Phased Speaker Array : Phase of Our Lives

ECE 445 - Senior Design

PROJECT PROPOSAL

February 8, 2019

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0.1 Introduction

Objective

Music can really brighten the mood and complement the atmosphere. What one may not realize, however, is that interference patterns greatly affect the quality of the sound. Say someone has a stereo in their living room, but likes to listen to music while preparing food in the kitchen. Destructive phase relationships can cause the listener to hear music that's tinnier and lacking warmth.

Our solution is to design a four speaker array which can "steer" the sound into a single direction. Our design will use one or more IR sensing cameras to detect where the listener is in the room and apply a linear time delay across the speakers to direct the sound towards the listener.

Background

A collinear array of speakers create overlapping signals with the peak intensity of sound across all frequencies extending out directly from the center of the array. By applying a linear time delay across the array, the line of peak intensity steers away from the center at an angle. With the help of IR sensors, we can track where a person is in the room and use this information to adjust how much we need to angle our line of peak intensity so that it runs through our listener.

Our project would allow a user listening to music to walk around a room and experience little to no phase cancellation. Therefore, our project would be useful for audio enthusiasts who admire superior sound quality. In addition, our project holds great educational merit, as it provides a platform where one can model and physically experience the effects of wave interference.

High-Level Requirements

1. A numerical parameter we plan to use to quantify the quality of phase accordance will take the root-mean-square error (RMS error) of the time delays between signals (comparing them to an average, ideal time delay). When steering is implemented at 30° from center, phase accordance between signals will significantly improve, resulting in a lower RMS error. A specific range of values cannot be presented at the moment, but we hope to reduce the RMSE of the signals by 75%.

2. The sound quality improvement must be apparent to the user qualitatively.

3. The direction of the improved sound quality should be updated at least every two minutes so that the user could reasonably move about the room with the improved sound quality following the user.

0.2 Design

Block Diagram

Our design has several modules including: the signal input module, the control module, which contains the microcontroller and the DACs, the speaker array module, the power module, and the IR cameras. The control module takes a signal in and delays it accordingly. The speaker array takes the signals in and plays them through four collinear speakers.

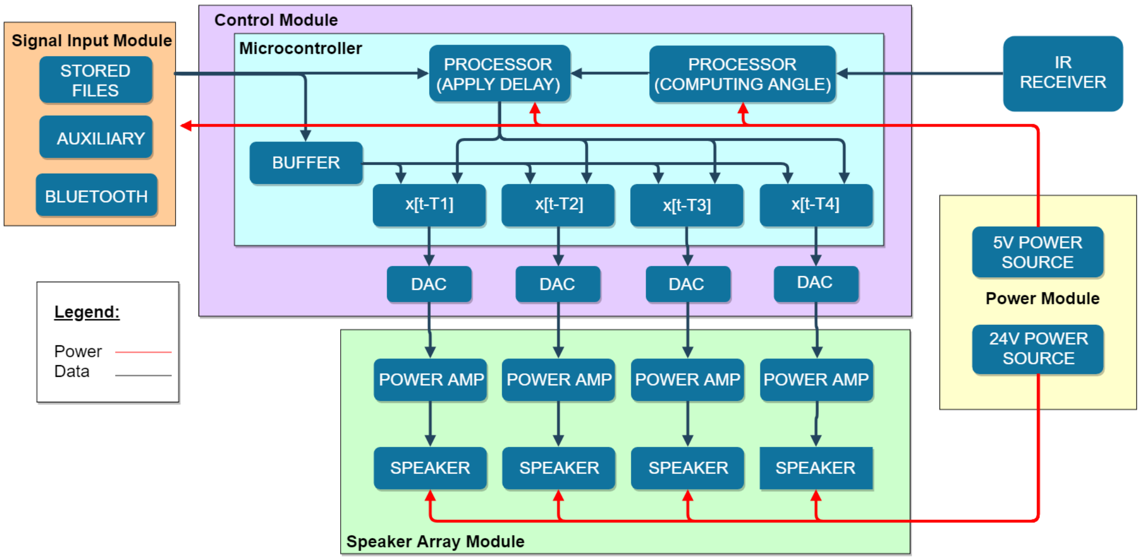

Figure 1: Block Diagram

Physical Design

The physical design will consist of an array of four speakers separated in the middle by two IR sensing cameras. The speakers and cameras will be contained in an enclosure with the approximate dimensions shown in the diagram. There will also be a separate module including the control module and input module.

Functional Overview and Block Requirements

- Control Module
  - **Microcontroller:** A microcontroller will be used to process the tracking information provided by the IR sensing cameras, do the necessary calculations to

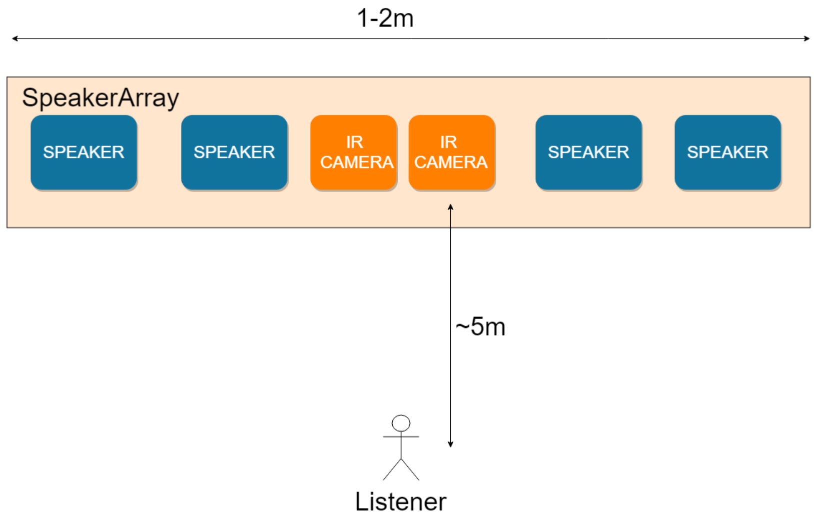

Figure 2: Physical Design

determine how much to delay each speaker in order to "steer" the sound, and apply the delays.

