Periwinkle

Physical Optimization of 2D Microphone Arrays

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Introduction

Unless one is in a sound room designed to reduce extraneous environmental sound, there will almost always be background noise picked up in audio recordings. Though when determining the location of the source for example (Direction-Of-Arrival, DOA), the target sound must compete with the background noise which can make the digital signal processing (DSP) more complicated and inaccurate. Microphone arrays, which are two or more similar microphones arranged in some pattern that work in tandem to record a sound input, can greatly help with this issue by reducing the signal-to-noise ratio (SNR). Microphone arrays work in two main stages, the capture of the signal via the hardware, and then the DSP via software uploaded to the board. The processing in stage 2 can be simplified and its accuracy improved by optimizing the microphones and board characteristics and microphone arrangement on the board of the first stage.

Input Source Signal

Beginning with the physics behind sound propagation; There are two types of wave propagation in space, transverse and longitudinal waves. Sound waves, which are longitudinal, oscillate parallel to the direction of propagation and have areas of higher and lower pressure, referred to as compressions and rarefactions respectively, Fig. 1 [7].

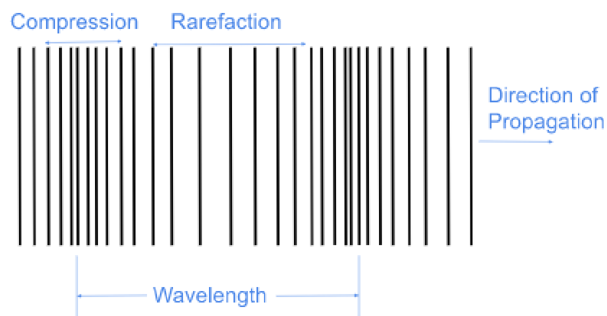

Figure 1. Longitudinal wave propagating in space, with key characteristics labeled [Adapted from 7].

In air, at around 68°F, this wave travels at 343 m/s [11]. The frequency of the most important parts of human speech lie between 250-8kHz [4]. Sound waves travel in the same direction in a straight line unless a change in the environment such as a reflection, refraction, or diffusion occurs, Fig. 2 [13]. These characteristics are essential for determining direction of arrival in the DSP stage.

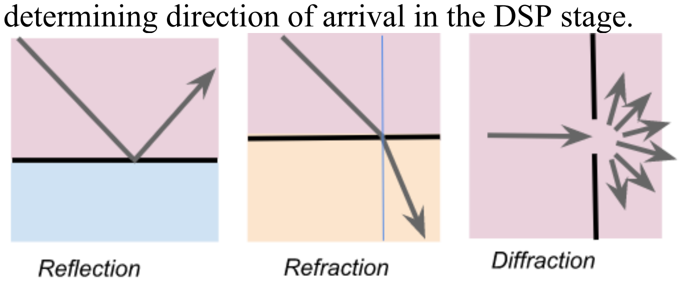

Figure 2. Incident wave that reflects (left), refracts (middle), and diffracts (right) [Left and right adapted from 12 and middle from 12].

Microphones and Board Hardware

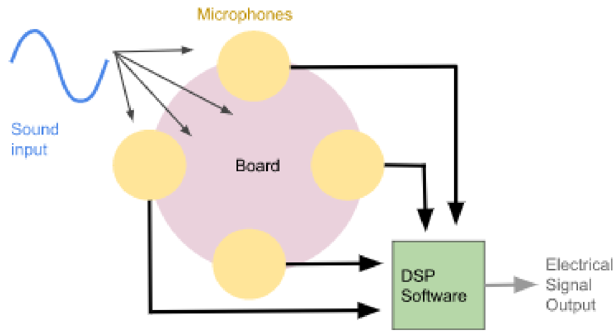

Figure 3. Overall process of a microphone array going from an input audio signal to a series of microphones and board hardware, and finally to a digital signal processing software to create an output electrical signal. [Adapted from 12].

By definition, all microphones in the array need to be similar, i.e. they need to have the same directionality, sensitivity, and phase [14].

Directionality is split into three basic categories: omnidirectional, unidirectional, and bidirectional. Each category determines the pattern in which the microphone is most sensitive with regards to the direction or angle of the incident sound (Fig. 4-6) [14]. For two or more microphones to be similar in directionality they would need to be of the same category, e.g. all omnidirectional.

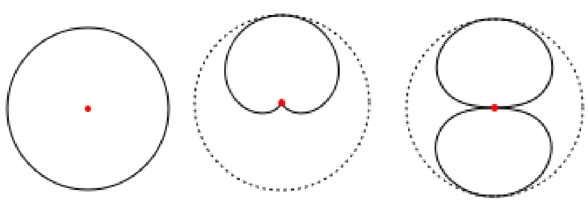

Figure 4: Omnidirectional (left), unidirectional (middle), and bidirectional (right) polar pattern, with microphone represented as the red dot pointing to the top of image [10].

