AN ENVIRONMENTAL EQUALIZER FOR UNDERWATER ACOUSTIC COMMUNICATIONS TESTED AT HYDRALAB III

A. Silva, F. Zabel, C. Martins, S. Ijaz & S.M. Jesus

Institute for Systems and Robotics, University of Algarve
{asilva,fzabel,cmartins,sijaz,sjesus}@ualg.pt

It is known that small changes in source and receiver locations can cause significant changes in underwater acoustic channel impulse responses. At HYDRALAB III an underwater acoustic experiment was conducted to show that a source depth-shift causes a frequency-shift in the channel impulse response and that such behavior can be used to implement an environmental-based equalizer for underwater communications that compensates for the performance loss due to the source depth-shift.

1. INTRODUCTION

The Underwater Acoustic Barriers 2007 (UAB'07) experiment was carried out at Hydralab III during the first two weeks of September 2007. During the first week experiments were conducted in the Trondheim Fjord to study and demonstrate point to point (P2P) underwater communication schemes based on Phase Shift Keying (PSK) and Orthogonal Frequency-Division Multiplexing (OFDM) modulations (Gomes, J. 2008-a and Gomes, J. 2008-b). In the second week the experiment took place in the Sletvik Fjord to demonstrate the underwater acoustic barriers concept for submarine intruder detection (Jesus, S. 2008). The work described in this paper was carried on September 4 and is integrated in the PSK underwater communications study.

Underwater acoustic communications presents serious limitations for attaining even modest data rates that are trivially achieved in terrestrial wireless radio. That is due to the significant delay spread that induces multipath and to the ocean environmental properties that are quite dynamic even in a short time period of a few seconds. In a communication system the objective of the channel equalizer is to compute a synthetic version of inverse channel Impulse Response (IR). When applied as a filter that IR inverser deconvolves the channel multipath that is responsible for the Inter-symbolic Interference (ISI) and therefore for the degradation of the communications performance. Moreover the channel equalizer should be adaptive in order to compensate for the underwater channel variability along the data transmission. Usually adaptive equalizers do not take explicitly in consideration the channel environmental properties and their implementation rely in a statistical approach that aims at minimizing the Mean Square Error (MSE) between the transmitted and the channel distorted received symbols.

The communication experiment conducted during UAB'07 aims at field testing an environmental-based equalizer for underwater communications named as Frequency Shift passive Time-Reversal (FSpTR). The FSpTR aims at minimizing the MSE by taking in consideration the environmental properties that are varying during the data transmission. In its present implementation the FSpTR (Silva, A. 2007) allows for the compensation of the source/receiver depth and source-receiver range variations. The experiment described in this paper was specifically designd for demonstrating with real data that the source depth variation results in a channel IR frequency shift and that the knowledge of such frequency shift can be used to improve the communication performance.

The FSpTR equalizer is based on the pTR operator that allows for the implementation of a simplified equalizer that deconvolves the channel multipath by filtering the received data with a time-reversed estimate of the channel IRs. However, one of the pTR primary causes of performance degradation is due to source and array movement. FSpTR applies a frequency shift to the IRs estimate in order to compensate those environmental changes resulting in an adaptive equalizer. Figure 1 shows (from left to right) the multipath between the source and the receiving array as well as the FSpTR operation.

