The 3D Tune-In Toolkit – 3D audio spatialiser, hearing loss and hearing aid simulations

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Abstract

The 3DTI Toolkit is a standard C++ library for audio spatialisation and simulation using loudspeakers or headphones developed within the 3D Tune-In (3DTI) project (http://www.3d-tune-in.eu), which aims at using 3D sound and simulating hearing loss and hearing aids within virtual environments and games. The Toolkit allows the design and rendering of highly realistic and immersive 3D audio, and the simulation of virtual hearing aid devices and of different typologies of hearing loss. The library includes a real-time 3D binaural audio renderer offering full 3D spatialization based on efficient Head Related Transfer Function (HRTF) convolution, including smooth interpolation among impulse responses, customization of listener head radius and specific simulation of far-distance and near-field effects. In addition, spatial reverberation is simulated in real time using a uniformly partitioned convolution with Binaural Room Impulse Responses (BRIRs) employing a virtual Ambisonic approach. The 3D Tune-In Toolkit includes also a loudspeaker-based spatialiser implemented using Ambisonic encoding/decoding. This poster presents a brief overview of the main features of the Toolkit, which is released open-source under GPL v3 license (the code is available in GitHub https://github.com/3DTune-In/3dti_AudioToolkit).

Keywords: 3D sound, binaural, Ambisonic, hearing aid, hearing loss, virtual environment.

Index Terms: [Human Centred Computing] Audio Feedback; [Social and Professional Topics] Assistive Technologies.

1 Introduction

The 3D Tune-In (3DTI) project (http://www.3d-tune-in.eu/) [1] [2] introduces an innovative approach using 3D sound, visuals and gamification techniques to support people using hearing aids. The consortium has joined forces to develop the 3DTI Toolkit, a custom, open-source, multi-platform C++ library to respond to a challenging set of requirements regarding real-time performance and portability [3].

Other tools exist which perform binaural and loudspeaker audio spatialisation and which are commercially available. Examples include the IRCAM Spat [4] suite, Facebook 360 [5], and Google Resonance Audio [6].

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2018 IEEE 4th VR Workshop on Sonic Interactions for Virtual Environments (SIVE)
18 March 2018, Reutlingen, Germany
978-1-5386-5713-3/18/$31.00 ©2018 IEEE

Compared to these the 3DTI Toolkit offers the following unique features:

- Support for multiple platforms, including mobile and web.
- Customization of HRTFs through ITD modifications
- Emulation of near-field sound sources through ILD modifications
- Binaural reverberation
- Open source

This paper focuses on the 3DTI Toolkit, outlining its different features and functionalities.

2 Features

The 3DTI-Toolkit is focused on binaural spatialization for headphone playback, although it also includes an alternate module for loudspeaker playback. In addition to spatialisation, the Toolkit also includes a hearing loss simulator and a hearing aid simulator, which can be inserted at the end of the process chain, after the binaural spatialiser. The hearing aid simulator uses as input the stereo signal produced by the binaural spatialiser. Then the hearing loss simulator uses as input the output of the hearing aid simulator and its stereo output is finally delivered to the audio interface.
All these modules can be enabled or disabled independently in the binaural case. The hearing aid and hearing loss simulators cannot be used with the loudspeaker module, as this module is designed as a spatialisation alternative based on a set of eight speakers around the listener. The features of each module are described in the following sub-sections.

2.1 Binaural spatialisation

Within this module, efficient spatialisation of anechoic sound files is performed by convolving them in the frequency domain, using an overlap-save approach, with Head Related Impulse Responses (HRIRs) correspondent to the desired sources positions, and interpolated from those of a Head Related Transfer Function (HRTF) set, selected by the user.
In order to process sources located at specific locations that are not included in the provided HRTF set, a barycentric interpolation approach is used among the three closest available HRIRs. The acoustic parallax effect is also taken into account; left and right HRIRs are selected independently according to the relative angle between each ear and the sound source. When using a specific HRTF set, data about the distance where the HRIRs have been measured (e.g. 1, 1.5, 2 meters) is used to set the parallax effect emulator and select the appropriate impulse response for each ear, at each distance and source angular position.
User-imported HRIRs should be provided with initial delays (Interaural Time Differences – ITDs) stored separately. The Toolkit

is then able to perform interpolations in the time domain between synchronized HRIRs, and to separately manage the ITDs. These are computed for the exact azimuth and elevation of the sound source (i.e. without taking into account the acoustic parallax effect), and added as a delay only to the contralateral ear. Alternatively, ITDs can be customized computing them for a specific user-inputted head circumference.