  * REQUIREMENT: Must be able to process digital audio signal faster than 44.1kHz.
  * REQUIREMENT: Must be able to store a large enough range of the audio signal to be present to steer the sound at a 60 degree angle.
  * REQUIREMENT: Must be able to output signals to the DAC's within 10 microseconds of each other (any greater delay can be compensated for digitally).

- **DACs:** The DACs will be used to convert the digital signal to an analog signal that the speakers can use. They will be placed at the output of the microcontroller and input to the power amps.
  * REQUIREMENT: Must support 44.1kHz sampling rate.

- **Signal Input Module**
  - **Stored Files:** Our design gives the user multiple ways to input a sound file. The first is that there will be a .wav file already stored in the device.
  - **Auxiliary:** Another option to input the sound file is to use an auxiliary cord to connect to a music playing device.
  - **Bluetooth:** The third option for inputting a sound file is to connect to Bluetooth, and be able to play a song remotely. This is a reach goal for the project.

If we are able to include this feature, the user could also remotely adjust the volume and even be able to turn on/off the tracker.

  * Requirement (For All): Must be able to convert an analog signal to a 16-bit digital signal.
  * Requirement (For All): Must transmit data at or faster than 44.1kHz.

- **Speaker Array Module**
  - **Power amplifiers:** The power amplifiers are needed to amplify the sound so that the speakers can use it. It will be at the output of the DACs and at the input of the speakers.
    * Requirement: Must be able to output at least 1W of power to speakers.
    * Requirement: Power supply must be less than or equal to 24V.
    * Requirement: Power output must be within 20% (1dB) of other speakers.
  - **Speakers:** The speakers convert the electronic audio signal of the song being played to the correct sounds. It will be at the output of the power amplifiers.
    * Requirement: Volume output must be within 20% (1dB) of other speakers.
  - **IR sensing camera(s):** IR sensing cameras will be used to detect where the listener is in the room. This tracking information (the x-y location) will be sent to the microcontroller to be processed. We would need two of these cameras because each one detects a range of about 33 degrees, so two cameras would give us a more reasonable range for a room.
    * Requirement: Must be able to detect angle towards infrared source within 5% accuracy.
    * Requirement: Must be capable of updating the position at least every 2 minutes.
- **Power Module**
  - **Power Supply (5V):** A 5V power supply will be used to supply power to the control and signal input module. The supply will need to be steady, well-filtered, and able to provide enough current to adequately power the digital circuitry involved in processing the audio signal.

  * REQUIREMENT: Must provide 5V ±5% at peak output current draw of 300mA.

- **Power Supply (24V):** A 24V power supply is necessary to provide power to the power amplifiers. The power amplifiers require a stronger power supply because the electrical output of the amplifiers are physically moving the diaphragms of the speakers. Therefore, a higher current draw should be expected.

  * REQUIREMENT: Must supply 24V ±5% at peak output current draw of 1A.

Risk Analysis

The part of our project that imposes the greatest risk of failure would be the control module. It demonstrates the most complex interfacing between modules and the success of the project relies nearly entirely on the ability of the microcontroller to delay an analog signal to four different degrees and send them to four different speakers. Furthermore, device calibration cannot be done by ear or human inspection; a professional-grade digital audio workspace, microphones with good audio clarity, and a reliable computer are needed to make sure the device is operating properly.

While calibration may be tedious, the end result will be impressive. In addition, our team has access to not only every item needed to calibrate the system, but also access to a wealth of university resources and insightful advice from our professors and TA's. In conclusion, our project will be challenging, but our determination and the supportive course staff will keep us focused and assure our project's success.

0.3 Ethics and Safety

On the surface, our project poses no immediate ethical or safety concern. Our project cannot endanger others, won't have a minuscule effect on global health, nor does it deal with any personal information. However, our project does pose a few health risks to those who operate it and to those who are in the direct path of sound.

The greatest risk our project poses to public health is that exposure to loud sounds for long periods of time can lead to hearing loss. To address this, we put proper constraints in place at multiple levels of the project to assure auditory safety. Our power amps will deliver at most 1W of power through each speaker, which will provide approximately 80dB of sound to a listener standing one meter away from the speaker array. We predict that we will likely restrict our speakers to only put out a quarter watt of power, but may require extra headroom in case outside noises become a concern while calibrating our system.

In addition, our project involves designing and constructing power amplifiers for the speaker array. The power amp will run off of a 24V power supply, so we must be conscientious of those who construct and operate this device. Our power amps will be enclosed and wires coming to and from the amplifier module will be fastened securely. In addition, multiple circuit breakers will exist at every level of power consumption to assure that any shorts won't harm the circuitry or, more importantly, the user.