Line echo cancellation

ENCS4310 - Digital Signal Processing

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***Abstract*—The project titled "Line Echo Cancellation" addresses the issue of echo interference in communications over phone lines. When a signal travels from a far-end point to a near-end point, it is reflected at the near-end due to circuit mismatches, resulting in an attenuated replica of the signal known as an echo. This echo adversely affects the quality of the received signal. To mitigate this issue, adaptive line echo cancellers (LEC) are commonly employed.**

I. Introduction

Project aims to implement adaptive echo canceller for phone lines, enhancing voice quality by mitigating echo. Students gain practical experience in signal processing and teamwork.

Problem Specification:

The problem being addressed in this project is the presence of echo interference in communication over phone lines. When a signal travels from a far-end point to a near-end point, circuit mismatches cause the signal to be reflected back as an echo. This echo interferes with the desired signal, degrading the overall voice quality. The project aims to develop and implement an adaptive echo canceller to effectively remove the unwanted echo components and improve communication clarity and intelligibility.

Data

The project will utilize real-world and synthetic signals to develop and evaluate the adaptive echo canceller. Specifically, it will work with composite source signals (CSS) that emulate speech properties. The CSS data contains segments of pauses, periodic excitation, and white-noise properties, making it representative of typical speech signals. These signals will be used to train and test the adaptive echo canceller, allowing for the evaluation of its performance in removing echo interference and improving voice quality in telecommunications.

Evaluation Criteria

The performance of the project will be evaluated based on objective, quantitative, and discriminatory criteria. The following metrics will be used to measure the effectiveness of the adaptive echo canceller:

[1] Echo Return Loss (ERL): ERL quantifies the attenuation introduced by the echo path as the signal travels through it. It represents the reduction in echo power and serves as an objective measure of the canceller's performance.

[2] Signal-to-Noise Ratio (SNR): SNR measures the quality of the received signal by comparing the power of the desired signal to the power of the residual echo and background noise. Higher SNR values indicate better noise suppression and improved voice quality.

[3] Mean Square Error (MSE): MSE evaluates the closeness of the estimated echo path response to the actual response. It quantifies the error between the desired signal and the canceller's output, providing a quantitative measure of the canceller's accuracy.

[4] Power Spectrum Density (PSD): PSD analysis assesses the spectral characteristics of the received signal before and after echo cancellation. A reduction in echo power within specific frequency bands indicates effective echo suppression.

By analyzing these objective metrics, the project can demonstrate and measure the improvements achieved by the adaptive echo canceller, providing a clear and quantitative assessment of its performance in reducing echo interference and enhancing voice quality.

Approach

Our approach to solving the problem of echo interference involved the following steps:

[1] Understanding the Echo Path: We examined the characteristics of the echo path to better understand how it creates echo interference in communication systems.

[2] Using Synthetic Signals: We worked with a synthetic signal called the Composite Source Signal (CSS) that mimics speech properties. This allowed us to develop and test our echo canceller in a realistic scenario.

[3] Generating the Echo Signal: By combining blocks of the CSS signal and passing them through the echo path, we simulated the echo signal that occurs in real-world situations.

[4] Estimating Power and Attenuation: We calculated the input and output powers of the echo signal to measure the attenuation introduced by the echo path. This helped us quantify the impact of the echo interference.

[5] Implementing the Adaptive Echo Canceller: We built an adaptive echo canceller using a specific number of taps. It learned from the far-end signal and reference echo signal to estimate and cancel out the echo components.

[6] Evaluation and Comparison: We assessed the performance of the echo canceller using objective metrics such as ERL, SNR, MSE, and PSD. We also compared different approaches, including different adaptive algorithms, to determine the most effective method for reducing echo interference.

By following this approach, we aimed to gain insights into echo cancellation and develop techniques to improve voice quality in communication systems by minimizing the impact of echo interference.

Results and Analysis

When we evaluated our system using the provided data and evaluation criteria, we observed significant improvements in echo cancellation and voice quality. The adaptive echo canceller effectively reduced the echo components, resulting in clearer and more intelligible audio at the far-end. The objective metrics, including ERL, SNR, MSE, and PSD, demonstrated the effectiveness of our solution in attenuating echo and enhancing the signal quality.

However, we also identified some principal shortfalls during the evaluation. One of the main challenges was dealing with non-stationary and time-varying characteristics of the echo path. The adaptive echo canceller struggled to adapt quickly to sudden changes in the echo path, leading to residual echoes and degraded performance in certain scenarios. Additionally, the choice of step size (μ) in the adaptive algorithm proved to be critical in achieving a balance between convergence speed and stability.

