Coherent Path Beamformer Front End for High Performance Acoustic 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 equilization 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 underwater 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 50 kHz and 25 kHz using a 64 element vertical receiver array and a 32 by 32 Mills Cross array 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 equilization methods. These results are being used to develop a low cost, high speed beamformer modem for use with 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 "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. In the Coherent Path Beamformer output, each channel represents a vertical beam that is focused in the direction of the collection of correlated spatially coherent energy arriving at the array of acoustic sensors. Nulls are pointed in the direction of the remaining other acoustic incoherent paths therefore canceling interference within the principal beam. The advantage of this approach is that it provides separation between the various incoherent multipaths arriving at the array. In this manner, the Doppler component of a single acoustic path can be effectively removed from the time series data. Another important advantage of the CPB approach is that it provides automatic tracking of the acoustic transmission source and a spatial signal processing gain. Thus, in addition to nulling out interference, the beam pattern of the CPB rejects reverberation and ambient noise. Finally, any remaining interference may be reduced using adaptive equalization. In developing the CPB, we have found that it is not necessary to update the CPB coefficients over the entire information packet, thus reducing the computations required to process the message. This holds true for message lengths of under a few seconds. We have developed a second adaptive beamforming approach based on an RLS beamformer. As with the CPB, the beamformer

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coefficients need only to be calculated using a short training sequence at the beginning of the message. The message consists of Gaussian spread spectrum wavelets that are random bi-phase encoded. After the beamformer is trained to match wavelets, the filter is locked for the remainder of the message sequence. The resulting beampattern is usually in the direction of the direct path. Both of these methods, CPB and RLS, and taken in combination with RLS equalization filters will be compared to determine the most effective method of communication in the shallow water environment.

WORK COMPLETED

All of the CPB test equipment has been fabricatad and is being used in the shallow near shore region of Boca Raton (and soon Dania) which serves as an acoustic modem testing laboratory. Several 64 elemant receiver arrays operating at 25 kHz (Mills Cross), 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 and a pinger format for our General Purpose AUV Modem for remote transmission of digitally encoded PSK waveforms for measurment of the acoustic channel transmission characteristics. During this reporting period, various methods of coherent space/time processing are compared for a condition of a marginally overspread channel (BL≈1) operating at 50 kHz. When the BL product (product of bandwidth spread and time spread) of the channel is greater than one, some types of adaptive signal processing may not work very well. Various combinations of spatially adaptive and time adaptive methods were considered. The Coherent Path Beamformer (CPB) and RLS adaptive beamformer, both in combination with RLS time filtering, were compared. Also considered in the analysis is the combined RLS space/time adaptive processor. Many experiments using broadband PSK transmissions in shallow water have been conducted to provide data for testing these various processing methods. Because of the rapid time variation of the multipath, the BL product of the impulse response at this test site was nearly unity. In addition, signals undergoing multiple surface reflections contain more doppler shift and arrive at the receiver array at very steep angles, thus corrupting the later portion of the impulse response more severely. In this environment, the adaptive beamformer followed by RLS equalization effectively reduced this form of reverberation and provided significant improvement over either the RLS beamformer or the RLS space/time processor in terms of reduced transmission errors. 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 is now commercially available from Edgetech.

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, and the RLS filter compensates for Doppler and the residual component of the channel impulse response function. To obtain Fig.1, the output of the coherent path beamformer was processed by the RLS filter, decoded, and decision feedback was used to update the RLS filter. Since the binary decision cannot be made until the entire

wavelet has been obtained, two filters were operated under each hypothesis. At the end of each wavelet, the two RLS filter outputs are matched filtered with the assumed transmitted wavelett and the filter associated with the lowest error is retained. The CPB processor followed by RLS filtering provided the best overall performance (100% correct decoding). In a similar manner, the 8 staves of data were processed by the CPB, followed by RLS filtering to evaluate the effect of spatial averaging on the beamforming methods of processing. Spatial averaging resulted in no noticeable increase in size of the error circles and performance remained at 100% correct decoding. It can be inferred from the size of the error circles in both of these cases that baud rates of 20 k is possible using QPSK. There is a slight rotation in the error circles, caused by Doppler, which is easily removed by applying a constant phase shift to each output. A larger quantity of time domain filter taps removes the effect caused by Doppler, but when implemented will add significantly to processing time. As previously mentioned, a RLS beamformer followed by a RLS time processor was tested. As with the CPB, the RLS beamforming was implemented using a short training sequence and frozen for the remainder of the packet. The performance of this form of processor is not illustrated here because it is similar to the CPB followed by RLS equalization. However, performance of the RLS beamformer is not as robust as the CPB and required high SNR to achieve similar results. The RLS beamformer performs best with short training sequences where the direct path signal is the cleanest and separated from later arrivals that contain large Doppler spread. Fig.2 shows results of an integrated RLS space/time solution. We note that the system produced minimum a-prior error energy even though the decoded message produced many bit errors (56% correct decoding). This is typical unstable behavior that occurs when a large number of spatial taps are used for the space/time solution. In this case, 64 spatial taps, and 10 time domain taps led to a use of a total of 640 filter taps. The large number of errors is attributed to the migration of the adaptive processor to other minimum in the error energy function, which led to smaller a-priori error but incorrect decoding of the message. For BL $\approx$ 1, the observed performance of the RLS integrated space/time filter is disappointing. As previously mentioned, it is hypothesized that the large numbers of spatial taps causes the algorithm to migrate to other minima in the presence of the large channel time variations.

