COHERENT PATH BEAMFORMER FOR HIGH PERFORMANCE MODEMS

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LONG-TERM GOALS

Our long term goal is to develop an adaptive beamformer "front-end" that can be used with most commercial modems to provide high data rate performance(>200 k baud) suitable for transmission of video information from AUV's. As a second but equally important long term goal, based on experimental data, we will contribute to a better understanding of environmental acoustics related to information transmission underwater. We will use this knowledge to develop a test model for evaluating under water acoustic modem and other shallow water sonar system performance. In consort with this goal, will develop a low cost reliable single channel modem for AUV applications.

OBJECTIVES

Our Scientific objectives in this effort are to conduct at-sea acoustic transmission experiments at frequencies of 240 kHz, 100 kHz, 50 kHz, and 25 kHz using large (64 elements) vertical acoustic receiver arrays to measure and characterize the underwater acoustic channel. We are using this experimental data to evaluate the performance of the Coherent Path Beamformer under various environmental conditions and to compare the CPB to diversity methods. These results are being used to develop a low cost single channel modem and an optimal hardware/software CPB system to be constructed and tested at-sea on AUV's.

APPROACH

A method of separating signals received by an acoustic array into statistically uncorrelated components (Principal Components) is developed by LeBlanc, and presented in a paper[13] "Angular-Spectral Decomposition Beamforming for Acoustic Arrays". Briefly, the Principal Component Beamformer is an array time series data reduction method that allows one to observe the statistically uncorrelated components of wave energy arriving at an array of acoustic sensors. The method can be used to discriminate signal from noise, or interference through the use of a selection process of the principal components of wave energy. Direction of the sources of wave energy are easily established by applying a beamforming vector to each principal component. Initially, we use the Principal Component Beamformer to analyze experimental data taken in shallow water environments. Later, the Principal Component Beamformer method will be used as a spatial filter for separating signals from interference for use with high performance modems.

In the Principal Component Beamformer, the components of the N element array output vector are the analytic realization[12] of the sampled output of the array elements. The output of the Principal Component Beamformer is also an N element vector, and is obtained by applying a orthonormal transformation to the input vector. In addition, to being orthonormal, the transformation is required to generated uncorrelated outputs. From these two requirements, it is shown that the transform matrix is

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unique and consist of the eignevectors of the input data covariance matrix. For each of the principal components, the angular distribution of acoustic energy can be obtained from an FFT of each eigen vector. This is powerful method of analyzing time series obtained from an array of acoustic sensors. Rejection of interference from other ray paths is an important aspect of the Principal Component Beamformer that is very beneficial to the modem application.

The Coherent Path Beamformer design is for use with high performance modems. In the CPB, a multi-element sonar processor utilizes only one of the eigenvectors to process the incoming acoustic waves to generate a single time series. The spatially filtered time series data from the array is processed by the modem to obtain the transmitted character series. At periodic intervals of time, the modem will allow the Principal Component Beamformer to update the spatial filter with new channel coefficients. The decision logic in the controller is used to select the channel with both high signal to noise ratio and the most stable and dependable coherent path. Environmental data such as water depth, sea state, temperature, and seafloor composition, if available, may also be factored into the selection of the most stable path.

WORK COMPLETED

All of the CPB test equipment has been fabricated and is being used in the shallow water near shore region of Boca Raton which serves as an acoustic modem testing laboratory. Several 64 elemant receiver arrays operating at 50 kHz, 100 kHz, and 225 kHz have been developed for use in acoustic propagation experiments. In addition, we have developed a multi-frequency acoustic pinger for remote transmission of arbitrary analog waveforms and digitally encoded waveforms for measurment of the acoustic channel transmission characteristics.

We have conducted many experiments in shallow water to characterize the acoustic communication channel, and evaluate modem performance using various encoding methods and waveforms. The experiments have been conducted at transmission ranges of 50 to 500 meters and at the above mentioned frequencies. Our results indicate that high reverberation levels are present in the shallow water transmissions. We have found that the adaptive beamformer (CPB) reduces transmission errors significantly when using wide band spread spectrum psk encoding methods.

In addition to the above, we have developed a MFSK frequency hopping modem for use on AUV’s. Reliable transmission to 1 km from boat to AUV, and AUV to AUV have been demonstrated when operating in its high reliability, low baud rate mode. A new version of the above modem hardware is completed. The new model utilizes a single DSP and a specially designed high efficiency Class D amplifier to provide high reliability at low energy consumption. In addition to running the above mentioned MFSK software, it can utilize the recently developed signal processing software (developed from the coherent path modem test) that utilizes a Gaussian spead spectrum randomized PSK transmission mode that provides higher baud rate and more reliable transmission at lower power consumption levels. The modem is low cost and will be commercially available soon.