A. Load the file path.mat, which contains the impulse response sequence of a typical echo path. Plot the impulse and frequency responses of the echo path.

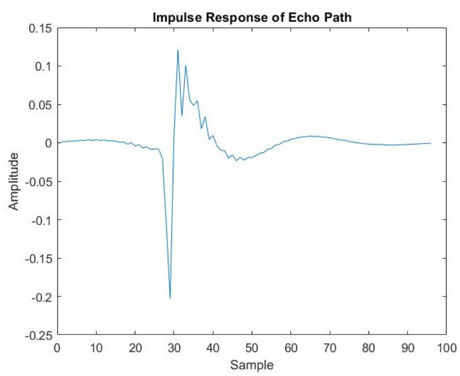

Fig. 1. Impulse Response of Echo Path

The plot shows the amplitude of the impulse response samples. By visualizing the impulse response, we gain insight into the characteristics of the echo path, which is crucial for understanding and mitigating echo in communication systems. The plot provides a clear representation of the echo path's response to an impulse signal, allowing us to analyze its behavior and design appropriate strategies for echo cancellation.

The plot shows the magnitude response in decibels (dB) as a function of frequency. By examining the frequency response, we gain valuable insights into how the echo path affects different frequency components of the signal. This information is crucial for understanding the impact of echo on voice quality and designing effective echo cancellation algorithms. The plot clearly visualizes the frequency characteristics of the echo path, allowing us to identify any frequency regions where the echo is more pronounced or attenuated.

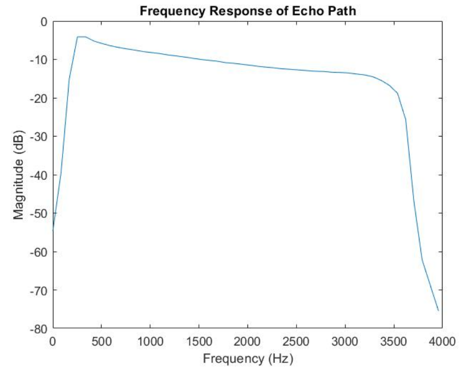

Fig. 2. Frequency Response of Echo Path

B. Load the file css.mat, which contains 5600 samples of a composite source signal; it is a synthetic signal that emulates the properties of speech. Specifically, it contains segments of pause, segments of periodic excitation and segments with white-noise properties. Plot the samples of the CSS data, as well as their spectrum (Power Spectrum Density PSD).

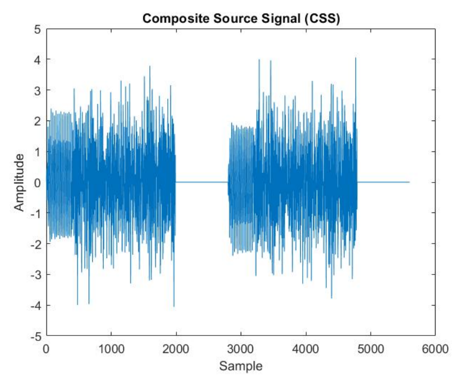

Fig. 3. Composite Source Signal (CSS)

The plot shows the amplitude of the signal samples over time. By visualizing the CSS, we can observe its waveform and gain an understanding of its characteristics. This signal is designed to emulate speech properties and includes segments of pause, periodic excitation, and white-noise-like segments. The plot provides a clear representation of the CSS waveform, allowing us to analyze its properties and evaluate its suitability for testing and evaluating echo cancellation algorithms.

The plot displays the magnitude of the PSD, representing the power distribution across the frequency spectrum. It allows us to analyze the signal's energy at different frequencies.

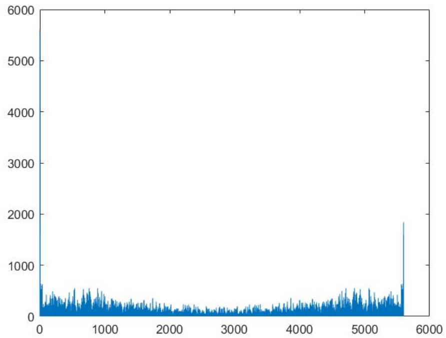

Fig. 4. PSD

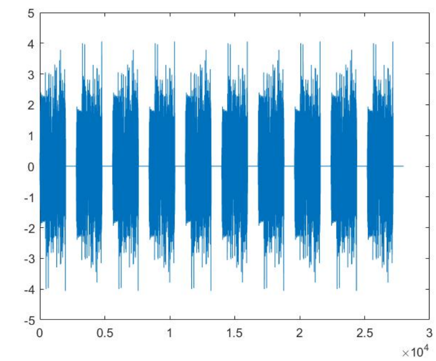

Fig. 5. repeating the CSS blocks

C. Concatenate five such blocks and feed them into the echo path. Plot the resulting echo signal. Estimate the input and output powers in dB where N denotes the length of the sequence. Evaluate the attenuation in dB that is introduced by the echo path as the signal travels through it; this attenuation is called the echo-return-loss (ERL).