Looking at the polar pattern for omnidirectional microphones (Fig. 4), the microphone will pick up the sounds from all directions equally, with no difference for varying frequencies. This can be useful if the direction of the source is unknown, but can pick up background noise. For unidirectional microphones, any sound within the accepted angle range dominates any signal from other angles, Fig. 4. This can be useful if the direction of the source is approximately known. If not, the microphones can be arranged in a pattern that extends their accepted angle range as discussed below in *2D Microphone Array Configurations*. As for bidirectional microphones, they are most sensitive to signals in two given opposite directions, Fig. 4. This is useful for capturing two separate audio signals simultaneously. However, it will reject distant lower frequency signals, which can interfere with the capture of human speech as it falls between 250-8kHz. Overall which directionality chosen for the array design depends on how much information is given for the target source direction, how many target sources are anticipated, as well as target frequency range [2].

Sensitivity within the accepted angle range can be defined as the gain of the microphone output signal with respect to its input signal, using Eq. 1 [5]. Typically for microphones to be similar in sensitivity for the purposes of a microphone array, there should be a maximum difference of sensitivity of 1.5dB.

$$Sensitivity = \frac{output\ signal}{1\ kHz\ input} \quad (1)$$

The desired level of sensitivity for a microphone depends on the anticipated target audio. A microphone with high sensitivity, such as an ECM microphone, is best suited for target sources that have quiet acoustics, less than 40dB. However, systems receiving a target source with loud sounds, greater than 130dB, would prefer a lower sensitivity microphone such as a Dynamic Microphone as it would be less likely to detect quieter background noises [2]. For human speech, which would be likely a mix of loud and quiet signals, a MEMs microphone would be ideal as its sensitivity range is between -46dBV and -35dBV [5].

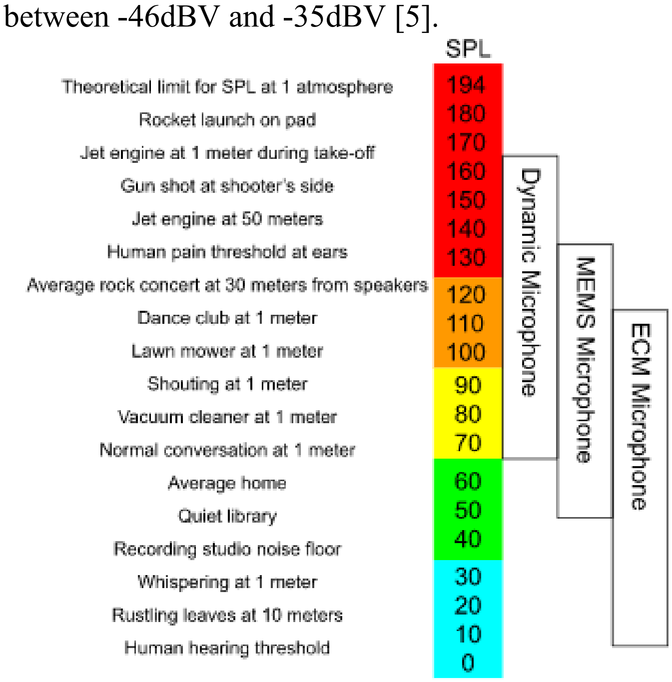

Figure 5: Examples for SPL values, as well as general

ranges for Dynamic, MEMS, and ECM microphones [Adapted from 2].

The size of the microphone must also be taken into consideration, as it impacts bandwidth, sensitivity, and board size. As seen in Eq. 2, frequency is inversely proportional to wavelength, so the higher the frequency, the shorter the wavelength. The minimum diameter of a microphone to capture a signal is dependent on the wavelength, so the smaller the microphone diameter, the higher the frequencies it can detect [3]. However, the larger diameter microphones tend to be more sensitive [8].

$$c = f\lambda \qquad (2)$$

When considering the number of microphones to put in an array, one must consider how accurate the DOA of the overall device needs to be. Less microphones results in lower resolution and therefore less accuracy of DOA as there are larger angle ranges each microphone is expected to pick up [9]. While an infinite number of microphones would in theory be ideal, to support this design the board, regardless of microphone size, would be quite large. This may not be ideal if it needs to be portable or handheld, or if there needs to be room for other device hardware.

2D Microphone Array Configurations

Considering the above constraints for each of the physical components of the microphone array, a series of configurations can be made to optimize DOA estimation. These arrangements can be found via optimization algorithms. For example, if given a specified microphone size and a volume in which to arrange them, an algorithm can cycle through different configurations searching for well-conditioned transform matrices [6].

Though a simple example of a configuration for 360° cylindrical sound capture, spacing *n* unidirectional microphones evenly around the edge of a circular board each with an angle range of θ°, where θ=360°n, Fig. 6. This can be scaled up or down depending on the number of microphones and overall angle range for the device.

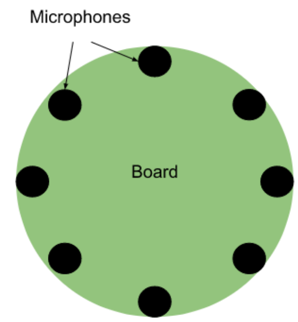

Figure 6: Eight microphone circular microphone array configuration [Adapted from 1].

Conclusion

In conclusion, a microphone array is an arrangement of microphones on a circuit board that allows the user to capture an input signal and process it into a usable electrical signal. The microphone's physical characteristics and arrangements are vital in the designer's ability to optimize the accuracy in direction of arrival analysis. This report went into detail about which characteristics were impactful, and when to consider each option depending on the context of the application for speech processing. These applications include but are not limited to DOA analysis, enhancement of SNR for sound recordings, distance speech capture, and more accurate speech recognition processing.

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