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Overview of Channel Equalization Technology for Underwater Acoustic Communication

Qianqian Wu, Feng Liu*

College of Information Engineering, Shanghai Maritime University, Shanghai 201306, China.

* Corresponding Author

Abstract

Underwater acoustic communication technology is related to the construction of national marine military power and the detection of marine resources, and has great research value. However, underwater acoustic communication is more difficult than terrestrial wireless communication, mainly because of the difference between the two transmission channels. The characteristics of underwater acoustic channel include limited bandwidth, fast time variation, strong noise interference, strong multipath effect, etc. These characteristics seriously affect the speed and quality of underwater communication. The channel equalization technology can compensate the received signal to a certain extent and eliminate the influence of the channel on the signal. Therefore, this paper briefly introduces the channel equalization technology of underwater acoustic communication. Then, the adaptive equalization technology of underwater acoustic communication is summarized, and the main research directions of the adaptive equalization technology of underwater acoustic channel at home and abroad are summarized. Finally, the prospect of the channel equalization technology of underwater acoustic communication is prospected.

Keywords

Underwater acoustic channel, channel equalization, adaptive equalization algorithm.

1. Introduction

Underwater communication mainly uses sound waves as the signal carrier, because high-frequency radio signals commonly used on land will decay rapidly in seawater, and optical electromagnetic waves will be seriously scattered in water. Only the acoustic signal has good propagation characteristics in water and can achieve long-distance propagation. However, the underwater acoustic (UWA) channel is a particularly complex channel. The propagation of sound waves in seawater will be affected by various marine geographical conditions, natural environment conditions and various random factors [2]. The acoustic signal propagating underwater will suffer from distortion, energy loss, volatility and other uncertain changes. In general, the characteristics of the UWA channel are summarized as follows: fast time-varying, strong noise interference, strong multipath effect, and limited bandwidth [3]. In order to realize high-speed and reliable UWA digital communication, diversity technology [4], equalization technology and channel coding technology [5-6] are often used to reduce the multipath propagation effect and improve the quality of the received signal. This paper briefly introduces the equalization technology, and analyzes the research status of adaptive equalization.

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2. Channel Equalization Technology

2.1. The principle of channel equalization

The equalization technique compensates for the intersymbol interference caused by the multipath problem by implementing a special filtering method in the receiver. It can be simply understood that the transfer functions of the equalizer and the channel are reciprocals of each other, and the effects cancel each other, thereby obtaining the best transmission waveform [7].

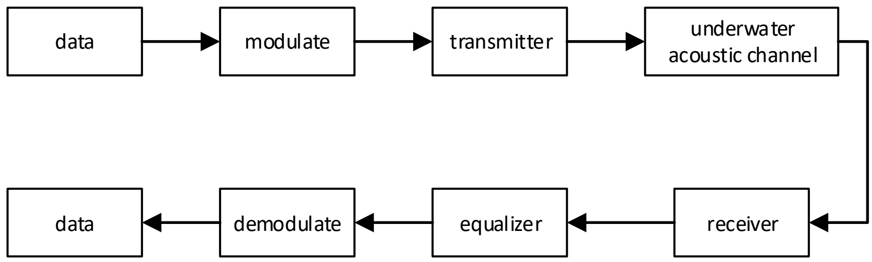

Figure 1: Block diagram of underwater acoustic communication system

The block diagram of UWA communication system is shown in Figure 1. Assuming that the transfer function of the transmitter is $T(f)$, the transfer function of the UWA channel is $C(f)$, and the transfer function of the receiver is $R(f)$, then the transfer function $E(f)$ of the UWA communication equalizer can be deduced as $E(f) = \frac{1}{T(f)C(f)R(f)}$ [8]. Theoretically, as long as the transfer function of the transmitter, the transfer function of the UWA channel and the transfer function of the receiver are known, the transfer function of the equalizer can be obtained. After the transfer function of the equalizer is obtained, the equalizer can be designed to compensate the channel and eliminate the signal distortion at the receiving end.

