國立陽明交通大學
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Antenna Array Beamforming: Underwater Sonar Application

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◆ Introduction

In the realm of wireless communication, the optimization of signal transmission and reception is paramount for achieving robust and efficient systems. One application is sonar systems, which leverage beamforming to enhance underwater signal processing. By employing arrays of hydrophones as antennas, beamforming techniques enable the system to focus on specific directions, improving signal reception and localization.

◆ Beamforming Concept

In a conventional beamformer, each antenna's signal is multiplied by a specific Fourier weighting, and the weighted signals are then summed together. The weights are chosen to optimize the array's response in a particular direction, forming a "beam" of heightened sensitivity in that direction. This process allows precise detection and localization of underwater objects or phenomena.

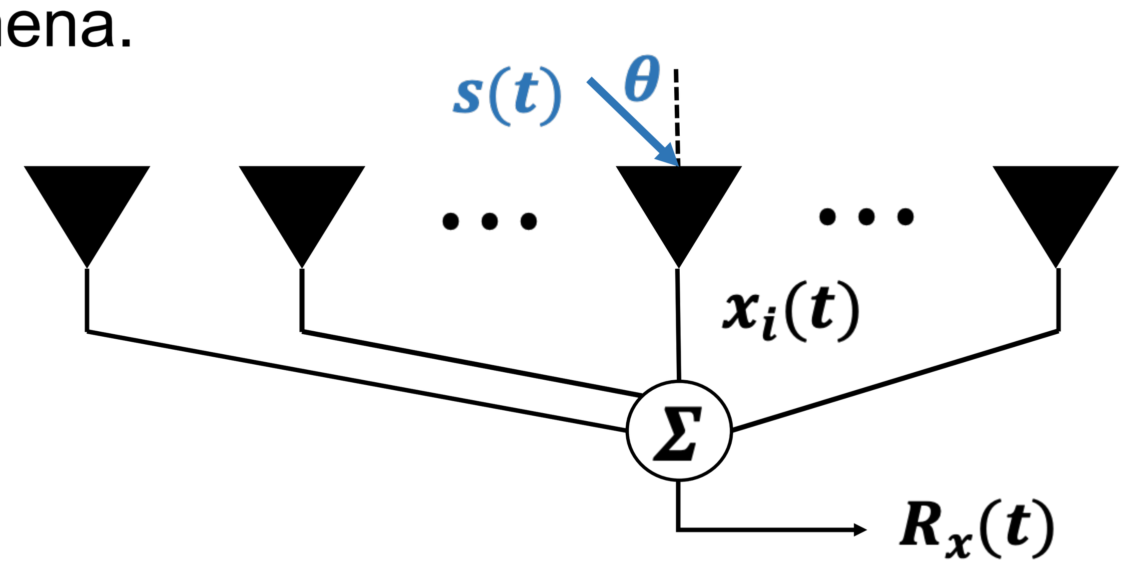


Fig. 1. N-Element uniform linear hydrophone array

◆ Direction-of-Arrival (DOA) Estimation

To determining the angle from which a signal arrives at an antenna array, I implement DOA Estimation by exploiting the array response (Fig. 2) of the antennas array.

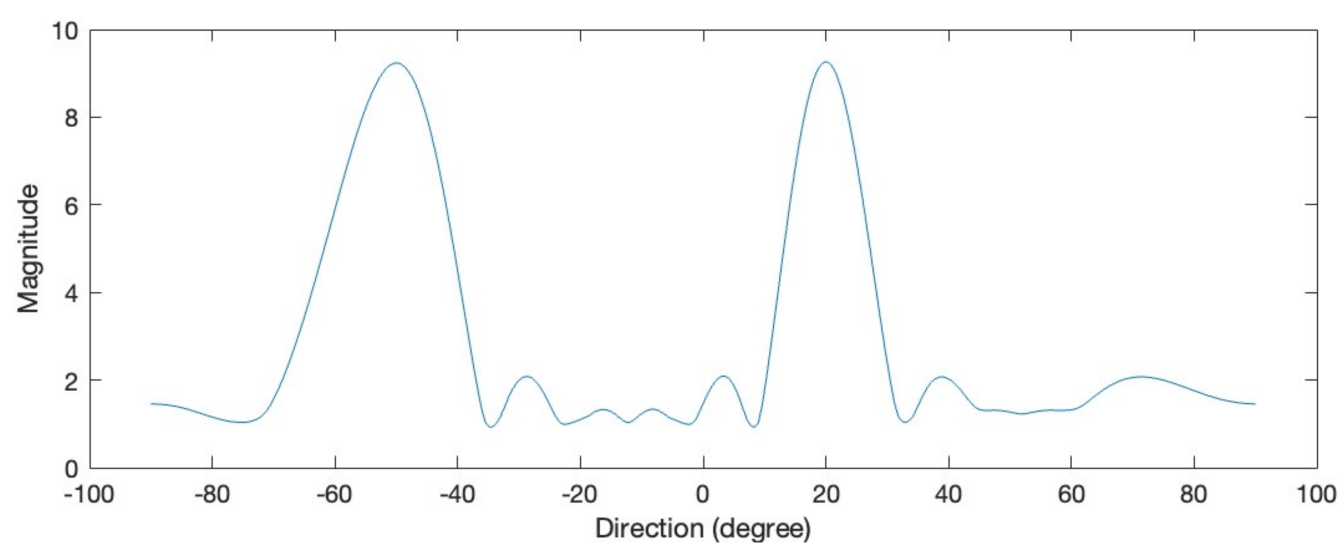


Fig. 2. Angle Response of Antenna Array

◆ Array Math

To reconstruct the transmitting signal, I apply array math shown below at the receiving end, which uses the result of DOA estimation as the array steering vector r

