ECHOES REDUCTION DURING DIGITAL DATA TRANSMISSION IN HYDROACOUSTIC CHANNEL – LABORATORY EXPERIMENT

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Summary

The possibility of using a hydroacoustic channel for digital data transmission is very limited. This is due to the effect of multipath propagation of the emitted acoustic wave and the damping of the mechanical wave in this medium, which increase with frequency. The first of these phenomena results in inter-symbol interference disturbances in data transmission systems, including even hundreds of symbols. Due to the number of reflections and, at the same time, the long memory time of the hydroacoustic channel, it is particularly difficult to ensure communication in water of harbour areas, channels and straits with a rocky bottom etc. Therefore, our goal is to develop a method of echoes reduction in the hydroacoustic channel, which could be used in broadband underwater communication systems. The article presents researches carried out on method of echo reduction in digital data transmission in the hydroacoustic channel. The effectiveness of the method will be evaluated based on a comparison of the impulse responses of the hydroacoustic channel determined before and after the elimination of the echo. Moreover the variance of in-phase component as well as coefficient of variation will be determined for transmitted digital data and compared before and after using proposed method of echoes elimination. The researches will be carried out for different carrier frequencies of the test signals. In the research, we will use simulation methods and experimental research conducted in the laboratory conditions.

Keywords: multipath propagation, echoes reduction, data transmission, hydroacoustic channel

1. INTRODUCTION

Propagation of sound in water is accompanied by a number of physical phenomena. Most of them have a negative impact on the possibility of using a sound wave for data transmission in hydroacoustic channel. An example of these phenomena can be refractions (positive, negative or variable sign), which affects the geometric range of hydroacoustic devices. Another phenomenon is the expansion of the wave front, which reduces the signal strength along with the distance from the sound source. The resistance of the environment, which increases as the frequency of the acoustic wave increases, also reduces the power of the received signal [5, 6]. Here it should be emphasized that the higher carrier frequencies allows faster data transmission, but at the same time reduces the distance at which data can be transmitted. A serious problem, especially when it comes to underwater communication, is the multipath propagation effect. Due to the relatively long memory time of the hydroacoustic channel, it causes inter-symbol interference, which under certain conditions may prevent transmission completely. This phenomenon is particularly evident in waters with strong hydrotechnical buildings (ports, canals), rocky bottoms, shallow water, etc. The multipath propagation effect results mainly from the reflection of an elastic wave from underwater obstacles. These obstacles may be specific underwater elements (walls, pillars, etc.), but also the surface of the water, the bottom as well as sudden changes in the physical and chemical properties of the water, for example salinity or temperature. This means that apart from the original sound, the receiver also receives reflected waves (echoes) of the transmitted signal. Echoes will have a lower level due to scattering, which depends on the frequency of the transmitted wave as well as on the material, from which the obstacle is made, its location and dimensions. Nevertheless, disturbances introduced by echoes may prevent proper reception of data transmitted using a hydroacoustic channel. This problem is very serious, because while there are many devices on the market for data transmission in the hydroacoustic channel, the vast majority of them can't cope with difficult propagation conditions, e.g. ports, where the effect of multipath is strong and the number of echoes reaching the receiver is significant.

For the above reasons, the authors of the article aimed to develop a method that would allow to reduce echoes during data transmission in the hydroacoustic channel.

This article is dedicated to research carried out in area of hydroacoustic and telecommunication. It must be noted that methods of echo reduction (echo cancellation, echo suppression) are commonly used in telephony [7]. There are some reports of using this kind of signal processing in radiocommunication. In such cases, adaptive filtration [9], blind separation [3] or convolution methods with the inverse impulse response of the transmission channel [1] are most often used. These methods suffer from a one serious disadvantage i.e. the transmission channel must be stationary in a relatively long time. In the case of underwater communication, this condition can rarely be met.

The structure of the article is as follows: the first part describes in detail the method of echo reduction using cepstral analysis. Further are presented results of simulation tests, the research laboratory stand and the results obtained from the tests in laboratory conditions. At the end, the results were discussed and the conducted works were summarized as well as further research directions were indicated.