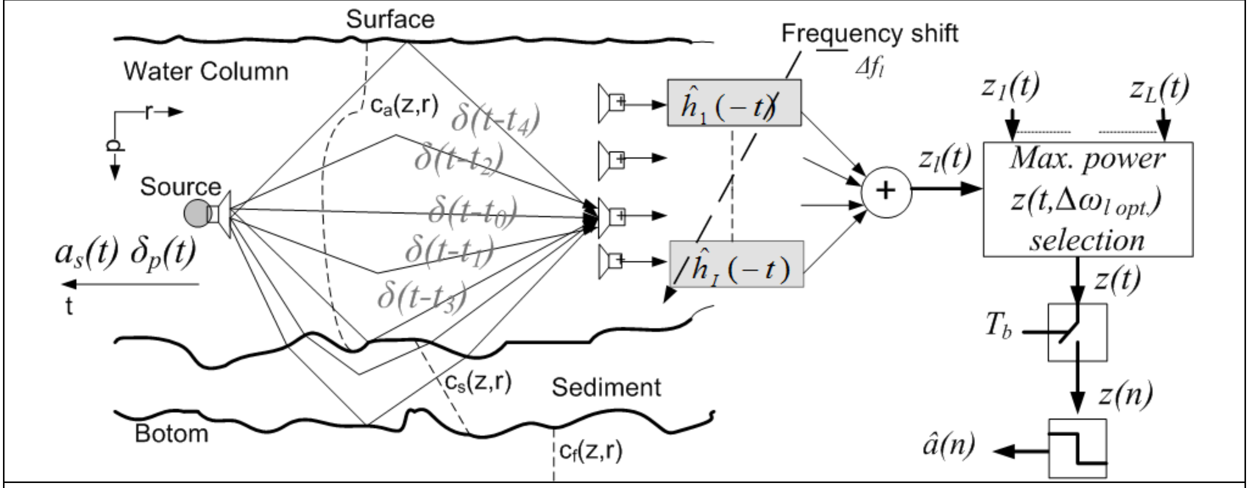

Figure 1: Probe and data signals underwater propagation (left); Block diagram of FSpTR equalizer (right): (i) filtering of hydrophone received data with time-reversed FS IR estimates, (ii) addition of filtered signals for each FS, (iii) selection of the FS signal with maximum power, (iv) down-sampling to the symbol rate and (v) estimate of transmitted symbols.

In addition to the scientific objectives, UAB’07 also served to test a telemetry buoy prototype as described in section 2. Section 3 describes the results obtained and section 4 gives some conclusions.

2. HARDWARE EXPERIMENT DESCRIPTION

For the purpose of testing the environmental-based communication algorithms a set of electronic hardware was assembled in two main units: (i) a base station connected to shore that comprises a computer-based signal generator, a signal amplifier and an acoustic source; and (ii) a remote stand-alone telemetry buoy that comprises an array of hydrophones and a PC104+ based telemetry unit with data storage and processing capabilities. Moreover both units are WLAN equipped for the real time monitoring of the acquired signals at the base-station side. Both units have been designed and implemented at the University of Algarve and the UAB'07 was used, also, as an engineering test for their functionality.

The telemetry unit is a pre-commercial prototype named Acoustic Oceanographic Buoy (AOB) and in terms of main characterisstics of height (1.2 m), diameter (16 cm), weight (40 kg) and autonomy (12 hours) tend to those of a standard sonobuoy. Nevertheless, the AOB presents advanced capabilities as: stand-alone or network operation, local acquired-data storage, dedicated signal-processing, GPS timing and localization, real-time data transmission and two arrays for acoustic signals and temperature acquisition. Figure 2 shows (on the left) the software and hardware AOB components and their interconnections. The AOB is an easy to use system where only two maintenance operations are required: recharging batteries and downloading stored data. It is light enough to be deployed by hand from a ship or a RHIB and robust enough to operate under rough sea conditions. At sea the AOB can be operated in a free drifting mode with self time-synchronization and localization with GPS precision. Figure 2 (right) shows a robustness test with the AOB being towed by oceanographic vessel R/V Gunerus wile in operation.

During the experiment the transmitting source was suspended from a fixed platform 10 m from the base station hanged by a crane, at an initial depth of 5 m. The receiver was a vertical array with 16 hydrophones uniformly spaced at 4 m between 6 m and 66 m depth, suspended from the free drifting AOB. The communication range was approximately 1 km with the bottom depth increasing from 12 m at the source location near shore to about 110 m at the AOB location. R/V Gunnerus was used for the deployment of the AOB and also performed a number of CTD casts during the communication experiment.

Several carrier frequencies were considered for the PSK-modulation transmissions: low frequency at 3200 Hz, medium frequency at 6250 Hz and high frequency at 12000 Hz. The medium frequency transmissions, under consideration in this paper, comprise a set of 50 chirp signals followed by a data set of 100 seconds. The chips transmission where used for channel IR estimate and to study the channel variability and Doppler spread. Each chirp bandwidth ranges from 5 to 7.5 kHz with a 0.1 sec duration and 0.2 sec of silence for transient die out. The data bandwidth ranges from 5.5 to 7 kHz with a PSK-2 modulation and 1000 bits/sec baud-rate.

