UNDERWATER ACOUSTIC COMMUNICATION AND HARDWARE IMPLEMENTATION

Student : Seungyeon Lee, Ling Lin, Liting Zheng, Jun Hong   Mentor : Dr. Yun Ye, Dr. Shenglan Yuan

Introduction

Underwater acoustic communication (UAC) is crucial for many industries like commercial, scientific, meteorology, agricultural, military. Its practical applications include scuba divers signaling, submarine navigation, and tsunami detection. This research demonstrates UAC by developing an adaptive embedded hardware platform for signal propagation, data reception, and algorithmic analysis.

Methods

Hardware Configuration: We configure the Eclypse Z7 board using Xilinx software to transmit an audio underwater through the UW30 speaker and record the audio with a hydrophone.

Data Analysis: Using MATLAB, we apply two algorithms:

- **Mean Squared Error (MSE) Algorithm:** Quantifies the difference between the transmitted and received values. The MSE equals zero when signals matches perfectly.
- **Adaptive Least Mean Square(LMS) Algorithm:** Adapts to changing conditions by updating filter coefficients to minimize the mean squared error between the desired and actual output.

Figure 1: Hardware and Software Used for UWA System

Experiment Date: 5/11/24
Transmitter Location (Constant): 30cm from both corners of pool in the shallow end
Frequency: 44100 Hz
Pool Dimensions: 18.3m x 22.86m

Range	Depth	Notes
3m	0m	Starting point is based on where table was, by the corner of the shallowest part of the pool Receiver is always 30cm from south pool wall Went west from starting point, going towards 1.21m pool deep end Pool contained fans which may disrupt signal
	0.5m	
	1m	
5m	0m	
	0.5m	
	1m	
10m	0m	Fans were closest to this end Receiver is still 30cm from south pool wall, but at this range it was 1.67m from the far edge
	0.5m	
	1m	

Table 1: Location Documentation for 5/11/24

Experiment Date: 5/18/24
Transmitter Location (Constant): 30cm from both corners of pool in the shallow end
Frequency: 44100 Hz
Pool Dimensions: 18.3m x 22.86m

Range	Depth	Notes
D1 (6m)	0m	Starting point is based on where table was, by the shallow part of the pool Went north from starting point, first 1.21m are at a constant depth, then it starts to slope
	0.5m	
	1m	
D2 (12m)	0m	Pool is sharply sloped when depth is between 1.5m and 2.13m (around 12m north from starting point)
	0.5m	
	1m	
	118cm/ Pool floor	Speaker was 118cm (touching pool floor)
D3 (21.3m)	0m	Pool is deepest (3.66m depth)
	0.5m	
	1m	
	3.66m	Speaker was 118cm deep, receiver was touching pool floor (3.66m)
D4 (~29.2m)		Fans by this side, receiver is diagonal from the starting point (furthest possible distance)
	3.66m	Speaker was 118cm deep, receiver was touching pool floor (3.66m)

