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APPLICATION OF TIME REVERSAL TECHNIQUE IN SHALLOW WATER ENVIRONMENT

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Underwater acoustic communications in shallow water environment is a challenging problem due to the intersymbol interference caused by time-varying dispersive multipath channel. The paper describes this effect and the passive time reversal technique and its spatial and temporal focal properties to reduce channel fading and intersymbol interference which causes severe distortions of received communication signals. Recently time reversal technique is a method introduced to the underwater acoustic communication. In a significant multipath environment the time reversal process offers unique opportunity for solving the multipath problem and recovering the original signal at the focus. Communication systems can be divided into incoherent or coherent modulation. In this article coherent underwater acoustic communication method was presented by using passive phase conjugation and 16QAM (quadrature amplitude modulation) as a modulation method. Presented results confirm the utility of the passive phase conjugation in shallow water environment to underwater communications.

Keywords: underwater communications, time reversal, passive phase conjugation.

1. Introduction

Underwater sound propagation is primarily determined by transmission loss, noise, reverberation, and temporal and spatial variability of the underwater acoustic channel. Noise and transmission loss are the principal limitations for the available signal-to-noise ratio, while the time-varying multipath influences signal design and processing, often imposing severe limitations on a system performance. Two fundamental mechanisms of multipath formation are reflection at the boundaries (bottom, surface and any objects in the water), and ray bending. In shallow water propagation occurs in surface-bottom bounces in addition to possible direct path. Multipath propagation contributes to signal fading, and causes intersymbol interference (ISI) in a digital communication system.

In order to achieve higher data throughputs over the severely band limited underwater channel, bandwidth efficient modulation techniques, such as phase shift keying or quadrature amplitude modulation must be used instead of frequency shift keying based signaling schemes. Thus, many of the ongoing research focused on the development of phase coherent underwater acoustic communication methods for application in highly dispersive shallow water channels. The combined effect of long intersymbol interference caused by multipath propagation and rapid phase variations makes coherent demodulation very difficult in the underwater acoustic channel. At high data rates the intersymbol interference requires adaptive algorithms on the receiver side that lead to computationally intensive and complex signal processing. However, if many multipath signals are received, even adaptive filters cannot remove all of them and solve this problem. The challenge of reliable system is to overcome this impediment to assure reliable communication.

The phase conjugation technique, also called time reversal acoustics (TRA) can environmentally adapt the acoustic propagation effects of a complex medium in order to focus energy at particular target range and depth. Using TRA, the multipath structure is reduced because all the propagation paths add coherently at the intended target location [1, 2]. This property of time reversal acoustics suggests a potential utility of this method in underwater acoustics with applications in underwater communications. This method is less complicated then adaptive methods and effectively mitigates the multipath propagation problem.

2. Passive time reversal

Figure 1 shows the basic scheme for underwater communication using passive time reversal technique.

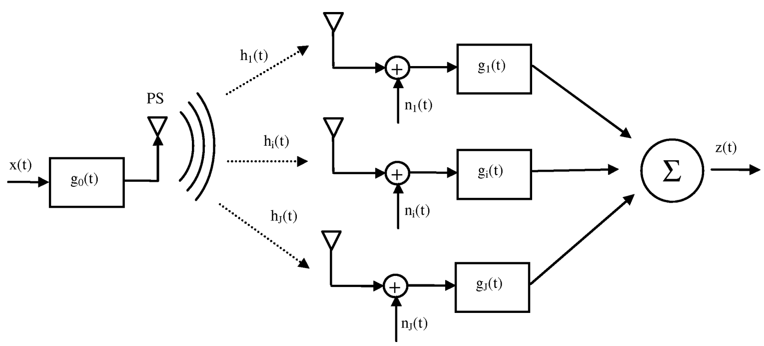

Fig. 1. Passive time reversal communication system.

Time reversal technique can be implemented in an active or passive mode. Both active and passive method takes advantage of spatial diversity to achieve spatial and temporal focusing, a useful property for communications in an environment with strong multipath [3]. For communication purposes, the main difference between active and passive implementations is the direction in which the information flows. In the active case, information can be sent from the array to a distant source, while in the passive case the source sends information to the array. Passive phase conjugation is synonymous with passive time reversal in the time domain and this procedure begins by sending a short probe pulse in advance of the data packet to correlate with the received data [4]. This signal is used to estimate the channel impulse response h_j.

The received signal has a form:

$$r_j(t) = h_j(t) * x(t) \tag{1}$$

and

$$x(t) = g_o(t) \tag{2}$$

is a transmitted signal and $*$ denotes convolution operator.

Passive phase conjugation applies matched filtering at each receiver element and finally the received signal can be written as:

$$z(t) = \sum_{j}^{J} g_j(t) * r_j(t) = \left[\sum_{j}^{J} h_j(-t) * h_j(t)\right] * x(t) = Q(t) * x(t), \tag{3}$$

where $g_j(t) = h_j(-t)$ and the term in the bracket called the Q-function is a sum of the autocorrelation functions of all individual paths impulse responses. Ideally time reversal yield a Q-function should be a delta function. In practice this function has many sidelobes, which cause significant intersymbol interferences [5].

