

Implementation of 3D Audio using Interpolated Head-Related Transfer Functions

Mike Heilemann
Kedar Shashidhar
Alex Venuti

Terms / Acronyms

HRIR: Head-Related Impulse Response

HRTF: Head-Related Transfer Function

CIPIC: Center for Image Processing and
Integrated Computing (University of
California Davis)

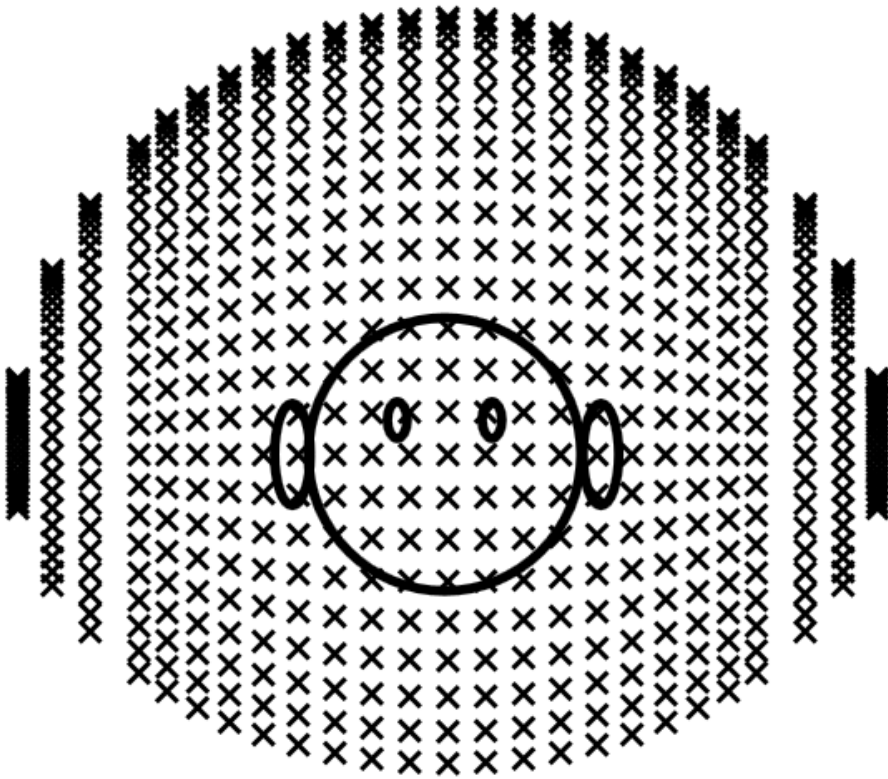
Azimuth: horizontal angle (from directly ahead)

Elevation: vertical angle (from directly ahead)

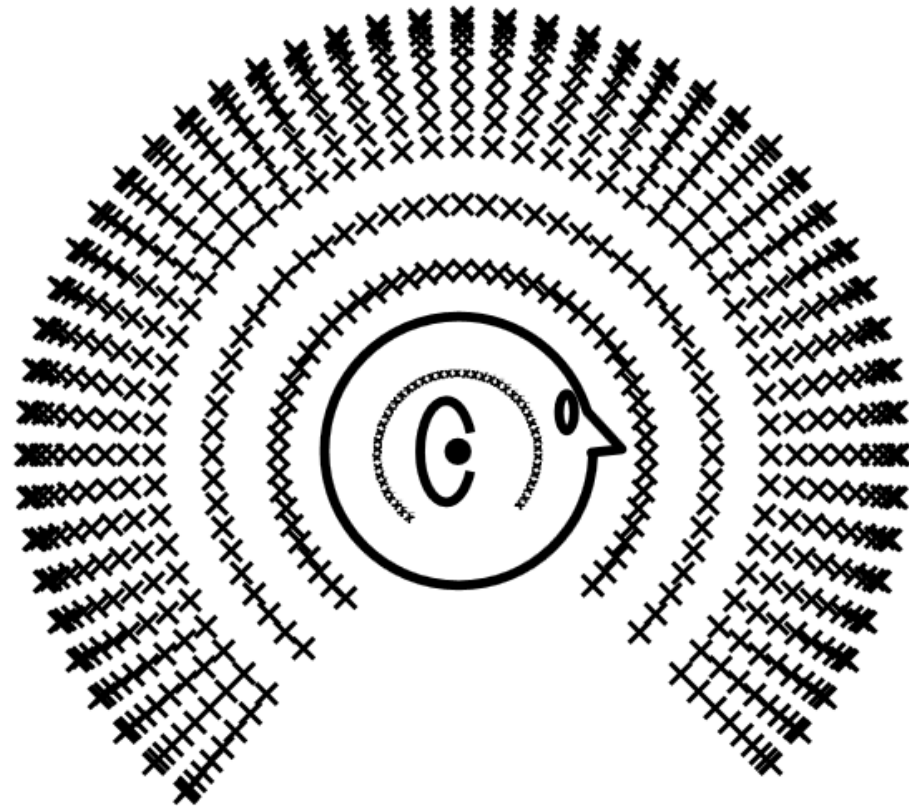
Goals

- Understand existing HRTF code for Matlab
- Choose method for interpolating impulse responses
- Modify existing Matlab code using interpolation algorithms in attempt to reduce number of stored impulse responses necessary to recreate 3D soundfield
- Investigate real-time applications of 3D audio

