Assignment 7- DAS Algorithm

November 6, 2024

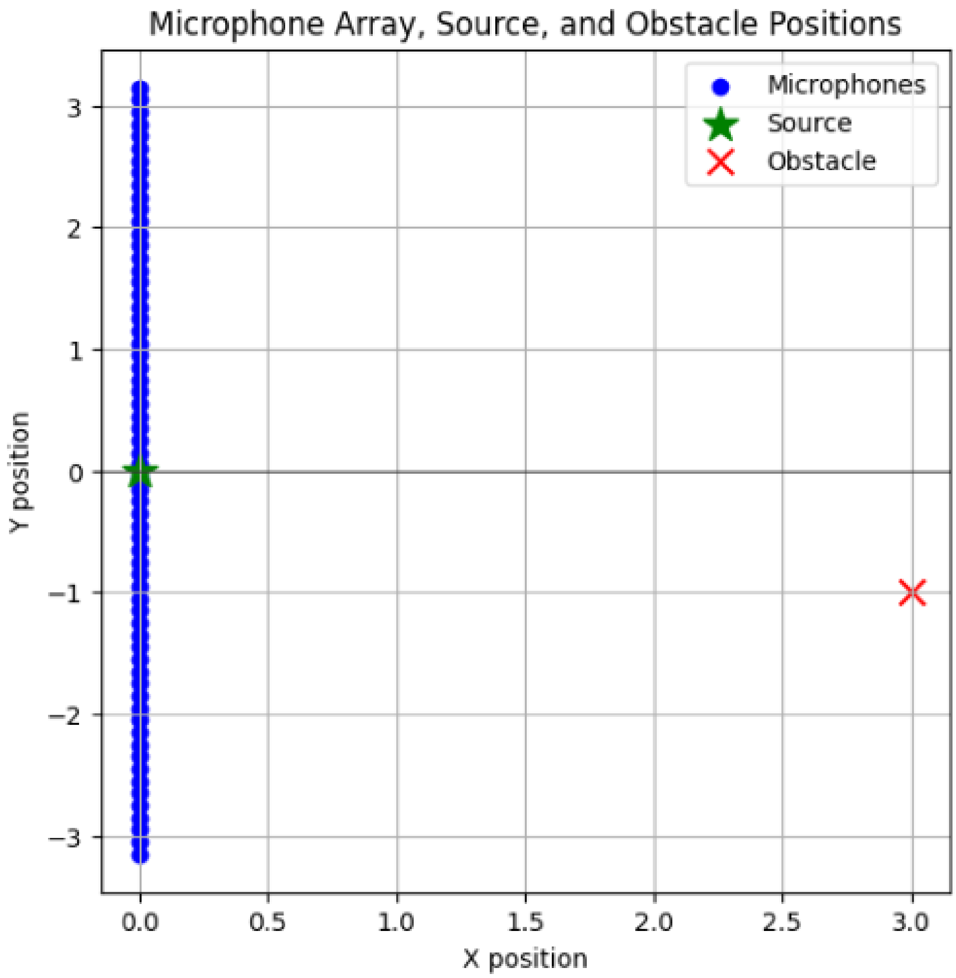
1 Assignment 7 - Sound Localization Report