2. METHOD DESCRIPTION

We assume that as a result of multipath phenomena, in the received signal, the transmitted signal and its echoes created by reflections of transmitted signal from underwater obstacles, have been added to each other. Delay of echoes depends on length of path of propagation and amplitude depends on material of obstacle. So we can write as follow:

$$x(n) = s(n) + \sum_{i=1}^{M} \alpha_i s(n - n_i) \qquad (1)$$

where: $x(n)$ – received signal, $s(n)$ – transmitted signal, n – discreet time (sample), α_i - the amplitude factor of the i-th echo, n_i – delay of the i-th echo resulting from the multipath propagation, M – the number of significant echoes of the transmitted signal.

Developed method of echoes reduction based on observation that in result of cepstral analysis there are maxima corresponding to the echoes of original signal. The cepstrum is an inverse Fourier transform, of the spectrum of the signal expressed in a logarithmic scale, what can be written as follows [2, 8, 10]:

$$C\big(x(n)\big) = F^{-1}\Big(ln\Big(F\big(x(n)\big)\Big)\Big) \qquad (2)$$

where: F – Fourier transform, F^{-1} – inverse Fourier transform.

The cepstrum contains components related to the echoes-free signal (later defined as original signal), as well as the components resulting from the presence of echoes. The components derived from echoes can be filtered by linear filtration methods. According to the conducted researches, in suggested solution we propose to filtrate only this components which corresponds to the appearance of individual echoes. It must be noted that result of cepstrum analysis is symmetrical to half the length of the signal being analysed. Components connected with occurring echoes appears on left and right side of cepstrum. According to the conducted research, only components on left side should be filtered. Because the information about echoes is not known in advance so filtration is made in two steps. Firstly, there are searched components with locally maximum values in a given range (chosen so as not to delete information about the original signal). In location of selected components the cepstrum is multiplied with inversed Hanning window with a given width (width of few components). It causes zeroing components corresponding to the appearance of echoes. Such modified cepstrum will be used to reproduce the signal in the time domain. Here we use the property that the cepstrum function is a reversible function. This process can be written as follow [2, 8, 10]:

$$x(n) = C^{-1}\big(x(n)\big) = F^{-1}\left(exp\left(F\left(C\big(x(n)\big)\right)\right)\right) \tag{3}$$

Figure 1 presents a block diagram of the system performing the operation of multipath effect elimination from the input signal.

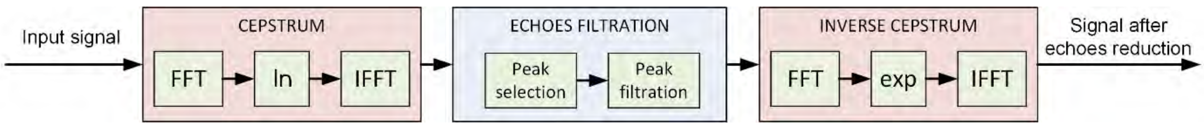

Figure 1 The block diagram of signal processing during echoes reduction

Our research confirmed that the filtration process of selected components of cepstrum should be repeated several times (in investigated cases 3 to 5 times) to get the best result.

Assessment of effectiveness of the developed method of echoes reduction will be carried out based on a comparison of channel impulse response estimates determined for the original signal (recorded) and after echoes reduction. In the impulse response of the hydroacoustic channel there are maxima, which correspond to the echoes of the transmitted signal which are reaching receiver as a result of the multipath propagation. The most important will be change of levels of significant echoes identified in channel impulse response. Estimation of hydroacoustics channel impulse response can be determined using pseudo-random binary sequence [4, 11]. The estimate of channel's impulse response can be determined using module of cross-correlation function between the pseudo-random binary sequence and the received signal brought to baseband. The cross-correlation can be calculated according to the formula:

$$R_{zy}(k) = \sum_{n=0}^{N-1-|k|} z(n)y^*(n-k) \tag{4}$$

where: $z(n)$ – represents a pseudo-random sequence, $y(n)$ – received signal brought to the baseband.

Based on (4) the estimation of impulse response of the hydroacoustic channel can be determined as follow [4, 11]:

$$I_R(k) = \sqrt{\left(\sum_{n=0}^{N-1-|k|} z(n)y_s^*(n-k)\right)^2 + \left(\sum_{n=0}^{N-1-|k|} z(n)y_c^*(n-k)\right)^2} \tag{5}$$

where:

$$y_s(n) = x(n)\sin(2\pi f_n n) \tag{6}$$

$$y_c(n) = x(n)\cos(2\pi f_n n) \tag{7}$$

where: f_n – carrier frequency.