CIPIC HRTF Database



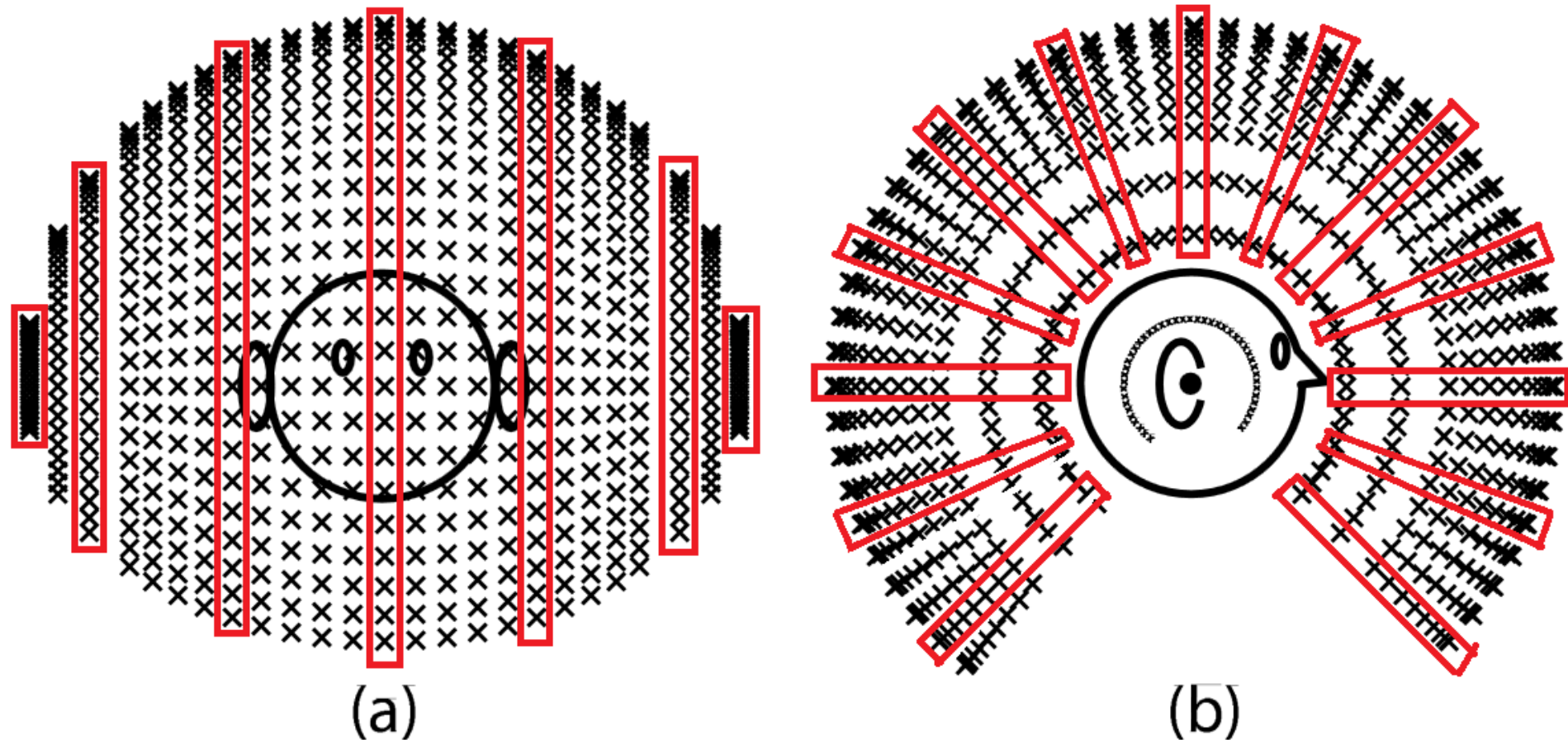
(a)



(b)

Locations of data points (a) front (b) side

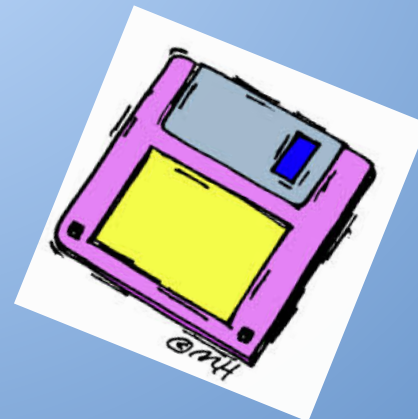
CIPIC HRTF Database



Locations of data points (a) front (b) side

Advantages of Interpolation

- Won't have to physically measure impulse response at as many points
- Reduce size of HRIR array to maximize memory efficiency
- Allows for smoother transition between points



Interpolation Method

Vector-Based Amplitude Panning:

$$\mathbf{p} = g_n \mathbf{l}^n + g_m \mathbf{l}^m + g_k \mathbf{l}^k$$

$$\mathbf{p}^t = \mathbf{g} \mathbf{L}_{nmk}$$

$$\mathbf{g} = \mathbf{p}^t \mathbf{L}_{nmk}^{-1} = [p_1 \quad p_2 \quad p_3] \begin{bmatrix} l_1^n & l_2^n & l_3^n \\ l_1^m & l_2^m & l_3^m \\ l_1^k & l_2^k & l_3^k \end{bmatrix}^{-1}$$

$$y(t) = g_n \cdot (x * h_n)(t) + g_m \cdot (x * h_m)(t) + g_k \cdot (x * h_k)(t)$$

$$\hat{h} = g_n \cdot h_n + g_m \cdot h_m + g_k \cdot h_k$$

Description of Matlab Functions

- **getNearest3.m**
 - in - elevation, azimuth, HRIR struct
 - out - three nearest points in sound field and corresponding impulse responses
- **SweepTest.m**
 - user declares two azimuth and elevation values
 - will sweep audio in a straight line between two points using three point interpolation

