**Lab 5：Channel estimation and time-domain equalization**

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| **Introduction**  **Experimental objective:**  Understand channel estimation and time-domain equalization algorithms in digital communication, and be able to use LabVIEW for experimental verification  **Least mean square (LMS) algorithm:**  Least Mean Squares (LMS) is a commonly used adaptive filtering algorithm used in the fields of system identification, signal processing and adaptive filtering. Its goal is to estimate the unknown parameters of the system by minimizing the mean square error. The basic principle of the LMS algorithm is to minimize the mean square error between the output of the filter and the desired output by continuously adjusting the weights of the filter. Specifically, the LMS algorithm updates the weights of the filter by gradient descent based on the difference between the current input signal and the desired output signal. In this way, the weights of the filter gradually converge to the optimal values over time, thus realizing the estimation of the system parameters. The advantages of the LMS algorithm are its simplicity and ease of implementation, its high computational efficiency, and its adaptability to nonlinear and time-varying systems. However, the LMS algorithm also has some drawbacks, such as high requirements for the statistical characteristics of the signal, and relatively weak suppression of noise and interference.  17022242837331702224521704  **Matrix representation of convolution:**  1702225566667  1702225593806  1702226178414  **Construction of the Toplitz matrix:**  The Toplitz matrix, abbreviated as T-matrix, was proposed by Bryc, Dembo, and Jiang in 2006. The elements on the main diagonal of a Toplitz matrix are equal, as are the elements on the lines parallel to the main diagonal; the elements of the matrix are symmetric about the subdiagonal, i.e., the T-matrix is a subsymmetric matrix. Simple T-matrices include forward displacement matrices and backward displacement matrices. Constructing a Toplitz matrix can be accomplished by the following steps: Determine the elements on the primary and secondary diagonals: First determine the values to be placed on the primary and secondary diagonals. Fill the matrix using a repeating pattern: Use the selected primary and secondary diagonal elements to fill the rows and columns of the matrix. Fill Remaining Elements: Fill the rest of the matrix as needed if other non-zero elements exist.  17022249779581702224997151  **indirect equalization algorithm:**  1702226686483Eq  Except in trivial channels Eq can not be satisfied exactly. The reason is that an FIR filter requires an IIR filter. The parameter nd in Eq is the equalizer delay and is generally a design parameter. Generally allowing nd > 0 improves performance. The best equalizers consider several values of nd and choose the best one. A straightforward approach is the least-squares equalizer. The key idea is to write a set of linear equations and solve for the filter coefficients that ensure that the Eq minimizes the squared error. Writing Eq in matrix form1702224997151  The matrix is a type of Toeplitz matrix, sometimes called a filtering matrix.Assuming that is full rank, which is guaranteed if any of the channel coefficients are nonzero, the linear least squares solution is 1702226899963  The squared error is measured as 1702227062307 The squared error can be minimized further by choosing nd such that Jf [nd ] is minimized. This is known as optimizing the equalizer delay.The equalizer order is Lf . The choice of Lf is a design decision that depends on L. The parameter L is the extent of the multipath in the channel and is determined by the bandwidth of the signal as well as the maximum delayspread derived from propagation channel measurements. The equalizer is an FIR inverse of an FIR filter. As a consequence the results will improve if Lf  is large. The complexity required per symbol, however, also grows with Lf .Thus there is a tradeoff between choosing large Lf to have better equalizer performance and smaller Lf to have more efficient receiver implementation.  1702225922508  **Lab results & Analysis**：   1. Minimum mean square algorithm (block diagram, programming process, simulation results)   **block diagram**  IMG_256  **simulation results**  IMG_256  h[0]=1 h[1]=0.3 h[2]=0.1 channel estimate length= 4 equalizer length = 4    h[0]=1 h[1]=0.3 h[2]=0.1 channel estimate length= 2 equalizer length = 2   1. Toplitz matrix construction, indirect equalization algorithm (block diagram, programming process, simulation results)   **block diagram**  C:\Users\Administrator\Documents\Tencent Files\328786803\Image\C2C\A15~%NJX9EW~MWLA`8ZYMLY.png  **simulation results**  **setting**    **results (change the equalizer length from 1 to 6)**    Length=1 Length=2    Length=3 Length=4    Length=5 Length=6  3.Analyze the effect of equalizer length on the equalization effect, and verify the relationship between equalizer length and SNR.  **setting**      As the length of the equalizer increases, the SNR becomes larger and larger. 1 to 3 has a larger variation, while 3 to 6 tends to flatten out, and the maximum length of the equalizer under this condition was tested to be 22, and the SNR tends to be infinite when it is larger than 22.  4. USRP verifies the effectiveness of the indirect equalization algorithm and explains the experimental results.  When symbol rate is 100k  equalizer length=1      equalizer length=6      When symbol rate is 1M  equalizer length=6      equalizer length=1      The results of effectiveness of the indirect equalization algorithm show that as the equalizer length getting higher, the SNR is higher, the signal we receive is better. And as the symbol rate getting higher, the signal we receive is worse. | |
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| **Experience**  **蔡浩宇**  IMG_256IMG_256  C:\Users\Administrator\Documents\Tencent Files\328786803\Image\C2C\}G9Q88Z]KQAHNQZ7Y4P{]SG.pngC:\Users\Administrator\Documents\Tencent Files\328786803\Image\C2C\M@$`BVGS_N7R%}[C}9Y5GW6.pngC:\Users\Administrator\Documents\Tencent Files\328786803\Image\C2C\A15~%NJX9EW~MWLA`8ZYMLY.png  曹子惠      **Experience**  In the process of completing the channel estimation and equalization using LabVIEW for the wireless communication experiment, we encountered some confusion regarding the construction of the Toeplitz matrix. Initially, I found it challenging to correctly understand how to construct the matrix using the given data and apply it to the channel estimation and equalization algorithms. To address this issue, I firstly sought clarification from classmates, discussing the specific steps and mathematical principles involved in creating the Toeplitz matrix. Additionally, I engaged in thorough research, exploring relevant literature and online resources to deepen my understanding of the concept. This involved studying the mathematical background behind Toeplitz matrices and their application in signal processing. Furthermore, I experimented with sample data and used trial-and-error methods within LabVIEW to test different matrix construction techniques. Through this iterative process, I gained practical insights into effectively constructing the Toeplitz matrix for the given scenario. | |
| **Score** | 100 |