Environmental-based passive time-reversal in underwater communications

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Passive time-reversal (PTR) receiver is known as a low complexity channel equalizer that uses multichannel probing for time signal refocusing, reducing inter-symbol interference caused by multipath propagation. PTR is very sensitive to channel estimate accuracy. The proposed Environmental-based PTR (EPTR) aims to improve PTR communications performance by replacing the conventional noisy channel estimates with focalized noiseless channel replicas computed by an acoustic propagation model. The environmental focalization optimizes an "a priori" physical parameter search space to obtain "a posteriori" channel impulse response (CIR) replicas that best match the observed data. When focalization succeeds modelling errors are mitigated and the output noise-free replicas improve time-reversal performance.

The problem: improve PTR communications in multipath shallow water channels

Channel compensation in underwater communication at high data rate is challenging, and particularly difficult in the shallow water case, characterized by a double time-delay and frequency spread. Channel distortion is often attributed to one or more of the following effects: multipath propagation, time compression/dilation induced by relative source-receiver motion and wind driven acoustic scattering at the sea surface.

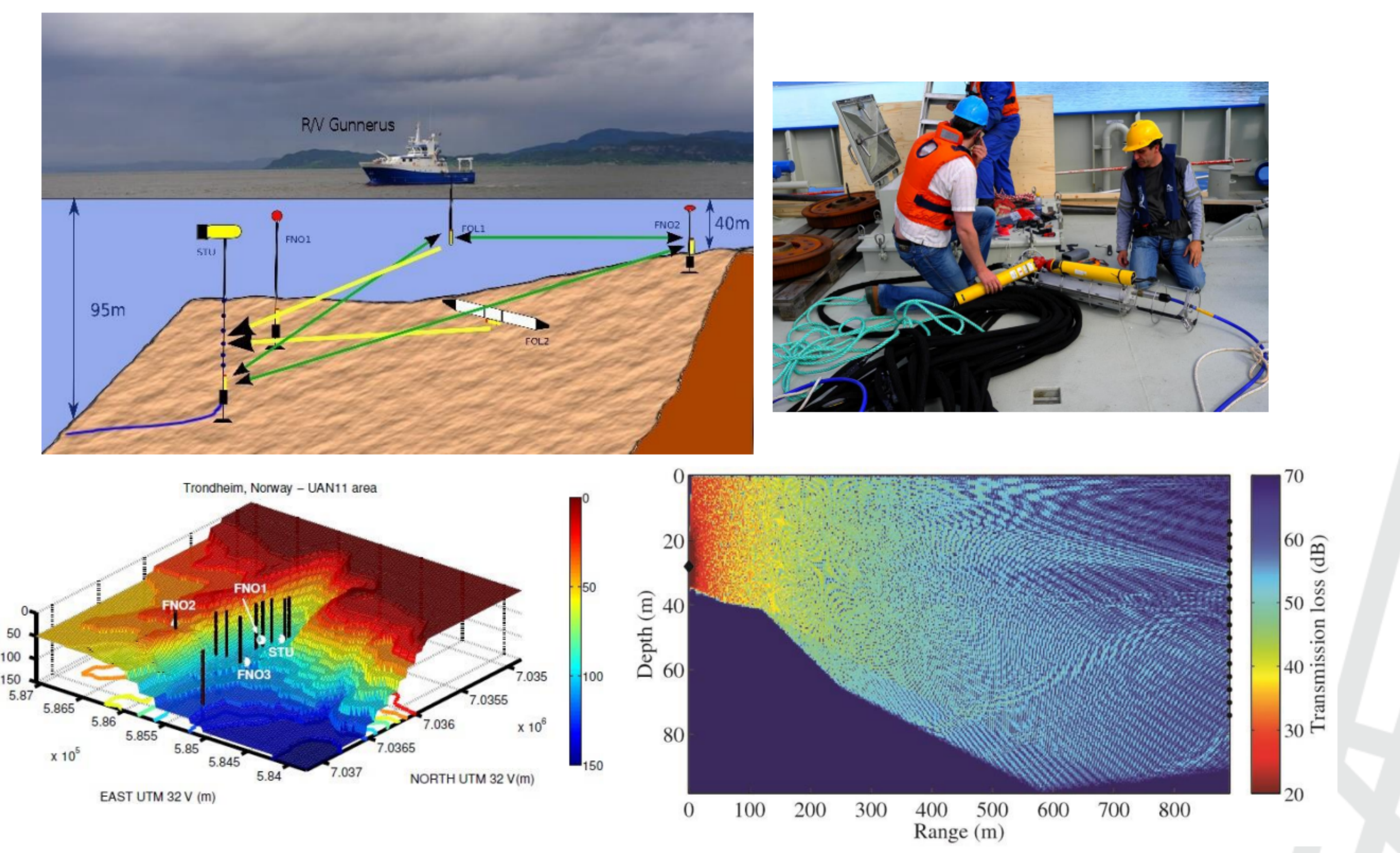

Fig.1: Scenario of one transmit-receive leg of the UAN11 sea trial (top-left). Modem Kongsberg cNode-Mini used for single-input-multiple-output link (top-right). Bathymetry and sensors positions (bottom-left). Transmission loss modeled for the multipath shallow water transect (bottom-right).