Table 2: Location Documentation for 5/18/24

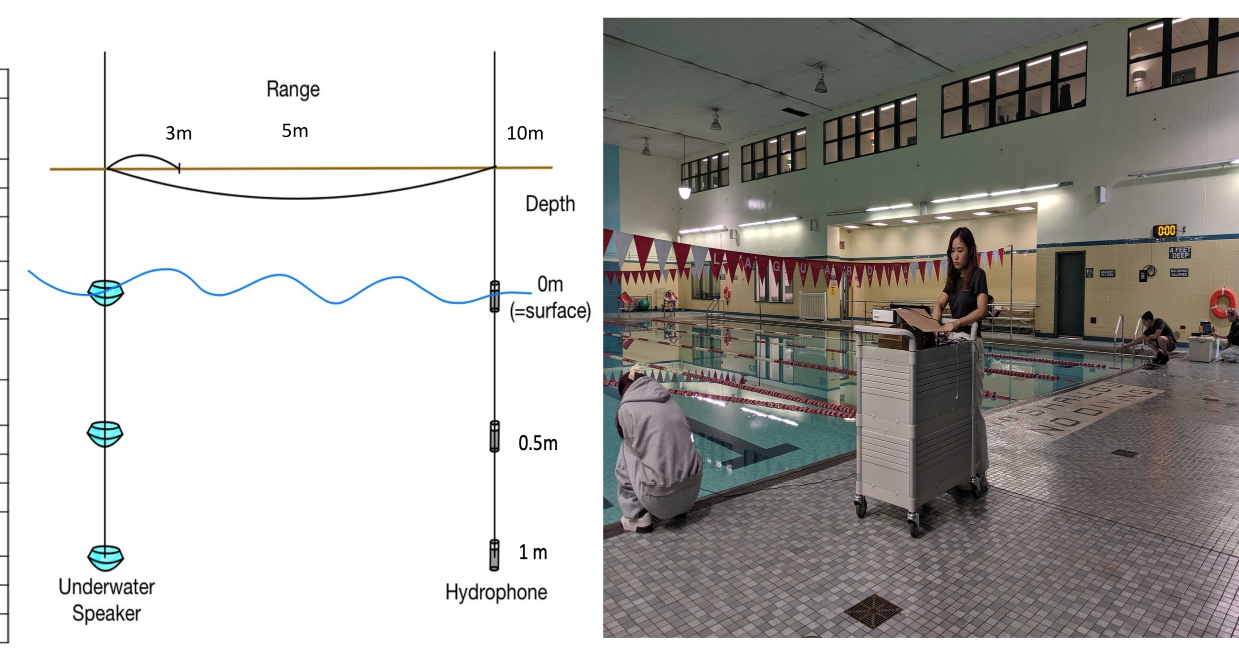


Figure 2: Experimental Set up

Results & Discussion

Hardware Configuration

Using the Xilinx Vivado Design Suite, we took the source code from the Digilent Zmod library to transmit the signal through the board, which failed. Our solution involved defining a fixed buffer size and transfer length instead of directly allocating these based on the length of the signal, using "chunks" to allocate the buffer, keeping a fixed buffer length instead of adjusting it based on the size and step values, and freeing the buffer after each use. With these changes, the board manages to transmit the signal successfully.

