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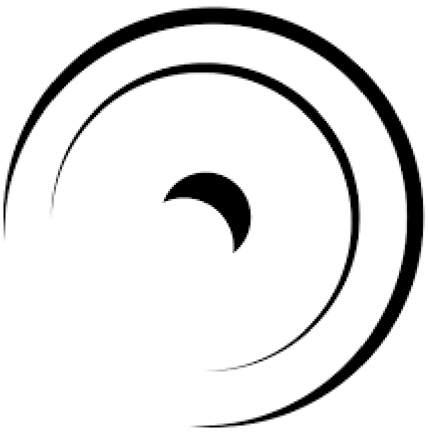
DESC9115: Digital Audio Systems | Final Written Review

AD-3D

Individualised Audio



Problem Description

Individualised 3-dimensional audio modelling is a rarely used or produced form of technology. It would allow any person to hear sounds truly as they would sound to them but without having to actually build a physical model of the design. This enables any person to design a virtual acoustic environment that will closely replicate the sounds and sound quality as if they were in that environment.

The **AD-3D** (Audio Designer – 3-Dimensional) is a system that will individualise any audio input to a specific listeners ears, allow multi-channel (stereo, 5.1, 7.1) designation of signal, and placement anywhere in 3-dimensonal space in a customised virtual space through headphones.

Similar products exist that will map out acoustic flows, present data related to changes in frequency content and volume and allow a limited amount of macro control. The **AD-3D** improves on this by using the principles of HRTFs (Head Related Transfer Functions) to individualise and model the user's virtual acoustic environment.

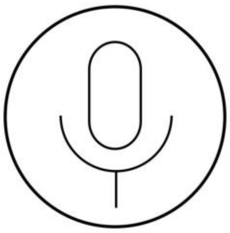
Due to the individualised and versatile nature of this digital audio system it can be utilized for a wide variety of purposes:

Home theatre design:
Users can virtually test out a variety of different speaker positions to determine which sounds the most pleasant to their ears without the need to constantly move large and heavy cabinets.

Sound design:
As podcasts and music listening is constantly evolving and changing, the **AD-3D** allows users to individualise their listening experience.

Tele-Conferencing:
Businesses and individuals seeking to have multi person telephone conversations can converse as if all other members are right beside, in front or any other direction around them, creating a seamless real-life auditory environment using **AD-3D**.

3D recreation:
Recreation of cinema style 5.1 and 7.1 audio without the need for an expensive home theatre system that is tuned precisely to the listener's ear, allowing ultimate control and enjoyment using the **AD-3D** system.



Specification

The **AD-3D** system works by a number of different digital operational chains.

Individualising sound to the listener's ears:

The first section will use a series of tones on both the left and right ears that will calibrate the system to the user's ears. The tones will sound as if coming from different heights, with the user choosing the tone that sounds closest to ear level. This will allow the system to accurately process auditory placement data based on HRTFs for each individual.

A tone will be given to find a rough ear height level which will be denoted by a numeral. This numeral will be used to choose from a series of additional tones of differing heights which the system will compare the strings of to give the user's individualised pinna size estimation.

Splitting and audio input into multiple channels:

A stereo input can then be added and split into multiple channels e.g. 5.1 surround sound. This is achieved by low- pass filtering of the channels to create a subwoofer channel by retrieving its filter coefficients then filtering by frequency both left and right channels. The channels are then defined with predefined gains and a 90° phase shift on the surround left and surround right channels. The 4 channels (left, right, surround right and surround left) are then created by adding delays and combining the relevant gain with filtering.

Low Pass Filter Equation: $$Fc = \frac{1}{2\pi RC}$$

Phase shift Equation: $$\varphi = \frac{4\pi fcR}{C}$$

Audio mapping and playback:

Measured data by CIPIC of an ear's response to a known sound source at different positions around and above the head is referenced when the user defines a spot for each channel in 3-dimensional space. The channel will be filtered by an FIR filter that will equalize the signal's frequency response as if it has arrived from above, behind, to the side or anywhere around the user's head. So as not to limit it to the measured spots of CIPIC, it is interpolated by referencing the CIPIC data and generating a tetrahedral mesh via Delaunay triangulation of the closest CIPIC points and allowing placement at any location.