$$r = a(\theta_1)s_1(t) + a(\theta_2)s_2(t)$$

$$\Rightarrow a^H(\theta_1)r = a^H(\theta_1)a(\theta_1)s_1(t) + a^H(\theta_1)a(\theta_2)s_2(t)$$

$$\Rightarrow a^H(\theta_1)r = m \cdot s_1(t) + a^H(\theta_1)a(\theta_2)s_2(t)$$

$$\approx m \cdot s_1(t)$$

$$\Rightarrow s_1(t) = \frac{a^H(\theta_1)r}{m}$$

By applying array math, I reconstruction the transmitting signal with negligible error.

◆ Simulation Result

I use QPSK modulation techniques to process the transmitting and receiving signal, the constellation diagram (Fig. 4, Fig 5) are plotted.

In addition, I analyze Signal-to-Noise Ratio (SNR) versus Bit Error Rate (BER), which intuitively shows the system's behavior.

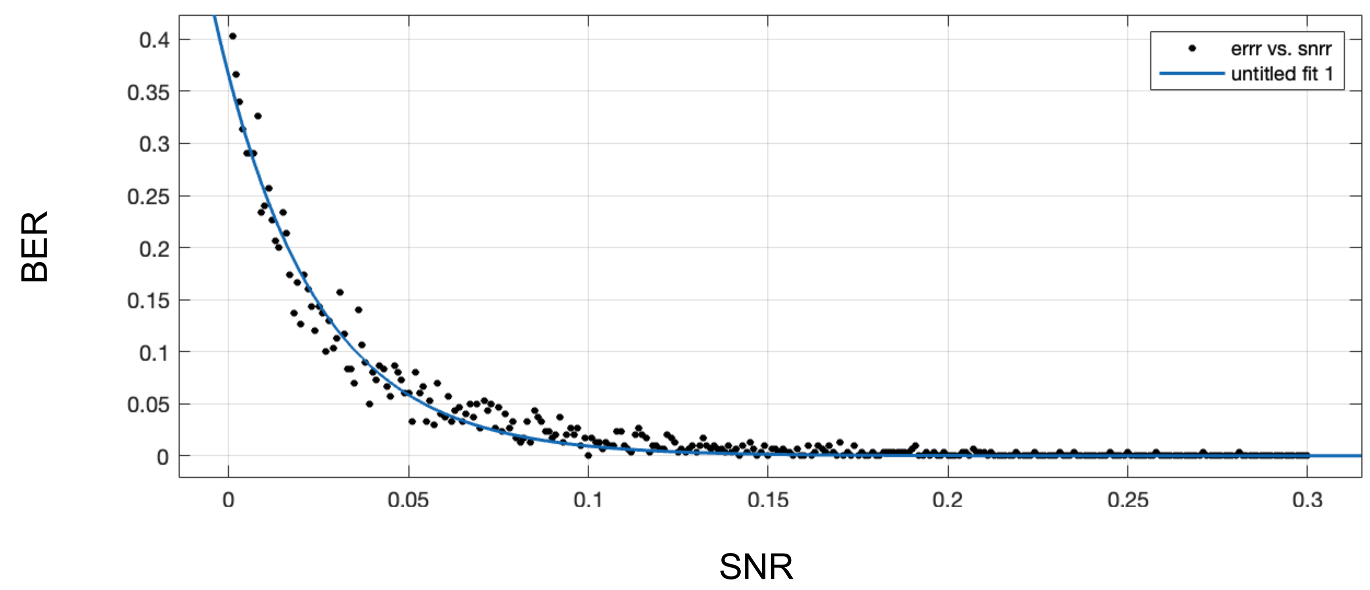
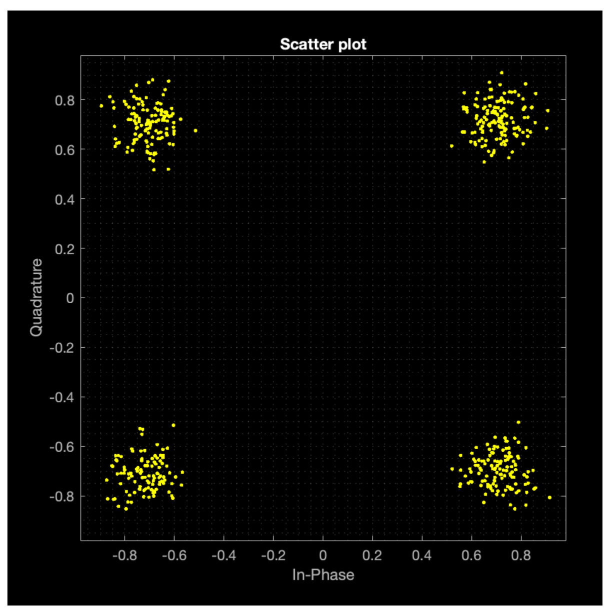


