Phased Acoustic Array for Directed Sound

Abstract

The performance of the “average” audio speaker coupled with the underlying physics of acoustic waves does not provide the necessary cancellation of noise in order to direct and focus sound spatially. This creates unwanted noise pollution that can be disruptive for people nearby. The current solution for isolating this leakage of sound is through the use of headphones or sound domes; although practical, these solutions can become cumbersome for the user. Research has been done in sound directivity through non-linear and ultrasonic techniques; however nothing has been developed for mainstream consumer use.

We propose to tackle this problem by implementing a linear beam-forming acoustic array with time delayed audio samples produced using a microcontroller. A time delay is applied to each speaker based on the distance from the target point, so wave fronts from all speakers will add constructively at the focus. A 15 dB sound level difference between the focus and elsewhere is desired to achieve a difference between a comfortable audio volume and a sound level that is not distracting. This implementation provides a cost efficient alternative to current market products.

Authors

Matthew Byrne EE ’11
Miguel Gonzalez EE ’11
Andrew Townley EE ’11
Nickolaus Woodruff EE ’11

Advisors

Professor Nader Engheta
Dr. Brian Edwards

Demo in Raisler Lounge, Towne
10:30-11:30, 1:30-2:30

Team 15
Department of Electrical and Systems Engineering
University of Pennsylvania

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Acoustic Wave Physics

Our project is analogous to the concept of phased antenna arrays. This concept is used in radar to electronically steer a beam of radio waves by adding phase delays to the signals at each antenna. Additionally, an amplitude weighting can be applied to provide further beam shaping.

Extending this concept to audio is straightforward in many ways. Pressure waves in air follow the same wave equation as electromagnetic waves, and they have comparable wavelengths (440 Hz audio wavelength = 375 MHZ EM wavelength). However, to fully extend the concept to broadband audio, a time delay, rather than a phase delay, is used. The time delay ensures that wavefronts that travel different distances will add up coherently at the target point.

Microcontroller Architecture

Our “phased” array is controlled by a master microcontroller that speaks to four slave microcontrollers, assigning each a unique node number. The master takes in user input about the x and y distance of the focus from the array over the serial port and computes and applies the necessary time delays for each speaker to the slaves. The slaves then sample audio input through an ADC. Delayed audio samples are sent through a DAC to the speakers. Below is a photo of the circuit realization of our system, and to the right and below is a photo of the complete array.

Hardware Design

Measurement Setup

Experimental Results

Focus at 440 Hz

Focusing at 440 Hz

Audio Power level (dB)

Focus at (0,2.44m) without absorber
Focus at (0,2.44m) with absorber
Focus at (2m,2m) without absorber
Simulated Fallback for Focus at (0,2.44m)

Simulations

To guide our design, we simulated various phased array geometries and algorithms in COMSOL, a numerical finite-element method solver, using its built-in acoustics package. This allowed us to make any necessary approximations that would simplify the time delay phasing without sacrificing much performance. The above figure models an array of speakers as monopole sources. When a Gaussian envelope is applied, the array forms a direct beam. The red represents areas of greater sound pressure.

Phased Array Realization

Conclusion

Time domain acoustic arrays have been shown to be effective at single frequencies, but performance is dependent on room conditions and geometries. Further work should focus on a way to calibrate out these effects, likely requiring an FIR filter implementation for each speaker.

Another limitation was the limited speaker density due to the physical width of the speakers themselves. This meant that spatial control of higher frequencies could not be achieved. Using smaller, quieter speakers packed more closely would alleviate this issue. Still, as a basic proof of concept, the prototype constructed shows that sound can be steered in spite of reflections.