During the researches, a sinusoidal signal modulated by a pseudo-random binary sequence PRBS with the use of BPSK (Binary Phase Shift Keying) modulation was used. In our research we are using Gold sequence as PRBS.

As second assessment we will use statistical parameters which characterize constellation during digital data transmission. During research we will use Binary phase-shift keying (BPSK) modulation (sometimes called phase reversal keying PRK or two phase shift keying 2PSK) which is the simplest form of phase shift keying. We will use two phases 0 and 180 degree. During demodulation each symbol can be represented by a complex number, and the constellation diagram can be regarded as a complex plain with the horizontal real axis representing the in-phase (I component) carrier (cosine wave) and vertical imaginary axis representing the quadrature (Q component) carrier (sine wave). An ideal constellation diagram for BPSK will show two position of the point representing each symbol. But, because of noises, distortion, multipath propagation, carrier frequency change etc. during passing through communication channel, the values of amplitude and phase after demodulation may differ from the correct value for each symbol. It causes that point on constellation diagram, representing received symbols, will be offset from the correct position of symbol. If the aforementioned phenomena causes a significant dispersion, it can lead to a situation in which the point representing the symbol will be in the region represented by another symbol. In this situation demodulator will misidentify that symbol what results in an error [12]. One of the measures of dispersion is variance. We will determine this value only for I axis, because of used BPSK modulation, before and after echoes reduction what should shows the influence of presented above method on the possibility of correct data reception. To calculate this parameters we will use following formulas:

$$\sigma_I^2 = \frac{1}{m}\sum_{m=0}^{M-1}(y_{Ic}(m) - \mu_I)^2 \tag{8}$$

where:

$$\mu_I = \frac{1}{m}\sum_{m=0}^{M-1} y_{Ic}(m) \tag{9}$$

$$y_{Ic}(m) = \left|\sum_{l=0}^{L-1} y_c(m+l)\right| \tag{10}$$

Where: L – length of single symbol in samples.

Moreover, we will determine coefficient of variation which is defined as the ratio of the standard deviation to the mean value:

$$v_I = \frac{\sigma_I}{\mu_I} \tag{11}$$

This coefficient will show the extent of variability in relation to the mean value. The higher the coefficient of variation, the greater the dispersion and the worse the average representing the population, and therefore constellation has a lower cognitive value.

All mentioned above parameters, estimated impulse responses and variations of in-phase components of constellation diagram as well as coefficient of variation, determined before and after echoes reduction should show the usability of the proposed echoes reduction method in hydroacoustic communication systems.

3. RESULTS OF RESEARCH

In the first stage of the research, to properly assess the correctness of the adopted solutions and to have the possibility to influence all parameters, controlled test conditions were prepared in a simulation environment. Simulation tests were carried out in the Matlab computing environment. The first task was to prepare test signal. Therefore, the results of measurement carried out under real conditions based on measurement of impulse responses of hydroacoustic channels were used [11]. For the selected estimation of impulse response the significant echoes were identified (figure 2).

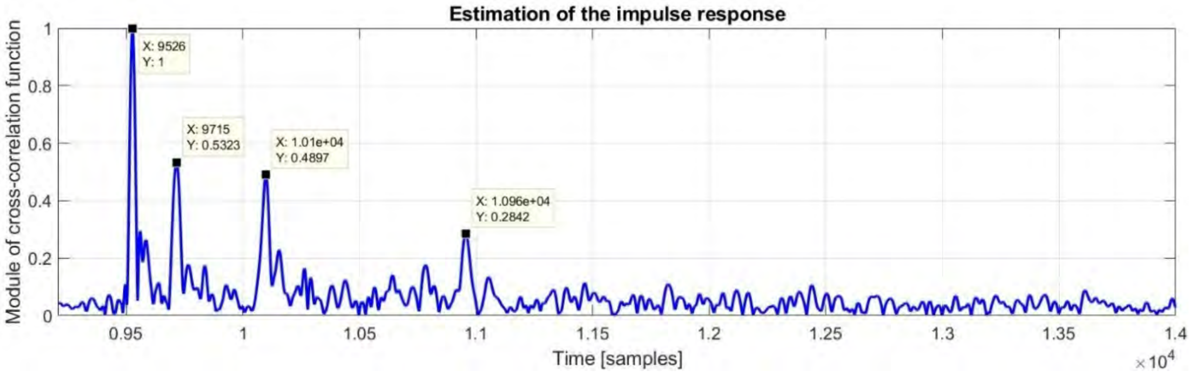

Figure 2 Estimation of impulse response of hydroacoustic channel with marked significant echoes used during signal generation in simulation researches