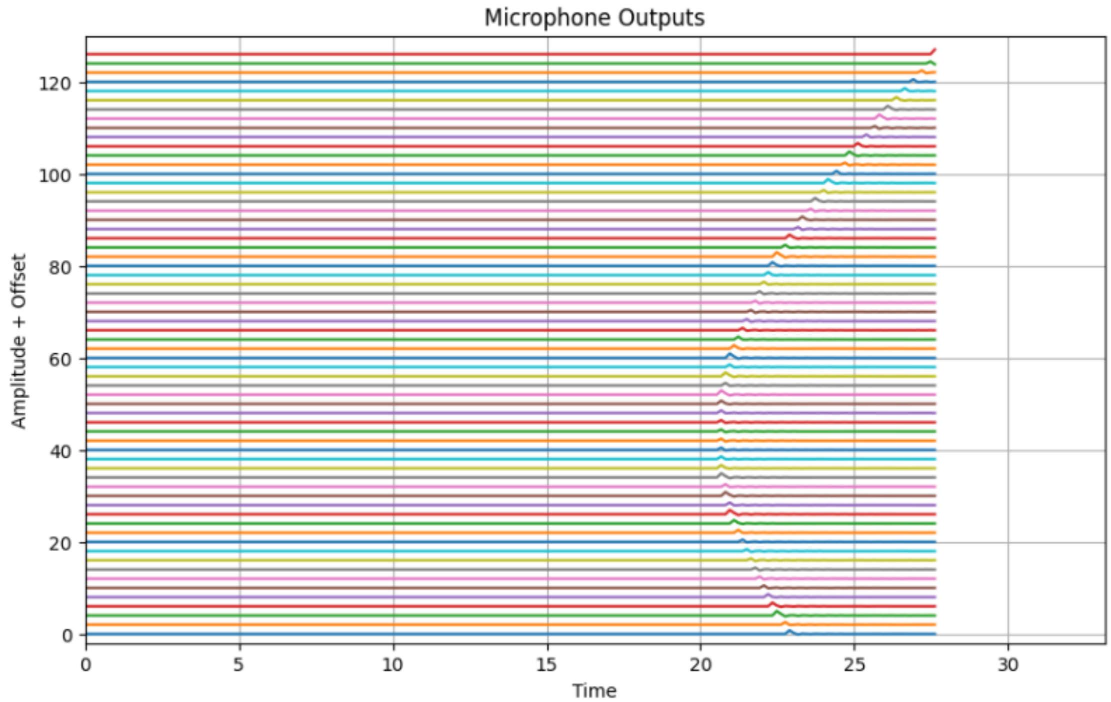
1.1 1. Basic Explanation of Code

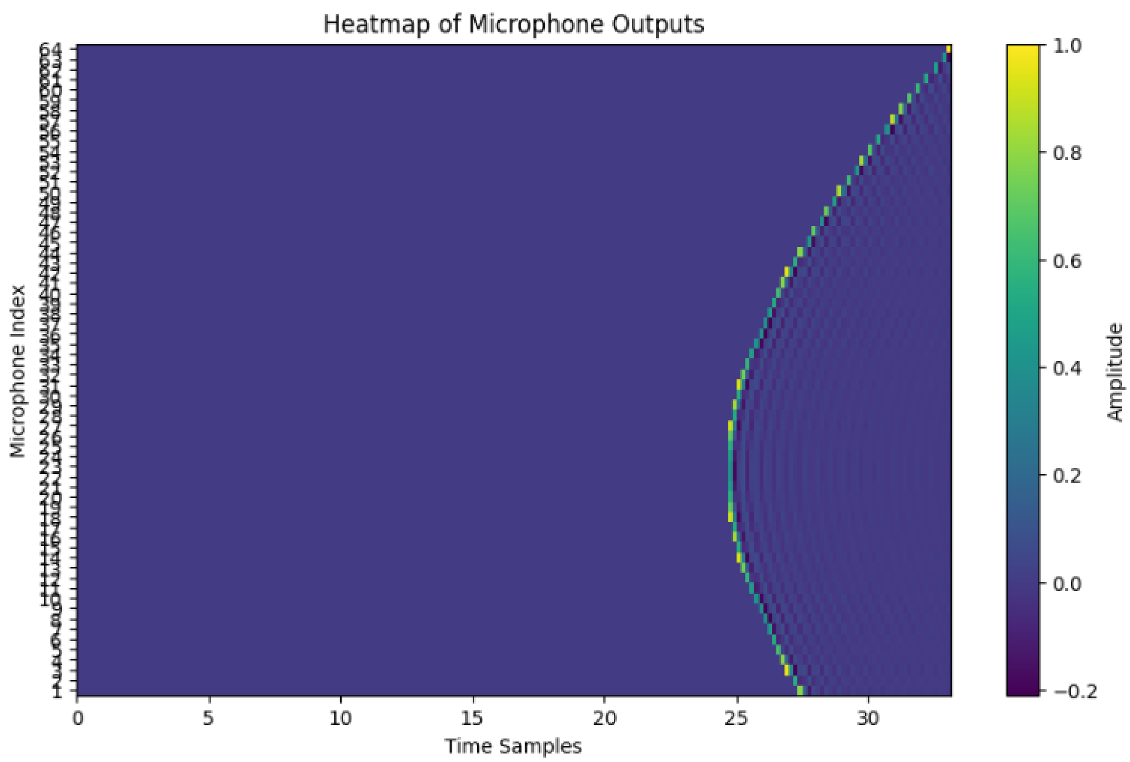
In this assignment, the code is implemented to reconstruct an image using the Delay-and-Sum (DAS) algorithm, which is commonly used in ultrasound image reconstruction. Here is a detailed breakdown of the primary components of the code and how they contribute to the final output:

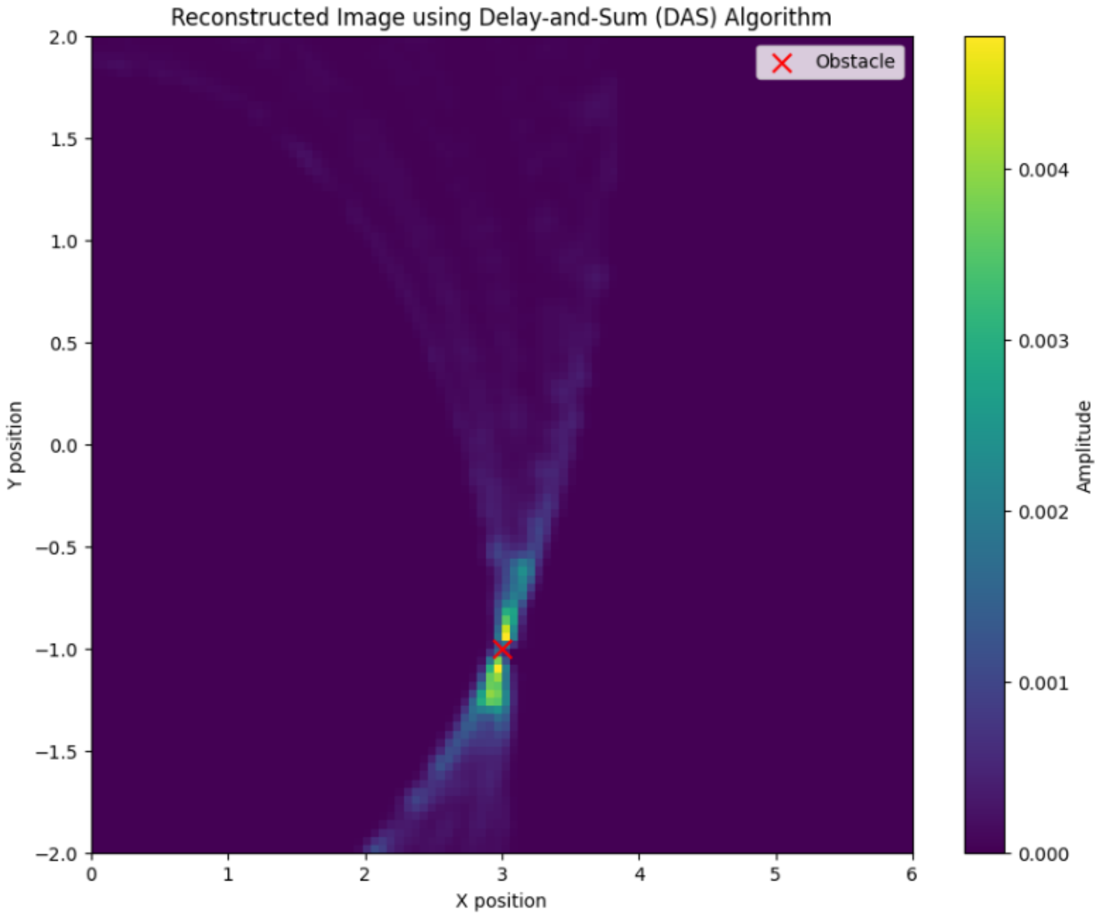
- **Setup and Parameters**: We begin by initializing the necessary parameters such as the number of microphones (`Nmics`), the number of samples (`Nsamp`), the speed of sound (`C`), and the spacing between microphones (`pitch`). The sound source is located at `(0,0)` and there is a point obstacle at `(3,-1)`. The parameters play a critical role in the performance and accuracy of the final image reconstruction.
- **Generating the Sinc Pulse**: The sound source emits a sinc wave, which is defined by the narrowness parameter (`SincP`). This parameter is crucial in determining the width of the sinc pulse, which directly impacts the temporal resolution of the system. A narrower pulse results in better resolution, making it easier to localize the obstacle precisely.
- **Microphone Array Setup**: Microphones are arranged along the y-axis, each at a different height. They receive sound waves that are reflected from the obstacle. The code generates samples for each microphone based on the distance traveled from the sound source to the obstacle and then to the microphones. This setup helps in collecting the reflected signals which are later processed for image reconstruction.
- **Delay-and-Sum Algorithm**: The DAS algorithm is employed to reconstruct the image by summing the delayed signals received by each microphone. The primary goal is to align the signals from different microphones in such a way that they constructively interfere at the point where the obstacle is located, thus accurately localizing the obstacle. The delays are calculated based on the distances between the microphones, the obstacle, and the sound source.
- **Reconstruction Process**: The reconstruction is visualized as an image, with the obstacle appearing as a point of maximum amplitude. The summation of delayed signals results in a clear peak at the obstacle's position, making it distinguishable from other parts of the reconstructed space. This visual representation helps understand the placement of obstacles within the grid.