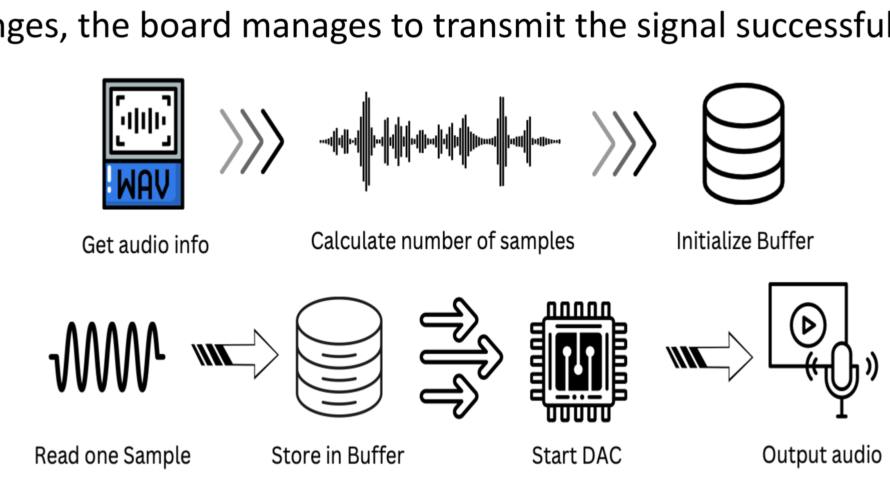


Figure 3: Hardware Set up

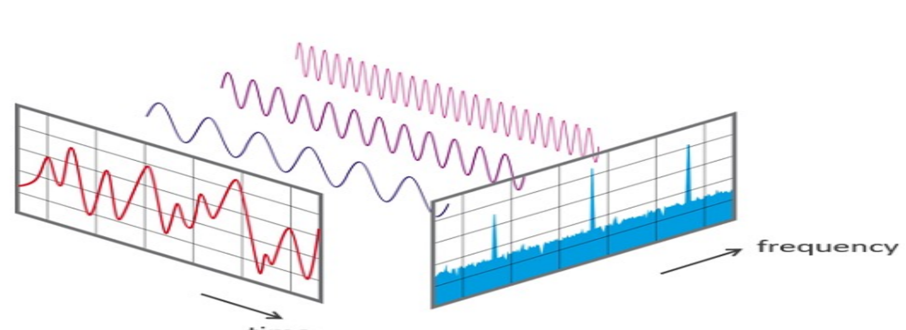
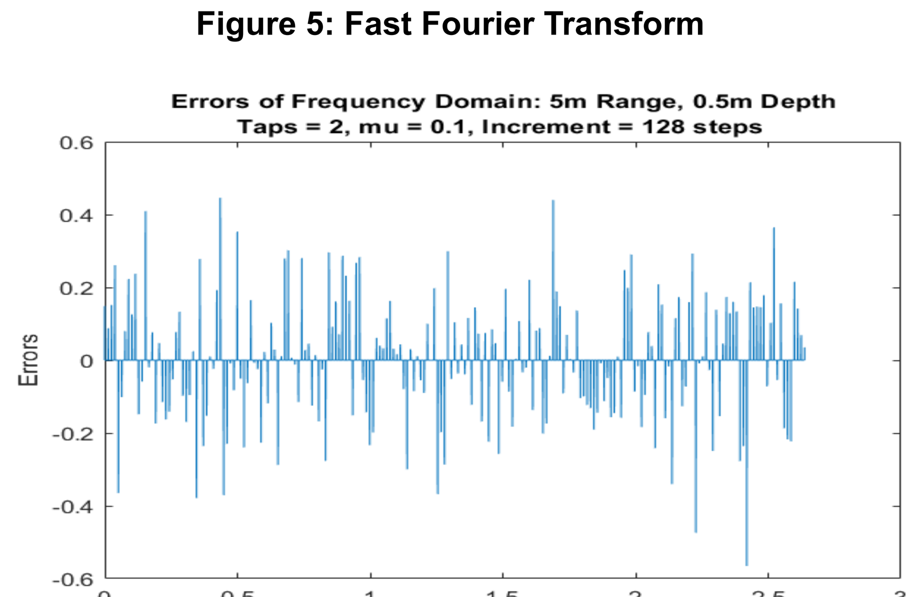
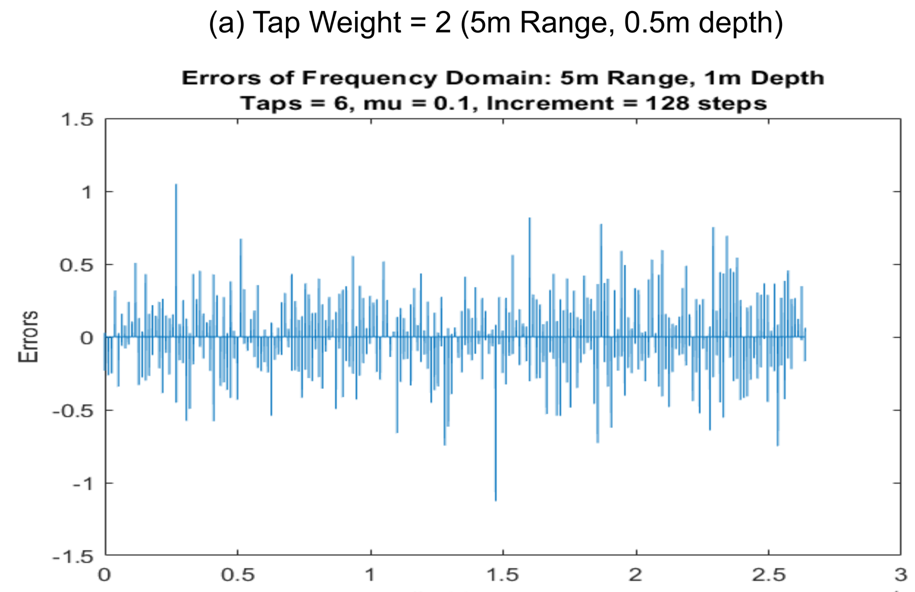