Knowing the delays as well as the level of the echoes amplitudes, a test signal was generated by simply summing the dispersed signals with the appropriate time delays and signal amplitudes. The signal was then subjected to an echo reduction process according to the method described above. The impulse response estimate was again determined for the result signal. Figure 3 shows the impulse response estimate before and after echo reduction.

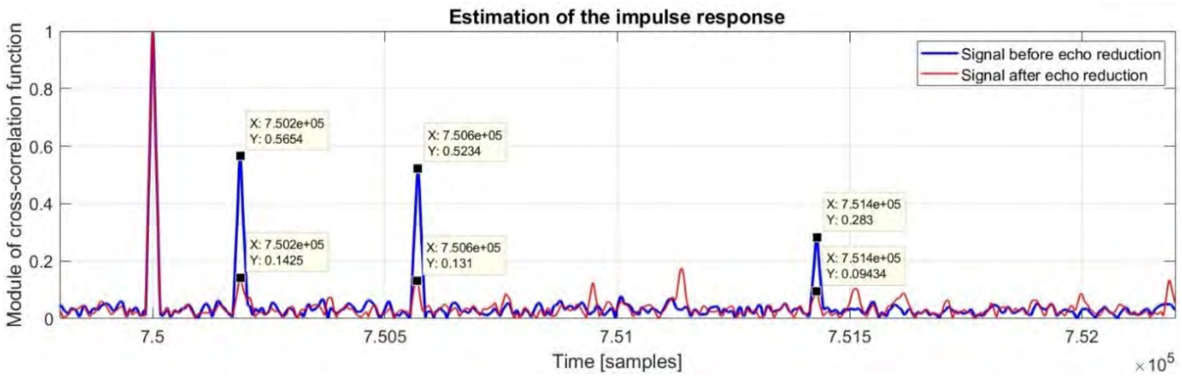

Figure 3 Estimation of impulse response for signals before and after echoes reduction

Simulation studies allows us to follow the process of reducing echoes over time. Figure 4 shows how the impulse response changes as a result of the applied method.

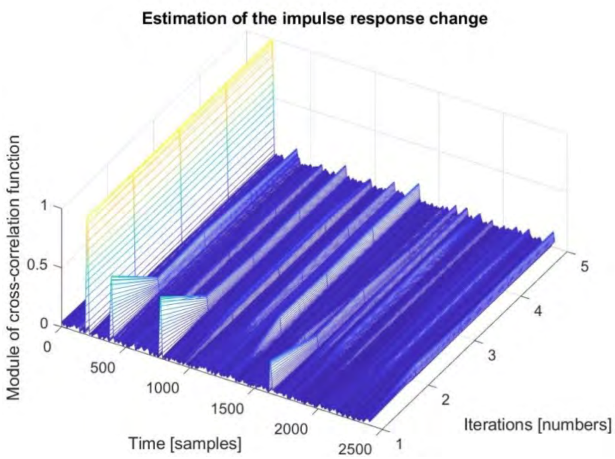

Figure 4 Changes in estimation of impulse response during echoes reduction process

As it is shown the level of significant echoes decrease 4 to 3 times relatively to signal before echoes reduction. Simulation tests were repeated for different carrier frequencies which changes in the range from 10 kHz to 150 kHz. The results obtained were similar. This allows to draw the initial conclusion that the solutions adopted in the method of echo reduction are applicable.