2.2. Classification of equalizers

The equalizer can be divided into frequency domain equalizer and time domain equalizer according to the research angle [9]. The frequency domain equalizer compensates the frequency characteristics of the channel through the frequency characteristics of an adjustable filter, thereby correcting the frequency characteristics of the system and making the transmission process close to distortion-free transmission. This method is suitable for the situation where the channel characteristics are unchanged and low-speed data is being transmitted. The time domain equalizer directly corrects the distorted response waveform, increases the number of taps by increasing the order of the equalizer, and eliminates the components on the non-zero coordinates of the channel impulse response as much as possible, so as to meet the channel transfer function conditions without intersymbol interference. Time-domain equalization can be adjusted according to the change of channel characteristics, which can effectively reduce inter-symbol crosstalk, so it is widely used in high-speed data transmission [10].

3. Adaptive channel equalization

Before the advent of adaptive equalization technology, the coefficients of each tap of the equalizer were set in advance. When the channel changes, the channel estimation technique is usually used to estimate the channel in real time and adjust the tap coefficients according to the estimation result [11]. However, the calculation of filter coefficients through channel estimation involves matrix inversion calculation, and the longer the channel length, the greater the

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computational complexity. At the same time, for a fast time-varying channel, this method of determining tap coefficients and channel estimation in advance cannot track the changes in time, which will lead to rapid performance degradation [12-13]. Each coefficient of the adaptive equalizer is automatically adjusted according to the judgment result of the equalization output. When the error value of each equalization output is smaller than a certain value or the coefficient adjustment range is smaller than a certain threshold, the equalizer tends to be stable and converge. The main feature of the adaptive equalizer is that it has a feedback structure, which can feed back the equalized output to the equalizer to guide the adjustment of the coefficients. Figure 2 shows the block diagram of the adaptive equalizer.

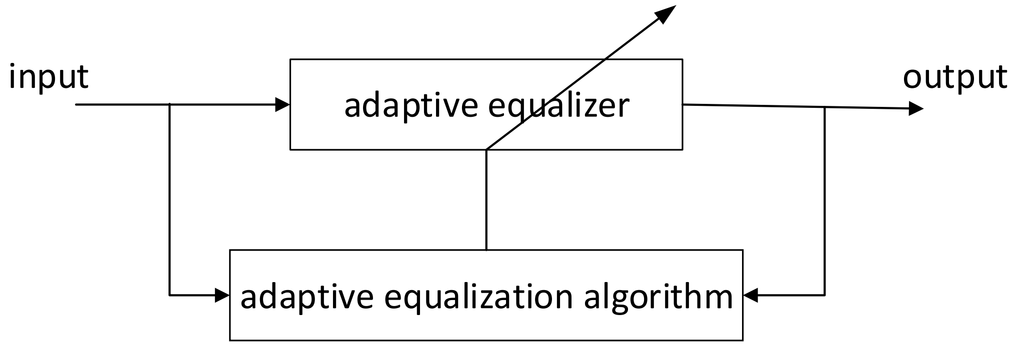

Figure 2: Block diagram of adaptive equalizer

The adaptive equalizer adjusts the tap coefficients according to the corresponding criterion strategy to adapt to the change of the channel, so as to adjust the equalizer coefficients in real time. The coefficient adjustment algorithm of the adaptive equalizer should ensure the decrease of the error and the convergence of the coefficients. Adaptive equalization algorithms can be roughly divided into two categories: least mean squares (LMS) adaptive algorithms and recursive least squares (RLS) adaptive algorithms. RLS is an algorithm that recursively deduces the tap coefficients of the filter at time n through the tap coefficients of the transversal filter at time n-1. The criterion it follows is to make the sum of the square of the difference between the actual output value and the expected value of each symbol filter multiplied by the weight coefficient to be the smallest. The RLS algorithm has good performance and fast convergence speed, but the calculation is complicated, which is not conducive to real-time processing [14]. The LMS algorithm, namely the minimum mean square error (MMSE) algorithm, is designed based on the minimum mean square error criterion, that is, the mean square error value between the actual output and the expected output of the algorithm is the smallest. When implementing the LMS algorithm, it is not necessary to implement more complex algorithms such as logarithmic operations and differential operations. Therefore, the algorithm is computationally efficient, easy to transplant, and has a relatively simple structure [15].

