Periwinkle

Impact of Room Architecture on Sound Localization

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Introduction

Our Senior Design group is currently developing a device to assist individuals with hearing impairments in determining the directionality of sounds. The device, which takes the form of a circular microphone array, is equipped with an LED corresponding to each microphone. The LEDs illuminate to indicate the direction from which the sound originates. Although this concept may seem simple, it is far more complex in practice. To elaborate, simply treating each microphone as though it were connected to a cup and string, where sound directly transmits to the device, oversimplifies the matter since sound behaves differently in reality.

Sound Directionality

The way that sound waves travel is determined by the source of the sound and the medium through which it propagates. When sound waves are emitted from a source, they radiate outward as spherical waves, with the energy of the wave distributed evenly across the surface of the sphere. As these waves encounter different boundaries, they can either be reflected, absorbed, or transmitted, causing changes in the directionality of the sound.

In a room, the presence of boundaries such as walls, floors, and ceilings can significantly impact the way that sound waves propagate within it. For instance, if a room has parallel walls, the sound waves will bounce back and forth between the walls, creating a standing wave pattern. This can lead to certain frequencies being reinforced or canceled out, depending on the phase of the reflected waves. Consequently, the room can have a very directional response, with certain frequencies being more pronounced in certain parts of the room.

In contrast, rooms with irregularly shaped walls or significant absorption materials will diffuse or absorb sound waves as they reflect off the walls, resulting in more even, non-directional sound throughout the room. Additionally, the size of the room can also play a role in the directionality of sound. In smaller rooms, sound waves will be reflected back and forth more frequently, resulting in a more directional response. In contrast, larger rooms provide more space for the waves to spread out, leading to a less directional response. Understanding how sound waves interact with different boundaries and room sizes is crucial in designing an effective device to aid hearing-impaired individuals in determining sound directionality.

Impulse Response & Room Acoustics

The impact of a room's shape on sound directionality is a crucial consideration in the design of our device. One approach to addressing this issue is to determine the impulse response of the room. The impulse response is a measure of how a system reacts to a brief input signal, or an impulse, and can be determined through impulse response testing. This technique involves generating a short, loud burst of sound in the room and measuring the resulting sound waves as they reflect off the walls and other surfaces.

Figure 1. Effect of the room on sound localization represented as a linear system

In signal processing, the impulse response of a system is commonly used to understand how it will affect a signal passed through it. For instance, the impulse response of a filter is used to understand how it will modify the frequency spectrum of a signal. Similarly, the impulse response of a communication channel can be used to understand how the channel will distort or degrade a transmitted signal. In our case, we can view the room as the system and a person talking as the input signal. Therefore, if we can determine the impulse response of the room, we can use it to determine how the room will affect sound under different conditions.

The mathematical principle behind this approach is that any discrete time signal can be expressed as a weighted sum of shifted impulses. Additionally, the superposition principle states that the total response of a system to multiple inputs is equal to the sum of the response of the system to each individual input. Furthermore, the response of the system to a scaled input is equivalent to the scaled response of that input. By knowing the impulse response of the system, we can represent the output of our device as a sum of scaled and shifted impulse responses. This enables us to determine how the device will respond to different sound inputs, taking into account the room's impulse response.

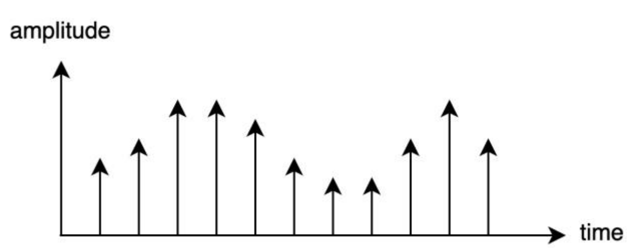

Figure 2. Signal represented as weighted sum of shifted impulses

Testing Sound Directionality

In the context of our Senior Design project, understanding anechoic chambers and their properties is useful in testing our device. Anechoic chambers are designed to minimize sound reflections, making them ideal for testing our device's directionality. These rooms use absorbing materials and shapes to cover the walls, floor, and ceiling. Typically, acoustic foam or fiberglass is used as the absorbing material, which converts sound waves into heat as they pass through the foam. The way in which these materials are placed in the room is also important, with irregularly shaped walls that scatter sound waves in multiple directions. Walls are typically covered in spikes or similar shapes made from acoustic foam, and the chambers have thick outer walls to prevent outside noise from interfering[2].

While there are no perfect anechoic chambers at Tufts University, there are several rooms around campus designed to reduce sound reflections, such as the Digital Design Studio Recording Room in Tisch Library. These rooms are more than sufficient for our testing purposes, allowing us to evaluate our device's ability to distinguish between multiple human voices and distinguish human voices from other sounds. However, it is important to test our device in other locations that may not be ideal, such as buildings with a lot of sound reflection. In such situations, we can use different strategies, such as filtering out specific frequencies to determine the direction from which the sound came.

It is crucial to note that the goal of our project is not to improve the audio quality but to determine the direction of the sound. Therefore, it is essential to consider various factors that affect sound directionality, such as the shape of the room and the materials used in the chamber. Additionally, different microphones in the array may pick up different frequencies, which can be used to determine the source of the sound. Testing our device in different environments will allow us to evaluate its performance in various conditions and improve its effectiveness in real-world settings.

Conclusion

After completing our Senior Design project, I now have a deeper understanding of how to apply the concepts we discussed in this report to real-world scenarios. Our team successfully designed and implemented a device that can accurately determine the direction of sound in various environments, including those with significant sound reflections. The experience of working on this project has been invaluable in solidifying my understanding of the technical aspects of sound processing, as well as the practical considerations involved in designing a functional device. Overall, I am proud of what we were able to accomplish and confident in our ability to apply this knowledge to future projects in the field of audio signal processing.

References

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