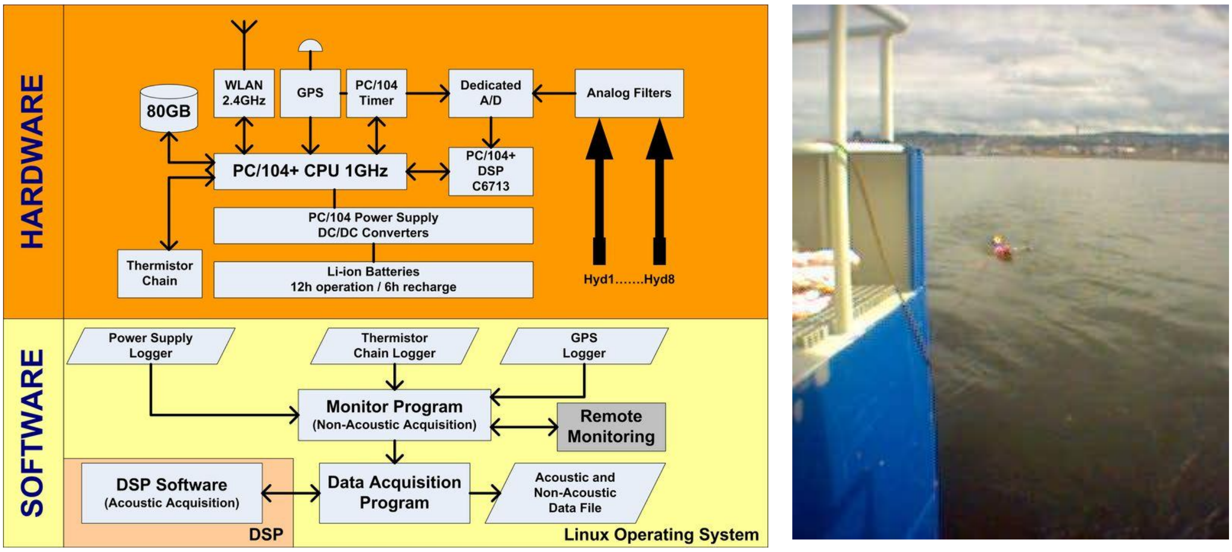

Figure 2: AOB hardware and software block diagram (left). AOB being towed by Gunnerus to test its robustness wile in operation (right)

3. EXPERIMENTAL RESULTS

Figure 3 shows in the left panel, the IR estimates, obtained by pulse compression of the chirp-probe sent previously to the data transmission, along the hydrophone array. It can be seen two initial strong paths followed by a large number of unstructured multipaths. Figure 3 (right), shows the sound speed profile (ssp) along the water column where it can be observed a more stable behaviour at the middle of the water column that motivate the use of only the top ten hydrophones for the FSpTR processing. During the data transmission the crane was used to change the source depth from 5 to 5.5 m at about 15 s of the data frame. The AOB GPS data shows that there is no source-array range variation and the sea state zero corroborates the assumption that the hydrophone depth is almost constant. Figure 4 (feft) shows the initial 30 s of the pTR output $z_l(t)$ (see Fig. 1) power for $L = 20$ frequency shifts between -600 and 200 Hz. In this Figure it can be seen that the frequency shift that gives the maximum power (indicated by *) changes from 0 to about 300 Hz just after 15 s, revealing that the IRs mismatch generated by the source depth shift causes a frequency shift in the channel IRs.

Figure 4 (right) shows the MSE between $z(n)$ and the transmitted symbols $a(n)$ for the equalizer without frequency shift, solid line, and with the frequency shift obtained by the *-line of Fig. 4-left, dashed line. It can be seen that the frequency shift partially compensates for the source-depth shift since the MSE results, after 15 s, for the frequency shift case are better than those without frequency shift. In fact the global results show a MSE gain of -1.6 dB that result in an improvement of the Bit Error Rate (BER) from 9.2 to 1.6%.