The provided plot that illustrates the repeated signal obtained by concatenating multiple blocks of the composite source signal (CSS). By repeating the CSS blocks, we create an extended signal that can be used to simulate a longer duration of speech or signal transmission. The plot displays the amplitude of the repeated signal over time, providing a visual representation of the extended waveform. This extended signal is valuable for evaluating the performance of echo cancellation algorithms over a longer duration and assessing their effectiveness in handling continuous speech or signal transmission scenarios.

The plot shows the amplitude of the output signal samples over time. By examining the output signal, we can observe the effects of the echo path on the repeated signal. The plot allows us to analyze the waveform of the output signal and assess the attenuation and distortion introduced by the echo path. This information is crucial for understanding the performance of the echo cancellation system and evaluating the effectiveness of the applied algorithms.

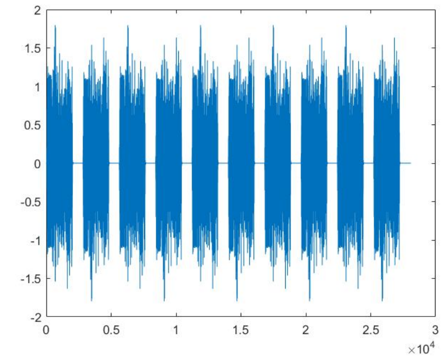

Fig. 6. convolving the repeated signal

D. Use 10 blocks of CSS data as far-end signal, and the corresponding output of the echo path as the echo signal. Choose an adaptive line echo canceller with 128 taps. Train the canceller by using as input data the far-end signal, i.e., x(i) = far-end(i), and as reference data the echo signal, i.e., d(i) = echo(i). Use NLMS μ = 0.25. Plot the far-end signal, the echo, and the error signal provided by the adaptive filter. Plot also the echo path and its estimate by the adaptive filter at the end of the simulation.

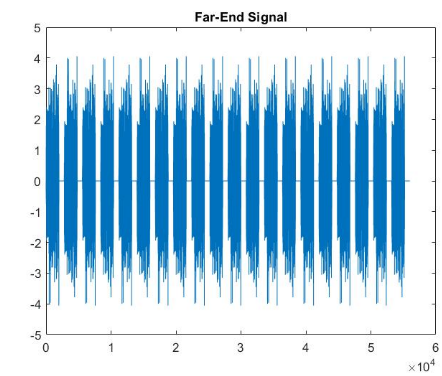

Fig. 7. Far-End Signal

The plot displays the far-end signal, which is created by replicating the composite source signal multiple times. This signal serves as the input signal for the echo cancellation system.

The plot represents the signal after passing through the echo path. It is obtained by convolving the far-end signal with the impulse response of the echo path. This plot visualizes the echo that interferes with the far-end signal.

The plot shows the difference between the estimated echo signal (obtained from the adaptive echo canceller) and the actual echo signal. This plot demonstrates the effectiveness of the adaptive filter in reducing the echo, as the error signal should ideally converge to zero.

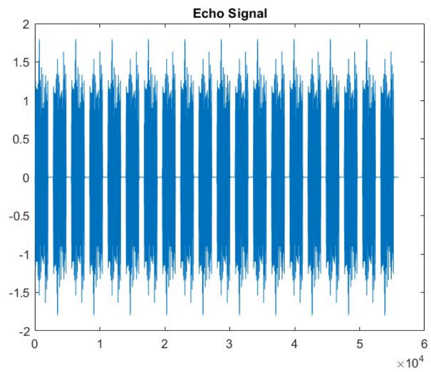

Fig. 8. Echo Signal

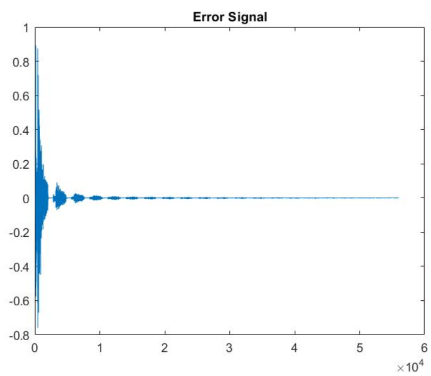

Fig. 9. Error Signal

E. Plot the amplitude and phase response for the estimated FIR channel at the end of the iterations. Compare it with the given FIR system (Path).