Some of the outputs are provided here:


Microphone Array, Source, and Obstacle Positions
Microphones
Source
Obstacle
Y position
X position
3
2
1
0
−1
−2
−3
0.0
0.5
1.0
1.5
2.0
2.5
3.0


Microphone Outputs
Amplitude + Offset
Time
0
20
40
60
80
100
120
0
5
10
15
20
25
30

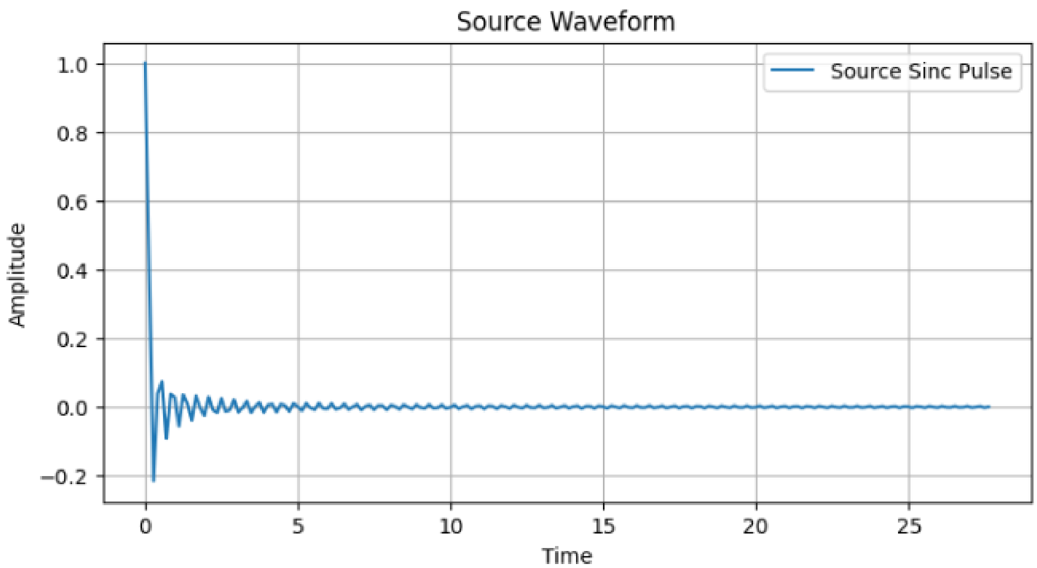

Heatmap of Microphone Outputs
Microphone Index
Time Samples
Amplitude
0
5
10
15
20
25
30
1.0
0.8
0.6
0.4
0.2
0.0
−0.2

