



The multipath problem in a shallow water hydroacoustic channel

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This paper presents a multipath problem in a shallow water acoustic channel. Underwater acoustic communication is mainly affected by channel variations, multipath propagation, and Doppler shift. The transmitted signal can go through multiple paths in order to reach the receiver. These multiple paths can cause significant time spread in the received signal. Multipath propagation in an underwater acoustic channel causes significant degradation of the underwater acoustic communication signals. Multipath propagation in a shallow water is caused by reflection and scattering of the transmitted signals at the surface and the bottom. The results of the computer experiments are presented in this paper. The arrival times of the boundaries reflected signals were detected by means of the cepstral analysis. The underwater channel was described as a convolution channel. The transmitted signal was chose to be a CW pulse. In this work the received signal is analyzed, and the results are interpreted in connection with the multipath propagation and the homomorphic deconvolution method is discussed as a means of combating the multipath problems. In order to examine the multipath problem in a shallow water hydroacoustic channel the software model of the underwater channel was used. The application of the cepstral analysis to identify and remove the major multipaths present in the received acoustic signal and recover the original transmitted signal has been investigated. Initial results suggest that this may be possible and the multipath problem in a hydroacoustic channel can be solved by the homomorphic deconvolution technique that removes an undesired additive component from the complex cepstrum.

1 Introduction

Underwater acoustics is one of the fastest growing research in acoustics. Acoustic communications in shallow water had been a difficult problem due to the channel characteristics of the underwater acoustic channel. Underwater acoustic channels present a number of challenges to the designers of communications systems. One of their most important characteristics is multipath propagation. For long-range underwater acoustic communications the main problem encountered is just the presence of multipath propagation caused by reflection and scattering of the transmitted signals at the bottom and the surface. Reflections from channel boundaries and diverse objects dominate the multipath structure. The transmitted signal can go through multiple paths in order to reach the receiver. Acoustic signals in shallow water normally interact repeatedly with both the sea surface and bottom. Signal degradation caused by multipath propagation is the major problem. Multipath propagation causes the transmitted signal to take numerous, time-varying different-length paths to the receiver. Each path can possibly have multiple surface interactions causing additional frequency spreading due to motion of the water. Time-varying multipath propagation is one of the major factors that limit acoustic communication performance in shallow water. Shallow water propagation is very sensitive to changes in the geometrical parameters like water depth, source-receiver range or bottom slope leading to variations in the impulse response of the underwater acoustic sound

channel. Sound propagation in shallow water regions is also strongly dependent on sea bed properties [7].

Normal mode approaches have been widely used in underwater acoustics and are derived from an integral representation of the wave equation. When propagation is described in terms of normal modes, changes in the environment translate into energy transfer between modes. In this paper, the numerical simulations were performed using the PROSIM broadband normal mode model working in Matlab environment [10]. This software is a product of three years efforts of group of scientists. PROSIM is a research project under the MAST-III initiative, partially financed by the European Commission. The organisations that participated in this project are: Thomson Marconi Sonar SAS in France, NATO Saclantcen Undersea Research Centre in Italy, TNO-FEL Physics and Electronics Laboratory in the Netherlands, Heriot-Watt University in the UK and University of North Wales in the UK. The authors made the results available to the public.

In this paper the numerical simulations were performed using broadband channel simulator called PROSIM. The received FM and CW signals are analysed, and the results are interpreted in relation to the communication signals.

2 Propagation model

The PROSIM software package is able to simulate the effect of the fluctuating shallow water propagation channel to an input broadband acoustic signal. It can be

used for simulations of broadband sound propagation through both a time- and range-varying propagation channel. This software is mainly intended for shallow water applications [1, 5]. The main application is acoustic systems design with particular emphasis on acoustic communication systems for which channel stability and fading are the major problems. The PROSIM range-dependent, broadband model has been developed based on the adiabatic approximation. The broadband normal-mode model is based on a model called ORCA. This model is based on dividing the acoustic environment into stratified layers with depth dependent properties assuming that the inverse of sound speed squared varies linearly with depth in each layer. The acoustic field within each layer is described analytically by using a sum of Airy functions. The software consists of oceanographic and acoustic models, which perform specific tasks to describe the complexity of the real ocean. In this paper, the acoustic part of package was used. This package consists of a broadband normal mode code for calculating the received signals in the time domain and this signals can be matched filtered in the case of FM transmissions.

The PROSIM broadband normal mode model is in more detail described in [2, 4].

3 Homomorphic deconvolution

Homomorphic deconvolution has been successfully applied in a variety of areas [6]. Homomorphic systems can be divided into a canonical representation consisting of a cascade of three individual systems (Figure 1).

