IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 7876

Research paper © 2012 IJFANS. All Rights Reserved, UGC CARE Listed (Group -I) Journal Volume 11, Iss 10, October 2022

Study of Time Reversal in Underwater Communication

Neeraj Kaushik, Assistant Professor,
Department of Electrical and Communication Engineering, Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, India
Email Id- neeraj1604@gmail.com

***ABSTRACT:** In complicated settings, time reversal (TR) takes use of spatial variety to accomplish spatial and temporal concentration. The TR approach has been successfully used to phase-coherent acoustic communications in time-varying multipath ocean settings as an alternative to traditional adaptive multichannel equalization during the past decade. Intersymbol interference (ISI) is reduced by temporal focusing (pulse compression), and residual ISI is removed by single-channel equalization, resulting in near-optimal performance in principle. The spatial focusing feature allows multiuser or multiple-input–multiple-output (MIMO) communications to take place without the need of time, frequency, or code division multiplexing, and an adaptive TR technique may further minimize crosstalk between users or multiple transmitters. Using a block-based method with channel updates, TR communications may simply be expanded to time-varying channels. This article discusses TR communications in shallow and deep water, as well as current developments such as bidirectional equalization, multiuser communications with mobile users, and communication with a glider acting as a mobile gateway.*

***KEYWORDS:** Underwater Communication, Acoustic Waves, Inter-Symbol Interference, Time Reversal.*

1. INTRODUCTION

Large multipath spreads define underwater acoustic (UWA) channels, resulting in intersymbol interference (ISI) in acoustic communications, which lowers the quality of the received signal and necessitates correction (i.e., channel equalization). The multipath's time-varying nature necessitates constant monitoring of the receiver characteristics required for demodulation. Due to significant frequency-dependent attenuation of the physical medium, the usable bandwidth in UWA channels is restricted. Furthermore, even on relatively slow moving platforms, Doppler effects are significant due to the sluggish speed of sound propagation (1.5 km/s). As a consequence, UWA channels are regarded as one of the most difficult settings in which bandwidth-efficient, dependable (robust) communication may be achieved. The review article by Kilfoyle and Baggeroer covers almost every element of acoustic telemetry up to the 1990s, including channel equalization [1]. A time-reversal (TR)-based method for phase-coherent UWA communications was suggested in the early 2000s, as a result of a decade of TR physics research. TR communications has advanced much since then, and it is now widely accepted as a viable alternative to adaptive multichannel equalization, which was first developed in the early 1990s, and more modern multicarrier orthogonal frequency-division multiplexing (OFDM). This article attempts to provide a broad introduction of TR communications [2], including everything from fundamental physics to key characteristics of TR methods to the most recent advancements [1].

TR refers to the process of sending a received signal in time-reversed order on an array, with the array being referred to as a time-reversal mirror (TRM). The retransmitted signal converges back to the location where the original signal was produced sometimes referred to as the probe source (PS)] due to spatial reciprocity and TR invariance of the linear acoustic wave equation. TR and PC are interchangeable in the frequency domain because TR corresponds to phase conjugation (PC). TRM has received excellent evaluations in a number of studies. TR's temporal and spatial focusing capabilities are instantly applicable to communications, particularly in environments with a lot of multipath. The spatial concentrating provides a high signal-to-noise ratio (SNR) [3] at the intended receiver (PS) with a low chance of interception elsewhere, while the temporal compression mitigates ISI caused by multipath propagation.

To summarize, passive (uplink) TR is the same as active (downlink) TR, except that the communications link is in the other direction. PPC communication was first accomplished in shallow water (5–20 kHz) by Dowling utilizing a 14-element VRA.

Active TR is costly and difficult, if not impossible, to execute in reality because:

1. It necessitates the use of a number of transducers (TRM/SRA) that can both receive and send signals; and
2. There is typically a significant lag time (e.g., a few minutes) between receiving the PS signal and retransmitting a communication message generated at TRM, enabling the channel/environment to change and possibly violating the stationarity assumption.

This is particularly true for high-frequency signals like those used in acoustic telemetry [4] (e.g., 10–20 kHz), where channel coherence times may be as short as a few hundred milliseconds. Active TR communications have only been proved effective in benign shallow-water settings up to the midfrequency band (e.g., 3–4 kHz). Those early, restricted examples of active, downlink communications are still useful for confirming the TR concept's applicability to communications, even if they aren't practical. Because TR-based communications evolved from the TR physics, it is customary to believe that TR-based communications exclusively refers to two-way, active, downlink, MISO communications. However, with the same theoretical performance, the TR idea may be used to the one-way, passive, uplink, SIMO communications. One of the most important features of passive TR or PPC, is its ability to handle time-varying channels efficiently on the fly.

