Biomimetic Sound-Localization in the Plane Utilizing Head-Related Transfer Functions

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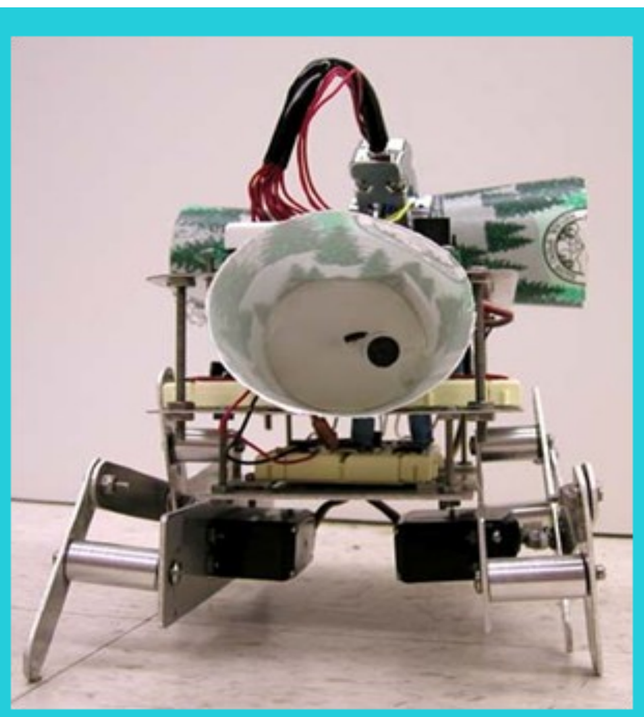
Existing Approaches & Problems:

- Multiple microphone array
  - Result: complex system
- Inter-aural time delay (ITD)
  - Analyze phase differences between sound arriving @ two ears
- Inter-aural intensity difference (IID)
  - Analyze intensity differences between sound arriving @ two ears
- Back-front confusion in 2D
- Cone of confusion in 3D



3-Microphone Sound-Localization Hexapod

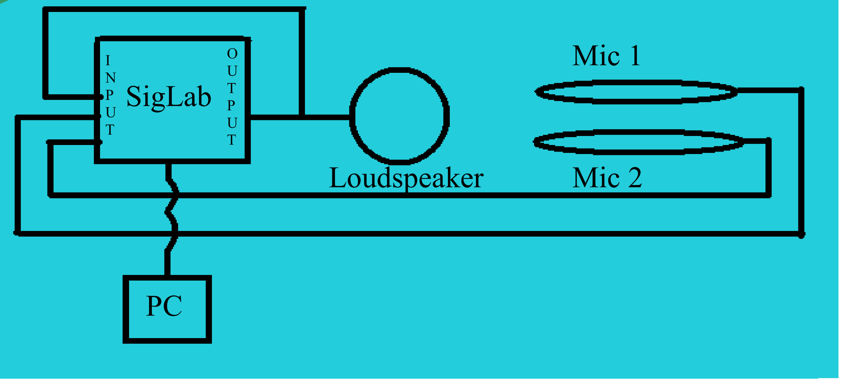
Proposed Method:

