



Article Title: Delay and Sum Beam forming Technique to Detect the Arrival Estimation of Sound Waves

Delay and Sum Beam forming Technique to Detect the Arrival Estimation of Sound Waves

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ABSTRACT

This research aims to enhance the accuracy of Direction of Arrival (DOA) estimation using hydrophone arrays through the application of beamforming methods, particularly focusing on the Delay and Sum Beamforming technique. The study follows a systematic approach, utilizing Matlab for signal generation, analysis, and testing, accompanied by power plots. It also includes a series of steps for the analysis and testing of Delay and Sum Beamforming. The investigation compares traditional DOA estimation methods with Delay and Sum Beamforming and proposes future enhancements, such as exploring alternative beamforming techniques and potential applications of advanced methods like Deep Neural Networks.

Keywords: Direction of arrival (DOA) estimation, Delay and sum (DAS) beamforming, Hydrophone array

1 Introduction

This research focuses on direction of arrival (DOA) sensitivity, resolution, and dynamic range. Therefore, estimation in the marine environment. Traditional there is a need for efficient solutions to improve the methods have limitations, while beamforming offers efficiency of marine operations and advance research in advantages like better dynamic range and accurate DOA this field estimates. We explore target localization using the delay and sum beamforming algorithm, which is valuable for

1.1 Theoretical comparison

Underwater applications. Power plot analyses, sum Delay and sum (DAS) beamforming offers advantages analyses and comparisons with traditional methods are over traditional methods. It achieves higher accuracy performed. While delay and sum beamforming has with fewer sensors, reducing the array size requirement limitations, incorporating techniques like adaptive compared to time delay estimation. DAS beamforming beam forming and exploring deep neural networks can is simpler and more robust than the phase comparison enhance the system's performance, offering potential for method, as it only relies on time delay calculations. It future improvements.



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2 Methodology

2.1 Problem statement

The estimation of direction of arrival (DOA) in underwater acoustics is crucial for various applications, provides better spatial resolution than the amplitude comparison method by utilizing time delays to align signals. Additionally, delay and sum beamforming is advantageous over maximum likelihood estimation due to its simplicity and ease of implementation without complex optimization algorithms. These advantages make DAS beamforming an efficient and effective technique for direction of arrival estimation.

2.2 Generation of hydrophone signals

Fundamental knowledge of signals, systems, its parameters and signal processing is essential to generate sensor signals. The main simulation work in this paper initiates from the generation of hydrophone signals, which includes series of sub - simulations such as generation of sine waves, cosine waves and sinusoidal / cosine impulse waves using Matlab. In practical applications, ships typically use multiple hydrophones to sense sound waves from a target.

Consider the three hydrophones as, x_0 , x_1 , and x_2

Outputs of hydrophones with time of arrival difference, y_0 , y_1 , y_2

In the case of 'N' number of hydrophones, x_0 , x_1 , x_2 , $x_{(N-1)}$

Outputs,

y_0 , y_1 , y_2 , $y_{(N-1)}$

2.3 Related equations and inter-elemental spacing

The relationship between the wavelength (λ) of a sound wave and its frequency (f) is: $\lambda = c/f$ Where c is the speed of sound in the medium through which the wave is propagating. In water, the speed of sound is approximately 1500 meters per second.

For a sound wave with a frequency of 1.2 kHz in water, the wavelength is given by:

$$\lambda = c/f = 1500/1200 = 1.25 \text{ meters}$$

To avoid spatial aliasing, the spacing between hydrophones (D) should be less than half the wavelength of the sound wave:

$$D < \lambda/2$$

Substituting the value of λ for a 1.25 kHz sound wave in water:

$$D < 1.25/2 = 0.625 \text{ meters}$$

This means that the hydrophones should be spaced less than 0.625 meters apart to avoid spatial aliasing for a 1.2 kHz sound wave in water. If the hydrophones are spaced farther apart than calculated distance, the beamforming algorithm may not clearly determine the direction of arrival of the sound wave and this leading to reduced directional sensitivity and accuracy of DOA estimation.