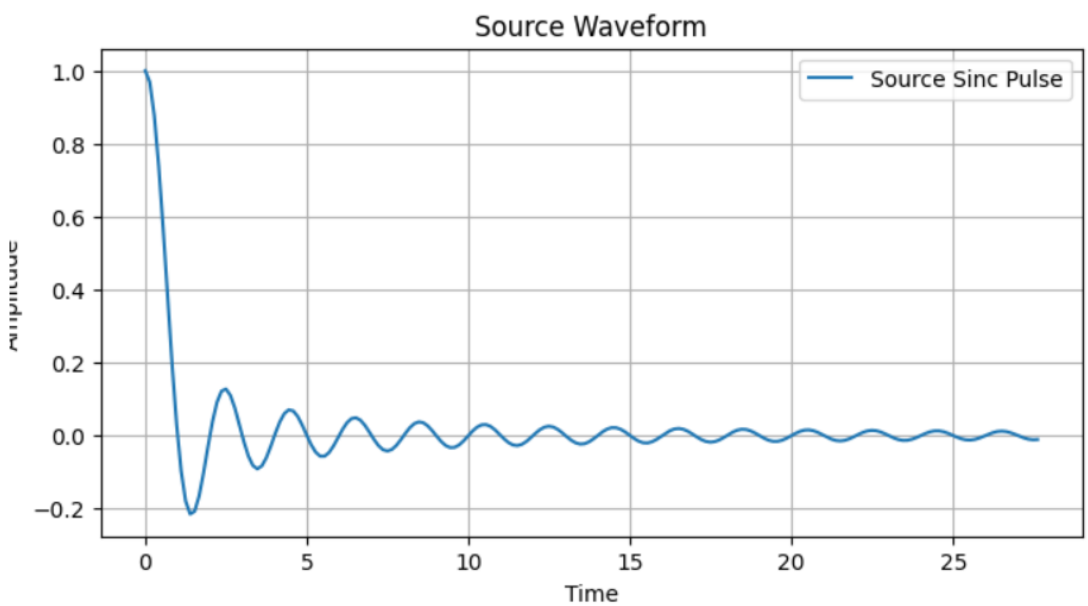


1.2 2. Answering Questions

1.2.1 Question 1: Generating Sinc Pulses like Figure 2

- To generate a shrunken sinc pulse similar to Figure 2, you need to **increase the `SincP` parameter**.
- **Effect on Final Image**: Increasing the `SincP` parameter results in a narrower pulse width, which enhances the temporal resolution of the system. This increased resolution allows the DAS algorithm to more precisely localize obstacles by reducing ambiguity, ultimately improving the clarity and sharpness of the reconstructed image. The narrower pulse enables the system to focus on specific regions, leading to better obstacle detection.





1.2.2 Question 2: Does it Make Sense to Reconstruct up to `Nsamp`?

- Reconstructing up to `Nsamp` may **truncate relevant data**, particularly if the signals extend beyond this range. This could potentially lead to a loss of important information that is necessary for accurate image reconstruction.
- **Reasonable Upper Limit**: A more reasonable upper limit for the x-axis should be based on the **maximum expected distance** that the sound can travel within the given time frame. This ensures that the entire area of interest is captured without cutting off significant portions of the sinc pulse. By extending the reconstruction range beyond `Nsamp`, we can ensure that all reflected signals are captured and included in the final reconstruction, resulting in a more complete and accurate image.