RESULTS

In analyzing the results to date, we have observed nearly complete separation of the coherent spatial components of the pulsed PSK transmissions. The eigen vector beamformer collects correlated energy over a time scale corresponding to the inverse of the bandwidth. The eigen vectors are calculated and updated on a continuous basis and utilized to spatially filter multipath corrupted transmissions. In our shallow water environment, volumn and boundary reverberation in the vertical direction is much higher than expected. Figure 1a shows a time series history taken from a single channel of the array of a packet of spread spectrum psk encoded digital information and the summed eigen beams, after transmission over 600 feet of range in 30 foot water depth off Boca Raton. The initial pulse at the begining is a 20 ms chirp pulse that is matched filter processed by the receiver and then used for synchnrozation by the decoding process. After applying the beamformer to the signal packet in all 64 channels, as shown in Figure 1b, we note a significant reduction of the reverberation when compared to what is present in the single channel data. Figure 2a and 2b, show the bandlimited impulse response of the acoustic channel. This result was obtained by matched filter processing the chirp pulse for the single channel case (Figure 2a) and the 64 channel beamformer (Figure 2b). This also shows a significant reduction in the reveberation levels for the beamformer. In Figure 3a-d, the differential phase error in the decoding of the PSK sequences is shown at 500 baud and 4000 baud for the single channel case and the beamformer case. Both at 500 baud and 4000 baud, the beamformer provides a significant reduction in phase error thus permitting the user to obtain higher baud rate by making use of multiple locations in the phase plane.

IMPACT/APPLICATIONS

The experimental results are providing a new insight to the understanding of how shallow water propagation conditions affect the information capacity of digital data transmission for sonars operating in the frequency range of 50kHz to 200kHz. Test data using DPSK encoding of text sequences random noise pulses is helping to establish error rates, adaptation time constants, and the influence of the environment on the stability of the various modes of propagation. Principal component analysis of the received data and pseudo noise transmissions using moving platforms will provide an important insight into the frequency smear of each of the various multipath receptions. This information will be invaluable in generating models for use in testing acoustic modem designs and other sonar systems in shallow water environments.

TRANSITIONS

Currently, the low cost single channel modem that uses Gaussian spread spectrum wavelets with compenstation and the associated hardware is being transisition to a commercial oceangraphic instrumentation company. Manfacture of the modems is scheduled for early 1998 and will be avaliably for AUV utilization at relatively low cost.

RELATED PROJECTS

The Coherent Path Beamformer project has two important objectives: High bandwidth underwater acoustic communication, and the development of a tool for obtaining a better understanding of the underwater acoustic channel in shallow water. Success in these objectives will be extremely beneficial to other projects in the ONR AOSN effort as well as other Navy objectives in shallow water acoustics.