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2.4 Steps in design methodology

1. Sound waves
2. Array of hydrophones (generation of sensor signals)
3. Beamforming (delay and sum beamforming)
4. Estimation of direction of arrival

2.5 Algorithm for DOA estimation using delay and sum beamforming

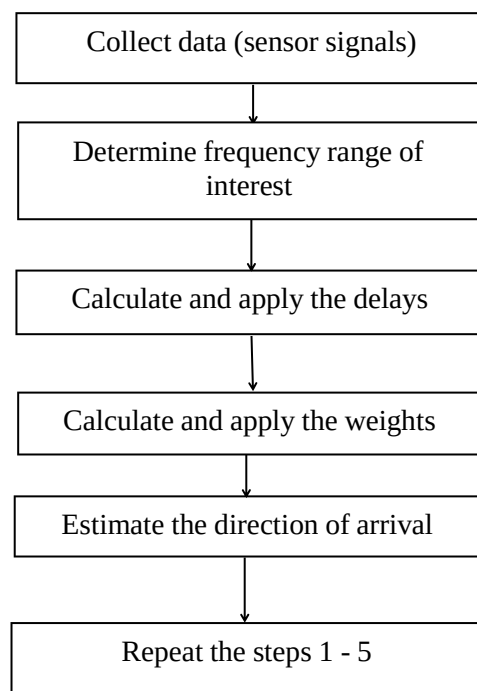


Figure 1: Block diagram of algorithm of direction of arrival using delay and sum (DAS) beamforming

The algorithm to estimate the direction of arrival (DOA) by delay and sum beamforming in time domain consists of the following steps:

Collect data: Set of samples are collected from an array of sensors

Determine the frequency range of interest: The frequency range of interest is calculated, based on the application requirements.

Calculate and apply the delays: The delay between each pair of sensors is calculated and apply it to sensor output.

Calculate and apply the weights: The weights for each sensor are calculated according to the delay and the desired beam pattern. And apply it to sensor output.

Estimate the DOA: The DOA is estimated

Repeat steps 1-5: The process is repeated continuously to track changes in the DOA.



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2.6 Delays

Assuming a planar wave front and a uniform sensor array, the delay applied to the signal received at a sensor can be calculated using the following equation:

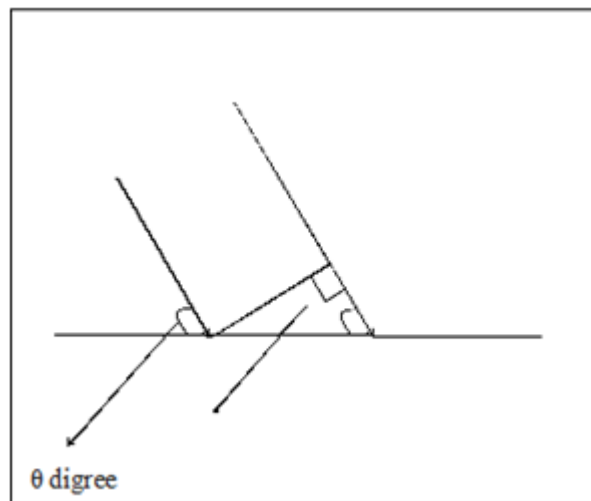


Figure 2: Calculation of delay (τ) with sensors

Consider figure 2:

$S_1, S_2 \dots$ are the sensors

'D' is the inter elemental space between the sensors Consider the right angled triangle s_1s_2F ,

$$\cos(\theta) = d'/D$$

Therefore, $d' = D \cos(\theta)$ = distance Delay (τ_0) on first sensor = distance / Speed = $D \cos(\theta) / \text{Speed}$
of sound wave in water = $D \cos(\theta) / 1500$ meters per second

Delay (τ_1) on 2nd sensor = $2 D \cos(\theta) / 1500$ meters per second

Delay (τ_2) on 3rd sensor = $3 D \cos(\theta) / 1500$ meters per second

2.7 Delaying, weighting and summing

Delaying:

Consider the 3 sensors such as $x_0(t)$, $x_1(t)$, $x_2(t)$ Corresponding sensor outputs are $y(t)$, $y_1(t)$, $y_2(t)$ Corresponding calculated delays (τ) are,