Using an adaptive algorithm to mitigate intersymbol interference, no channel estimation is required, but relatively long training symbols are required to achieve convergence. The convergence speed and convergence result of the algorithm are the important basis for evaluating the quality of the adaptive algorithm, and the performance of the equalizer can be improved by optimizing the adaptive algorithm.

4. Research achievements at home and abroad

At present, the main research contents of equalizer in UWA communication include: combining with phase-locked loop technology to improve phase tracking capability [16], combining with space diversity or time inversion technology to improve system performance [17-19], improving the structure of the equalizer and improving the equalization performance of the algorithm [20], combining with the decoder to construct iterative equalization [21] and so on.

Next, we mainly introduce the research status of adaptive equalization algorithm in UWA communication.

In 2019, Qin et al. proposed a low-complexity RLS type sparse direct adaptive equalizer for multiple-input multiple-output UWA communication, and experiment showed that this method has faster convergence and better performance [22]. Wu et al. proposed the sparse control proportionate minimum-symbol-error-rate decision feedback equalizer in [23], which took advantage of the low bit error rate (BER) advantage of the minimum-symbol-error-rate (MSER) criterion and at the same time took advantage of the sparseness of the channel equalizer to allocate more equalizer taps with larger values. Large weights increased the convergence speed of the equalizer. The simulation results verified the effectiveness of the scheme. In [24], Jun Tao et al. comprehensively compared proportionate-updating-type sparse direct adaptive equalizer (DAE) and zero-attracting-type sparse DAE, and proposed sparse partial tap update DAE in single-carrier UWA communication. This scheme had performance improvement over existing sparse DAE. In [25], the deep learning based receiver proposed by Zhang et al. alternately adopted online training and testing modes to adapt to the temporal variation of UWA channels, obtained better detection performance, and significantly reduced training overhead. In [26], Zi Ye et al. proposed a fully adaptive low-complexity joint iterative channel equalization and channel decoding technique. This scheme only needs to update a small number of coefficients, which reduces the complexity of the equalizer and is more suitable for real-time processing. In [27], Sui et al. proposed an orthogonal frequency division multiplexing UWA channel equalization method based on the variable-step LMS algorithm. Simulation results demonstrated the improvement of this scheme in terms of BER performance. In 2020, Qin et al. extended a dynamic compressed sensing technique called sparse adaptive orthogonal matching pursuit (SpAdOMP), adopt the dynamic compressed sensing technique to seek a way to track the dynamics of the DAE structure, in addition to its coefficients. The taps of the resulting SpAdOMP DAE are updated with the affine projection algorithm, experimental results showed it significantly outperformed existing DAEs [28]. In [29], Xi et al. proposed an improved proportional normalized minimum symbol error rate algorithm for the adaptive turbo equalization of deep-sea vertical acoustic communication, incorporating the sparse perception proportional method into the framework of the MSER standard to achieve faster convergence. In [30], Zi Ye et al. proposed an original self-optimizing algorithm whose step size is adaptively updated and assisted by soft information provided by the channel decoder in an iterative manner. It leads to good BER performance by achieving a good trade-off between the convergence speed and accuracy over time-varying channels. In general, the research contents of the adaptive equalization algorithm in UWA communication include: improve the BER performance, reduce the training overhead and speed up the convergence speed of the adaptive algorithm, reduce the complexity of the adaptive algorithm.

5. Conclusion

This paper introduces the characteristics of underwater acoustic channel, including fast time-varying, strong noise interference, strong multipath effect, limited bandwidth, etc. These factors greatly affect the quality of underwater acoustic communication. Channel equalization is widely used as an effective method to improve signal quality. This paper introduces the principle and classification of equalizers, adaptive equalization and typical adaptive equalization algorithms, and analyzes the research status of adaptive equalization algorithms for underwater acoustic channels. These equalization technologies are constantly developing and improving, and it is expected that underwater acoustic communication will be as reliable and fast as wireless communication in the near future.

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