HRTF Estimation point using Delaunay Triangulation equation:

$$X = g1A + g2B + g3C + g4D,$$

Gi = scalar weights:

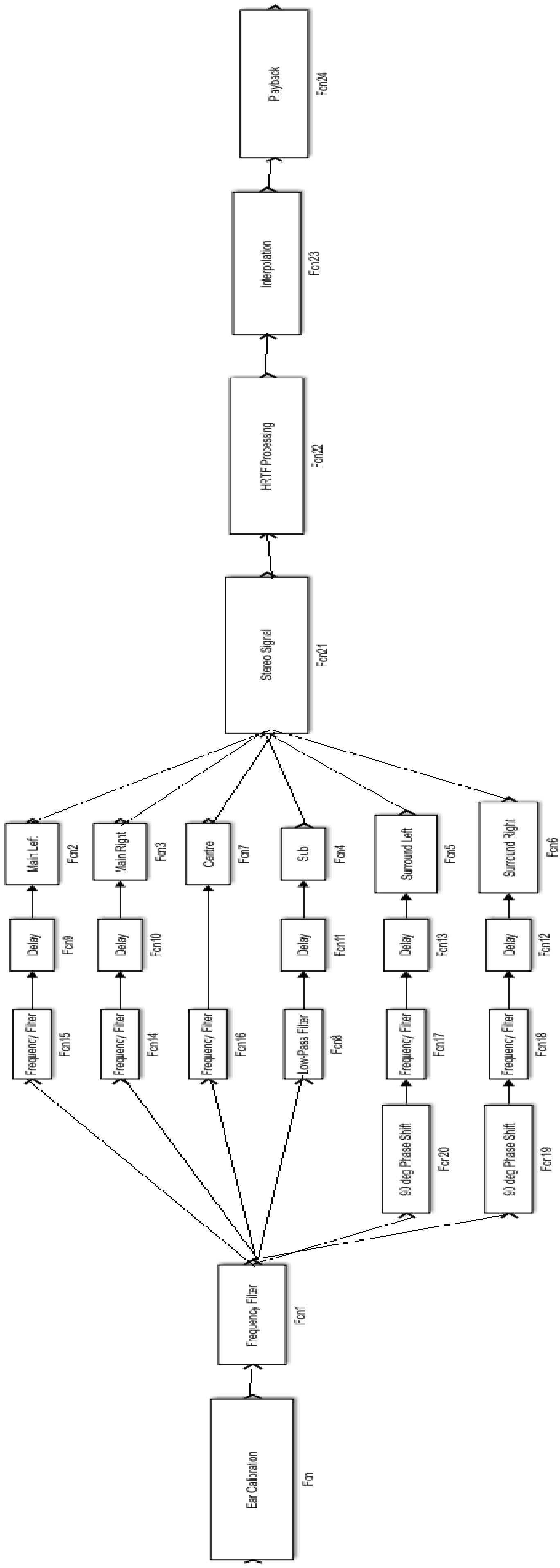
$$\sum i = 14gi = 1$$

gi = barycentric coordinates of a point and can be used as interpolation points to estimate HRTF positions

