On Equalization for Mobile Digital Acoustic Underwater Communications

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Abstract

Issues related to ocean dynamics, low speed of wave propagation, complicated sea boundaries, source-receiver motion, among others, make the ocean environment very hard for high data rate digital communications. Equalization is mandatory for mitigating inter-symbol interference reaching successful message recovery and conventional equalizers can lack for stability due to algorithm convergence issues. This investigation explores digital equalization with time-variant passive time reversal (TVpTR), including acoustic propagation physical parameters influence, reduced norm probing and Doppler compensation, aiming at improving system performance. For that, acoustic propagation modeling, global optimization, matched filtering and compressed sensing theory are researched in the scope of Digital Acoustic Underwater Communications (DAUC) applications.

Objective

To equalize multichannel DAUC systems in order to mitigate channel interference using time-variant channel impulse response estimates and physical model.

Ocean acoustic propagation in SIMO TVpTR system

- Boundaries impose propagation in a waveguide, on which multiple paths cause inter-symbol interference;
- Bandwidth constrained by frequency selective attenuation;
- Ocean dynamics and sensors motion causes Doppler distortion;
- Single-Input-Multiple-Output (SIMO) sensors configuration is required for passive time reversal, capturing the most important modes of water column.
- Equalization with Time-Variant Passive Time Reversal (TVpTR) goes toward successful message recovery.

Fig.1: Transmission loss in acoustic propagation

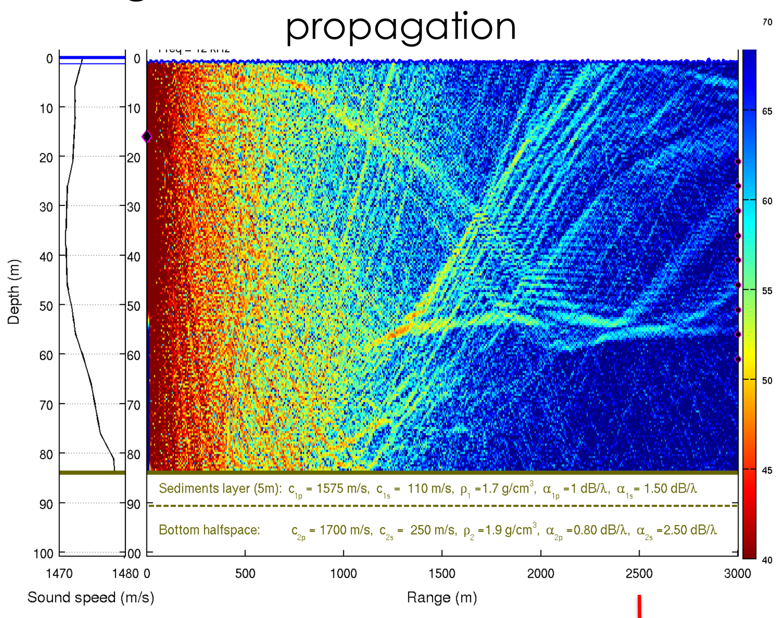


Fig.2: Eigenrays structure

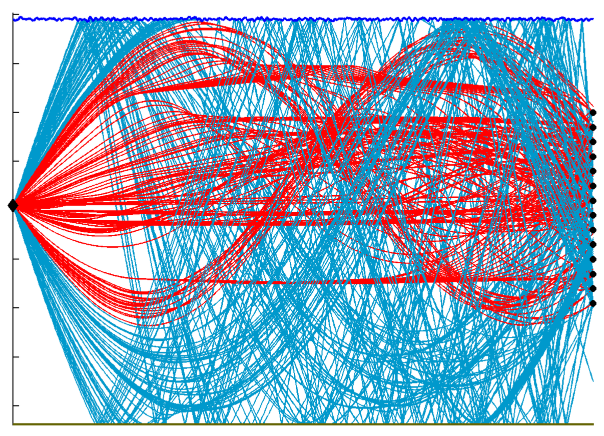
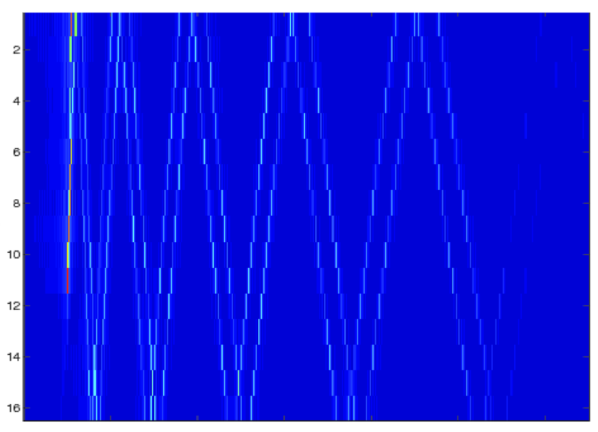