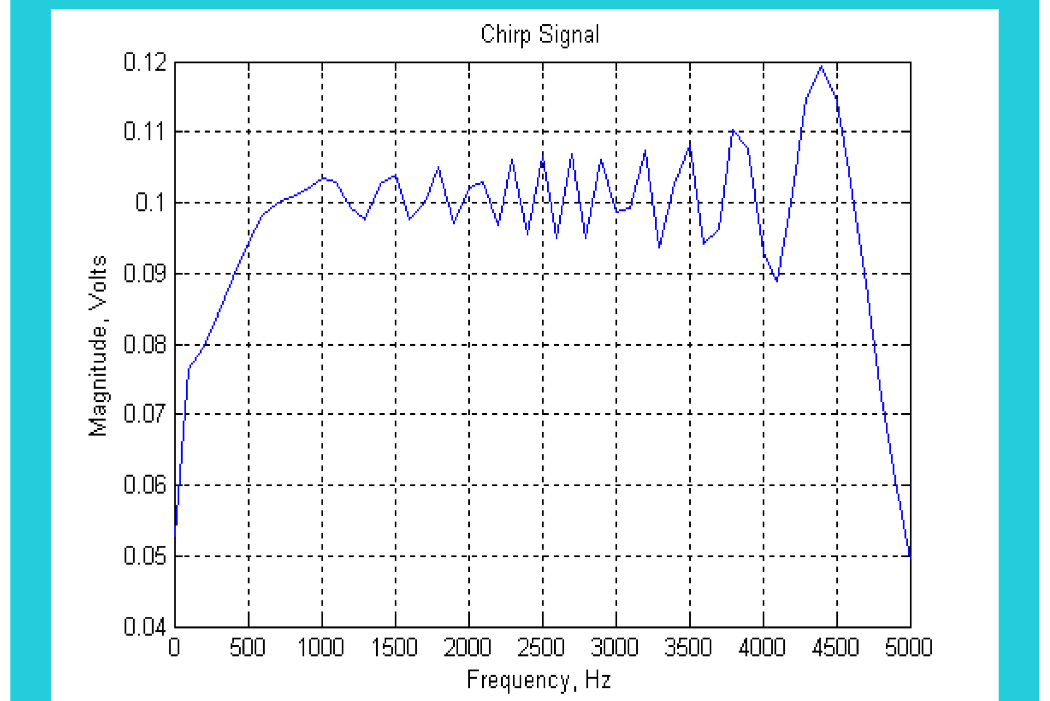
By capturing the relative attenuation of a range of frequencies, Head Related Transfer Functions (HRTFs) yield directional information that is richer than that from either the ITD or IID. Direction-dependence of these frequency attenuations makes HRTFs theoretically distinct for all 3D sound source directions.

$$\frac{\mathrm{HRTF}_R(f,\theta,\varphi)}{\mathrm{HRTF}_L(f,\theta,\varphi)} = \frac{\mathrm{Output}_R(f,\theta,\varphi)}{\mathrm{Output}_L(f,\theta,\varphi)} = \frac{\mathrm{FFT}(\mathrm{Output}_R(t,\theta,\varphi))}{\mathrm{FFT}(\mathrm{Output}_L(t,\theta,\varphi))}$$

2 Microphones and Loudspeaker

Measurement System:





Output Signal from SigLab to Loudspeaker

Database parameters as a matrix:

$\boldsymbol{\theta} = 0{:}\Delta\theta{:}360\text{-}\Delta\theta$
m = Length(θ)
$\boldsymbol{f}$ = frequency vector
size(Database) = length($\boldsymbol{f}$) x m

Matching algorithm:

Least square method:

$\theta_{match} = [\ (\ \mathrm{index}\ (\ \min\ (\ \Sigma\ (\ (\ R - R_0\ )^2\ )\ )\ )\ - 1\ )\ \mathrm{x}\ \Delta\theta\ ]$

R = TestData x ones (1, m)