Reduction of Data Points

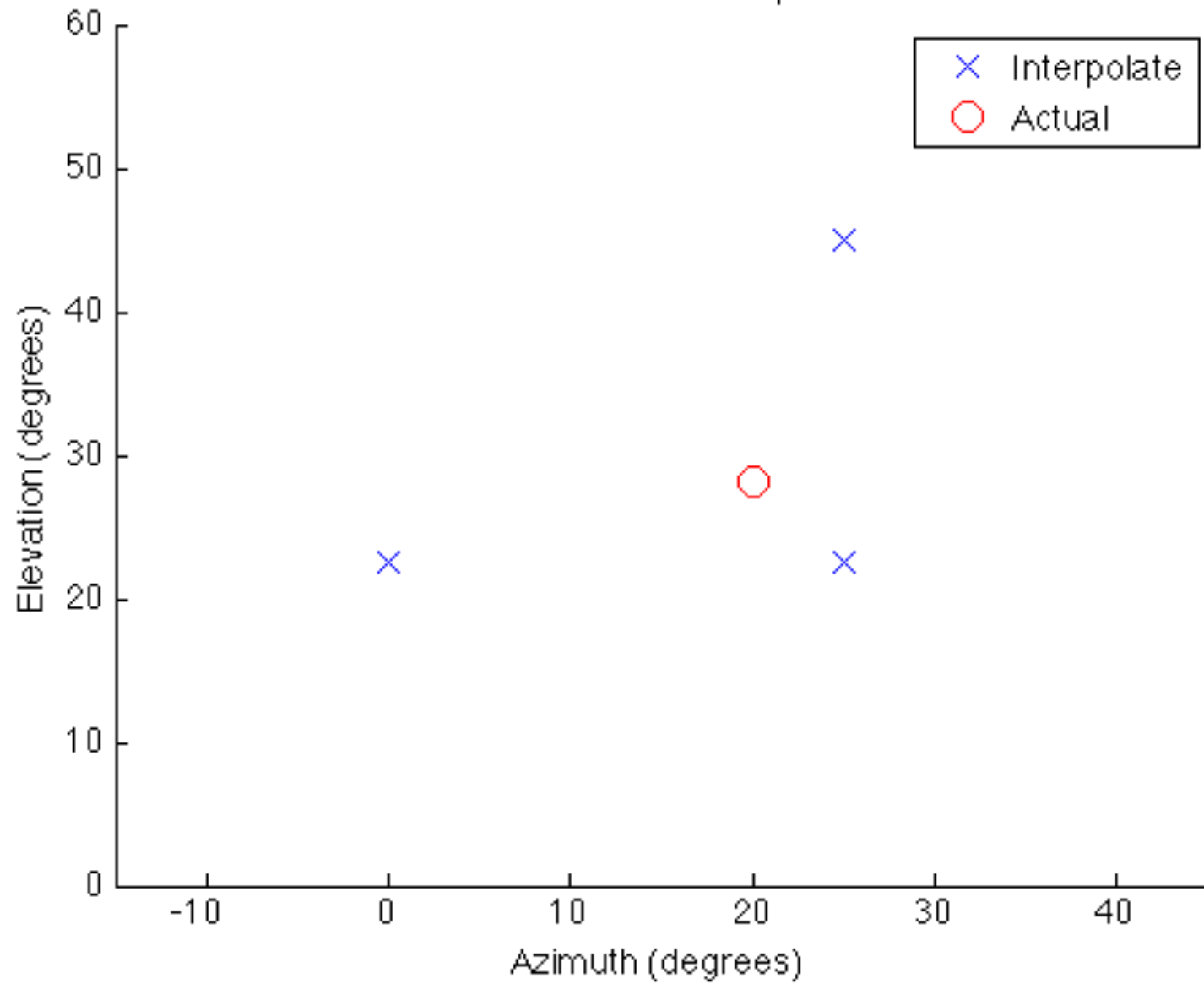
- Original HRIR Points
 - Azimuths - 25
 - Elevations - 50
 - Total Pts - 1250
- Points Needed with Interpolation
 - Azimuths - 7
 - Elevations - 13
 - Total Pts - 91

Time/Frequency Response Comparison

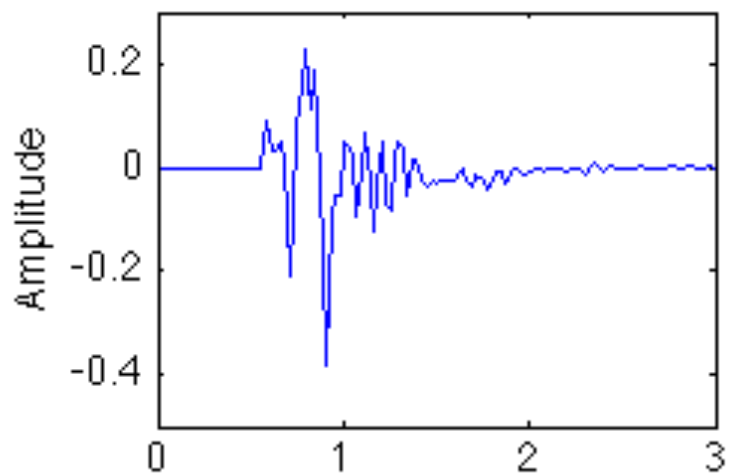
The following figures use
this example point:

