Homework 3: HRIR Generator

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Website Link: https://interactive-ear-modeling.vercel.app/

Github Link: https://github.com/mml260/Interactive-Ear-Modeling

Purpose

This project extends the outer ear and middle ear model into a transparent, simple binaural renderer. A source direction and baseline ear geometry produce left and right HRTFs, which are transformed into HRIRs and convolved with a mono source to create stereo audio.

Model Details

Each ear receives the existing directionally dependent outer ear response, a small elevation dependent reflection, a frequency head shadow gain, and a phase delay. The geometric timing relation is ITD = head diameter / sound speed x sin(azimuth). A 1 ms common delay keeps both HRIRs causal without changing interaural timing. All of the HRTFs are converted to independent left and right HRIRs using an inverse fast fourier transform at 48 kHz. The middle ear transfer function is applied to both the left and right channel changing the spectrum, but not creating any interneural time difference. The HRIR interneural time difference is estimated using cross correlation and a positive interneural time difference means that the source is coming from the left, while a negative time difference means the source is coming from the right.

Procedure

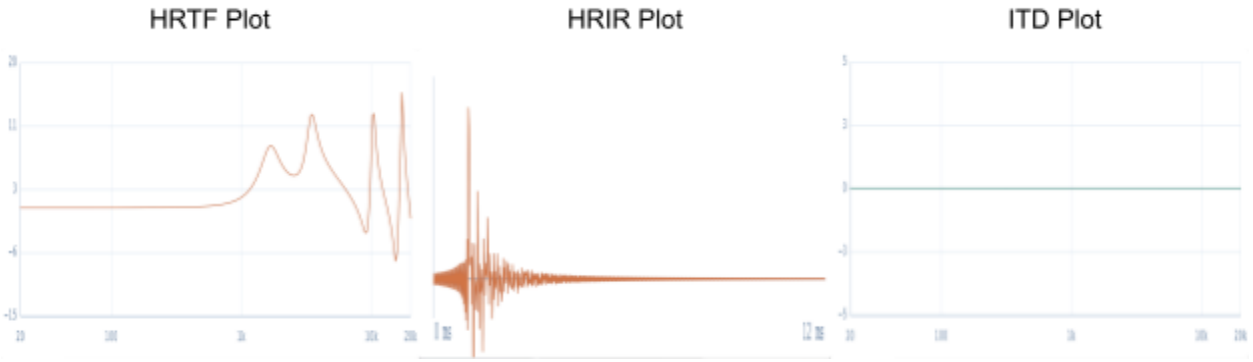
For every comparison case, the fixed case was loaded in the Binaural HRTF view, recorded the predicted and HRIR-estimated ITD, and exported the HRTF, HRIR, and ILD plots. Baseline geometry was restored before each case.

Case	Direction	Predicted ITD	HRIR estimated ITD
Median plane	0 deg az, 0 deg el	0.000 ms	0.000 ms
Lateral left	75 deg az, 0 deg el	0.493 ms	0.500 ms
Elevated front	0 deg az, 45 deg el	0.000 ms	0.000 ms

Median Plane (Front) Case

- 0° azimuth and 0° elevation
- Predicted and HRIR estimated interneural time delay of 0 ms
- The left and right HRTFs are matched so localization (horizontally) is not driven by interneural time delay