According the sound sources movements, ITDs will change between two consecutive audio frames. Samples in each audio frame are then stretched or compressed to produce the new ITDs, allowing for smooth transitions when sources are moving.

A resource manager module is included with the Toolkit allowing to read HRTF sets in the SOFA format [7].

The Toolkit can also add an extra ‘shadow’ (i.e. gradual increase of high-frequency Interaural Level Differences – ILD) in the contralateral ear for near-field sound sources, according to the spherical head model suggested by [8].

For far-field sources, a low-pass filter emulating frequency-dependent air absorption is also implemented.

In addition to the anechoic spatialisation, the 3DTI Toolkit integrates binaural reverberation capabilities using Binaural Room Impulse Responses (BRIRs). Using an efficient approach based on virtual Ambisonic [9], sound sources are encoded in the 1st Order Ambisonic domain, and decoded on an array of virtual loudspeakers, each of which is then binaurally rendered through convolution with BRIRs. Reverberation is therefore generated for all sources at the same time, keeping certain location-dependent characteristics. This approach, together with the use of uniformly partitioned convolution in the frequency domain, allows the Toolkit to efficiently compute large reverberating scenes, with virtually unlimited number of sources, maintaining high spatial accuracy for the direct sound (spatialised using direct-HRIR convolution).

In addition, the Toolkit supports different sampling rates and can work with different frame size. This allows to achieve very low latencies if the system is powerful enough or the scene to be rendered is not very complex. On the other side, a large frame size would allow to render very long reverberations at the expends of having a higher latency.

Finally, the Toolkit allows to move not only the sound sources, but also the listener, managing all the required geometric calculations.

2.2 Hearing loss simulator

The Toolkit also includes a hearing loss simulator which aims to enable individuals with no hearing impairment to understand how hearing loss can compromise everyday activities. The hearing loss simulator includes a multi-band dynamic range compressor/expander, to emulate the frequency- and level-dependent features of hearing loss, and an automatic configurator of hearing loss emulation from the user-inputted audiogram. This automatic configurator follows a model designed to emulate the perceived loudness by people with hearing loss reported in literature [10]. It consists of a multiband expander, where threshold, ratio and gain for each band is selected according to the hearing loss of that band to fit the perceived loudness referred above.

In addition, a frequency smearing algorithm, based on the Baer and Moore model [11] [12], for emulating the broadening of the auditory filters has also been developed. It consists in a smearing process produced by convolving a Gaussian bell with the magnitude of the input signal in the frequency domain. The bell width can be selected asymmetrically, defining two width parameters for upward and downward smearing.

Finally, a temporal distortion (jitter), for emulating the decrease in the precision of neural synchronization in the midbrain [13] is also included. It consists in a jitter process which is applied only to low frequency components of the input signal by shifting samples according to a dark noise, which is generated by low-pass filtering white noise. Samples are shifted to non-integer positions and after that, the signal is resampled again at the sampling frequency. Power and bandwidth of this noise can be controlled, as well as the crossover frequency which splits input signal in lower and upper components.

This hearing loss simulator has been designed to emulate a sensorineural hearing loss, but with the right choice of settings it can be used to emulate other types of hearing loss (e.g. conductive hearing loss).

2.3 Hearing aid simulator

To complement the hearing loss simulation, a hearing aid simulator has been implemented allowing hearing impaired individuals to use the 3DTI applications without having to rely on their own hearing aids. In addition, the implementation of virtual hearing aids within the 3DTI Toolkit allows the simulation of space-related functionalities such as microphone directivity.

The hearing aid simulator includes a dynamic equalisation with the possibility of configuring, for each band, an arbitrary number of different gains for different input levels. This allow to compensate for different hearing loss curves at different signal levels.

In addition, a re-quantisation (i.e. bitrate reduction) process is included before and/or after the dynamic equaliser, in order to simulate the specific acoustic and AD/DA conversion features of a given hearing aid. This way, quantisation noise of low quality hearing aids can be simulated.

Finally, directional processing (e.g. omnidirectional, cardioid, etc.) is included as well. Although this process has been integrated as part of the binaural spatialiser, as has to be applied to each source, depending of its position, it is a common feature in modern hearing aids. Therefore, it is reported here as part of the hearing aid simulator, but, in terms of implementation, it is not part of the process applied to the stereo output of the spatialiser, but a process applied to each source before binaural spatialisation.