Azimuth = 20 degrees
Elevation = 28.125 degrees

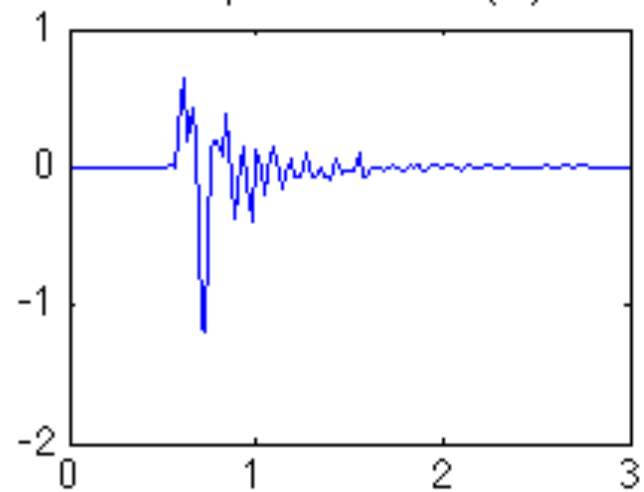
Location of Points Interpolated



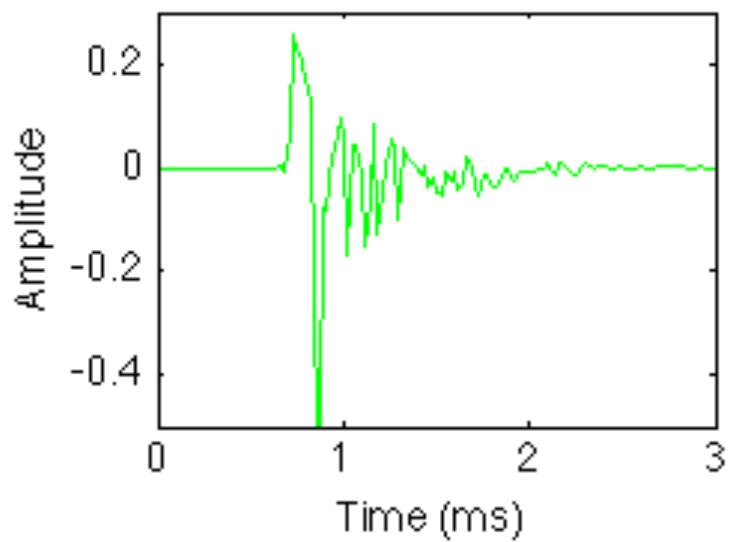
Interpolated HRIR (L)



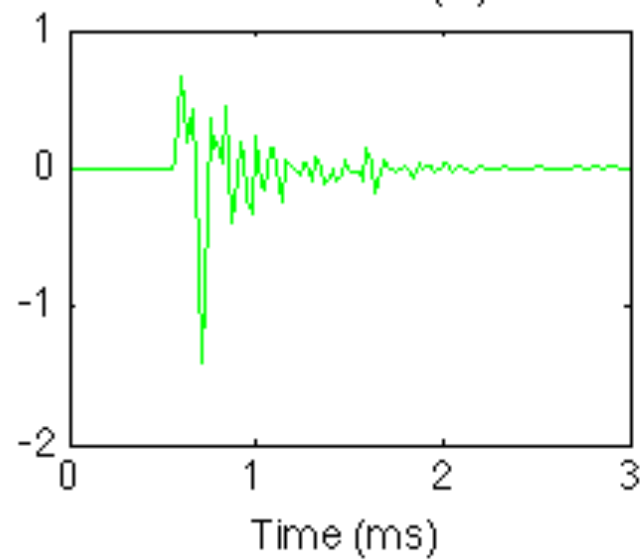
Interpolated HRIR (R)



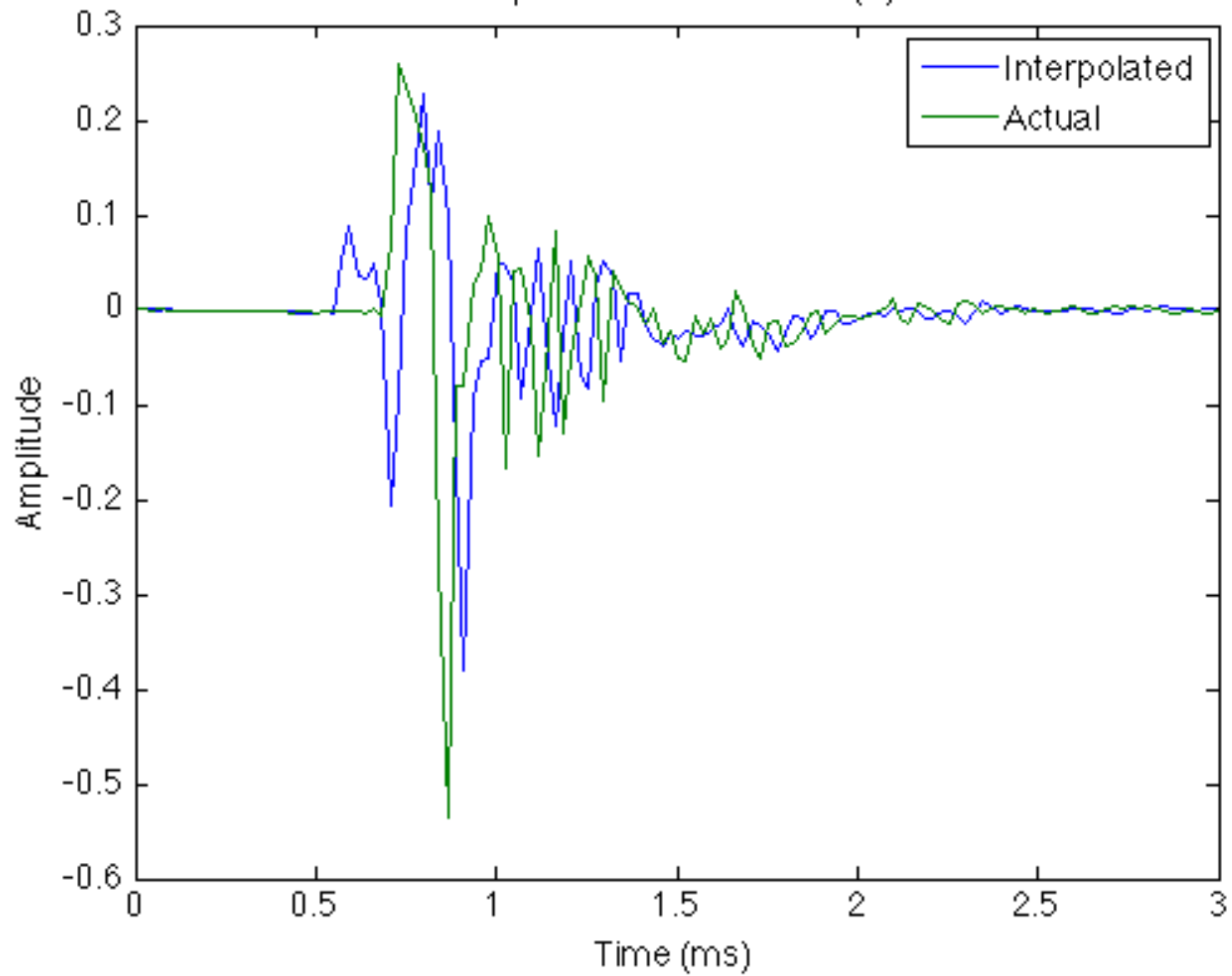
Actual HRIR (L)