The next stage of the research was carried out in laboratory conditions. For this purpose, a measuring stand was prepared which consisted of the following elements: transmitting path: laptop with NI SignalExpress software, a NI USB-6259 multifunction I/O device, an Etec PA1001 power amplifier, and Reson TC4013 hydrophone; the receiving path: Reson TC4013 hydrophone, Reson EC6061 amplifier, NI-9222 voltage input module, laptop with NI SignalExpress software [4]. The researches were carried out in the water tank which had dimension of (width × length × depth) 120 × 143 × 110 cm. The used water tank is a very difficult environment for data transmission in the hydroacoustic channel. This is due to strong reflections from the boundaries of tank and its small size, which results in short times of many echoes.

In determining estimation of hydroacoustic channel impulse response we used Binary Phase Shift Keying (BPSK) modulated signals. The signal carrier frequency was changed between 10 kHz and 150 kHz and was modulated at a rate f_{symb}=25 ksymbols/sec by linear binary sequence of length 2047 bits. After recording received signal it was processed according to the described above method of echoes reduction. Figure 5 shows chosen results of estimation impulse response before and after echoes reduction. Results of tests conducted for other carrier frequency were similar.

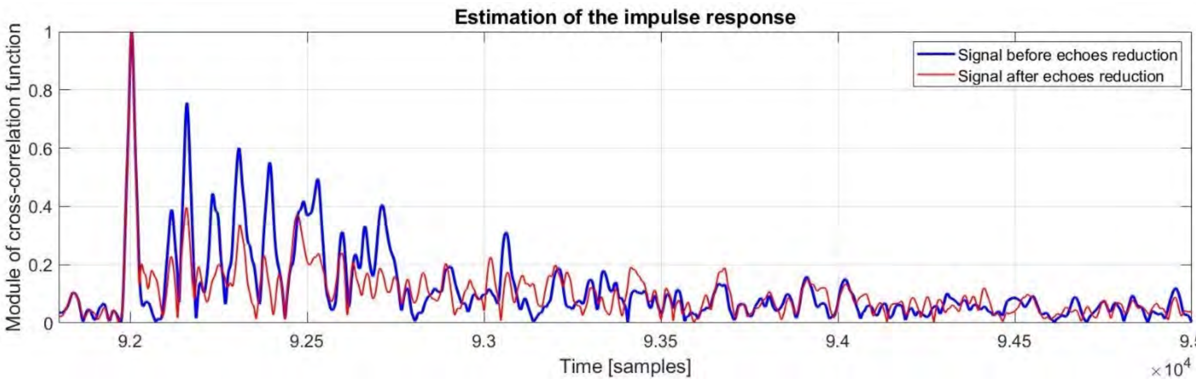

Figure 5 Estimation of impulse response for signals before and after echoes reduction during laboratory condition researches

As it is shown most of significant echoes level decrease almost 2 times. This suggests that the method works even in such difficult conditions as during laboratory tests.

In the next step of the research, the influence of the described echo reduction method on the data transmission in the hydroacoustic channel was checked. Using the same measurement system we transmitted information organized as follow: first 14 bits were set as logical ones (synchronization bits) and next 140 bits was data bits. Data were transmitted using bandwidth from 10kHz to 120kHz. The assessment of the impact of the presented method on data transmission was based on a change in the variance of the I component as well as coefficient of variation. Figure 6 and 7 presents constellation for signal transmitted at carrier frequency equal to 100kHz and two bandwidth respectively: 10kHz and 90kHz.

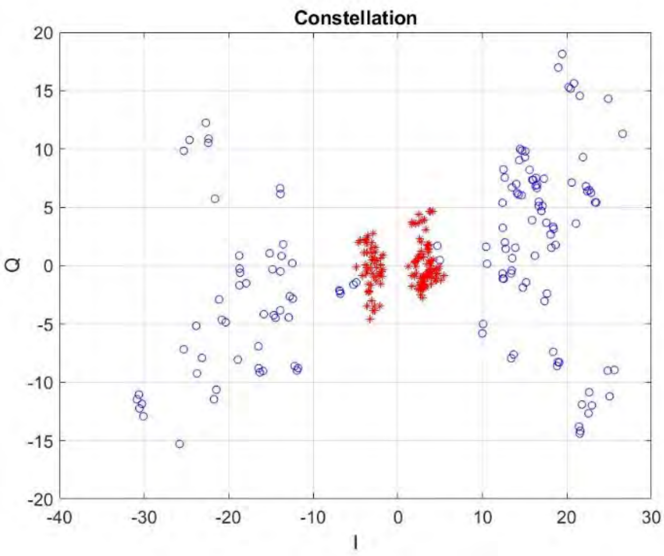

Figure 6 Constellation before (blue colour) and after (red colour) echoes reduction during laboratory condition researches for transmission of data at carrier frequency of 100kHz and bandwidth 10kHz

