First Responder Assisting Sensor Payload

By Alexandre Dumontheil, ECE '23

Introduction

Human hearing is a remarkable ability that permits detecting sounds of varying loudness and frequency (pitch). It is also possible for the brain to locate where a sound is coming from in 3D space by analyzing very small changes in timing and volume of audio signals. This article aims to explore how humans do this to replicate it with microphone arrays and mathematical algorithms. This project aims to develop a mobile robot operated remotely by first responders that can locate and detect victims in disasters. By improving the design of the system and adding sound localization capabilities, the team hopes to increase the bot's accuracy, usefulness and save more lives.

Sound in nature

Sound Properties

Sound is energy that is best understood as vibrations traveling through the air. Each sound is a wave with three properties: frequency, the times a sound wave repeats per second; amplitude, which is the intensity of the sound; and temporal variation which is the sound's duration and how far it travels. As sound travels, its intensity decreases over distance, becoming quieter and quieter. If sound reaches human ears, the complex hearing organs turn the vibration into an electrical signal that the brain processes as noise.

Spatial Sound

The components most crucial to spatial localization originate from an area of the ear called the external ear. This includes the general ear shape, the ear canal, and the eardrum. The brain uses the difference between the signals received by each ear to determine where a sound is coming from. These differences originate from the shape of the head and the ears, which affects sound coming to each ear differently. The differences in the signals can be split into timing differences (delay in the signal) and level differences (sound pressure/loudness levels). These two types of difference can additionally be perceived by microphones placed in the same position as the ears.

Microphones

Common microphone types

Microphones convert vibrations into an electrical signal and work strikingly similarly to human ears, where a membrane vibrates and converts sound waves into a different form of energy. The two most common types of microphones used today are dynamic and condenser microphones. Dynamic microphones are often cheaper, don't need extra power but are less sensitive to low volume audio signals. Condenser microphones are more sensitive but require voltage and are often less sturdy due to more fragile and complex circuitry contained within them.

Important properties to consider while choosing a microphone model are bandwidth (the range of frequencies capable of being detected), the frequency response (microphone sensitivity at different frequencies), Volume sensitivity (the minimum and maximum pressure rating of the model), power requirement, sturdiness, reliability, size, weight and cost. The following figure is a comparison of two different microphone types and the considerations associated with each model:

Figure 1. Pros and Cons analysis of two industry famous dynamic and condenser microphones, the SHURE SM 57 and the AKG C214 model.

Microphone Polar Patterns

Microphones also have directionality, which refers to their sensitivity to sound coming from different directions. A microphone's directionality is labeled as its polar pattern, which will often fall within one of four main categories: Omnidirectional (sensitive to sound from all directions), Cardioid (most sensitive to sound from the front), figure eight (sensitive to sound from the front and back but not the sides), and shotgun (highly specialized Cardioid pattern that only picks up sound directly in front of it).

These patterns are crucial for sound localization as they affect the recorded microphone signal quite differently. The following is a diagram showcasing the different polar patterns and their directionality:

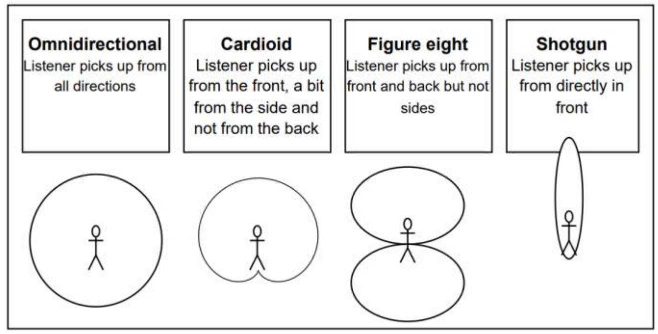

Figure 2. Microphone directionality common patterns. Included polar patterns are: Omni, Cardioid, Figure eight, Shotgun

Microphone Array Techniques for Sound Localization

2D Localization with Circular Mic Arrays

The previous exploration of sound, spatial hearing and microphone basics can be applied to understanding a microphone configuration and data processing algorithm to implement spatial hearing in a robot. The field of spatial audition in robots is still facing difficulties with implementing an human ear-based localization system but more successful methods of implementing robot audition have been microphone arrays which are efficient and robust to ambient noise, ideal for application in an urban disaster scenario.

A circular microphone configuration array is one where cardioid microphones are positioned facing outwards on a cylinder. Time delays and level differences between the received signals can be used to yield the directionality of an incoming sound. This yields 2D localization data in a plane, ideal for indicating to a first responder the direction angle where a potential victim might be located. An example setup for the array is as follows:

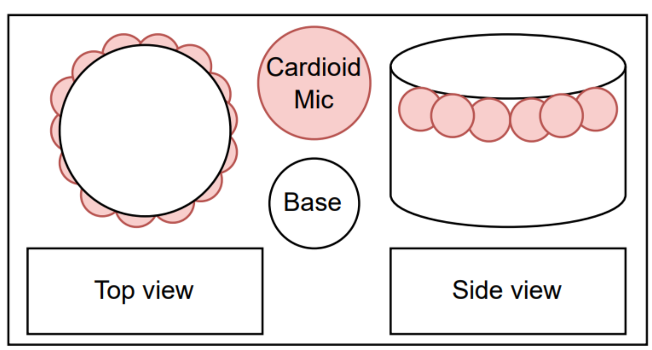

Figure 3. Circular microphone array configuration

3D Localization with 6-microphone Array

A more recent method of sound localization on a robot is a 6-microphone array yielding 3D localization. These microphones are configured as follows:

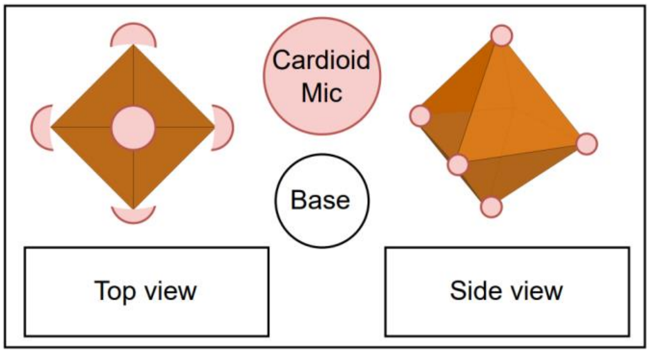

Figure 4. Octahedron microphone array configuration

This octahedron configuration consists of 6 microphones, 4 on a plane positioned 90 degrees from each other and two microphones facing up and down. This setup can be used to estimate three important properties of an incoming sound signal: its distance, azimuth angle and elevation angle. This is determined through mathematical derivations applied to the recorded audio signal at each of the microphones.

These mathematical derivations and the octahedron configuration of microphones yield impressive localization results. Simplifying this schematic into a 2D localization system to decrease the processing demands could also be achieved by removing the microphones at the top and bottom of the octahedron. More experimentation on this technology as well as research on microphones and analog to digital converter components will highlight the feasibility of an audio localization feature within the project payload.

Conclusion

There are a myriad of different microphone configurations and algorithms applied to the question of implementing auditory localization within a robot. This paper hopes to highlight some of the basic mechanics behind audio localization as well as two possible microphone configuration and general algorithms that can be experimented with and implemented on future versions of the senior design project.

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