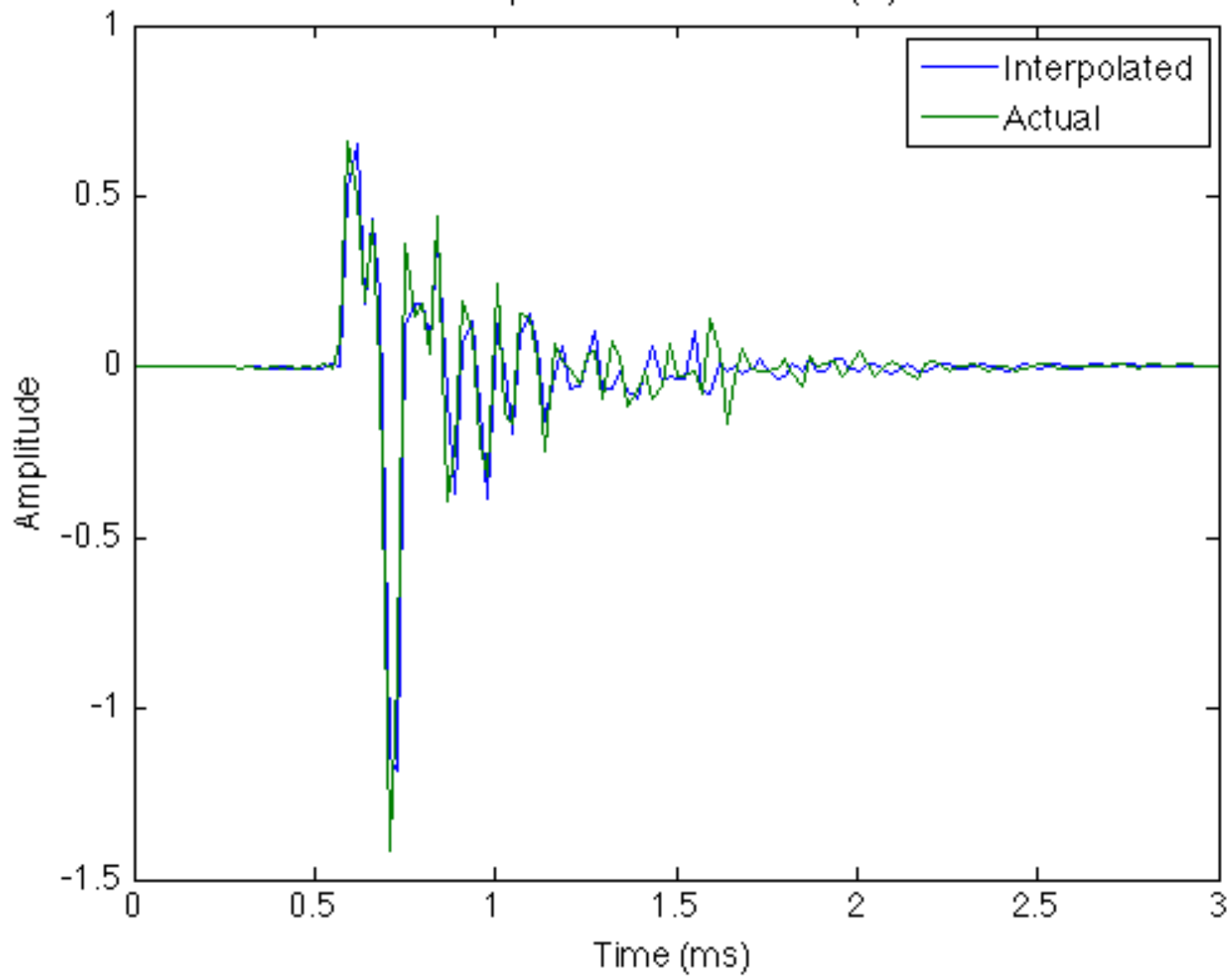
Actual HRIR (R)