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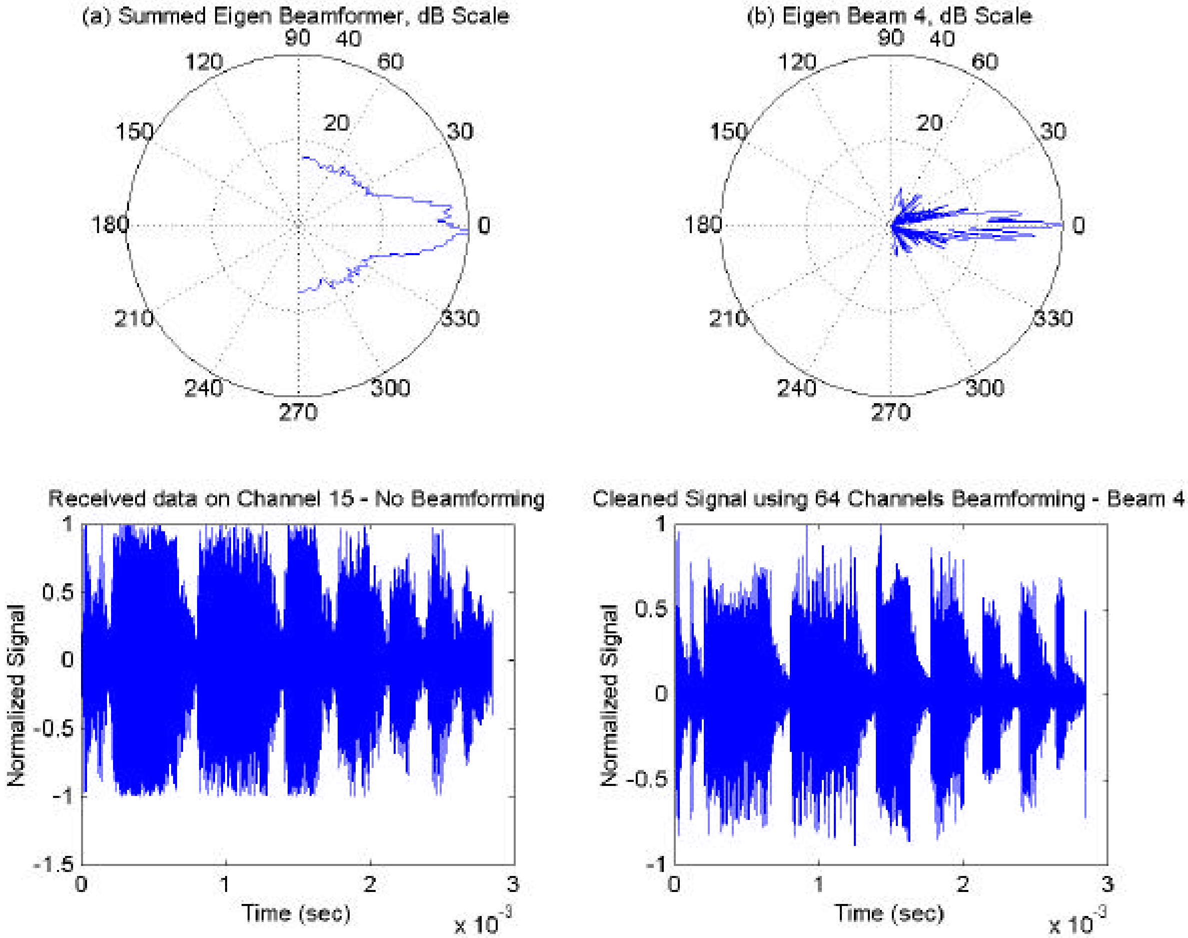