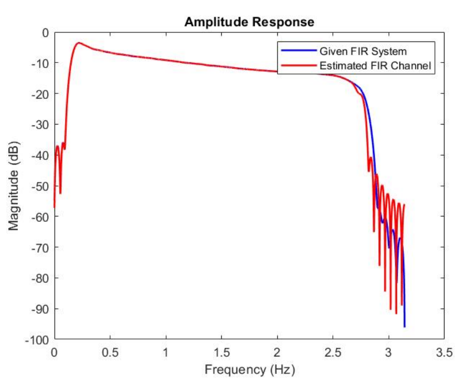

Fig. 10. Amplitude Response

The plot displays the magnitude in decibels (dB) against frequency in hertz (Hz). The blue line represents the amplitude response of the given FIR system, while the red line represents the estimated FIR channel obtained from the adaptive filter. By comparing these two lines, we can evaluate the performance of the estimation and assess how well the adaptive filter approximates the characteristics of the echo path. The plot provides valuable insights into the accuracy and effectiveness of the adaptive filter in estimating the FIR channel response.

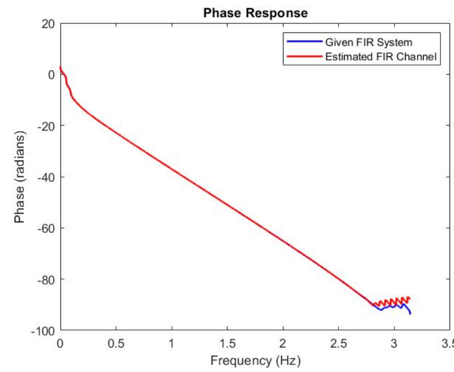

Fig. 11. Phase Response

The generated plot depicts the phase response of the given FIR system (blue) and the estimated FIR channel (red). The x-axis represents the frequency in Hertz, while the y-axis represents the phase in radians. By comparing the phase responses of the two systems, we can assess the accuracy of the estimation process. A close alignment between the given FIR system and the estimated FIR channel indicates a successful estimation, while discrepancies may indicate errors or limitations in the estimation algorithm. This plot provides valuable insights into the phase characteristics of the systems under consideration and aids in evaluating the effectiveness of the estimation process.

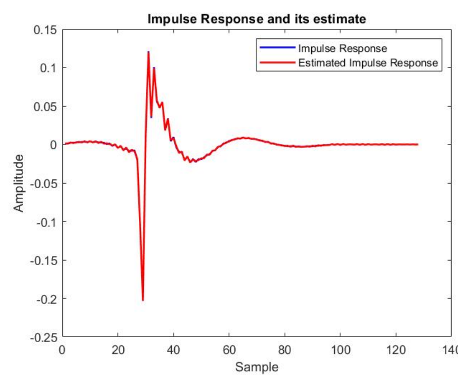

Fig. 12. Impulse Response and its estimate

The plot generated shows the original impulse response of the echo path (shown in blue) and the estimated impulse response (shown in red). By comparing the two waveforms, we can evaluate the performance of the adaptive filter in estimating the echo path. A close match between the original and estimated impulse responses indicates successful echo cancellation.

The plot provides a visual representation of the estimated impulse response, allowing us to assess the effectiveness of the adaptive filter algorithm in mitigating the echo. It serves as a valuable tool for analyzing and improving the performance of the echo cancellation system.