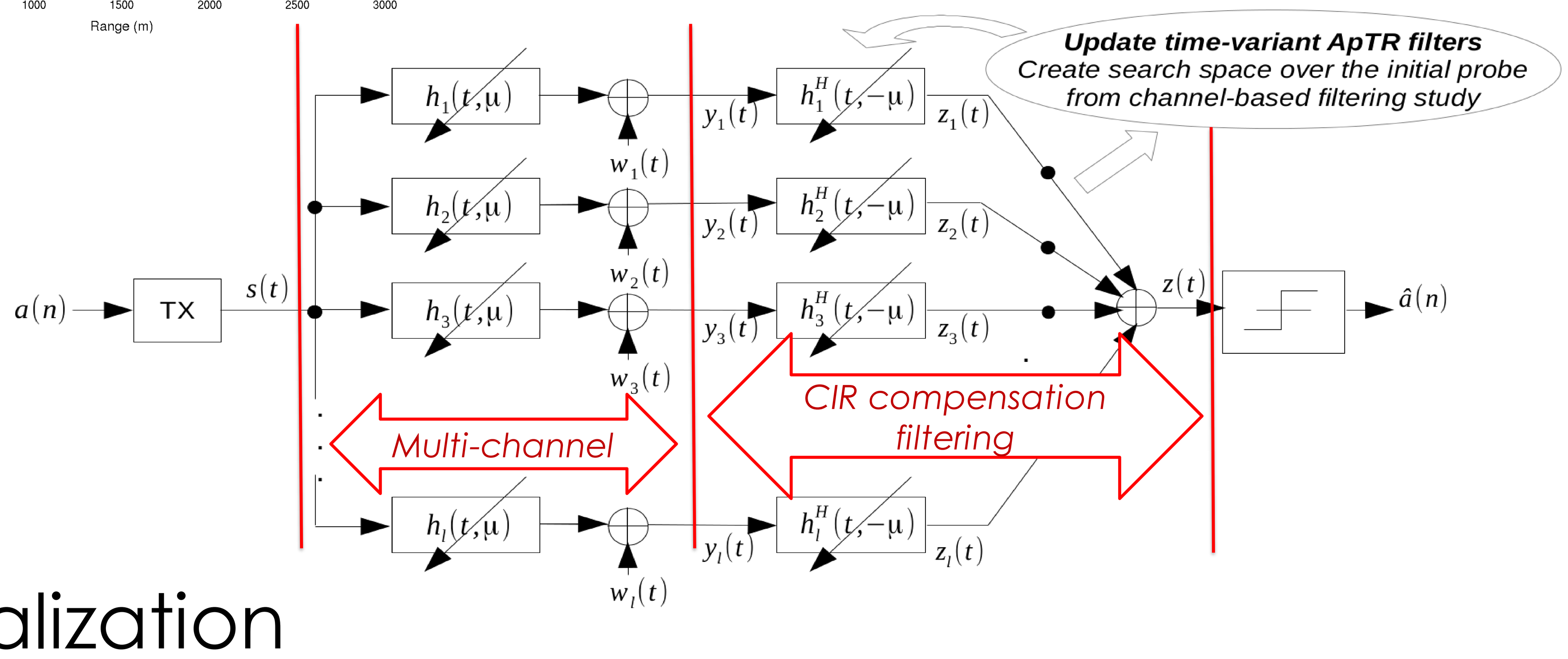
Fig.3: Wavefronts



*Acoustic propagation in shallow underwater (e.g., <200 m depth) forms complicated pattern of construtive/destructive interferences with multipath propagation (**fig.1,2**) and particular wavefronts on the hydrophones (**fig.3**).*