As a method for communication this procedure is passive in that the array needs only receive signals and does not need to transmit. The data stream is transmitted by the source and recorded by each element of the array. The signal processing step involves cross correlating the probe receptions and data streams at an array element. This cross correlation is done in parallel at each array element and the results are summed across the array to achieve the final communication signals, which are ready for demodulation.

3. Numerical simulation

3.1. The simulation environment

The Pekeris solution [6] of the normal mode method was used as the simulation method to study acoustic propagation in shallow water channel. This scenario is shown in Fig. 2. In this model, water depth h_w, sound velocity and density in water and at the sub-bottom, c_w, ρ_w, c_b, and ρ_b, respectively are all constant. The thickness of the sub-bottom is considered infinite and the transversal waves at the sub-bottom are ignored. The area of shallow water environment model is 100 m in depth. The normal mode model assumes the bottom to consist of a homogenous sub-bottom.

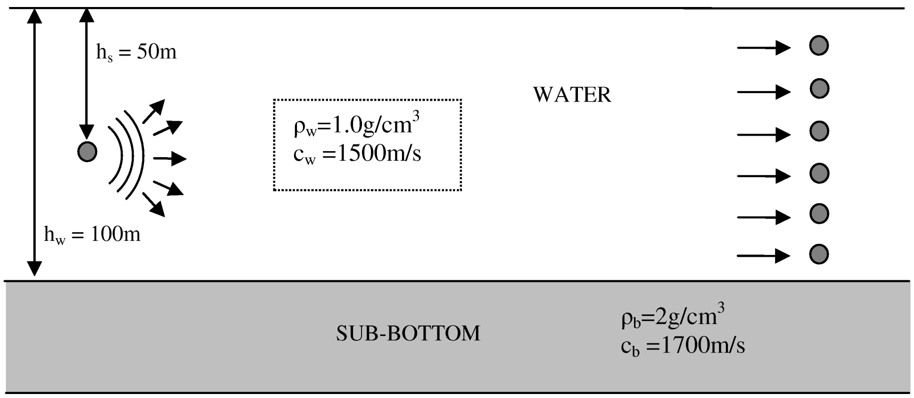

Fig. 2. Shallow water channel parameters used for simulation of the passive time reversal process.

3.2. Multipath propagation

In this numerical experiment Linear Frequency Modulated pulse was transmitted to examine the time-varying dispersive multipath shallow water environment. The transmitted signal was Hanning shaded chirp pulse of duration 100 ms, centre frequency of 1 kHz, and bandwidth of 500 Hz. The maximum source level was 200 dB re 1 μPa at 1 m. The transmitter depth was 50m and the TRA spans the water column from 15 to 90 m with 15 m element spacing in a 100 m water depth. The received signals at each sensor revealed the multipath arrival structures obtained in shallow water channel, as shown in Fig. 3. Besides the multipath arrival structure in shallow water environment was calculated using matched filtering, i.e. taking the envelope of the cross correlation sequence of received signal with the transmitted signal.

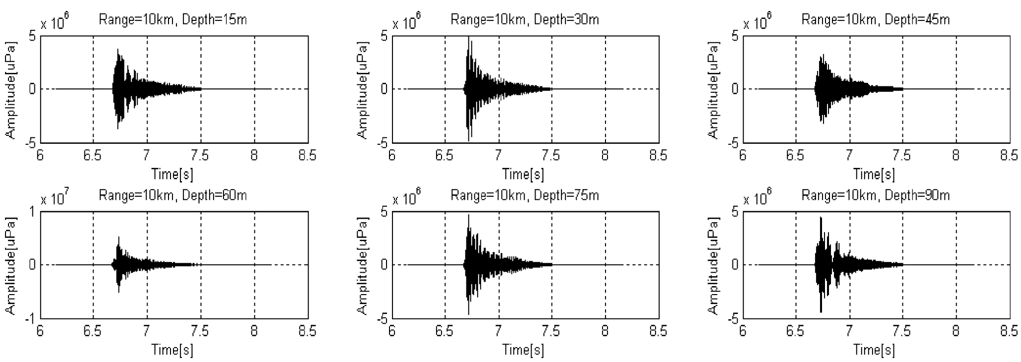

Fig. 3. Received signals.

This produces a sequence of impulses corresponding to each echo in the received waveform thereby providing a visualization of the impulse response. The results presented in Fig. 4 show clearly the variation in the multipath structure throughout the experiment.

