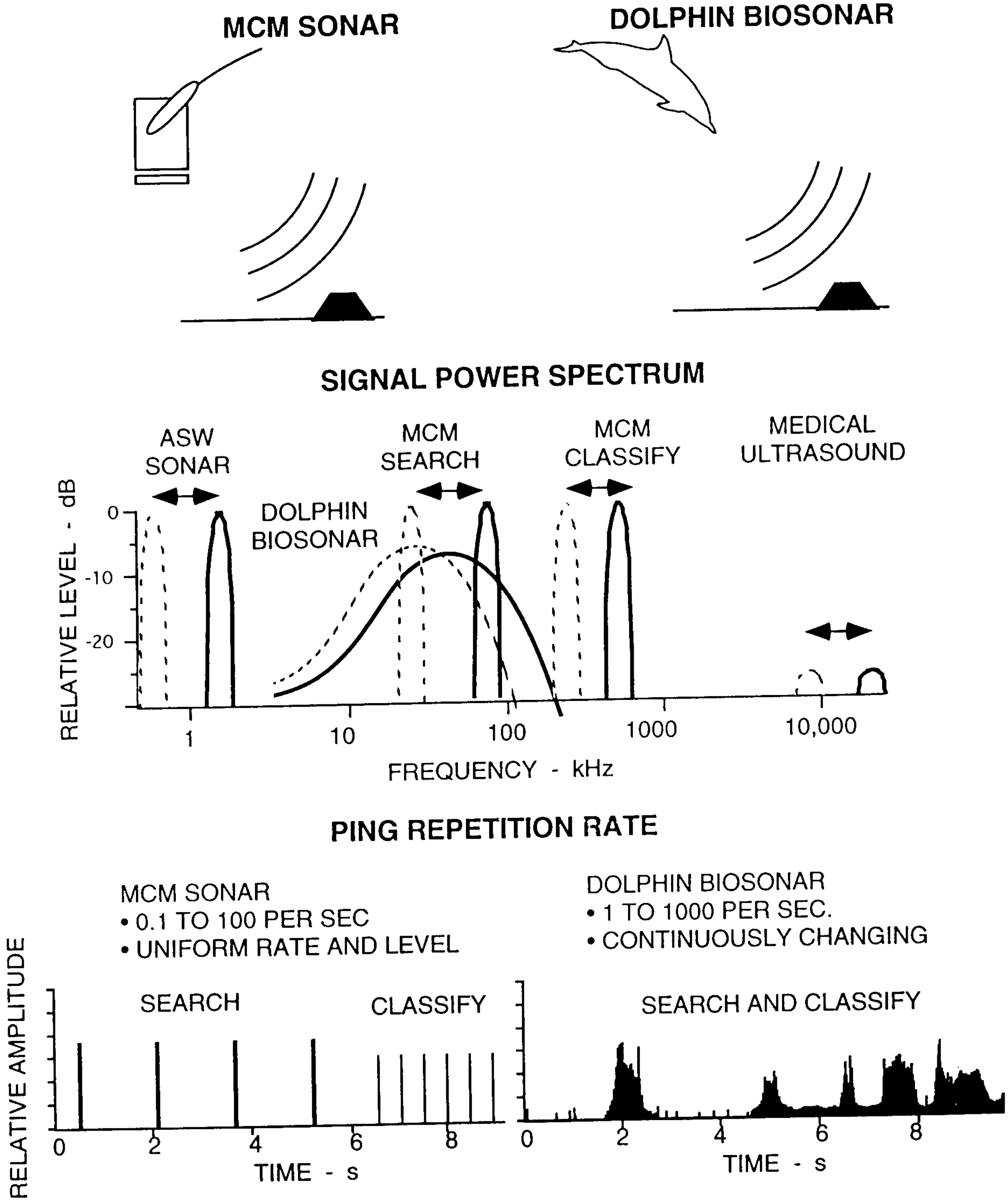

Figure 1. Comparison of characteristics of man-made and bio- sonars.