$\tau_0 = D \cos(\theta) / c$, $\tau_1 = 2D \cos(\theta) / c$, $\tau_2 = 3D \cos(\theta) / c$ applying the appropriate delay to each microphone, $y_0(t)$ is delayed to $y_0(t - \tau_0)$

$y_1(t)$ is delayed to $y_1(t - \tau_1)$ $y_2(t)$ is delayed to $y_2(t - \tau_2)$

In general, consider the Nth sensor,

$$y(N-1)(t) \text{ is delayed to } y(N-1)(t - \tau(N-1))$$

In Matlab, Delays are added in sensor outputs using zero padding. Zero padding is the shifting of signal by addition of zeros to the generated hydrophone output corresponding to



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the calculated delay. The zero padding helps to align the signals received by the hydrophones and to compensate for the time delays.

2.7.1 Weighting

Weighting is the process of multiplying each delayed signal by corresponding weight. Weighting helps to obtain accurate and robust result in direction of arrival estimation. In this proposed work, the weights are taken as unity to avoid the complexity of using more advanced methods for calculating the weights.

Hence the weights for 3 delayed signals considered as, $W_0, W_1, W_2 = 1$

Weighting on 3 delayed signals,

$W_0 \cdot y_0(t-\tau_0) = 1 \cdot y_0(t-\tau_0)$ - weighting on 1st delayed signal

$W_1 \cdot y_1(t-\tau_1) = 1 \cdot y_1(t-\tau_1)$ - weighting on 2nd delayed signal

$W_2 \cdot y_2(t-\tau_2) = 1 \cdot y_2(t-\tau_2)$ - weighting on 3rd delayed signal

In general weighting on Nth delayed signal,

$$W(N-1) \cdot y(N-1)(t-\tau(N-1)) = 1 \cdot y(N-1)(t-\tau(N-1))$$

2.7.2 Summing

In delay and sum beamforming, the critical process involves summing the time-shifted signals received by each microphone. This summation creates a composite signal with enhanced directivity, increasing energy in the desired direction and reducing energy in other directions.

sum is denoted as, $z(t)$

Consider the 3 sensors the sum is,

$z(t) = \sum W_n \cdot y_n(t-\tau_n)$, where the ' $\sum$ ' ranges from $m=0$ to $n=(3-1)$

In general, consider the N sensors the sum is,

$$z(t) = \sum W_n \cdot y_n(t-\tau_n), \text{ where the } \sum \text{ ranges from } n=0 \text{ to } n=(N-1)$$

2.7.3 Estimation of direction of arrival using energy and power equations

To obtain a direction of arrival (DOA) estimation plot using delay and sum beamforming, calculate the power and energy of the beamformer output as a function of direction of arrival. The energy based power equation is, Power = Energy divided by Time (1)

Power = Sum of squared magnitudes of the samples of beam formed output divided by Time interval over which the signal is measured (2)

Power = Total energy of beam formed output divided by Time interval over which the signal is measured (3)

The energy of the output signal is the sum of the squared magnitudes of the samples of the



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output signal. The time interval over which the energy is measured is equal to the length of the output signal divided by the sampling rate. Hence the equation (3) and (2) can also be written as,

$$\text{Power} = \frac{\text{Total energy of beam formed output}}{\text{divided by total length of beam formed output}}$$

2.7.4 Power plot

The main lobe of the power plot represents the direction of the signal of interest, while the side lobes represents the other directions. Therefore, the angle of the peak in the main lobe indicates the direction of arrival of the signal. The accuracy of the direction of arrival estimation depends on several factors such as the number of sensors, inter-spacing element, and the frequency of the signal. The direction of arrival in delay and sum beamforming can be obtained from the power plot by identifying the peak or highest energy level in the main lobe and determining the corresponding angle.