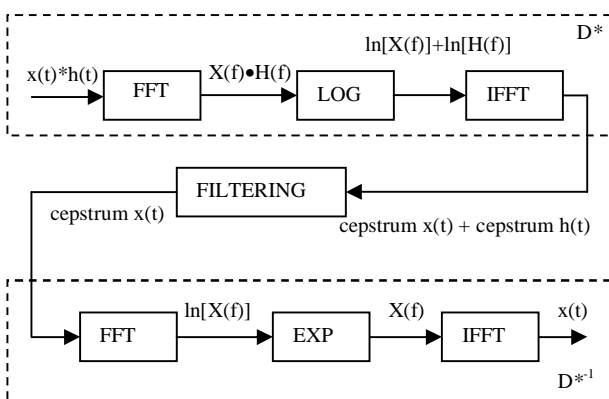


Figure 1: Canonic form for homomorphic deconvolution

The transformation of a signal into its cepstrum is a homomorphic transformation and the idea of the cepstrum is a fundamental part of the theory of the homomorphic systems for processing convolved signals [6, 8, 9]. Cepstral analysis uses a form of a

homomorphic system, which converts the convolution operation to an addition operation, and it can be used to detect echoes or periodicity. For the first time the cepstrum was defined as the power spectrum of the logarithmic power spectrum:

$$c(t) = |F[\log S(f)]|^2 \tag{1}$$

Another form of the cepstrum is the complex cepstrum, which is defined as the inverse Fourier transform of the complex logarithm of the complex spectrum. In terms of mathematical formula the complex cepstrum is given by:

$$c(t) = F^{-1}[\log X(f)] = F^{-1}[\log|X(f)| + j\phi_X(f)] \tag{2}$$

The cepstrum can be used for detection of any periodic structure in the spectrum, including harmonics, echoes and multipath. The power cepstrum is superior to the complex cepstrum because it does not have phase unwrapping problem. In the power cepstrum the phase information is lost, so the original signal can not be recovered from the power cepstrum. The power cepstrum is usually used to estimate the echo delay time, and then the complex cepstrum is used to remove the echo and recover the original signal. The complex cepstrum preserves phase information and allows reconstruction of the input signal after editing in the cepstral domain. In case of echo detection in echo hiding system, we do not need to recover the original signal so the power cepstrum is enough to estimate the echo delay. In the power cepstrum, the impulse corresponding to the echo delay is more visible than the peak in the complex cepstrum [8].

4 Simulation geometry

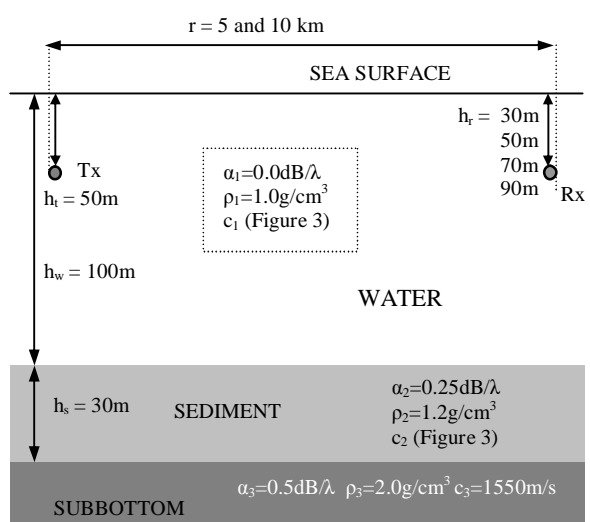


Figure 2: Simulation scenario

Figure 2 depicts the simulation geometry and indicates the environmental characteristics. The sound speed

profile chosen for calculations is shown in Figure 3. The channel consists of a water column of depth 100m. The normal mode model assumes the bottom to consist of single sediment overlying a homogenous sub-bottom. The thickness of sediment layer is 30m. The sediment parameters were set: sound speed linearly increasing from 1460 to 1510m/s, attenuation constant 0.25dB/λ and density 1.2g/cm³. The homogenous sub-bottom has sound speed, density and attenuation of 1550m/s, 2.0g/cm³ and 0.5dB/λ, respectively.

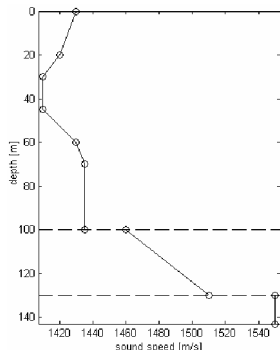


Figure 3: Sound speed profile

5 Signal processing

In these numerical experiments CW and Linear Frequency Modulated pulses were transmitted. LFM signals (“chirps”) have many properties, which make them an attractive choice for channel sounding. They are easily generated and channel responses can be processed in the time or frequency domain for underwater channel estimation. The multipath arrival structure was calculated using matched filtering, i.e. taking the envelope of the cross correlation sequence of received signal with the transmitted signal. This produces a sequence of impulses corresponding to each echo in the received waveform thereby providing a visualization of the impulse response.