Figure 5: Fast Fourier Transform



(a) Tap Weight = 2 (5m Range, 0.5m depth)



(b) Tap Weight = 6 (5m Range, 0.5m depth)

Figure 6: Plot of errors (in Hz) from LMS in Frequency domain

Adaptive Least Mean Square(LMS)

LMS – Time Domain

Starting with the original transmitted signal (a), we use different methods to adjust the signal delay and noise effects to predict the received signal. By comparing with the actual received signal (b), we determine the actual delay of the propagation in underwater.

- Predict the received signal(c) using the solved H: H(n) = inv(X(n))*Y(n)
- Predict the received signal(d) with the solved 50 H and adjusts the rest of the signal: H(n)= H(n-1) + μ * e(n)*X(n)

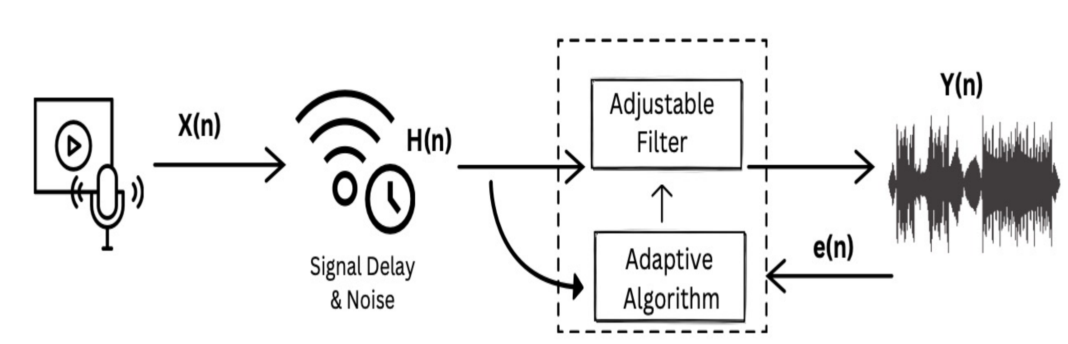
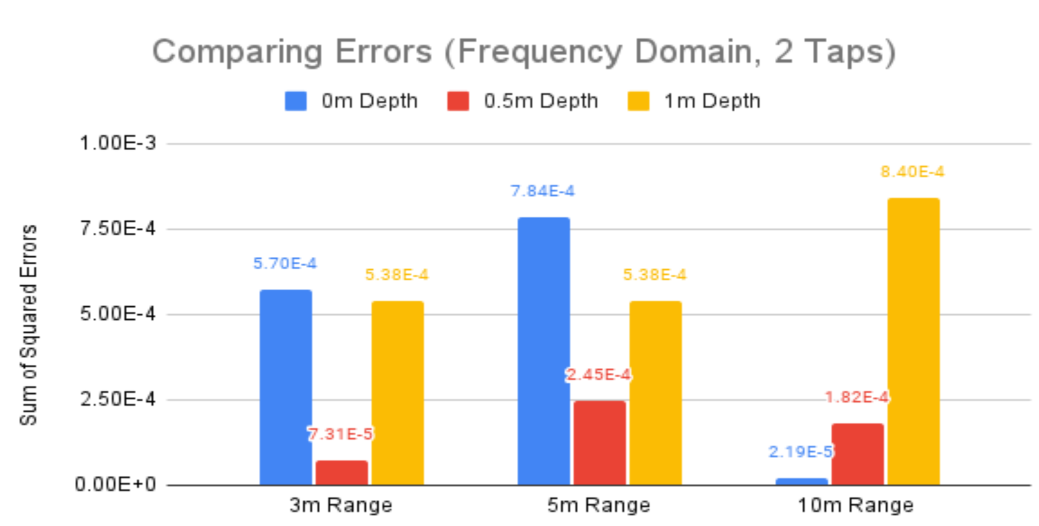