*Time-Variant Passive Time Reversal (**fig.4**) aims at compensating channel distortion by multichanel conjugate reverse filtering joint to Doppler compensation.*

Fig.4: Block diagram for TVpTR equalizer



Sparse channel estimation for TVpTR equalization

A SIMO DAUC system using TVpTR equalizer needs an accurate channel estimation. Boundary reflections cause multipath propagation, making the channel impulse response (CIR) for each hydrophone be sparse. This means that few amplitude peaks characterize the CIR, having the other parts relatively small amplitudes. Such sparse CIR can be well estimated with reduced norm criterion, substituting the well known pulse compression method by a regularized L1-norm least squares method. As result, better quality estimates are used in TVpTR equalizer, yielding error rate reduction.

Fig.5: Comparison of CIR snapshot estimates – Model (black), Pulse Compression (blue), Regularized L1-LS (red).

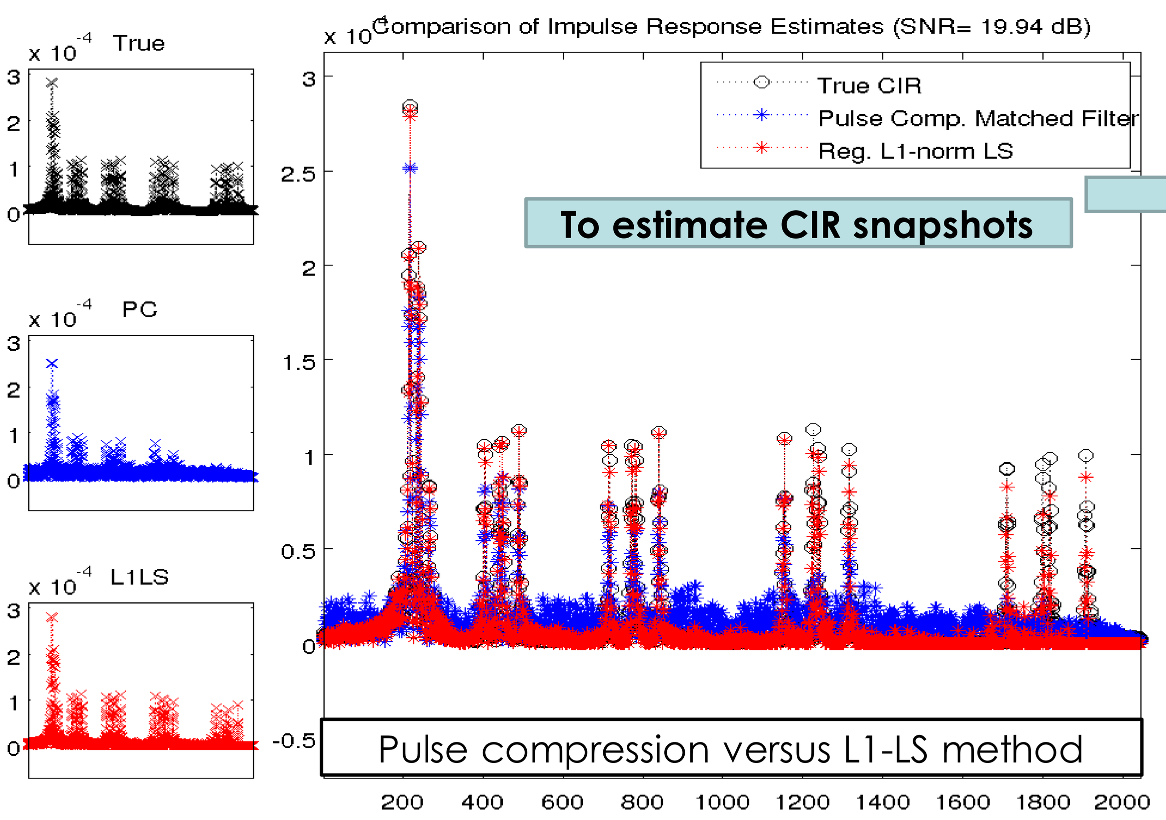
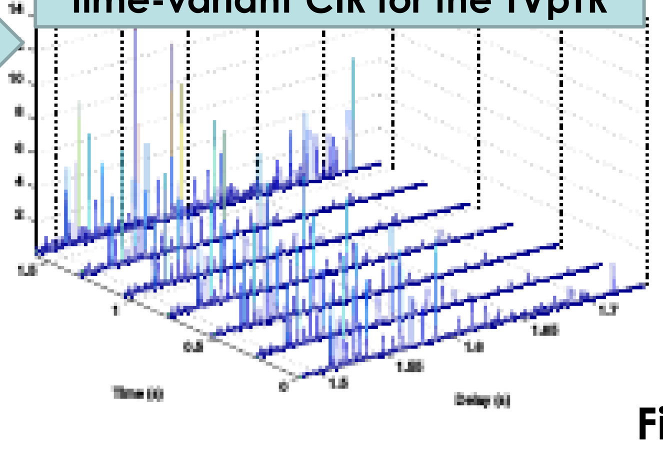