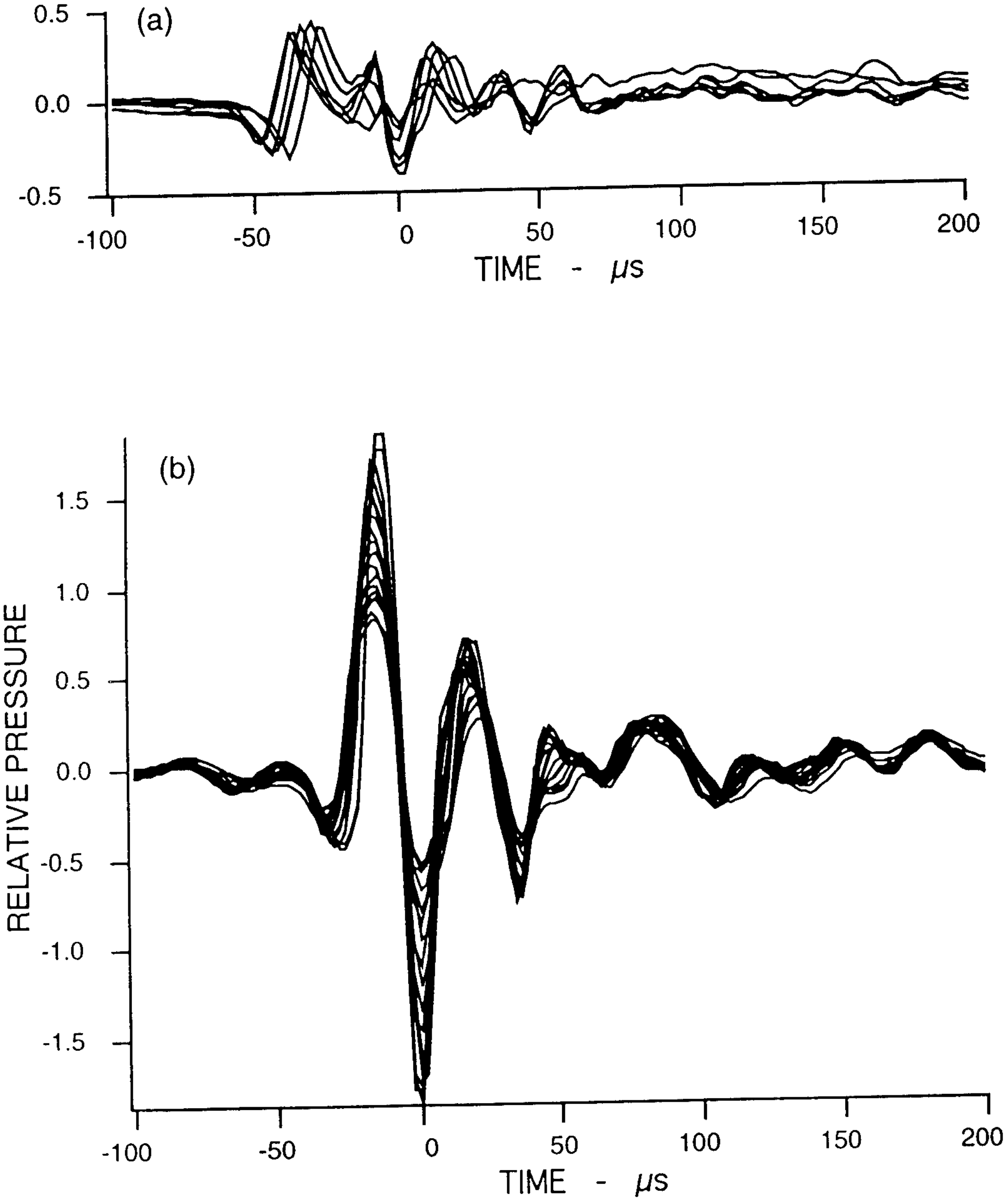

Figure 2. Examples of pulses with (a) constant amplitude and varying pulse frequency and (b) constant frequency and varying amplitude.