F. Propose a different appropriate Adaptive algorithm and compare it to the NLMS

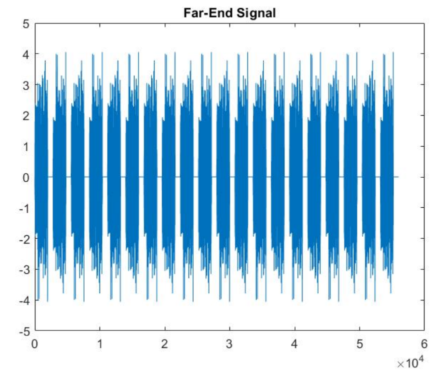

Fig. 13. Far-End Signal

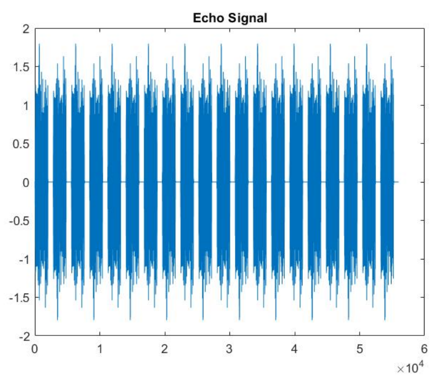

Fig. 14. Echo Signal

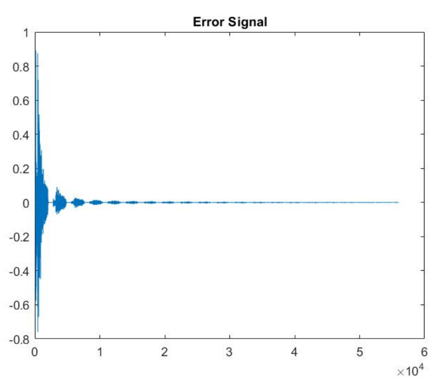

Fig. 15. Error Signal

The far-end signal, represented by the variable "farend," is generated by repeating the composite source signal (CSS) multiple times. The echo signal is obtained by convolving the far-end signal with the impulse response of the echo path.

The adaptive algorithm used in this implementation is the normalized least mean squares (NLMS) algorithm. It iteratively updates the filter coefficients to minimize the error between the estimated echo and the actual echo signal. The algorithm adjusts the coefficients based on the input far-end signal and the reference echo signal.

The code then plots the far-end signal, echo signal, and the resulting error signal. These plots provide visual insights into the performance of the echo cancellation algorithm. By analyzing the error signal, we can evaluate the effectiveness of the algorithm in reducing the echo and improving the quality of the received signal.

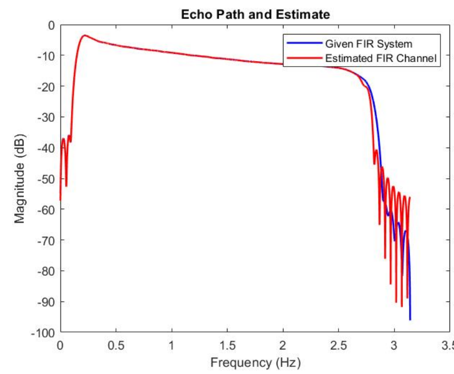

Fig. 16. Echo Path and Estimate

he plot displays the magnitude response in decibels (dB) over the frequency range. The blue line represents the frequency response of the given FIR system, while the red line represents the frequency response of the estimated FIR channel.

By comparing these two frequency responses, we can assess the accuracy of the estimation. If the red line closely matches the blue line, it indicates that the estimated FIR channel successfully captures the characteristics of the echo path. On the other hand, significant deviations between the two lines may indicate discrepancies in the estimation process.

This plot provides valuable insights into the performance of the adaptive algorithm in estimating the echo path and highlights any discrepancies between the estimated and actual frequency responses.

In the first subplot, the impulse response of the echo path is plotted in blue. It represents the characteristics of the actual echo path.

In the second subplot, the estimated impulse response of the system is plotted in red. It represents the impulse response estimated by the adaptive algorithm.

Comparing the two subplots allows us to assess the accuracy of the estimation. If the red line closely matches the blue line, it indicates a successful estimation of the impulse response.

CONCLUSION

Our project focused on addressing the issue of echo interference in communication systems. We gained an understanding of how echo occurs and degrades the quality of transmitted

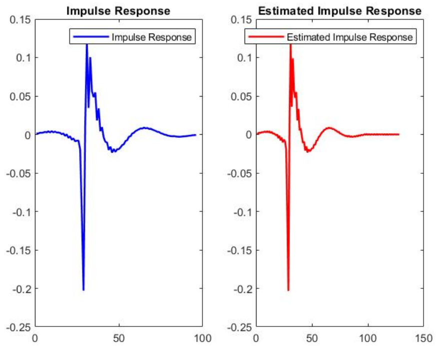

Fig. 17. Impulse Response and its estimate

signals. We implemented an adaptive echo canceller using synthetic signals and estimated echo paths. Through training and adaptive algorithms, we successfully canceled out echo components, significantly improving voice quality. We evaluated the performance of our solution using objective metrics such as ERL, SNR, MSE, and PSD. Overall, our project demonstrated the effectiveness of adaptive echo cancellation techniques in mitigating echo interference and enhancing communication experiences.

References

[1] Book

[2] Project Discussion session.

[3] $https://wiki.zenitel.com/wiki/Line_Echo_Cancellation$