Fig. 3. SNR vs BER exponential fitting plot



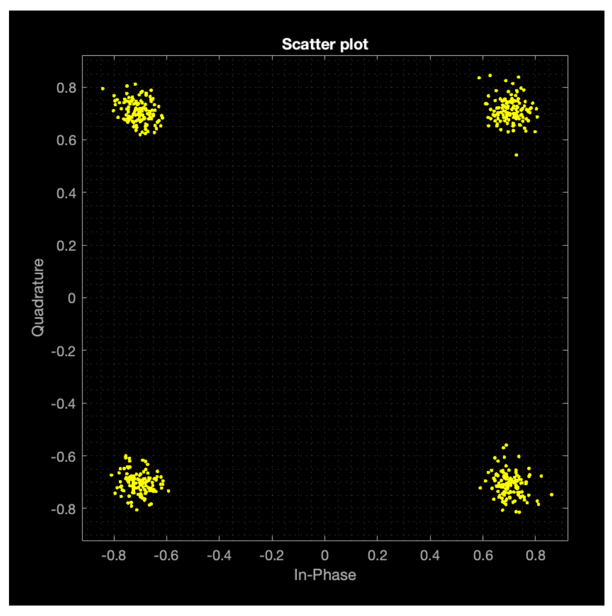


Fig. 4. QPSK Modulated signal Tx *Fig. 5. QPSK Demodulated signal Rx*

◆ Application: Underwater Sonar

Underwater sonar system integrates advanced beamforming approaches mentioned above like Direction-of-Arrival (DOA) estimation, array mathematics, and QPSK modulation skills. The source of signals emanates from school of fish, the hydrophones array is implemented as an antenna array, the array's mathematical representation aids in reconstructing the transmitting signal from the school of fish, and the DOA estimation can dynamically adapt its reception pattern which allowing for localization of fish clusters.

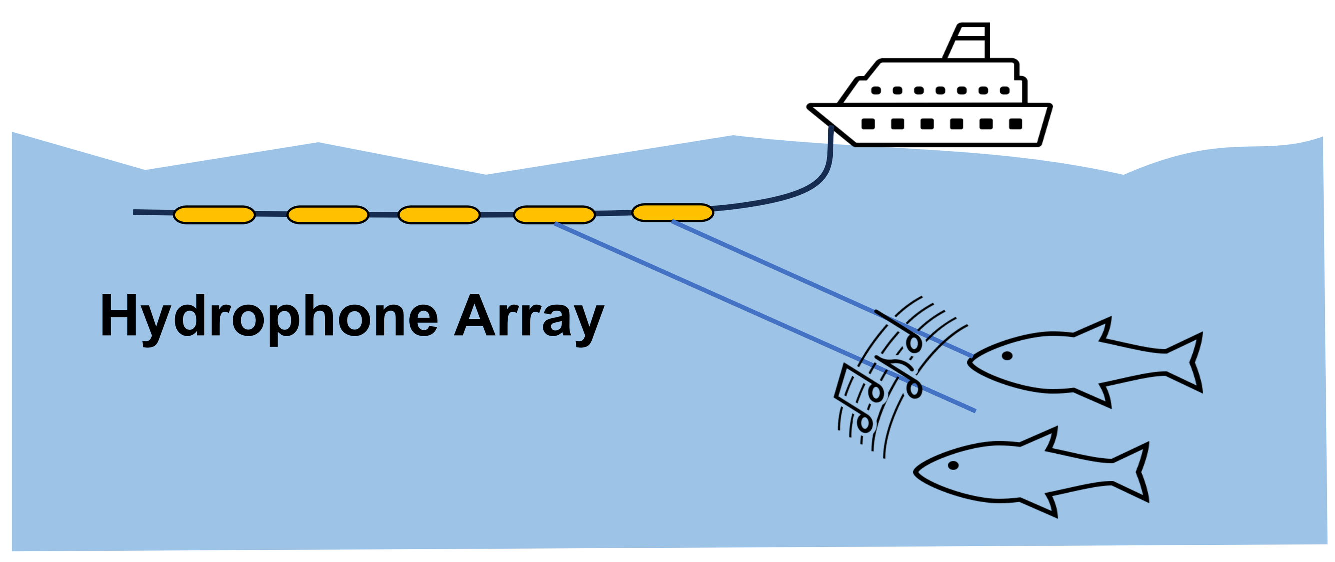


Fig. 6. Underwater sonar system using beamforming

◆ Conclusion

In conclusion, this project demonstrates the practical application of conventional beamforming in a real-world underwater scenario. By implementing beamforming approaches, we have explored how this technology address reliable and accurate underwater signal analysis.