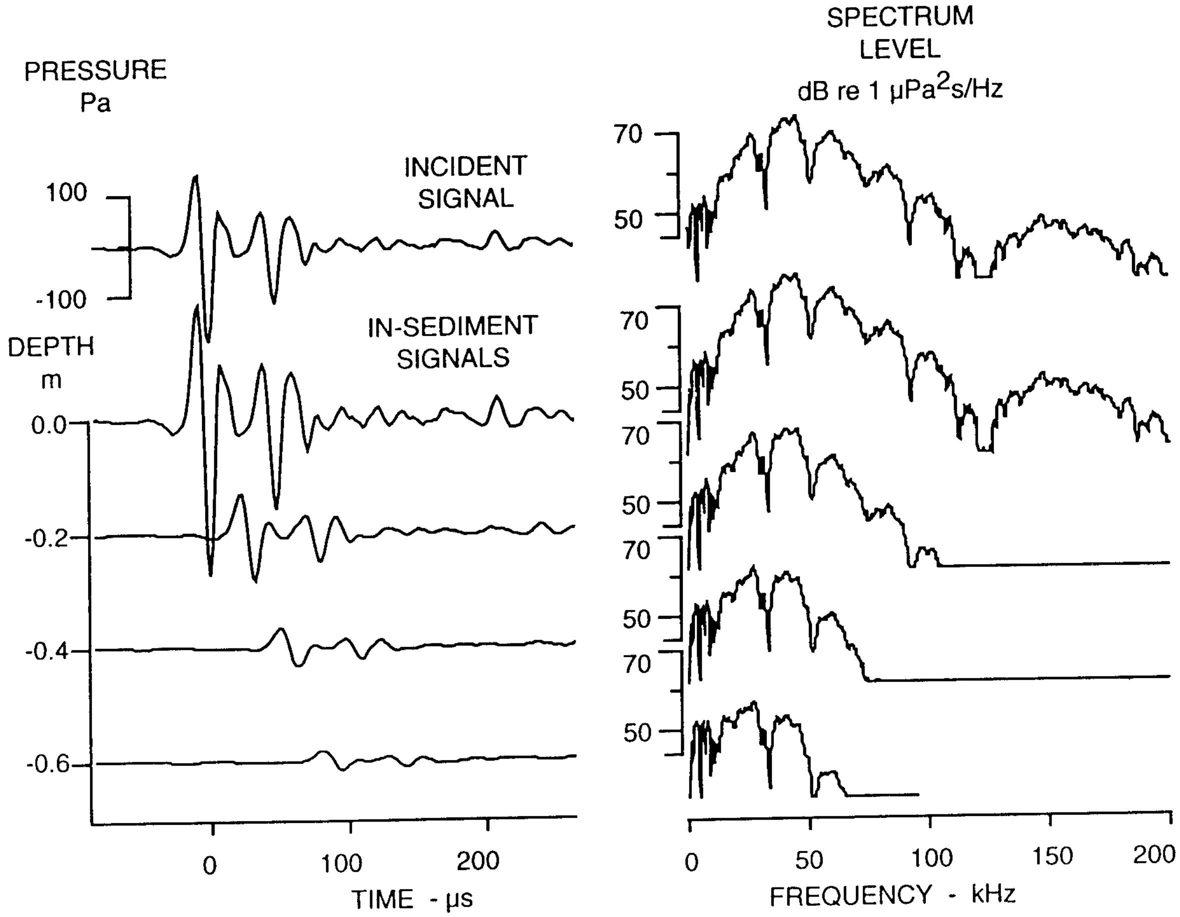

Figure 3. Computed acoustic pulses and energy density spectra at various depths in response to an incident pulse at a grazing angle of 20°.