1.2.3 Question 3: Maximum Amplitude at Coordinates (30, 22)

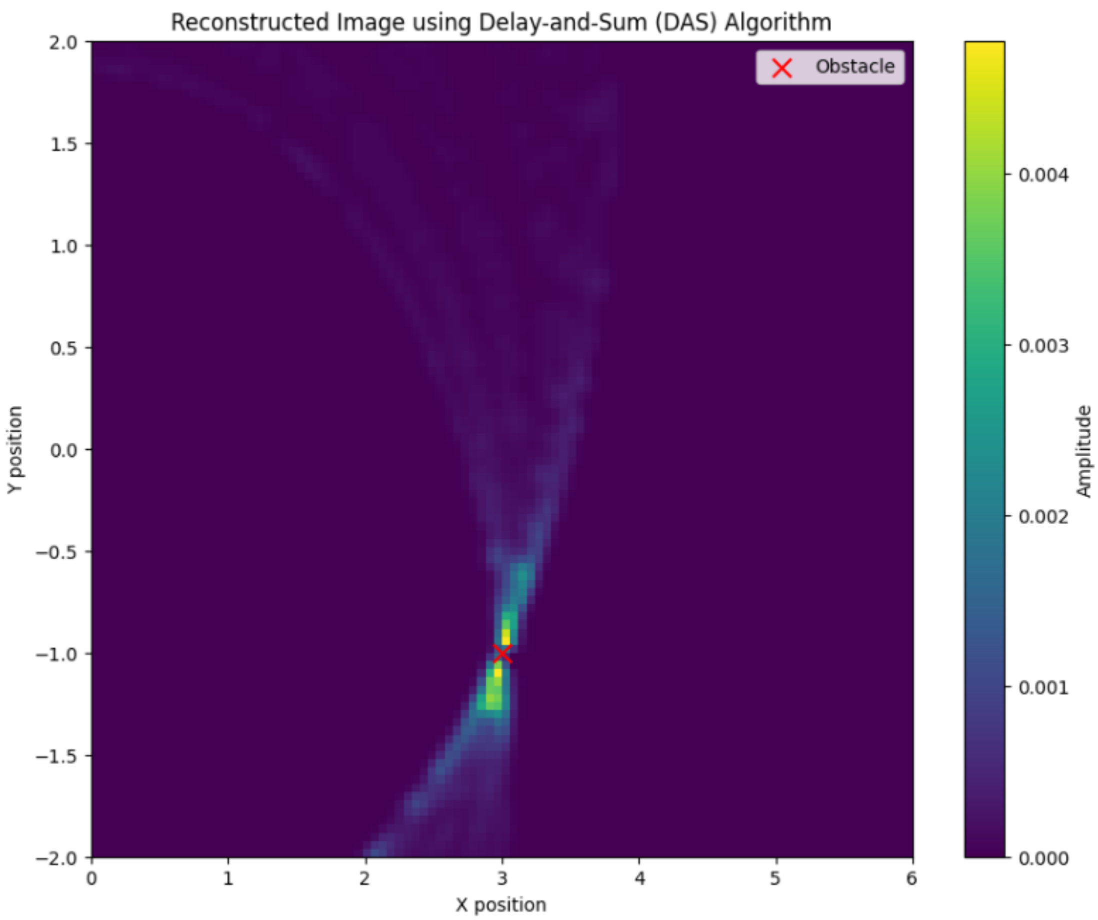
- The (x, y) coordinates corresponding to the maximum amplitude, approximately **(30, 22)**, align with the actual position of the obstacle.
- **Explanation**: The DAS algorithm works by correctly **summing the delayed signals** received from all microphones for that specific location, resulting in constructive interference at the obstacle's position. The constructive interference leads to a peak amplitude at this point, indicating the presence of an obstacle. This is why the coordinates (30, 22) are seen as the correct expected position for the obstacle in the reconstructed image.