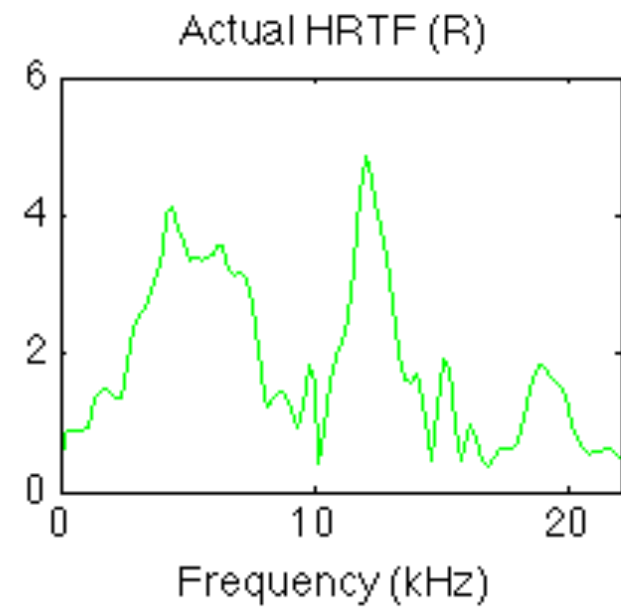
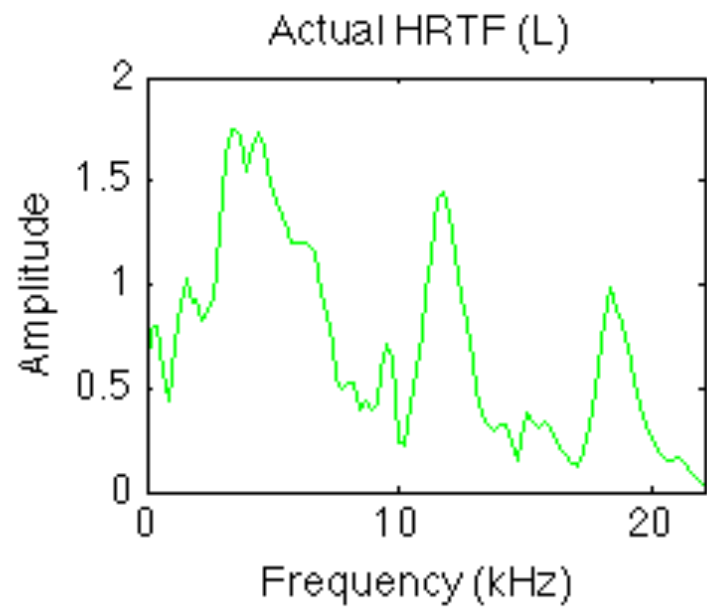
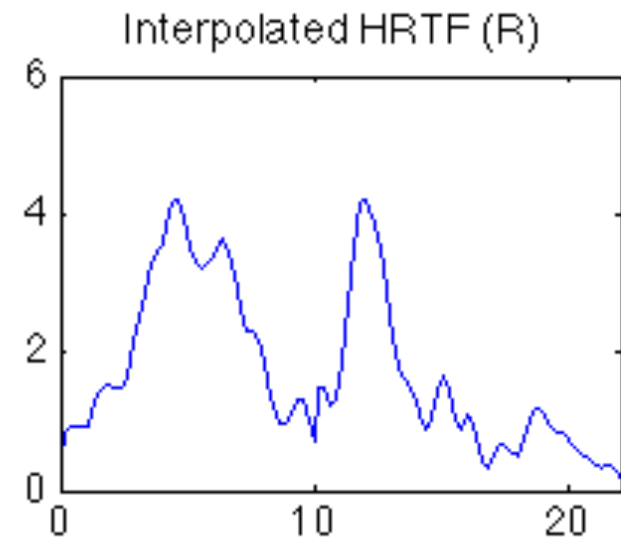
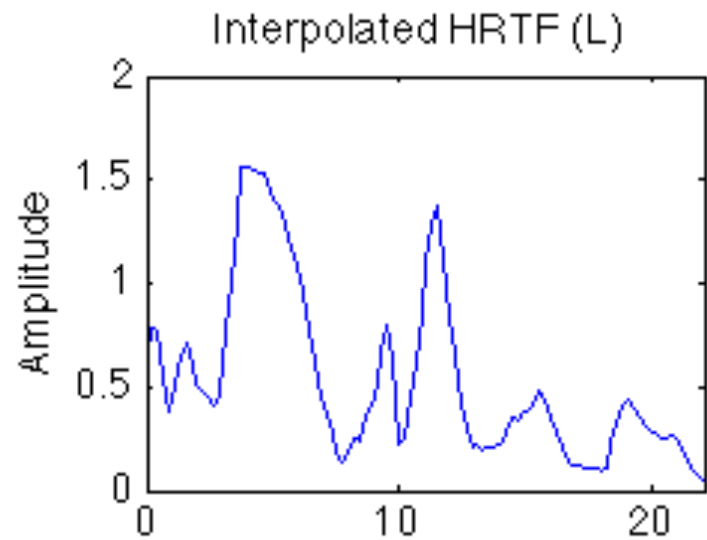


Interpolated / Actual HRIR (L)