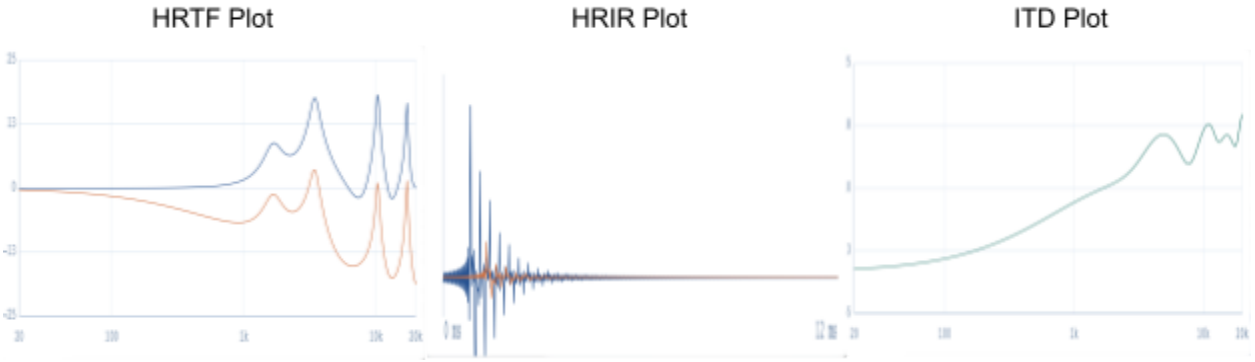
Figure 1: Median Plane Case result



Lateral Case

- 75° azimuth and 0° elevation
- Predicted ITD of 0.493 ms and HRIR estimated interneural time delay of 0.5 ms
- The right ear's response is increasingly attenuated as the frequency goes up, producing a high frequency shadow from the interneural level difference.

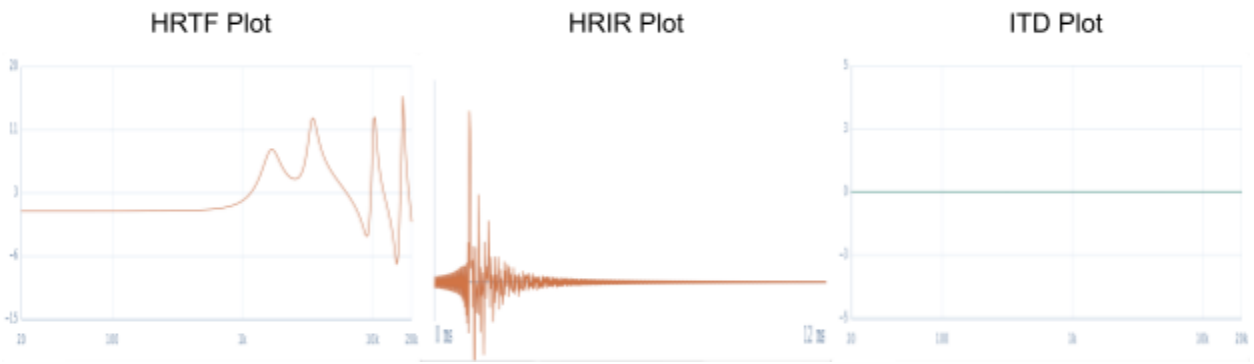
Figure 2: Lateral case result (blue = left, orange = r)



Elevated Case

- 0° azimuth and 45° elevation
- ITD of 0 ms
- Changing the elevation changes the delayed reflections while retaining the plane timing. This demonstrates the spectral cue mechanism rather than an interneural time difference or a head shadow cue.

Figure 3: Elevated Case result



Validation and Limitations

The outputs show the intended and expected behaviors of the renderer. For example, the interneural time difference increases with larger azimuth, the level difference becomes larger at higher frequencies, and the elevation changes the spectral peaks and notches. However, this model is much simpler than a measured head related transfer function and does not reproduce listener specific ear structure, room reflections, or head motion.

Binaural Audio Example

A short mono source of pink noise was rendered through the left and right HRIRs with linear convolution. Below are links to listen to the binaurally rendered audio and access the HRIR file.

HRIR link:
https://drive.google.com/file/d/1PP5GFsOzEhIfyd7knITSPForYNnnC9Mc/view?usp=drive_link

Rendered audio link:
https://drive.google.com/file/d/13xXrU9OgFkkT2uZ8S8iKWvkZbBRWzxMN/view?usp=drive_link

AI Use

AI was used as an engineering collaborator for model organization, testing, and interface implementation. One suggestion was corrected during validation: an initial case loader implementation merged a physical SourceDirection object directly into UI state. The UI state uses azimuth and elevation, while SourceDirection uses azimuth degrees and elevation degrees, so the buttons incorrectly remained at 0 degrees.