3 Results and Discussions

3.1 Signal generation

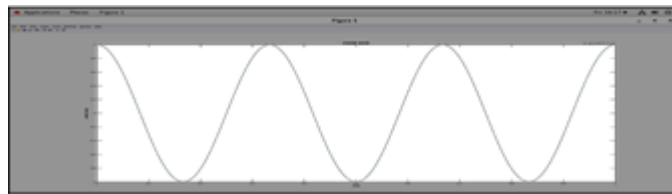


Figure 3: Matlab simulation result - Cosine wave (line plot) -x axis (time), y axis amplitude

3.2 Impulse generation from basic signals

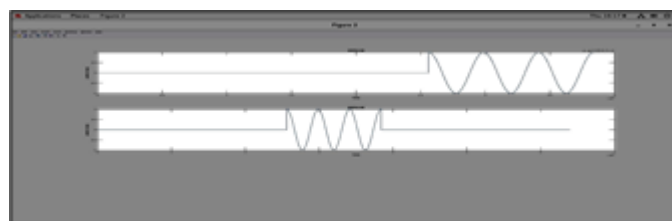


Figure 4: Matlab simulation result - impulse signal generated by zeros padding in Matlab, x axis (time), y axis (amplitude)

- Impulse generation (in Matlab):
- Define parameters such of sine and cosine waves, such as frequency, duration and sampling rate
- Generate sine and cosine waves
- Perform signal shifting by adding zeros before and after the original signal
- Plot the original and shifted signals



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- Perform the same steps

3.3 Sensor signals

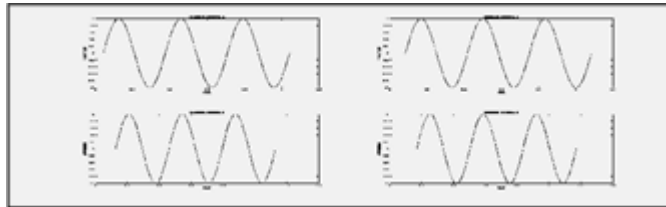


Figure 5: Matlab simulation result - 4 sensor signals - x axis(time), y axis (amplitude), frequency = 3 Hz

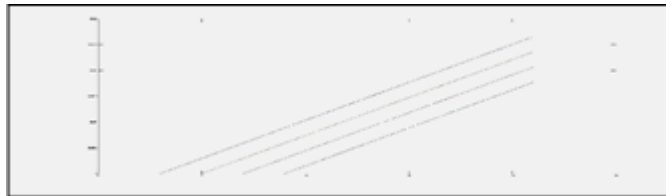


Figure 6: Matlab simulation result - time of arrival difference

Each colored slanting lines in (figure 6) shows each sensor signal, the delays occurred on the time axis of initial point of each colored line depicts the time of arrival difference.

3.4 Signal Matrix

After generating the sensor signals, the sensor signals are converted into a signal matrix for the further process of beamforming.

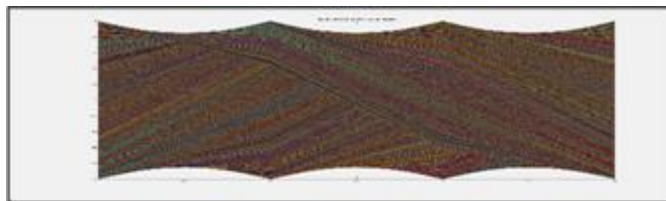


Figure 7: Matlab simulation result - formation of signal matrix from sensor signals

3.5 Delaying, weighting and summing of sensor outputs

Delaying:

$y_0(t-\tau_0)$ - 1st delayed signal
 $y_1(t-\tau_1)$ - 2nd delayed signal
 $y_2(t-\tau_2)$ - 3rd delayed signal
 $y_3(t-\tau_3)$ - 4th delayed signal

Amplitude weighting

Amplitude weighting: $W_0, W_1, W_2 = 1$ (assumed value)

$W_0 \cdot y_0(t-\tau_0) = 1 \cdot y_0(t-\tau_0)$ - weighting on 1st delayed signal

$W_1 \cdot y_1(t-\tau_1) = 1 \cdot y_1(t-\tau_1)$ - weighting on 2nd delayed signal



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$W_3 \cdot y_2(t-\tau_2) = 1 \cdot y_2(t-\tau_2)$ - weighting on 3rd delayed signal

Summing:

The final step in beamforming is the summing of the delayed and weighted sensor outputs to generate the beam formed output. It must be noted that the amplitude of the summing signal reaches its maximum at the direction of arrival.