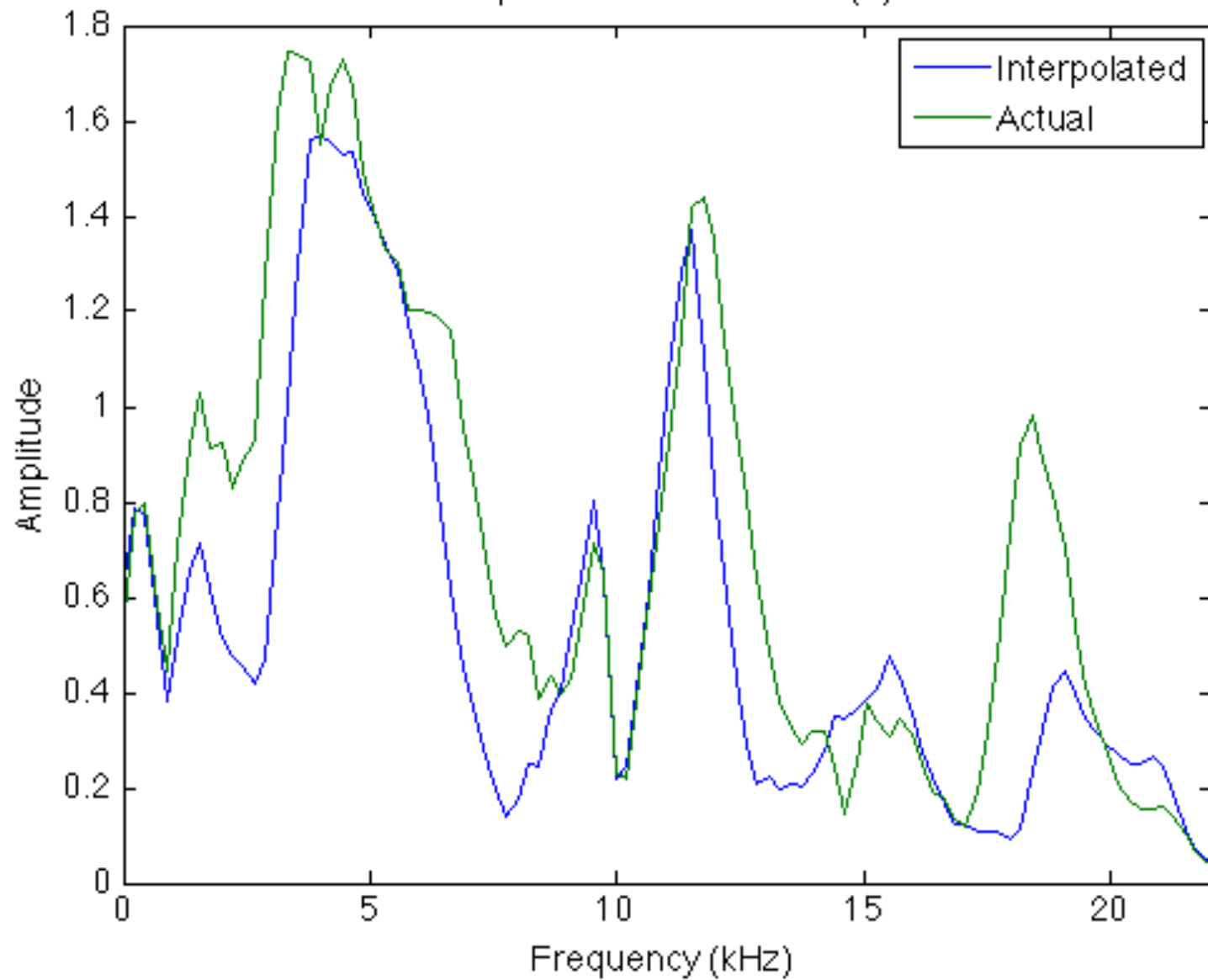


Interpolated / Actual HRIR (R)