The proposed environmental focalization of high-frequency physical model in PTR communications

The EPTR is based on environmental focalization of a high-frequency ray trace physical model. The approach inserts the high-frequency acoustic propagation model in the process of obtaining CIR replicas that best match the observed data for time-reverse filtering. This is performed through an environmental focalization algorithm running on an "a priori" physical parameter space to obtain the "a posteriori" best candidate CIR replicas. Thus, noisy channel estimates are substituted by the best fit noiseless channel replicas computed by the physical model, aiming at improving CIR accuracy for PTR filtering.

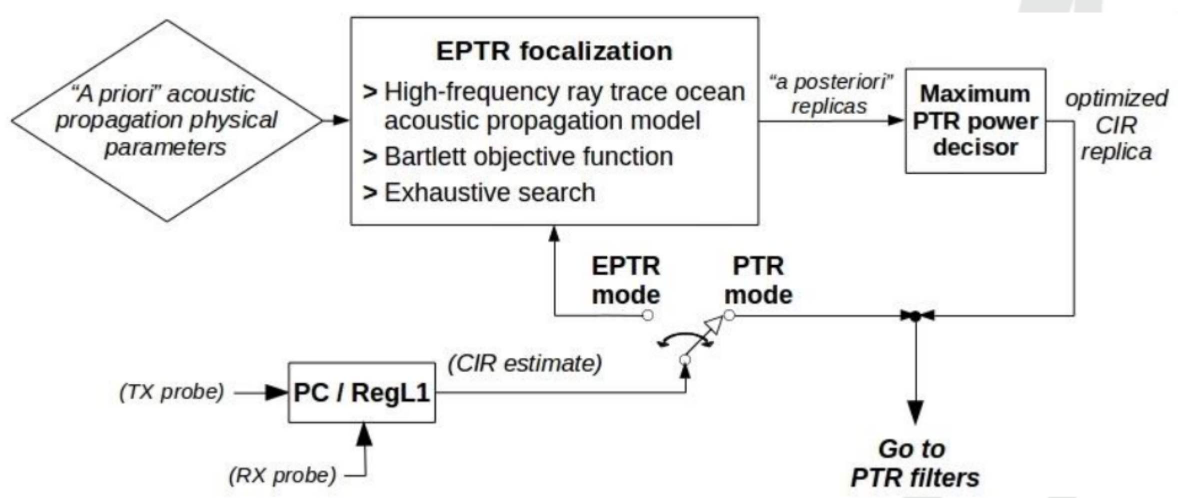

Fig.2: Simplified block diagram of the part of a single-input-multiple-output communication receiver that allows for the implementation of either the standard pulse compressed Passive Time-Reversal or the Environmental-based Passive Time Reversal processors.

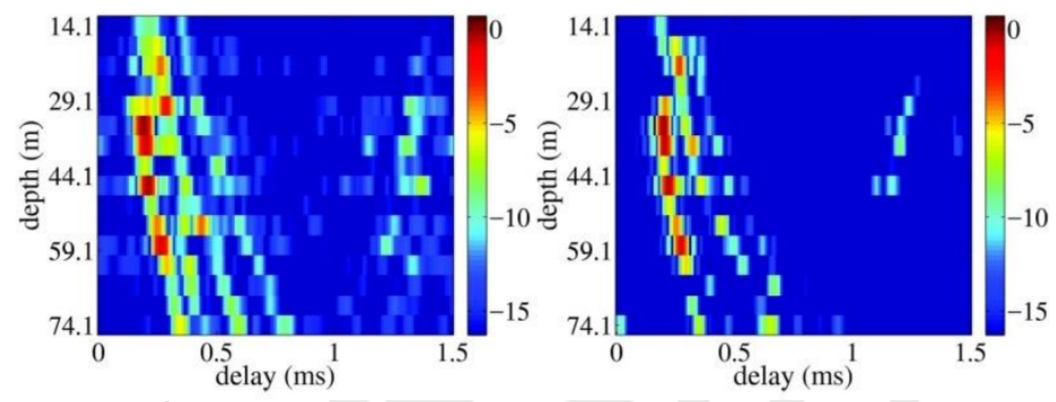

Fig.3: Noisy wavefronts estimated with pulse compression in PTR (left) and noise-free wavefronts modeled with environmental focalization in EPTR (right).