The hearing aid simulator has been designed to emulate a generalized hearing aid, but with the right choice of setting and parameters it can be used to emulate specific hearing aids types, brands and models.

2.4 Loudspeakers spatialisation

The 3DTI Toolkit can also perform loudspeaker-based sound spatialisation. This has been implemented using the Ambisonic technique. Multiple sources are encoded in a 2nd Order Ambisonic stream, which is then decoded for various loudspeaker configurations, allowing the user to customise each speakers' position. Encoding and decoding have been implemented using the Furse-Malhalm equations [14]. The reverberation is generated using a similar approach to the one used for the binaural module (i.e. based on virtual loudspeakers), allowing to simulate virtual environments in the Ambisonic domain with a fixed number of real-time convolutions, independently from the number of sources to be spatialised.

3 TEST APPLICATIONS AND WRAPPERS

The 3D Tune-In Toolkit is a standard C++ library to be included in audio tools. However, in order to demonstrate the Toolkit features to a wider audience (i.e. including also individuals without programming skills), and to allow high-level integration within other VR systems, two Test Applications were created for the binaural and loudspeaker modules respectively (both available for Windows and MacOS - http://www.3d-tune-in.eu/Toolkit-developers).

These Test Applications consists in an easy-to-use graphical interface which allows to access to all the features of the 3DTI Toolkit (see Sections above). Figure 1 shows a snapshot of the test application for the binaural spatialiser. The user can locate an arbitrary number of sound sources around the listener and spatialise them, enabling and disable each of the described features, as the anechoic spatialisation through convolution with a selected HRTF, loaded from a SOFA file, distance simulations, near field effects, environment simulation through convolution with a BRIR, etc. This application also allows to simulate hearing loss and hearing aid controlling through the user interface all the parameters which configure our simulators.

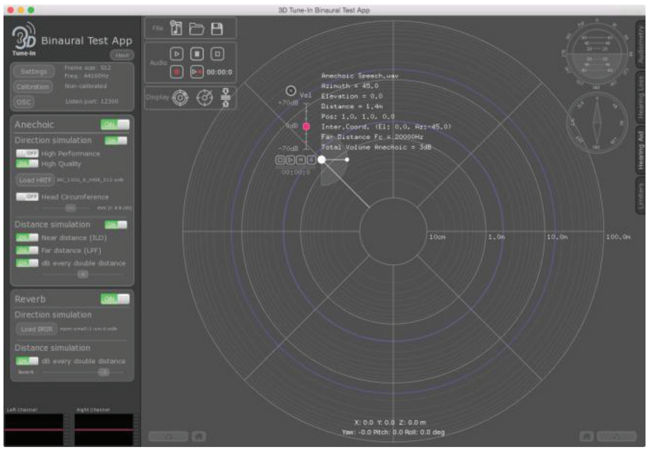

Figure 1: The interface of the 3DTI Toolkit Binaural Test App

In addition to this, the test applications can also be remotely controlled through any network using the Open Sound Control (OSC) communication protocol [15]. Using this feature, another application can control movement of sources and listener, allowing the use of the 3D Tune-In Toolkit without being necessary to build an audio tool to include the library.

Furthermore, a Unity wrapper has been developed in order to allow easy integration of the 3DTI Toolkit within the Unity game development environment [16]. Only anechoic spatialisation and hearing aid and hearing loss simulation are included at the moment in this wrapper. A Javascript wrapper, for integration of the 3DTI Toolkit in web-based applications, is also being developed.

4 Conclusion

This paper presents the 3DTI Toolkit, an open-source C++ library developed within the EU-funded project 3D Tune-In. The library enables developers to integrate efficient binaural and loudspeakers-based spatialisation into their applications. First version of the 3DTI Toolkit is released open-source under GPL v3 license, and its code is available, together with the test apps in GitHub (https://github.com/3DTune-In/3dti_AudioToolkit).

The Toolkit is currently being evaluated with special focus on how well it behaves with moving sources, estimating the distortion produced by our implementation in such situation. Interpolations of HRIR and BRIR are also being assessed and will be reported in future publications together with complete technical details of implementation, performance assessment and a comparison with other similar Toolkits.

5 Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 644051.

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