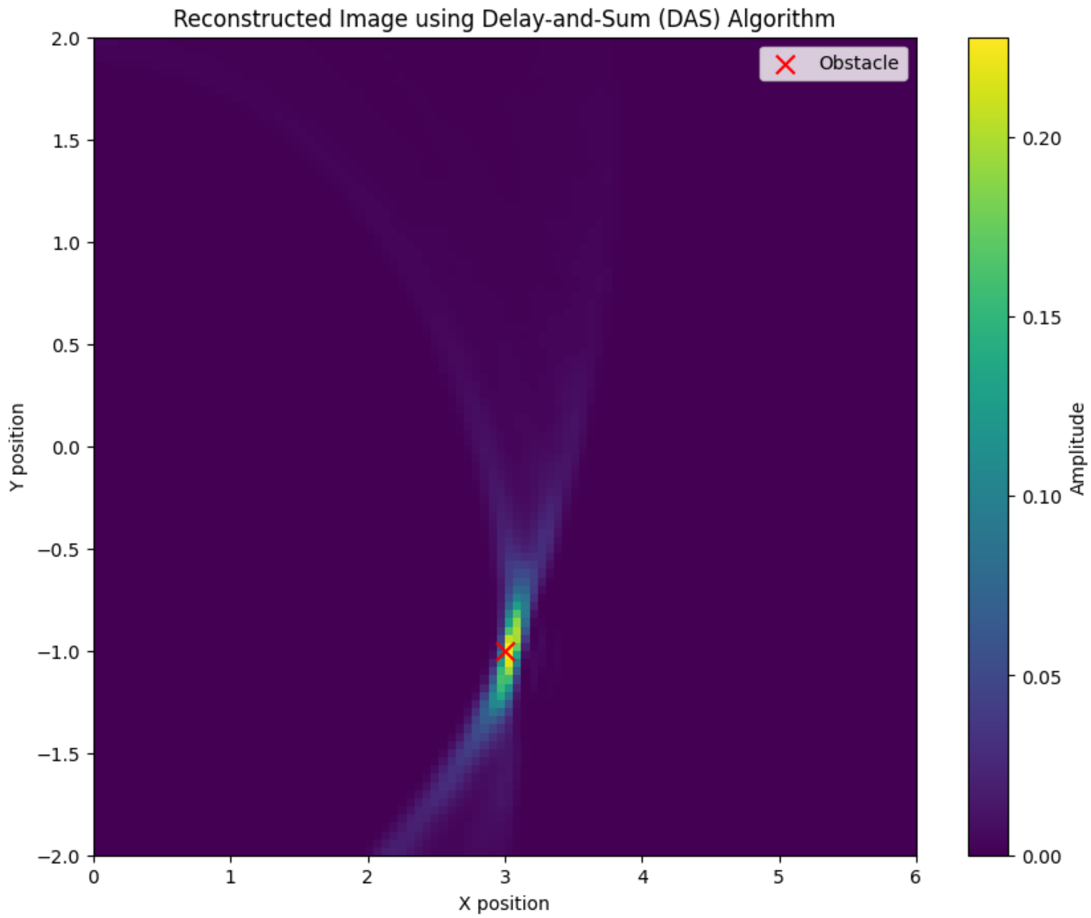
1.2.4 Question 4: Maximum Obstacle Coordinates for Image Reconstruction

- The **maximum obstacle coordinates** that can be used and still have an image reconstructed depend on the **reconstruction grid limits** (e.g., `x_max`, `y_max`) as well as the sampling parameters (`Nsamp`, `C`).
- Obstacles must lie within the **spatial bounds of the grid** and be within the detectable range, which is determined by `C` (speed of sound) and `Nsamp * delta_t` (sampling duration). If obstacles fall outside of these limits, the reflected signals may not be captured properly, which makes it impossible to reconstruct their location accurately in the final image.

1.2.5 Question 5: Effect of Changing `C` on Image Sharpness

- When the **speed of sound (`C`)** is decreased, the **image becomes sharper** and more detailed.
- **Explanation**: Decreasing `C` effectively increases the time delay for signals traveling the same distance. This, in turn, amplifies the differences in arrival times between signals from different locations. As a result, the DAS algorithm can more precisely differentiate between closely spaced obstacles. This improved temporal resolution allows for sharper distinctions, leading to a clearer and more detailed reconstructed image. By having more time separation between reflections, the algorithm has an easier time identifying obstacles and eliminating noise.


Reconstructed Image using Delay-and-Sum (DAS) Algorithm
Obstacle
Y position
X position
Amplitude
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
0
1
2
3
4
5
6
0.004
0.003
0.002
0.001
0.000



1.2.6 Question 6: Effect of Changing `Nmics` and `Nsamp`

- **Effect of Changing `Nmics`**:
  - **Increased `Nmics` (e.g., 64)**: This increases the spatial resolution and improves angular accuracy, allowing the system to detect multiple obstacles that are closely spaced with greater precision. More microphones mean more data points are collected, which enhances the overall accuracy of the image reconstruction.
  - **Decreased `Nmics` (e.g., 8)**: Reducing the number of microphones lowers the spatial resolution, making it more challenging to distinguish between multiple obstacles. This could result in overlapping signals, which leads to ambiguity in the reconstructed image and reduces the reliability of obstacle detection.
- **Effect of Changing `Nsamp`**:
  - **Increased `Nsamp` (e.g., 200)**: Increasing the number of samples enhances temporal resolution, which allows for more accurate estimations of delays and a finer localization of obstacles. More samples provide a clearer picture of the reflected signals, making the reconstruction more detailed and accurate.
  - **Decreased `Nsamp` (e.g., 50)**: Lowering the number of samples reduces temporal resolution, which may cause the reconstructed image to appear blurred and decrease the accuracy of obstacle detection. With fewer samples, the system has less data to work with, resulting in a less detailed reconstruction.