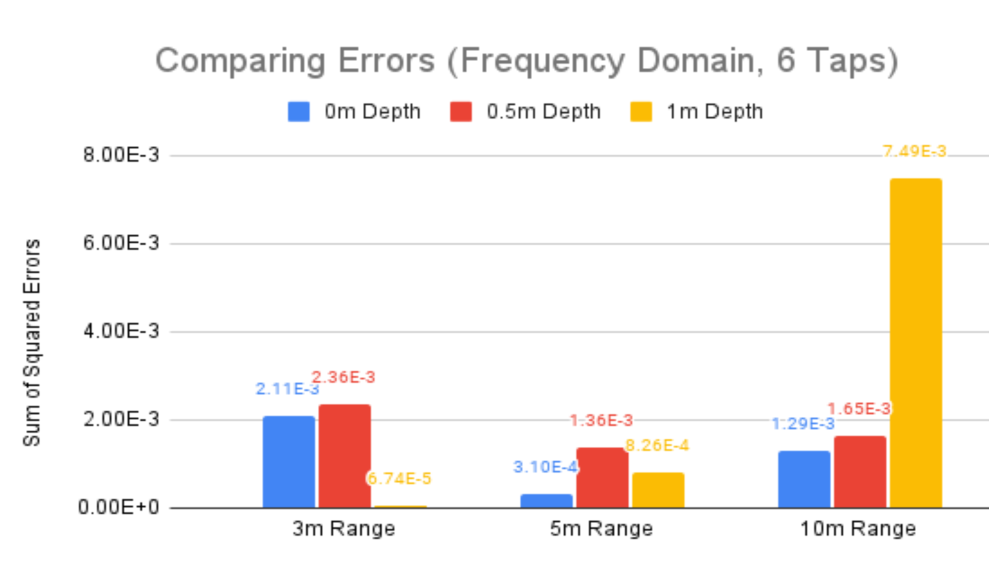
Figure 4: LMS algorithm

LMS – Frequency Domain

We can use the LMS algorithm in the frequency domain as well, by using "sliding windows" to obtain the frequencies with the highest magnitude, and then using the Fast Fourier Transform. We compare the averages of errors for all recordings, while manipulating the parameters to get as close to 0 as possible.