Figure 1

(a) Summed Eigen vectors beampattern and time history of a single channel

(b) Eigen vector beam no. 4 (direct path) and filtered time history

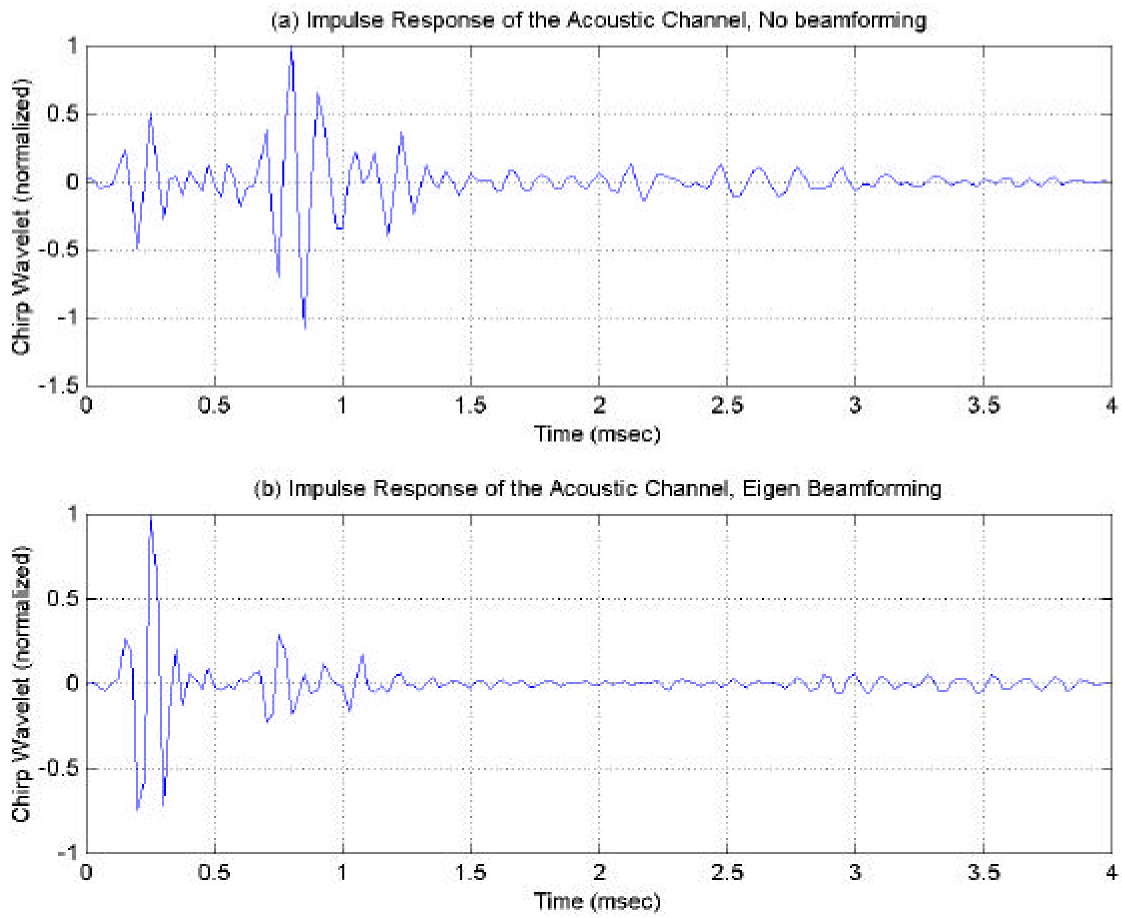

Figure 2

(a),(b) Effect of beamforming on impulse response

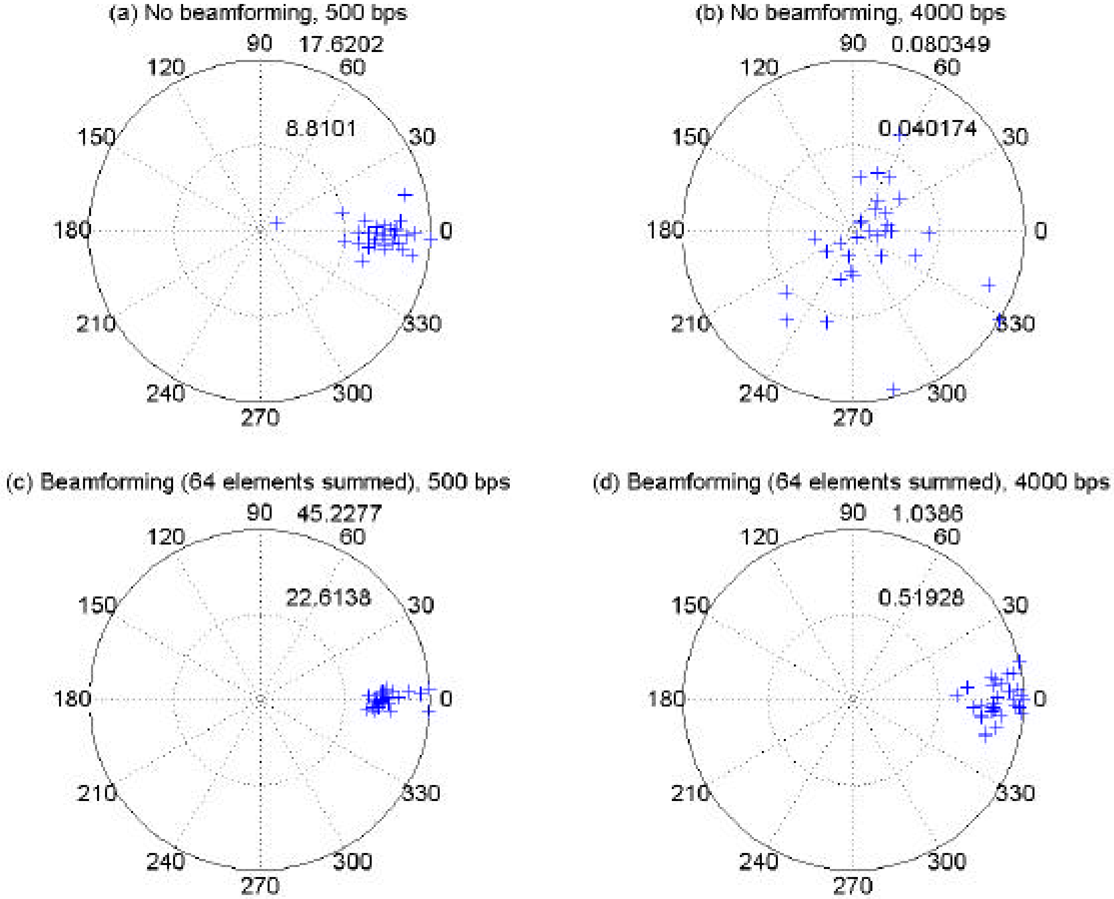

Figure 3 (a)-(d) Error circle before and after beamforming for 500 bps (a),(b) and 4,000 bps (c),(d)