2. DISCUSSION

TR or PC is important to current acoustic signal processing approaches that have stressed the use of environmental information, such as matched field processing (MFP). In MFP, we compare data from an acoustic array with output from a propagation model in order to locate a source and/or determine the propagation medium's characteristics. As a result, the comparison is made using replicas generated from an environmental acoustic propagation model, whose fidelity is intrinsically restricted by the model's environmental input. TR or PC has a significant advantage over MFP in the area of acoustic communications:

1) TR has a fully cooperative PS whose signal characteristics are entirely known by the receiver, allowing fully coherent broadband MFP; and

2) Except for clandestine communications, spatial sidelobes are not a problem for point-to-point communications between a source and a receiver.

TR communications, both active and passive, have already shown its promise, as well as its resilience and computational simplicity. Because the performance of TR is completely dependent on the behavior of the -function, it is ideal to have a -function that approaches a delta function to reduce the ISI. However, there is usually some residual ISI in reality. Furthermore, a discrepancy between the anticipated and real CIRs adds to the distortion. Gomes et al. suggested adaptive spatial combining with variable weighting in order to preserve the quality of the -function. A decision-feedback carrier-phase estimate based on maximum likelihood (ML) may be used for phase tracking before decoding.

Song et al., termed it a correlation-based DFE [5], successfully demonstrated passive TR-DFE. Using data gathered in a continental shelf experiment off the west coast of Portugal, Gomes et al. looked at the performance of different TR techniques. TR-DFE is now commonly used for TR-based communications, thus basic TR is often referred to as TR-DFE unless otherwise specified. Stojanovic [6] looked at a variety of possible underwater communication methods, including TR and channel equalization, and assessed their theoretical performance limits using a simple model channel under ideal circumstances. TR is said to need a high number of array elements in order to compete with other methods, which comes from a misunderstanding of the spatial variety utilized by TR and MFP. Song and Kim showed that utilizing a small 4-element array with sufficient spatial variety, TR coupled with equalization (TR-DFE) provides almost optimum performance. Song et al. [5] also compared the results of TR alone and TR-DFE.

While adaptive M-DFEs with a PLL have been successfully applied to UWA channels, the computational complexity is still a problem since the number of degrees of freedom (DOF) is proportional to the product of the equalization length in taps times the number of array elements. Because many acoustic channels are dispersive, the number of taps for fractional-spaced equalizers (FSEs) must cover the length of the channel sampled at the symbol rate times a factor (typically two). The increased number of DOF combined with insufficient data to enable the adaptation causes instability when updating adaptive filters at high symbol rates. As a result, since its inception, decreasing receiver complexity for efficient implementation has been a problem.

A spatial precombiner (also known as optimum beamforming) was developed, with the goal of reducing the total number of input channels to a lower number for later multi-channel equalization [7]. When the array components are tightly spaced (e.g., half the wavelength), a plane wave beamformer is a basic example of a spatial pre- combiner that mitigates ISI and channel fading by passing a dominant route while rejecting un-desirable multipath interference and noise [8]. This method necessitates angular separation of multipath components and, in most cases, additional array members, which is inefficient since not all multipath components are completely used. Instead of concentrating on specific multi-paths, eigen- vector beamformers [9] utilize the eigenvector corresponding to the greatest eigenvalue.

Each beam output does not always match physically to the individual component of the many routes since the array components are widely spaced (e.g., three to four times the wavelength) to guarantee spatial variety. The spatial precombiner and multichannel equalizer parameters should ideally be adjusted together to reduce the mean squared error (MSE) of the symbol estimations. Furthermore, since the multipath structure is not independent among the array components, it was suggested that the decrease in complexity may be accomplished at no loss in performance.

TR-DFE may also be used to time-varying channels. The fundamental concept is to use the TR method on a block-by-block basis, such that the channel remains almost time invariant inside each block and is then updated using observed symbols (decision-directed mode), reducing the gap between assumed and real channels. The size of the block is determined by the channel coherence time. Normally, the low-complexity LMS method is used for quicker multichannel estimation execution, whereas the RLS technique is used for faster single-channel DFE convergence. To leverage the sparsity of the UWA channels, greedy algorithms such as matching pursuit (MP) may be used instead of LMS channel estimation.

In most underwater channels, the geometry is constrained:

1) the motion is horizontal and uniform, and the speed is constant; and

2) The range separation (i.e., far field) is considerably larger than the water depth.

All significant routes will arrive at the receiver with a minimal angular spread relative to the horizontal under this assumption, enabling the compression or dilation to be represented by a single (mean) Doppler parameter. Resampling the received signal may then be used to compensate for the motion effect. Even in the absence of environmental fluctuations in the medium such as surface waves, internal waves, and so on, the residual Doppler for distinct routes collectively leads to a time-varying CIR at various time scales. It should be noted that no TR-based method has been described in the literature at tighter ranges (i.e., near field) where the Doppler spread may be significant owing to broad arrival-angle separation.

Synthetic aperture communication (SAC), on the other hand, may take use of the relative motion between a source and receiver pair by employing a virtual horizontal array to offer variety comparable to that given by a vertical array in a waveguide. Furthermore, because to the time gap between broadcasts or receptions, which allows for channel changes, there is a temporal divergence. Following an initial investigation using a simple on/off keying modulation, phase-coherent SAC has been successfully demonstrated for two different frequency bands (2–4 kHz and 8–20 kHz) and high-order constellations (e.g., 8PSK), and achieved a high data rate using two to five consecutive transmissions from a source moving at 4 kn over 3–6 km ranges in shallow water. Gliders fitted with a single hydrophone, on the other hand, can take advantage of the combined spatial and temporal variety created by continuous mobility in deep water [2].