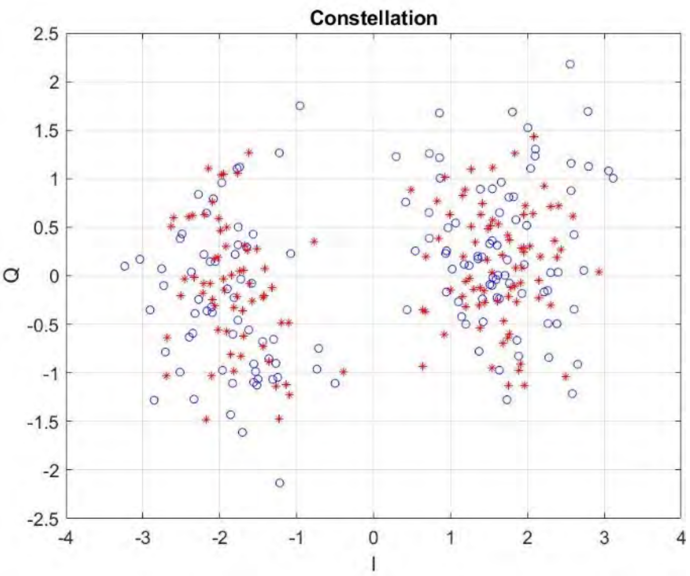

Figure 6 Constellation before (blue colour) and after (red colour) echoes reduction during laboratory condition researches for transmission of data at carrier frequency of 100kHz and bandwidth 90kHz

As it is shown in Figure 5 and 6 the value of variation for I component as well as coefficient of variation has been lowered after multipath effect elimination. In the first case (bandwidth 10kHz) variance of I component decrease form value 28.9815 to 0.6949 and coefficient of variation decrease from value 0.3186 to 0.2493. In the second case (bandwidth 90kHz) variance of I component decrease from value 0.3959 to 0.2479 and coefficient of variation decrease from value 0.3557 to 0.2901. It must be noted that for transmission made in narrow band the improvement is much better. In general, it can be said that the described above method allows to reduce the dispersion of transmitted data, which improves the ability to distinguish between logical states of transmitted information. Thanks to this, one should expect a reduction in the number of errors in the transmitted data and thus an improvement in the quality of transmission.

4. CONCLUSION

The article presents results of researches which concentrate on development and testing method of echoes reduction in signals transmitted by a hydroacoustic channel. The presence of echoes results from the occurrence of the phenomenon of multipath propagation and is undesirable for telecommunications systems operating in this environment. Long memory time of the channel causes significant inter-symbols interference.

In the described solution we used cepstral analysis to reduce echoes. We conducted studies of the developed method at the beginning in simulation conditions and then laboratory conditions close to real. Evaluation of the correctness of the echoes reduction method was performed in two stages. In the first one, we assessed the impact on the impulse response of the channel, which, among other things, allows us to identify and measure specific echoes. In this study, it is clear that the echoes have been reduced as a result of the described method. In the second stage, we used the data transmission with the simplest BPSK modulation. In this case, we assessed the impact of the method on the obtained constellation. We made the assessment of the constellation based on statistical values, i.e. the variance and the coefficient of variation. As it is shown in presented results we have achieved an improvement in the transmission quality i.e. reduced dispersion of I components, after echoes reduction. It should be noted that in the case of increasing the bandwidth in which data transmission occurs, the impact of the method on the transmission quality decreases. This may result from overlapping spectra of echoes and inability to separate them (each data packet is the resultant value of all replicas arriving during the chip's duration of the modulating signal transmitted). Conducted experiments in laboratory conditions confirmed the usability of the echo reduction method according to the described method.

Future research should concern the impact of echo cancellation parameters (number of peaks reduced in Cepstrum, number of reductions, reduction bandwidth, etc.) as well as real-time testing to confirm the suitability of this method in data transmission devices in the hydroacoustic channel.

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