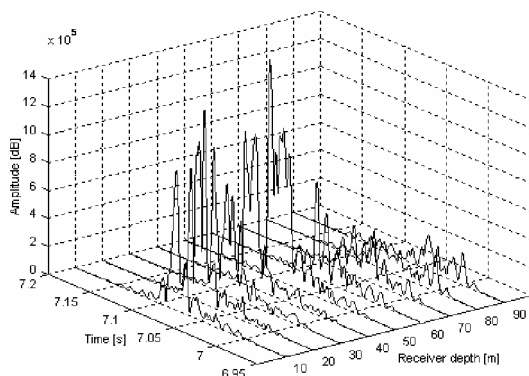


Figure 4: Matched filtered received signals at 10km range and different receiver depths

The result is presented in Figure 4 and it shows clearly the variation in the multipath structure throughout the experiment. The transmitted signal was Hanning shaded LFM pulse of duration 100ms, centre frequency of 600Hz, and bandwidth of 500Hz. The maximum source level was 200 dB ref. 1μPa at 1m. The transmitter depth was 50m and the receiver depth changed from 10m to 90m. Figure 4 revealed the multipath arrival structures obtained in shallow water. The matched filtered received signals show variability in the arrival time.

The next signal, which was sent to examine the time variability of the underwater channel, was a CW pulse. It was a Hanning weighted pulse with center frequency of 600Hz with pulse duration of 100ms, and the maximum source level of 200 dB ref. 1μPa at 1m (Figure 5). The numerical experiments were repeated at ranges of 5 and 10 km and with source depth of either 50m. The receivers were set at water depths of 30, 50, 70, and 90m, respectively.

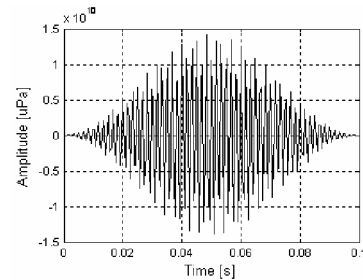


Figure 5: Transmitted CW pulse

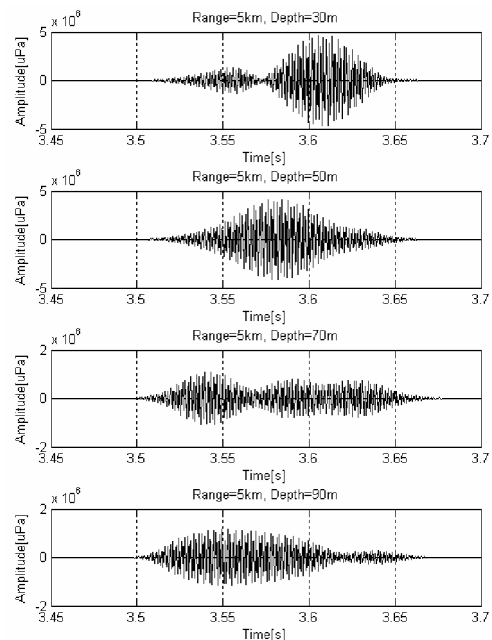


Figure 6: The received CW pulses at a range of 5 km and depths of 30, 50, 70, and 90m

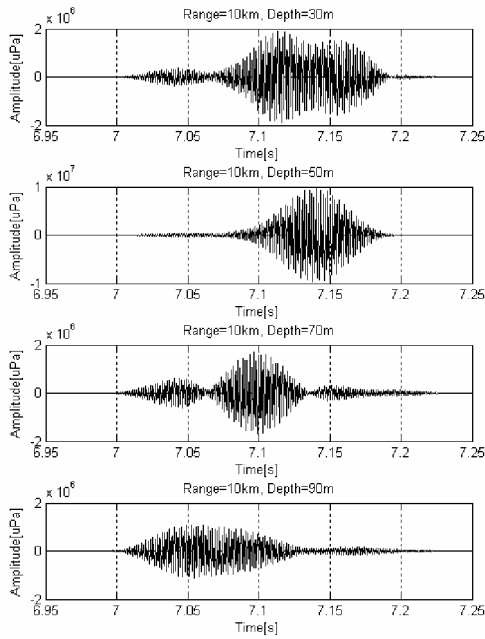


Figure 7: The received CW pulses at a range of 10 km and depths of 30, 50, 70, and 90m

Figures 6 and 7 illustrate the received signals. The multiple reflection effect is obvious. The received signals are heavily overlapped and it is not possible to distinguish the received signals from each other. It is observed directly from these figures that the time variability in the received signals increase with increasing range.

In order to test the theory of the cepstral analysis and the homomorphic deconvolution technique and the possibilities of taking advantage of this technique for detecting multipath effect in the underwater acoustic channel, the numerical example was simulated in Matlab environment. The hydroacoustic channel was described as a convolution channel. The source pulse was shown in Figure 8.