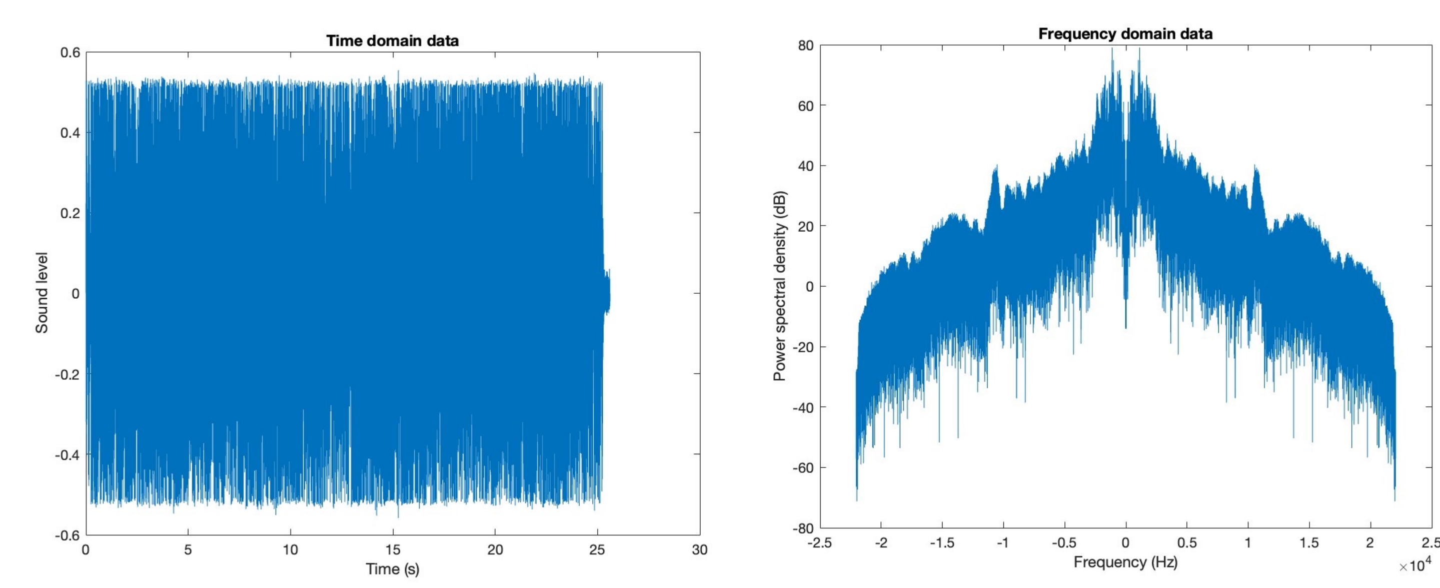


(a) Tap Weight = 2, mu = 0.1

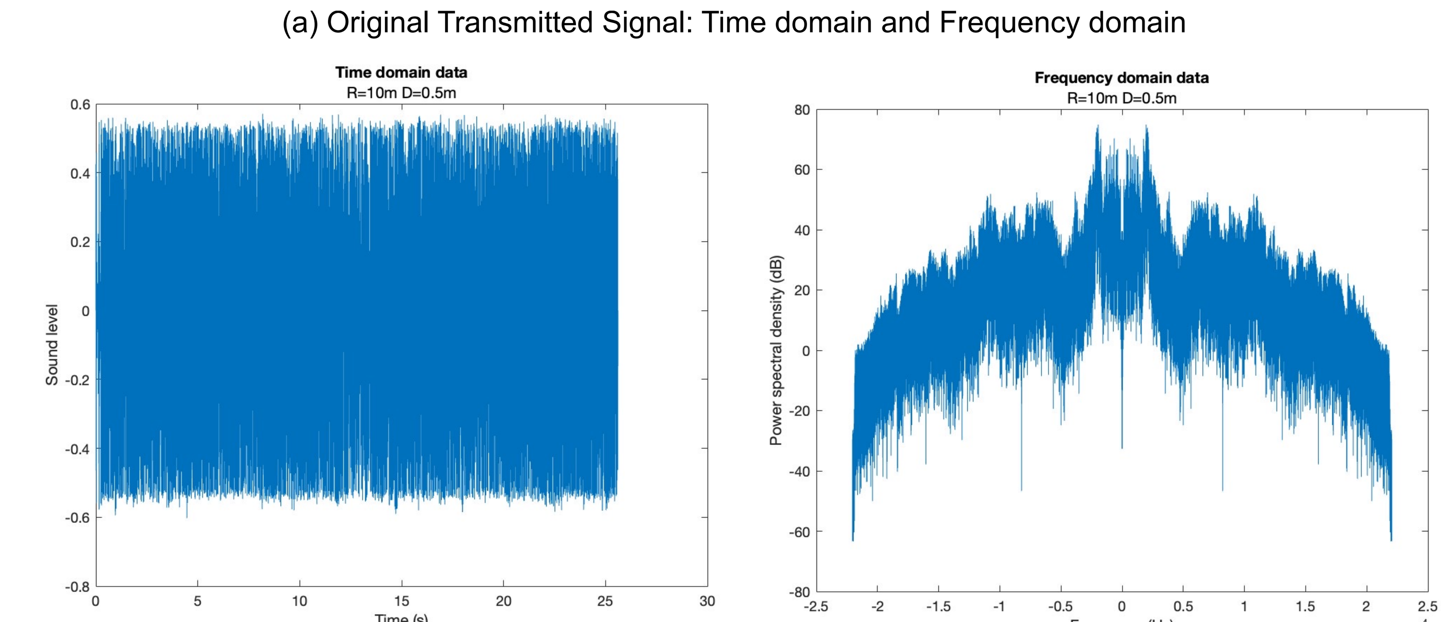