Experimental results of QPSK signals of the Underwater Acoustic Network'11 experiment

Results of 50000 QPSK symbols processed with EPTR and conventional pulse-compressed PTR on real data records acquired in May 2011 during the UAN'11 experiment in Trondheim (Norway), show that EPTR clearly outperformed the conventional PTR by an amount of 1 to 4 dB in mean-square error (MSE).

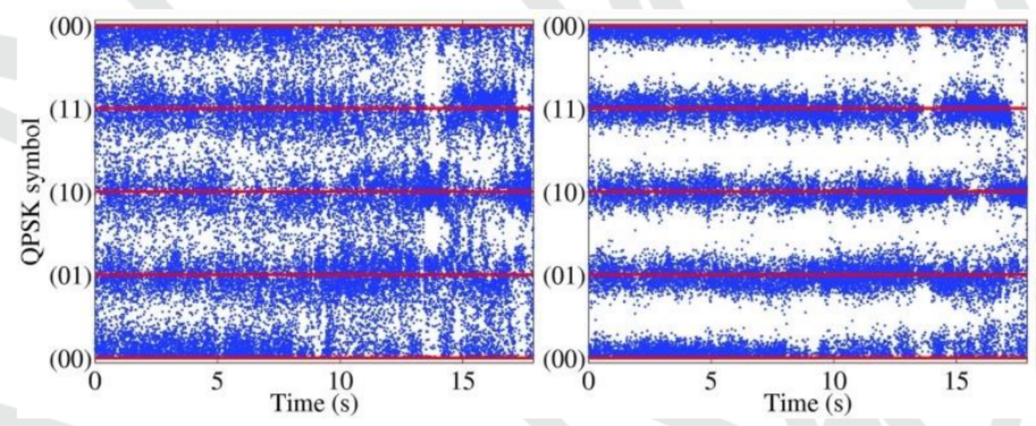

Fig.4: Received symbols along time after processing with the standard PTR (left) and with the EPTR based on PC (right). The vertical axis denotes the recovered QPSK symbols. The horizontal axis is the effective time of payload transmission.

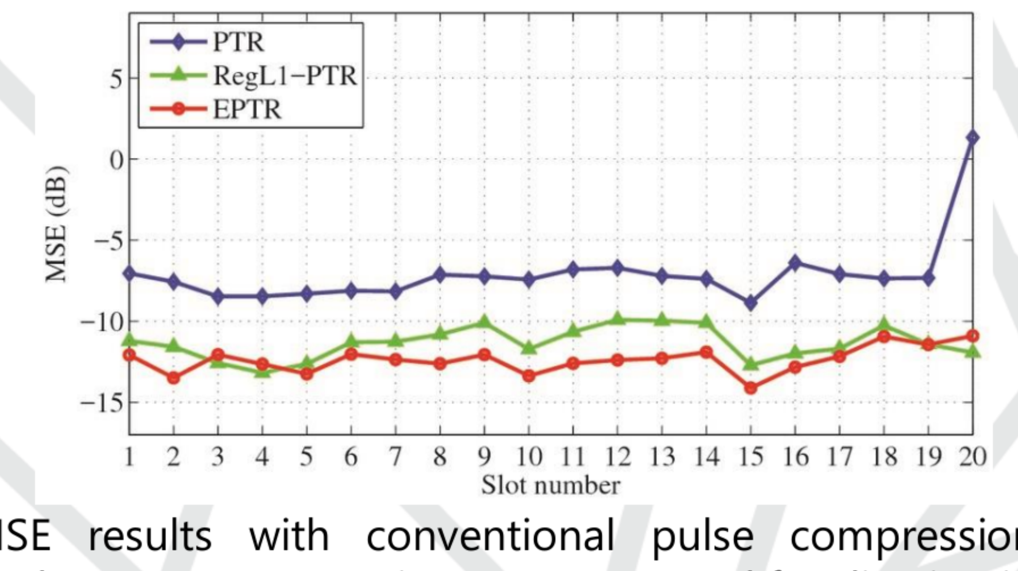

Fig.5: MSE results with conventional pulse compression in PTR (blue), regularized L1-norm (RegL1) in PTR (green) and focalization in EPTR (red).

Channel tracking was effective despite a reduced physical parameter search space that could be exhaustively covered with a low computational effort. To the authors best knowledge this is the first successful report [1] on the usage of a physical parameter fed numerical model for underwater acoustic communications channel equalization with real transmitted data in a useful underwater modem frequency band.

Also, more important than the actual comparative performance, that may vary from case to case, these results show that environmental model-based methods may be used with success on real data underwater communications, are robust and may efficiently use a priori environmental information and therefore potentially track a changing environment.

[1] L. P. Maia, A. Silva, S. M. Jesus, *"Experimental results of environmental-based passive time-reversal in underwater communications"*, in Proc. Oceans'17 IEEE/MTS (accepted), Aberdeen, United Kingdom, June 2017.