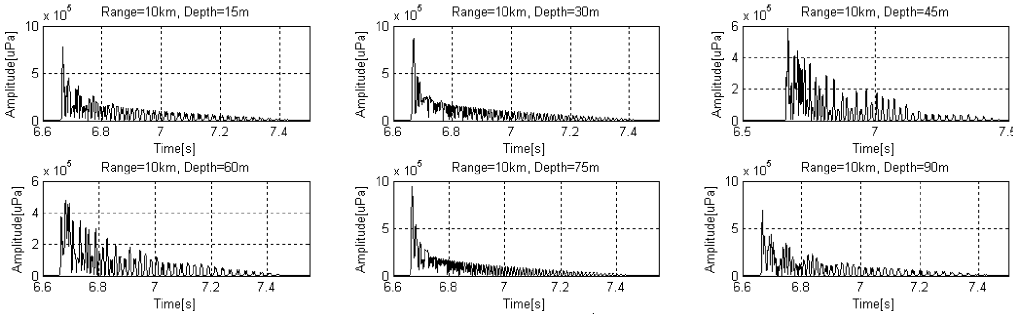

Fig. 4. Channel impulse response for a sound channel of 100-m depth.

3.3. Acoustic communication using passive time reversal

The simulation configuration using a TRM consists of 6 elements is shown in Fig. 2. The data sequences to be sent are modulated with conventional 16QAM scheme. In this system data transmission is suspended during the probe signal capture period. The entire measured channel response is used to create the communication symbols for a coherent quadrature amplitude modulation. In this simulation the in-phase and quadrature pulses were transmitted and created data signal of 1000 symbols.

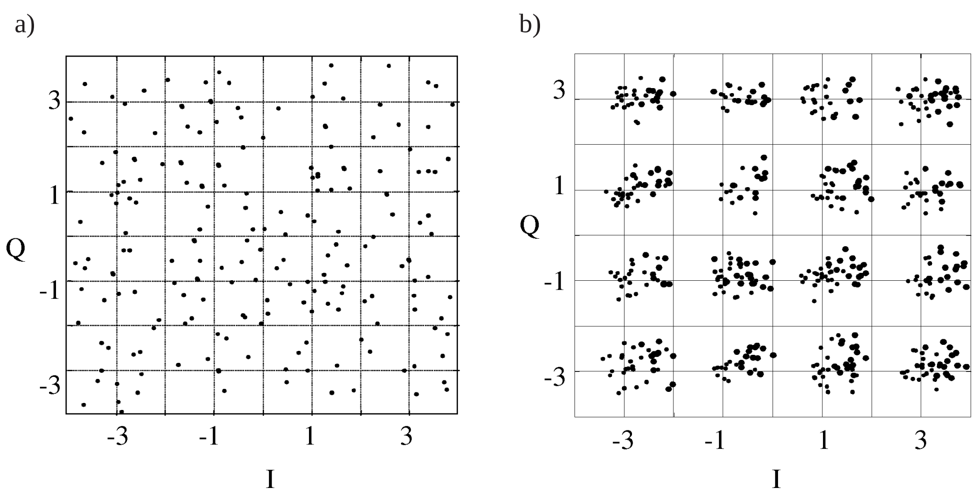

Fig. 5. Symbol constellation plot for the 16QAM demodulated signals.

Figure 5 shows the constellation diagrams after using passive phase conjugation method (Fig. 5b), and without using this method (Fig. 5a). In Fig. 5a the demodulation result is not good (output SNR $= 8.2$). This is because many multipath waves are received. In case b) the demodulation result is good (output SNR $= 19.4$) because multipath waves are utilized by passive time reversal method.

4. Conclusions

In the paper, the passive time reversal approach was discussed. The method uses receive-only array to perform acoustic communication. Passive phase conjugation method makes it possible to assure good underwater communication even in the environment where it may be very difficult by conventional methods. The preliminary results confirmed that passive time reversal reduced ISI and this method may be successfully used in underwater communication systems. Future work will be concentrated on experiments examining coherent and non-coherent communications schemes.

References

[1] Edelmann G. F., Hodgkiss W. S., Kim S., Kuperman W. A., Song H. C., Akal T., *Underwater acoustic communication using time reversal*, OCEANS 2001, Proceedings of MTS/IEEE, vol. **4**, pp. 2231–2235 (2001).

[2] Edelmann G. F., Akal T., Hodgkiss W. S., Kim S., Kuperman W. A., Song H. C., *An initial demonstration underwater acoustic communication using time reversal*, IEEE Journal of Oceanic Engineering, **27**, 602–609 (2002).

[3] Kuperman W. A., Hodgkiss W. S., Song H. C., Akal T., Ferla C., Jackson D. R., *Phase conjugation in the ocean: Experimental demonstration of a time reversal mirror*, J. Acoust. Soc. Am., **103**, 25–40 (1998).

[4] Rouseff D., Jaskson D. R., Fox W. L. J., Jones C. D., Ritcey A., Dowling D. R., *Underwater acoustic communication by passive-phase conjugation: Theory and experimental results*, IEEE Journal of Oceanic Engineering, **26**, 4, 821–830 (2001).

[5] Yang T. C., *Channel Q function and capacity*, OCEANS 2005, Proceedings of MTS/IEEE, vol. **1**, pp. 273–277 (2005).

[6] Officer C. B., *Introduction to the theory of sound transmission*, McGraw-Hill, 1958.