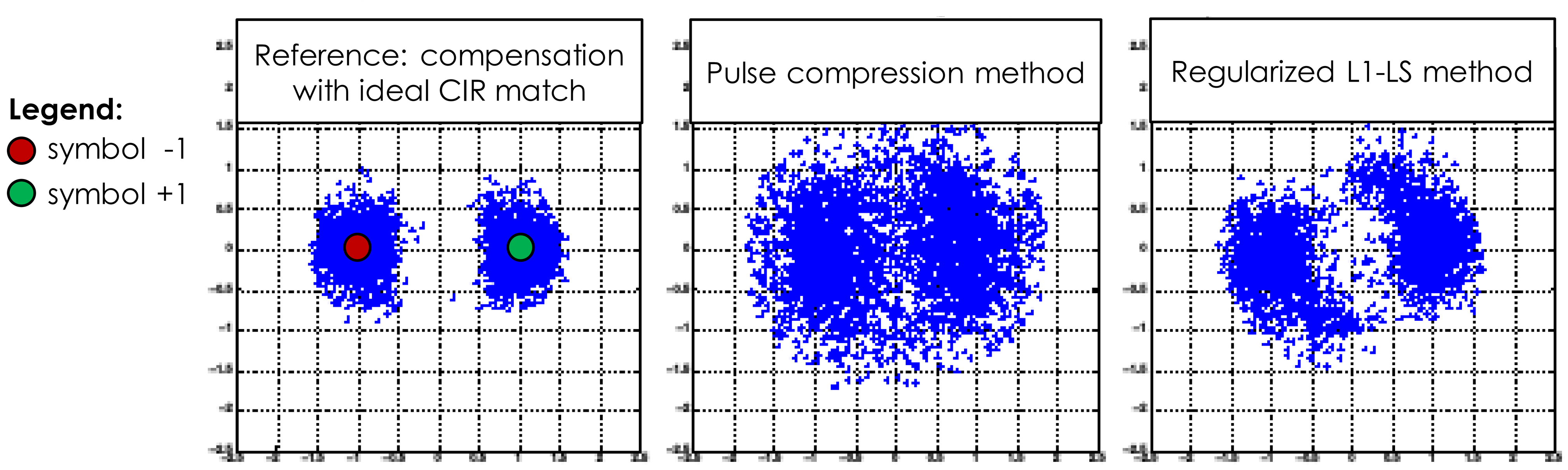
Fig.6: Time-delay CIR estimation



*TVpTR employs CIR snapshots estimated with a particular method (**fig.5**) in order to build bidimensional CIR in time-delay representation (**fig.6**).*

*Results for phase shift keyed signals are showed in constellation diagram (**fig.7**). On left diagram is a ground truth using modeled CIR. Center diagram shows pulse compression results and the right one shows results with L1-LS estimate.*

Fig.7: TVpTR equalized constellation diagram, source horizontal velocity 0.40 m/s



Work in progress

- Test real data from Radar2007 sea trial, Setubal, Portugal.
- Include a processor for optimize search space of CIR modeled by acoustic propagation physical parameters and CIR estimated by probe data.

Conclusion

The TVpTR equalizer tests showed that, under assumption of use accurate time-variant channel impulse response estimates, it is possible to reach reasonable high rate (2000 bps) message recovery. Sparse channel estimation joint to Doppler compensation is promissory to improve DAUC systems.

Acknowledgments

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