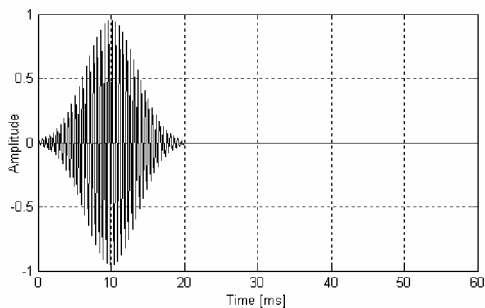


Figure 8: Source pulse with a Gaussian envelope whose waveform is given by eq. (3)

This is a CW pulse with center frequency of 2 kHz and pulse duration of 20 ms. The waveform is given in equation (3).

$$x(t) = \begin{cases} \sin[2\pi f(t-T)] * \exp\left[-\left(\frac{2}{T}\right)^2 * (t-T)^2\right]; & 0 \leq t \leq 2T \\ 0 & ; t > 2T \end{cases} \quad (3)$$

The received composite signal was modelled as the convolution of the transmitted pulse with the impulse response of the underwater channel. The received signal is shown in Figure 9.

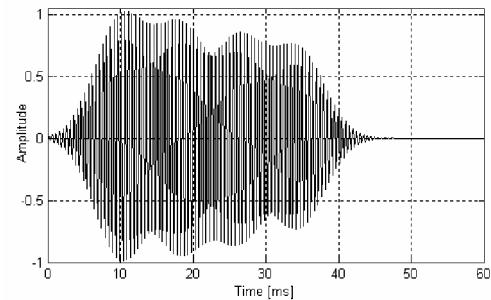


Figure 9: The received convoluted pulse

Figures 10 and 11 show the simulation results of the cepstral analysis. The peaks showed at this figures correspond to the time delay of the individual paths. The peaks in the power cepstrum are more prominent than the peaks in the complex cepstrum. Simulation experiments demonstrate the superiority of the power cepstrum in detecting the multipath propagation.

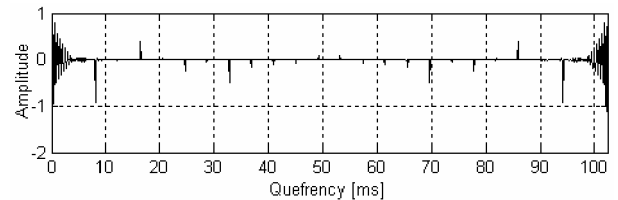


Figure 10: Complex cepstrum of Figure 9

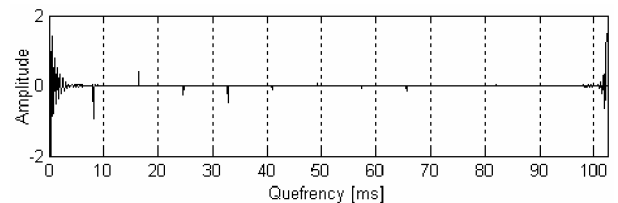


Figure 11: Power cepstrum of Figure 9

The transmitted signal was recovered by means of homomorphic deconvolution (Figure 12). This method allows the convolved signals in the time domain not only to be separated in the complex cepstrum, but also to remove an unwanted effect completely, and return to the original time signal without this effect.

The first and obvious observation from Figure 12 is that the multipath problem in a hydroacoustic channel can be solved by the homomorphic deconvolution technique that removes an undesired additive component from the complex cepstrum. Cepstrum shows very narrow peaks, which allow the identification and removal of echoes by filtering.

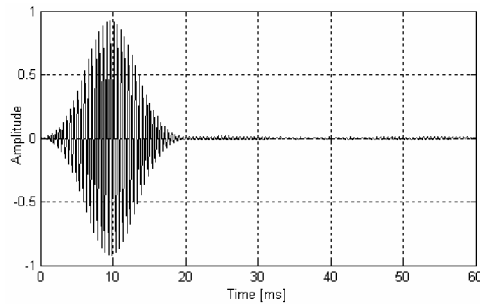


Figure 12: The recovered signal after homomorphic deconvolution

6 Summary

In this paper the long-range shallow water hydroacoustic channel has been considered. CW and FM signals have been reviewed in relation to an underwater acoustic channel. The multipath effect in a shallow water channel has been discussed. The received LFM pulses were all matched filtered showing variability in the arrival time and revealing the multipath structure. The results from numerical experiments clearly show temporal variability in the acoustic signals. The first results of the analysis of the data show promising results. The multipath problem in the underwater acoustic channel in shallow water can be solved by homomorphic deconvolution. Future work will concentrate on an extensive analysis of the response of the acoustical channel using CW and FM signals.

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