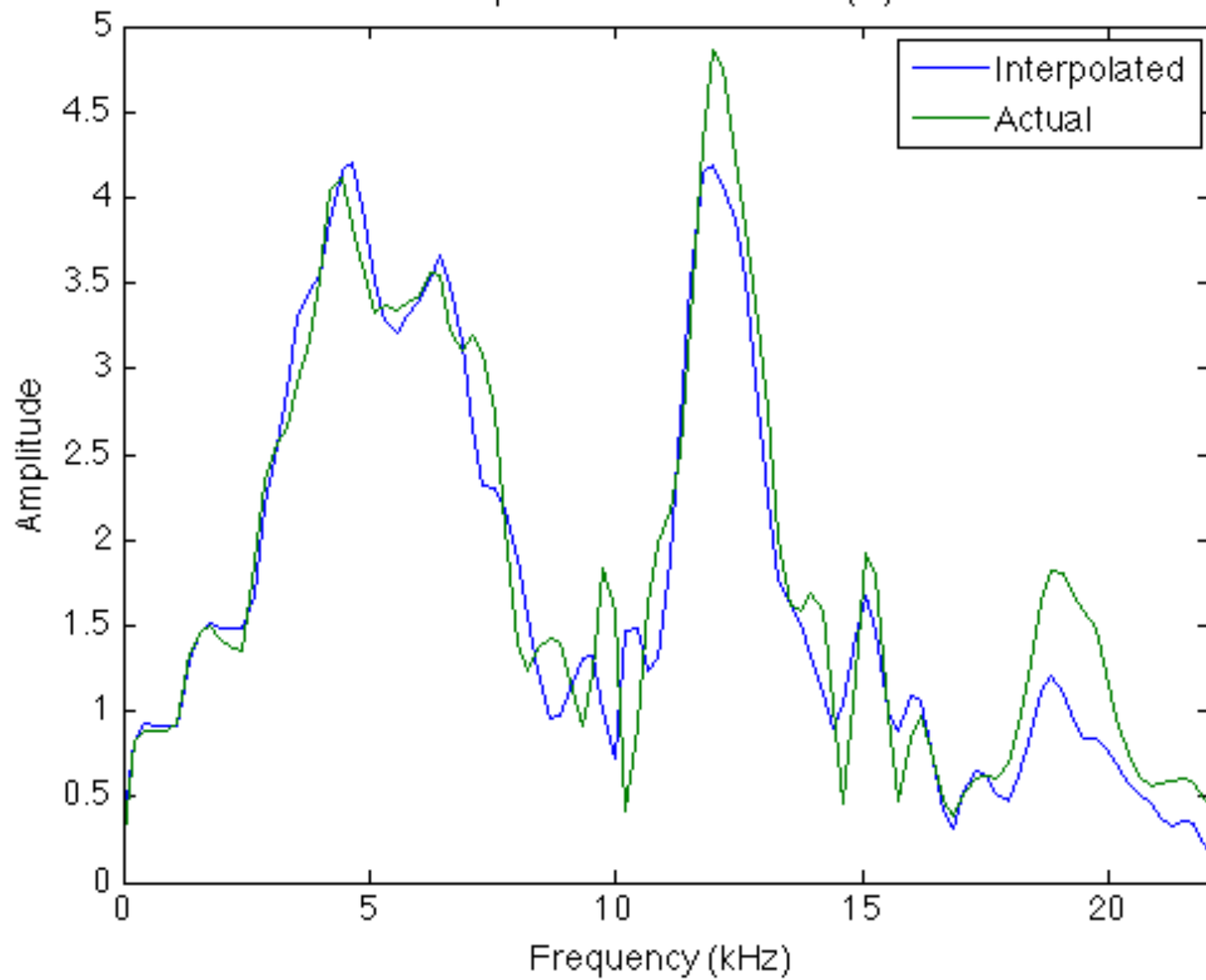




Interpolated / Actual HRTF (L)



Interpolated / Actual HRTF (R)



Audio Comparison

Files are in C:\HRTF examples

- example_act
- example_int
- example_int_corrected
- orbit1_all
- orbit1_reduced
- orbit2_all
- orbit2_reduced

Real-Time Aspects

The screenshot displays the RackAFX software interface, which is a real-time audio processing environment. The window title is "RackAFX(tm)" and the menu bar includes "File", "Modules", "User Plug-Ins", "Audio/MIDI", "PlugIn", "View", and "Help". The main workspace is a grid of 40 control modules, each with a vertical slider and a numerical display. The modules are arranged in four rows and ten columns:

- Row 1: Mix (20.00 %), Delay Time (100.00 mSec), Feed Back (0.00), Control 3, Control 4, Control 5, Control 6, Stutter Wet/Dry (0.00), Chunk Size (10000 Sample), Stutter Limit (220500 Sample).
- Row 2: Saturation (2.00), Asymmetry (0.50), Control 12, Control 13, Control 14, Control 15, Control 16, Control 17, Control 18, Control 19.
- Row 3: BPF Frequency (600.00 Hz), BPF Q Factor (0.12), Control 22, Control 23, Control 24, Control 25, Control 26, Control 27, Control 28, Control 29.
- Row 4: Bass Fc (500.00 Hz), Bass (0.00 dB), Treble Fc (1500.00 Hz), Treble (0.00 dB), Control 34, Control 35, Control 36, Control 37, Control 38, Control 39 (5).

On the right side of the interface, there are several real-time monitoring and control elements:

- Button Bank 0:** A list of radio buttons (Radio 11 to Radio 18) and a "CPU" meter.
- Button Bank 1:** A list of radio buttons (Radio 19 to Radio 26) and buttons for "Open", "Load", "Edit", "Rebuild", "Debug", and "> C++".
- Button Bank 2:** A list of radio buttons (Radio 27 to Radio 34) and buttons for "Trigger", "Tap Tempo", and "B3".
- Vector Joystick:** A diamond-shaped joystick with a blue dot in the center, labeled A, B, C, and D. Below it are dropdown menus for "A Controls", "B Controls", "C Controls", and "D Controls", and a "JS Program" button.
- Level Meters:** A set of seven vertical level meters labeled 5, 6, 7, 8, 9, and 10.
- Input/Send and Output/Return:** Two sets of level meters labeled "Input/Send (dB)" and "Output/Return (dB)", each with "L" and "R" channels. Between them are buttons for "Insert", "1-2 Aux", "2-2 Aux", and "Unity".

At the bottom left, the text "Prototype GUI Designer" is visible. At the bottom right, the text "MIDI:" is visible.

Problems With HRTF Interpolation Method

- HRTFs are different for each person
- More sensitive to Left/Right changes than Up/Down or Forward/Back
 - Evolutionary Hearing
- All points were at same radius
- Time lag between interpolated pts.



Practical Applications

Video Games

- Who wouldn't want to be able to close eyes and feel like they are actually in the game?

Room Acoustic Evaluation

- Allows you to examine acoustic properties of a room under different sound sources and room conditions

Hearing Aids

- Frequency-dependent hearing loss compensation.

References

Algazi, V. R., Duda, R. O., Thompson, D. M., & Avendano, C. (2001). The CIPIC HRTF database. In *Applications of Signal Processing to Audio and Acoustics, 2001 IEEE Workshop on the Applications of Signal Processing to Audio and Electroacoustics* (pp. 99-102). IEEE.

CIPIC Database - Copyright (c) 2001 The Regents of the University of California. All Rights Reserved

Doukhan, D., & Sédès, A. C. (2009). A Binaural Synthesis External for Pure Data. In *PD Convention*.

de Sousa, G. H., & Queiroz, M. (2009, September). Two approaches for HRTF interpolation. In *The 12th Brazilian Symposium on Computer Music (SBCM 2009)*.

Questions???