The need of some synchronization among the users has been a limitation in TR multiuser communications. Before decoding of data-bearing signals can begin, an initial estimate of the CIR from each user is expected to be known by the receiver (or the base station), and is acquired via receptions of channel probes from each of the users in the absence of multiple-access interference (MAI). The transmission of channel probes by users is arranged into time slots by the base station via a reliable feedback channel in this MAI-free state (from the base station to the user). This scenario would necessitate a significant amount of networking overhead and would be unfavorable in UWA channels, where the combination of short coherence times (typically less than a second) and long propagation delays (typically much more than a second) discourages the use of feedback and two-way communications. As a result, the SIC-ATR-DFE method has been extended to the situation when users broadcast asynchronously via a time-varying channel, using matching pursuit (MP) and iterative processing. Previously, the many users/transmitters considered were stationary. Given the difficulties for a single-user mobile example, a more general scenario including many users in motion, where the impact of various Dopplers must be taken into consideration, would be very hard. The multiuser signals may be spread throughout the Doppler dimension in such situations, making separation a difficult job. The MAI removal procedure must account for the effect of Doppler correction on the MAI prior to cancellation when decoding any one user's Doppler corrected signal [10].

3. CONCLUSION

TR communications, which were first suggested in the early 2000s as an alternative to traditional multichannel equalization, have developed significantly over the past decade (M-DFE). TR takes use of spatial variety to accomplish spatial and temporal focusing, which is directly relevant to communications in challenging maritime settings. However, the first idea was restricted to two-way, active, downlink MISO communications in time-invariant settings. Furthermore, with residual ISI, temporal focusing was not ideal, resulting in performance deterioration and saturation. As a result, after TR processing, single-channel equalization was used to eliminate the residual ISI (TR-DFE), resulting in almost optimum performance. With the same performance, TR may be used for one-way, passive, uplink SIMO communications of practical importance. The ability of passive TR or PPC to handle time-varying channels easily by utilizing a block-based method with channel updates has proven a benefit. Multiuser/MIMO communications were enabled by spatial focussing, which was then improved by ATR. The block-based TR-DFE has been successfully demonstrated in shallow and deep water for a variety of frequencies (from 50 Hz to 30 kHz), bandwidths (from a few hertz to 20 kHz), and distances (a few to thousands of kilometers), exploiting spatial or temporal diversity or both, and achieving high spectral efficiency. While many advances have been made in algorithm development, this review suggests that there is still much more research to be done, with a focus on the coupling of oceanography, acoustics, and communications for underwater acoustic communication system design and performance characterization in dynamic ocean environments.

REFERENCES:

[1] L. P. Maia, A. Silva, and S. M. Jesus, “Environmental Model-Based Time-Reversal Underwater Communications,” *IEEE Access*, 2017, doi: 10.1109/ACCESS.2017.2724304.

[2] H. C. Song, “An overview of underwater time-reversal communication,” *IEEE J. Ocean. Eng.*, 2016, doi: 10.1109/JOE.2015.2461712.

[3] M. J. Albers, “Signal to noise ratio of information in documentation,” 2004. doi: 10.1145/1026533.1026546.

[4] K. W. Jung *et al.*, “Performance of an acoustic telemetry system in a large fishway,” *Anim. Biotelemetry*, 2015, doi: 10.1186/s40317-015-0052-9.

[5] A. Song, M. Badiey, H. C. Song, and W. S. Hodgkiss, “Impact of source depth on coherent underwater acoustic communications,” *J. Acoust. Soc. Am.*, 2010, doi: 10.1121/1.3459843.

[6] M. Stojanovic and J. Preisig, “Underwater Acoustic Communication Channels: Propagation Models and Statistical Characterization,” *IEEE Commun. Mag.*, 2009, doi: 10.1109/MCOM.2009.4752682.

[7] I. Kodrasi and S. Doclo, “Signal-dependent penalty functions for robust acoustic multi-channel equalization,” *IEEE/ACM Trans. Audio Speech Lang. Process.*, 2017, doi: 10.1109/TASLP.2017.2699326.

[8] C. He, L. Jing, R. Xi, Q. Li, and Q. Zhang, “Improving passive time reversal underwater acoustic communications using subarray processing,” *Sensors (Switzerland)*, 2017, doi: 10.3390/s17040937.

[9] A. M. Deylami, J. A. Jensen, and B. M. Asl, “An improved minimum variance beamforming applied to plane-wave imaging in medical ultrasound,” 2016. doi: 10.1109/ULTSYM.2016.7728895.

[10] X. Li and P. Papson, “Time Reversal in Underwater Acoustic Communications,” *Int. J. Comput. Appl.*, 2012, doi: 10.5120/8318-1951.