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 25kHz 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 has provided an important insight into the frequency smear of each of the various multipath receptions. This information is 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. Edgetech Inc. is currently manafacturning modems.

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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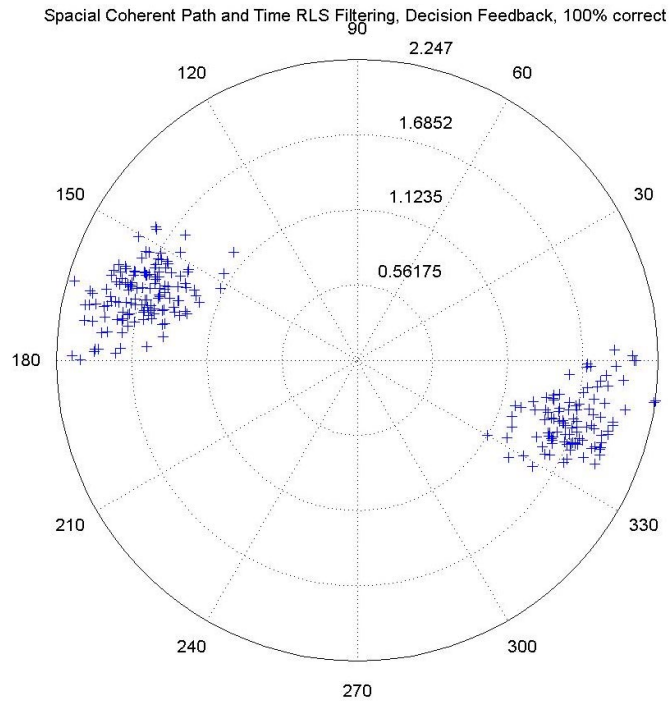
Spacial Coherent Path and Time RLS Filtering, Decision Feedback, 100% correct

Fig.1 Typical Performance of CPB beamformer
followed by RLS time domain processor (10 taps, 100% decoded)

(a) Averaged Beamformer, Decision Feedback

(b) Combined Space and Time RLS Decoding, Decision Feedback, 56.25% correct

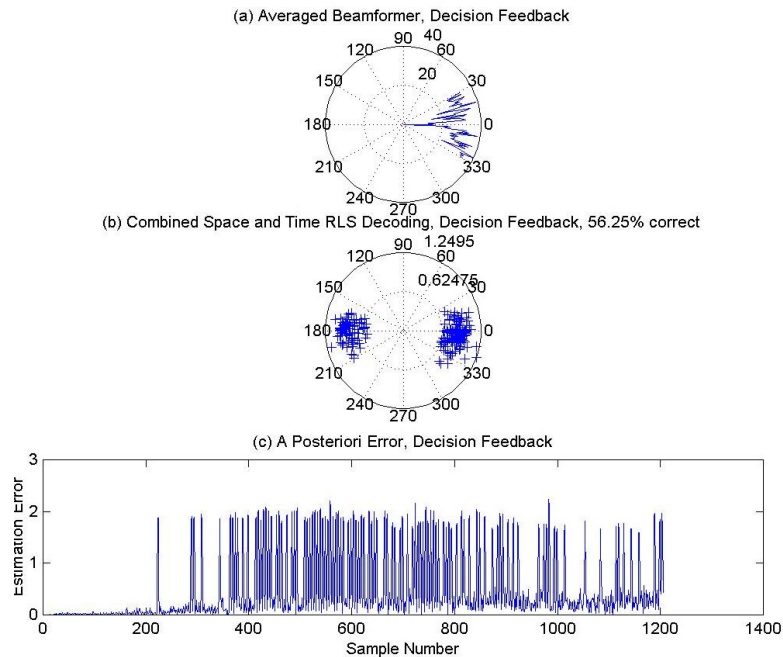(c) A Posteriori Error, Decision Feedback

Fig.2 Performance analysis of integrated RLS
*Space/time processor (64 spatial taps * 10 time domain taps, 56.25% decoded)*