Washington University in St. Louis
School of Engineering & Applied Science

TDOA SLaP (Time Difference Of Arrival Sound Localization and Placement)

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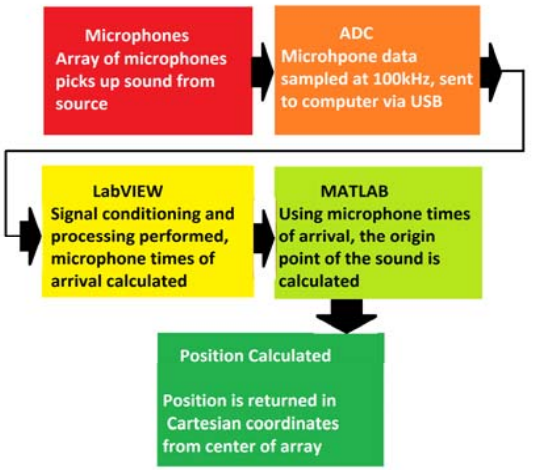
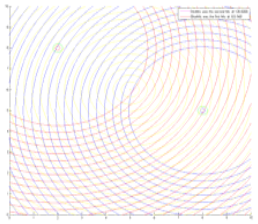
Abstract

In this project, we developed a system that identifies a sound of interest and returns the point of origin of the sound in 2D Cartesian coordinates. Our system uses an array of 4 omnidirectional DBX RTA-M microphones, with a sample rate of 100kHz, upsampled to 1MHz, and cross-correlated with each other to obtain the time difference of arrival (TDOA) for each microphone. The TDOA for each microphone is then run through an algorithm in MATLAB to return the origin point of the sound with 95% accuracy.

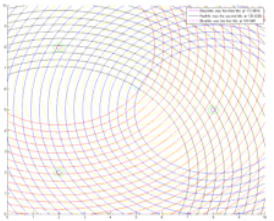
Process



Proof of Concept



2 Microphone Detection



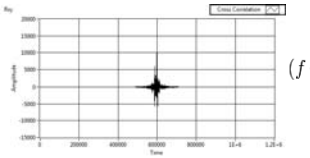
3 Microphone Detection

In order to get a better understanding of the physics of sound, we created a simple simulation of a point source propagating outward.

These screen captures from the MATLAB simulation demonstrate a simple visual model for how the system works as well as showing the need for one more microphone than the dimension in order to localize the source

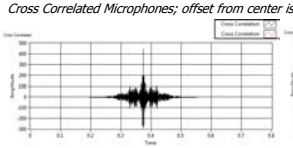
Cross Correlation

In order to verify that we are localizing the correct sound, we utilize a method called cross correlation that compares two signals against each other and tests how well they match using convolution. The peak of the convolution graph indicates the point of maximum correlation.
When detecting our initial signal, we used a matched filter that compared the signal against a template. After that test is passed, we compared the input from the microphones against each other using cross correlation determine the TDOA between each microphone pair. Below is the equation for cross correlation as well as an example of both the matched filter and two microphone inputs cross correlated with each other.

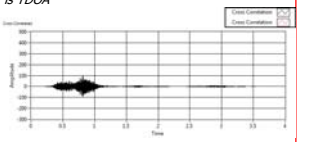


$$(f \star g)(t) \stackrel{\text{def}}{=} \int_{-\infty}^{\infty} f^*(\tau)\, g(t+\tau)\, d\tau$$

Cross Correlated Microphones; offset from center is TDOA



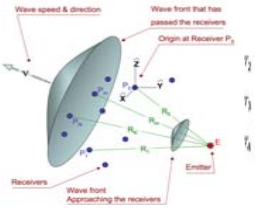
Dog Bark Correlated with Dog Bark



Dog Bark Correlated with a Lion Roar

Multilateration

Our algorithm for determining the origin sound location involves implementing the multilateration equations. Multilateration is a technique that is capable of returning the desired coordinates using only relative times. In the equations below, c is the speed of sound in the environment, T_i represents the time for a sound wave to travel to a microphone, (x,y) represents the sound origin, (x_i,y_i) represent the coordinates of a microphone in the array, and τ_i is the TDOA between a mic and the 'base', or the first mic hit. Normally, one more microphone than dimensions is needed, however in order to linearize the equations one can provide two more microphones than the number of dimensions.



$$\tau_2 = T_2 - T_1 = \frac{1}{c}\left(\sqrt{(x-x_2)^2+(y-y_2)^2} - \sqrt{(x-x_1)^2+(y-y_1)^2}\right)$$

$$\tau_3 = T_3 - T_1 = \frac{1}{c}\left(\sqrt{(x-x_3)^2+(y-y_3)^2} - \sqrt{(x-x_1)^2+(y-y_1)^2}\right)$$

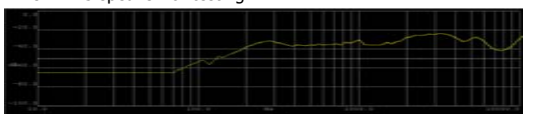
$$\tau_4 = T_4 - T_1 = \frac{1}{c}\left(\sqrt{(x-x_4)^2+(y-y_4)^2} - \sqrt{(x-x_1)^2+(y-y_1)^2}\right)$$

Multipath Interference

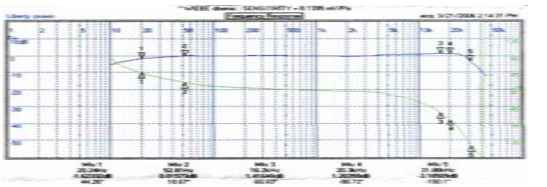
Multipath interference occurs when a wave from a source propagates to a detector by two or more paths and components of the waves interfere. We would have to account for this interference in our omnidirectional microphones in order to provide the correct times in our search algorithm.

Hardware

-4 DBX RTA-M microphones
-SM PR8E Pre-Amp
-NI USB-6212 ADC (400KSample/s aggregate)
-Dell A215 speaker for testing

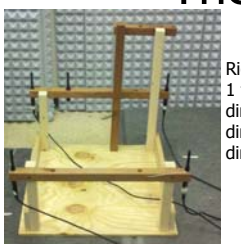


Frequency response of Dell A215 speaker



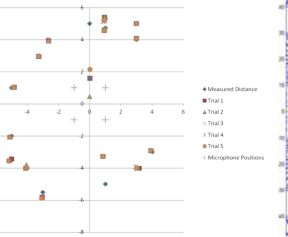
Frequency response of a DBX RTA-M microphone

The Rig

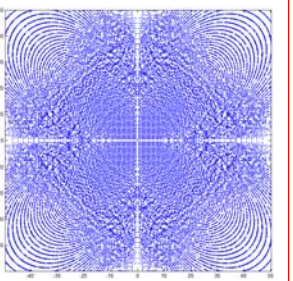


Rig allows for microphones to be offset 1 foot from the center in the y direction, 1 foot or 6 inches in the x direction, and 1 foot or 2 feet in the z direction

System Specifications



Live Test of System (Axes in Feet)



Points of Maximum Accuracy (Axes in Feet)

After extensive testing, the engineered system has the following specifications for localization
-Requires input times to be accurate within microseconds
-Average error 5%

References

-https://en.wikipedia.org/wiki/Multilateration
-http://blog.andersen.im/2012/07/signal-emitter-positioning-using-multilateration
-ieeexplore.ieee.org/iel5/89/29292/01323087.pdf?arnumber=1323087