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The 3D Tune-In Toolkit: A C++ library for binaural spatialisation, and hearing loss / hearing aids emulation

Arcadio REYES-LECUONA1[(1)], María CUEVAS-RODRÍGUEZ[(1)], Daniel GONZÁLEZ-TOLEDO[(1)], Carlos GARRE[(1)], Ernesto DE-LA-RUBIA-CUESTAS[(1)], Luis MOLINA-TANCO[(1)], Ángel RODRÍGUEZ-RIVERO[(1)], Lorenzo PICINALI[(2)]

[(1)]University of Malaga, Spain

[(2)]Imperial College London, United Kingdom

Abstract

This contribution presents the 3D Tune-In (3DTI) Toolkit, an open source C++ library for binaural spatialisation which includes hearing loss and hearing aid emulators. Binaural spatialisation is performed through convolution with user-imported Head Related Transfer Functions (HRTFs) and Binaural Room Impulse Responses (BRIRs), including additional functionalities such as near- and far-field source simulation, customisation of Interaural Time Differences (ITDs), and Ambisonic-based binaural reverberation. Hearing loss is simulated through gammatone filters and multiband expanders/compressors, including advanced non-linear features such as frequency smearing and temporal distortion. A generalised hearing aid simulator is also included, with functionalities such as dynamic equalisation, calibration from user-inputted audiograms, and directional processing.

Keywords: Binaural, Rendering, Hearing Aid, Hearing Loss

1 INTRODUCTION

The 3D Tune-In (3DTI) project (http://www.3d-tune-in.eu/), concluded in April 2019, aimed at supporting hearing aid users through 3D sound and visual technologies, and gamification techniques. One of the main outcomes of the project was the 3DTI Toolkit [3], a custom, open-source, multiplatform C++ library for binaural spatialisation and emulation of hearing loss (HL) and hearing aids (HA), which was created in order to address a challenging set of requirements regarding real-time performance and portability.

2 THE 3DTI TOOLKIT STRUCTURE AND FEATURES

The Toolkit is presented as a set of modules grouped into three main components: binaural spatialiser, HL/HA simulation, and shared modules for signal processing, buffer management and geometrical calculations. The distribution includes a collection of resources ready to be used by the Toolkit, including anechoic sample sounds, a selection of Head Related Transfer Functions (HRTFs) from the LISTEN database [6], and some original Binaural Room Impulse Responses (BRIRs). Finally, a set of modules to manage those resources is also included.

2.1 Binaural spatialiser

The structure of the spatialiser is arranged so that the anechoic path and the reverberation are processed separately. The anechoic path is spatialised by direct convolution with Head Related Impulse Response (HRIR) corresponding to the direction from where each sound source is coming. This HRIR is computed through barycentric interpolation among the nearest neighbours within the HRTF. The HRIRs need to have been processed in advance in order to remove the Interaural Time Differences (ITDs), and minimise comb filtering effects during the interpolation. The signal resulting from the convolution is then processed by a near-field simulator, which modifies the Interaural Level Differences (ILDs) according to a spherical head model, in order to account for the additional shadowing effect of the head when the sound source is located at distances closer than the one where the HRTF was measured. Finally, the ITD is simulated through a simple delay in the contralateral ear, allowing users to customise the rendering according to their own head circumference.

The Toolkit implements binaural reverberation through a virtual-loudspeaker approach based on low-order Ambisonic encoding, and the convolution of individual loudspeaker signals with BRIRs. Reverberation is therefore generated for all sources at the same time, but keeping certain location-dependent characteristics. This approach, together with the use of uniformly partitioned convolution in the frequency domain, allows the Toolkit to simulate large reverberating scenes, with virtually unlimited number of sources, maintaining high spatial accuracy for the direct anechoic path (spatialised using direct-HRIR convolution, as mentioned earlier).

2.2 HA/HL simulator

Optionally, after the spatialisation process, HA and HL simulators can be activated. The HA simulator is based on a dynamic equaliser, which can be configured using the *Fig6* formula [4], and allows for the simulation of directional microphones. The HL simulator is implemented with three cascaded processes: a multiband expander, a frequency smearing algorithm which can use a custom model as well as the Moore-Baer one [2], and a temporal distortion algorithm, which introduce a fully customisable jitter [5].

2.3 Resources manager

These modules are provided to facilitate the loading of files containing the HRTF, BRIR and IIR filters used for the near field compensation. HRTFs and BRIRs can be stored in SOFA files [1]. The HRTFs are assumed to be in the form of a set of synchronised (i.e. no ITD) impulse responses, storing the ITD data in the Delay field provided by the SOFA format. The BRIRs are assumed to be in the form of a set of impulse responses with the direct path removed. In addition to SOFA, a custom 3dti format can be used to store HRTF and BRIR, as well as the IIR filter coefficients look-up tables used for near field compensation.

3 FINAL REMARKS

The 3D Tune-In Toolkit is an open source library which is available in a public repository at `https://github.com/3DTune-In/3dti_AudioToolkit`. Several other releases of the 3DTI Toolkit are also available, including a Test Application, with a GUI, OSC remote control capabilities and installers for MacOS, Windows and Linux; a VST plugin for MacOS and Windows; and a Javascript wrapper for web-based binaural spatialisation[1]. A complete technical description of its spatialisation features has been recently published in [3]. A second paper is currently in preparation to describe the implementation of the hearing loss emulation.

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