Step 1: consider an angle of direction of arrival as 40 degree

Step 2: generation of sensor outputs (each signal parameters, frequency 30 Hz and Amplitude 1volts) Step 3: generation of 4 delayed sensor outputs

Step 4: summing and checking the amplitude of summed output with different angles, it should get maximum amplitude as 4 volts after summing of 4 delayed outputs with amplitude of 1 volts

i. Summing Of Delayed Outputs (Figure 5) At Angle 60 Degree

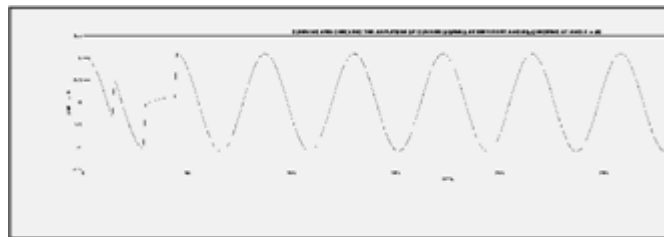


Figure 8: Matlab simulation result - summed output at an angle 60 degree, the maximum amplitude obtained is 1.5 volts

ii. Summing of Delayed Outputs (Figure 5) At Angle 40 Degree

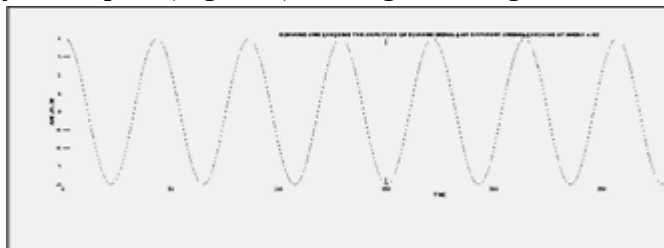


Figure 9: Matlab Simulation Result - Summed Output At An Angle 40 Degree, The Maximum Amplitude Obtained Is 4 Volts.

In the testing procedure, the known direction of arrival was set at 40 degrees. The amplitude of the summed output was then examined at different angles, including 60 degrees and 40 degrees. By analyzing the responses, it was observed that the maximum amplitude of 4 volts was achieved only at the 40-degree angle, which corresponds to the initial direction of arrival. Thus, it is evident that the maximum amplitude of the summed signal aligns with the direction of arrival.



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4 Direction of arrival - Power plot

The angle at which the peak occurs represents the direction of arrival of the signal.

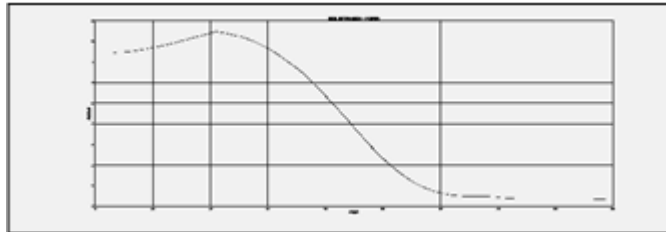


Figure 10: Matlab simulation result - DOA estimation at 20 degree - power plot (line plot), x axis (angle), y axis (amplitude)

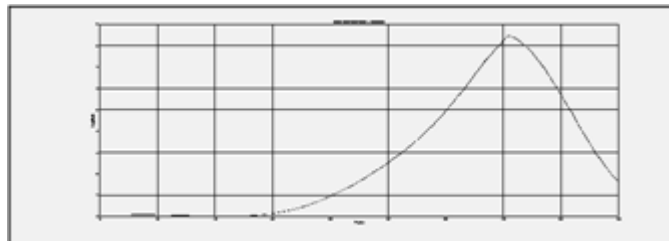


Figure 11: Matlab simulation result - DOA estimation at 70 degree - power plot (line plot), x axis (angle), y axis (amplitude)

5 Conclusion

This research work effectively addresses the prevalent challenge of direction of arrival (DOA) estimation. This study illustrates testing, and analysis, leading to the identification and highlighting of its prominent characteristics.

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