4. CONCLUSION

The Hydralab III initiative by their shore and ship facilities presents extremely good conditions to carry out underwater acoustic experiments. In September 2007 a team from University of Algarve performed, among others, an underwater acoustic experiment to demonstrate that a source depth shift generates a frequency shift of the channel IRs and that in a communications system such frequency shift can be used to partially compensate for the performance loss caused by such environmental variation. The attained results show that for 0.5 m depth shift a frequency shift of 300 Hz occurs and that when such information is used in a FSpTR equalizer an improvement from 9.2% to 1.6% was observed.

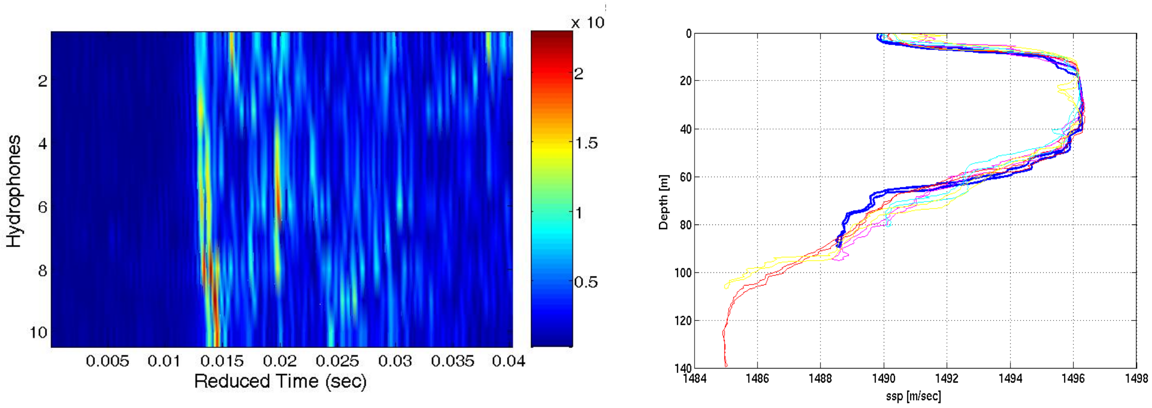

Figure 3: Arriving pattern estimated by pulse compression of the chirp probe (left). Sound speed profile, CTD measured by research vessel Gunnerus (right), the thick line shows the ssp at approximately the same time of the processed data and the thin lines others ssp taken on that day.

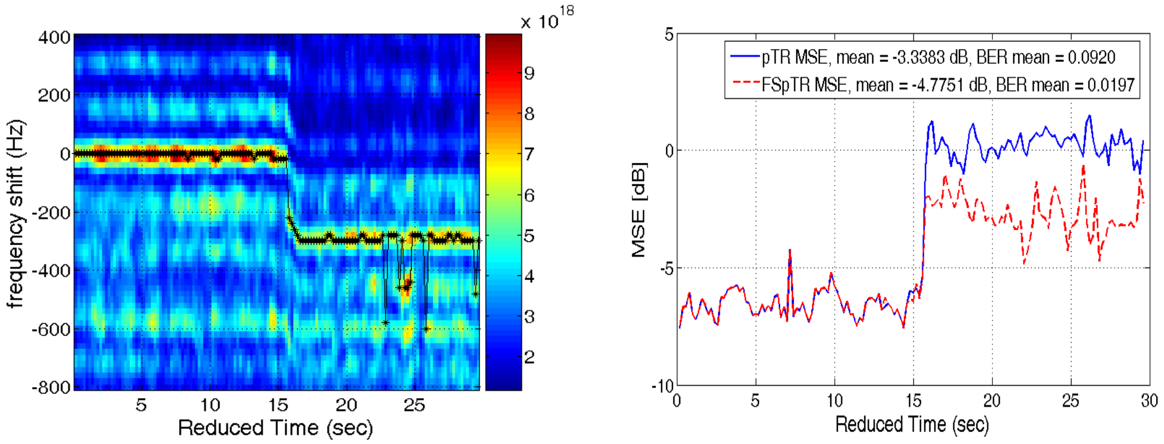

Figure 4: FSpTR $z_l(t)$ mean power as function of time and frequency shift for 10 hydrophones (left). FSpTR and pTR experimental MSE for 10 hydrophones with source depth shift at 15 s (right).

ACKNOWLEDGMENT

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