(b)Tap Weight = 6, mu = 0.1

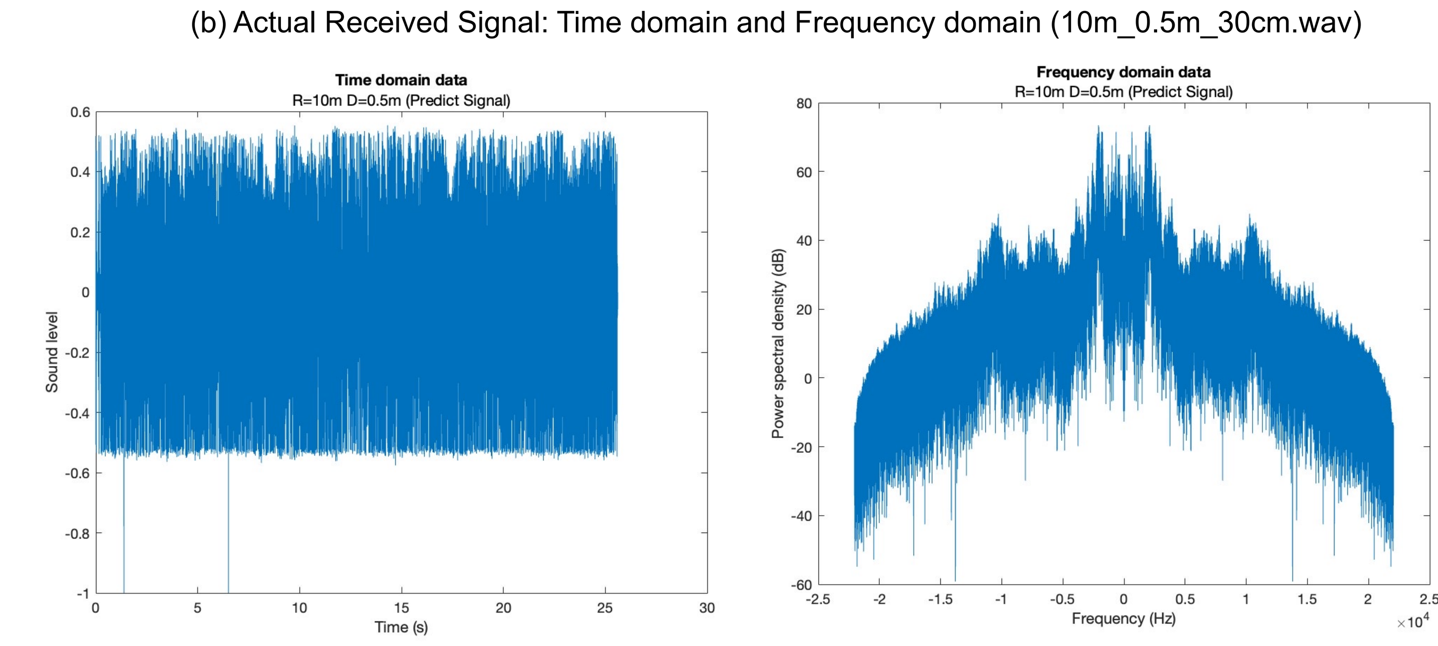
Figure 7: Comparing Errors in Frequency Domain of Ranges/Depths