H = HRTF

$$H\hat{}x = \sum i = 14giHi.$$

Signal Flow

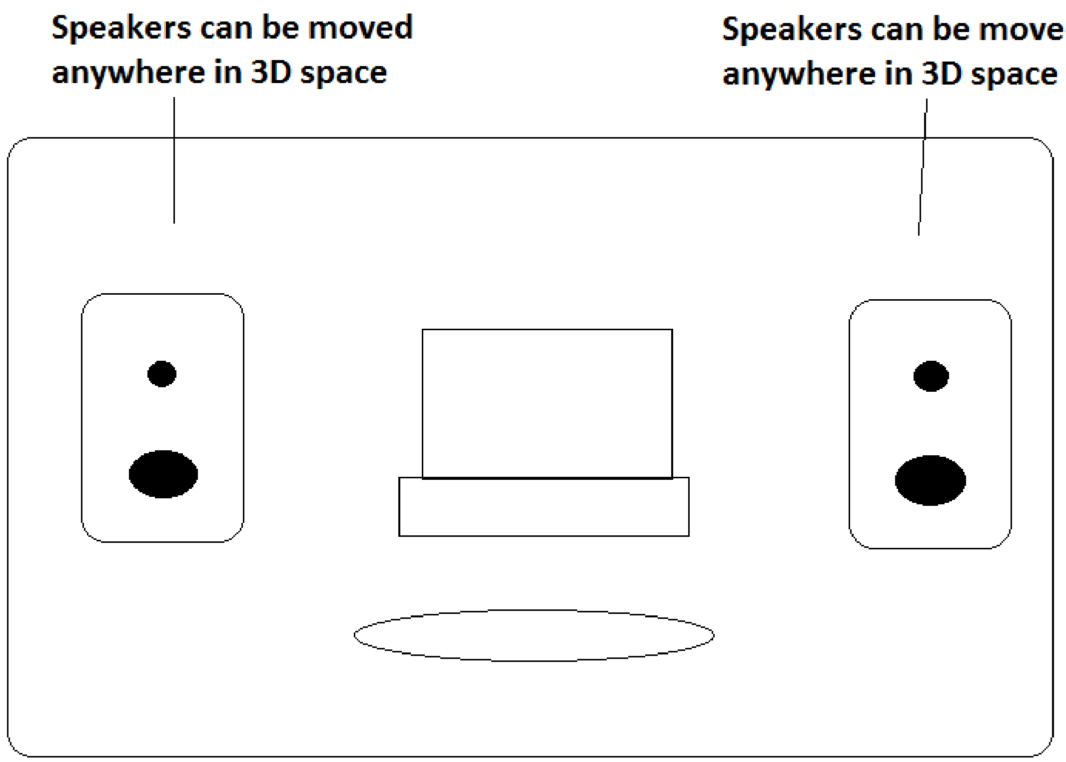

Playback
Fcn24
Interpolation
Fcn23
HRTF Processing
Fcn22
Stereo Signal
Fcn21
Main Left
Fcn2
Main Right
Fcn3
Centre
Fcn7
Sub
Fcn4
Surround Left
Fcn5
Surround Right
Fcn6
Delay
Fcn9
Delay
Fcn10
Delay
Fcn11
Delay
Fcn13
Delay
Fcn12
Frequency Filter
Fcn15
Frequency Filter
Fcn14
Frequency Filter
Fcn16
Low-Pass Filter
Fcn8
Frequency Filter
Fcn17
Frequency Filter
Fcn18
90 deg Phase Shift
Fcn20
90 deg Phase Shift
Fcn19
Frequency Filter
Fcn1
Ear Calibration
Fcn

Implementation:

Implementation of the **AD-3D** system, once a sleek GUI has been finalised, is designed to be incredibly user friendly with anyone being able to use it to full effect, but still based on complex digital audio principles. It will have 3 screens in total, mimicking the 3 core chains that the system runs on.

The first will be the calibration screen that allows the start of the calibration process. It features an easy to use system indicating if a sound in either the left or right ear sounds at ear level. The second screen will allow the user to import a stereo audio file which will be split into surround channels for placement in the following and final screen.

The final screen, and the most important, has a virtual environment with multiple speakers that can each be moved in relation to the room and the sound from each altered via the HRTF based interpolation system. As a speaker is moved around the environment, a change in sound will occur that lets the user choose which placement sounds the best for their purpose. As a speaker layout becomes ideal to the listener's ears, this can be saved and then used when applying this knowledge to the end user's goal. A diagram is provided below:



Evaluation:

Although the **AD-3D** can successfully produce individualised audio placement, the systems it uses could be improved and customised for a huge variety of different applications. Applying the same procedure to auditoriums would require a different interface and a larger amount of parameters that factor in individual aspects of the environment e.g. amount of seats, full versus half capacity, shape of walls, absorption of surfaces. With the application of these principles into inbuilt digital audio systems the versatility and benefits of the **AD-3D** is only limited by computational power.

An interesting implication of this system would be in virtual reality technology. It would be well suited to its user manipulated environment and allow an ease of use beyond that of computers or tablets.

Further implementations that could be used would be a calibration and equalisation of both headphones used by the user and loudspeakers within the systems virtual environment. Even on a general level, for example an option to choose from the top 10 most popular headphones and speakers, this could be implemented with a great degree of success and usage. This would allow an even greater degree of personal customisation and enjoyment of the versatility of the **AD-3D**.

References

Francis Rumsey (2001). *Spacial Audio*, Chapter 3

Hannes Gamper (2013). *Head-related transfer function interpolation in azimuth, elevation, and distance.* The Journal of the Acoustical Society of America.

Lucas O'Neil, B. C. (2014). *3-D Spatialization and Localization, and Simulated Surround Sound with Headphones.* N/A: Lucas O'Neil, Brendan Cassidy.

Zolzer, U. (2002). *DAFX.* West Sussex: John Wiley & Sons.

Matlab Code sourced from:

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