R_0 = Database

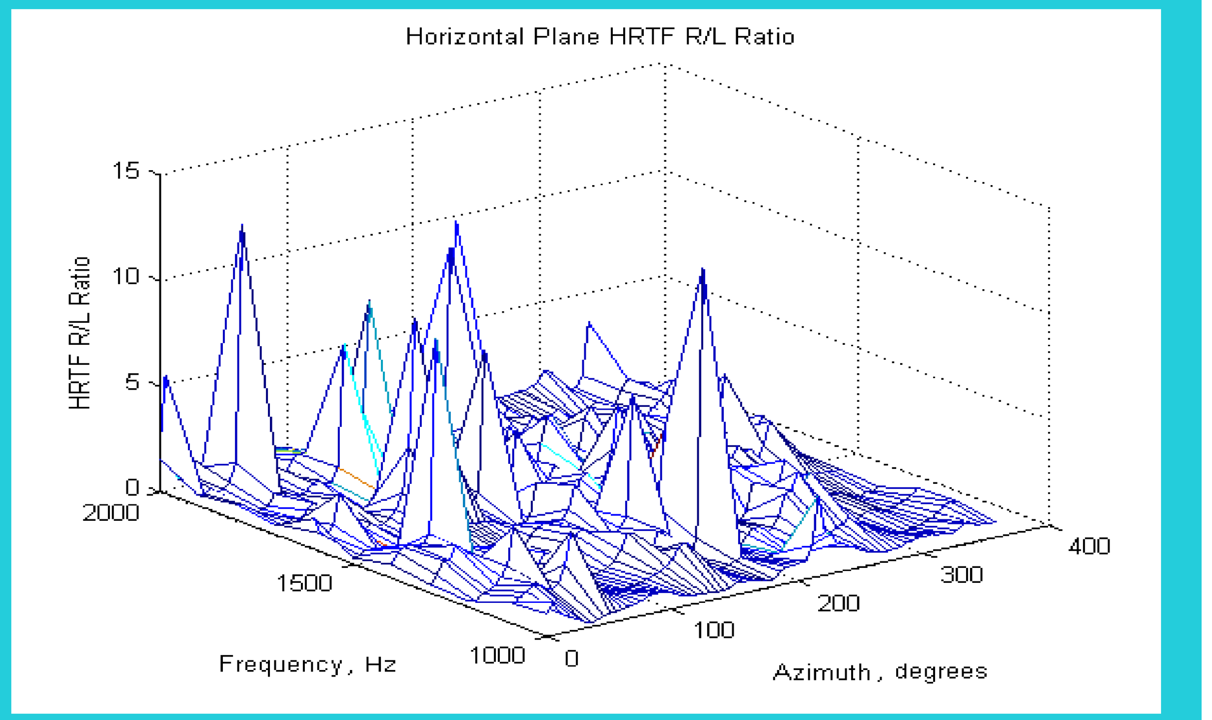
Standard deviation method:

$\theta_{match} = [\ (\ \mathrm{index}\ (\ \min\ (\ \Sigma\ (\ \#\sigma\ )\ )\ )\ - 1\ )\ \mathrm{x}\ \Delta\theta\ ]$

Note: The square above is performed on each element of the matrix.
The sums above are performed for each column of the matrix.
σ is a matrix containing the standard deviations for the data taken at each frequency of each position.

In general, $\#\sigma = \dfrac{x - \bar{x}}{\sigma}.$

Results:



Database of HRTF Ratios in Horizontal Plane

Matching Performance for Various Databases and Matching Algorithms

Positions	Increments [deg]	Database Data / Position	Test Data / Position	Number of Tests Run	Total Number of Data Tested / Position	Frequency Range Used for Matching [Hz]	Matching Method	Percent of Tests that Matched Correctly
12	30	25	5	6	30	1k – 2k	Least Squares	98.89
"	"	"	"	"	"	0 – 5k	Least Squares	82.67
"	"	"	"	"	"	0 – 5k	Least Std. Devs.	98.33
36	10	15	5	4	20	0 – 5k	Least Std. Devs.	99.86
72	5	5	5	1	10	0 – 5k	Least Std. Devs.	100

Adjacent Angles Matching Results (High values are necessary for interpolation.)

Positions	Increments [deg]	Database Data / Position	Frequency Range Used for Matching [Hz]	Matching Method	Percent of Tests that Matched Most with a Neighbor
12	30	30	0 – 5k	Least St. Dev.	33.33
36	10	20	0 – 5k	Least St. Dev.	36.11
72	5	10	0 – 5k	Least St. Dev.	58.33

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