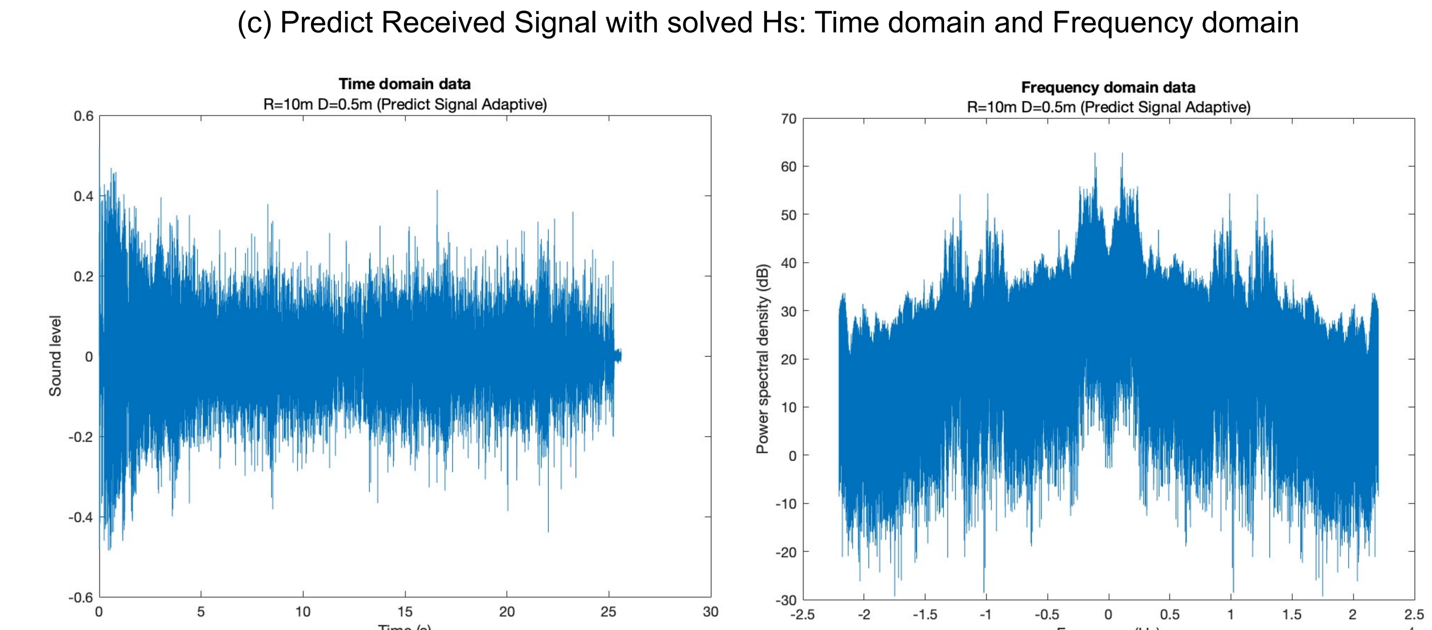
(a) Original Transmitted Signal: Time domain and Frequency domain



(b) Actual Received Signal: Time domain and Frequency domain (10m_0.5m_30cm.wav)



(c) Predict Received Signal with solved Hs: Time domain and Frequency domain



(d) Predict Received Signal with Adapt Hs: Time domain and Frequency domain

Figure 8: Actual and Predicted Signals in LMS Time Domain Analysis

Conclusion

Our biggest challenge throughout this research was configuring the hardware system and gaining familiarity with embedded systems and the Linux OS. Our solution for the erroneous code was to transmit the signal by allocating a fixed buffer size and deallocating it properly. We also realized the advantages and elegance of the adaptive LMS algorithm over the MSE, as it adjusts its coefficients to minimize the errors. When using the LMS for the signal in the time domain, we managed to get a successful predicted signal which closely matched the original. Using the LMS in the frequency domain, we found the best parameters to get the errors as small as possible. Through this experiment, we can see the drastic effects of acoustic wave propagation in underwater environments. Future steps and application with this research include potentially adding a hydrophone array, or acoustic localization techniques to improve signal reception and explore broader applications. These systems have many practical uses, such as underwater navigation or data collection.

References

●Simulink ●Xilinx Vivado Design Suite ●Digilent Eclypse Z7 ●FPGA

●Paul C. Etter, "Advanced Applications for Underwater Acoustic Modeling", Hindawi Publishing Corporation, Advances in Acoustics and Vibration, Volume 2012, Article ID 214839, 28 pages.

●Diego Andres Cuji Dutan, "OFDM Underwater Acoustic Communication System Implementation on FPGA", Master thesis, Northeastern University, 2019.