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Technical Note

Virtual Acoustics at the Service of Music Performance and Recording

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Virtual or active acoustics refers to the generation of a simulated room response by means of electroacoustics and digital signal processing. An artificial room response may include sound reflections and reverberation as well as other acoustic features mimicking the actual room. They will cause the listener to have an impression of being immersed in virtual acoustics of another simulated room that coexists with the actual physical room. Using low-latency broadband multi-channel convolution and carefully measured room data, optimized transducers for rendering of sound fields, and an intuitive touch control user interface, it is possible to achieve a very high perceived quality of active acoustics, with a straightforward adjustability. The electroacoustically coupled room resulting from such optimization does not merely produce an equivalent of a back-door reverberation chamber, but rather a fully functional complete room superimposed on the physical room, yet with highly selectable and adjustable acoustic response. The utility of such active system for music recording and performance is discussed and supported with examples.

Keywords: virtual acoustics, active acoustic architecture, room acoustics, room impulse response, low-latency convolution, performer-room interaction, music recording, acoustic enhancement, active acoustics.

1. Background

Since the introduction of fast signal processing chips able to calculate multiple FFTs with low latency it became possible to design convolution hardware and software suitable for real-time musical applications (Anderegg *et al.,* 2004). While studio post-production work can tolerate signal delays as they can be compensated by relative time-shifting of audio tracks during mixing and editing, the requirement for low latency must be strictly adhered to in live performance and recording. The most compelling application of fast convolution is room reverberation created from impulse responses measured in acoustic spaces. Shortly before the year 2000, Yamaha created SREV1 and Sony the DRE S-777 digital sampling reverberators, which since have been discontinued. Five years later, McGill University began collaborating with industrial partners to develop suitable hardware platform and later also to create software based convolution for applications requiring 24+ channels of high-resolution audio. Currently under development are two platforms of the Space Builder system, 'studio' and 'live', created as a tool for sound design in 22.2 channel audio accompanying UHDTV (ultra high definition television) and for supporting music performance in virtual acoustics, respectively. Both platforms utilize a convolution based workstation with multiple input and output channels. Space Builder is the processing engine of the McGill Virtual Acoustics Technology system (VAT), which includes microphones, loudspeakers, interconnections, and a motorized rigging system, used to create enhanced acoustic environments for music performance and recording, as described below. The earlier publication (AA) describes in detail the electroacoustic and signal processing aspects of the new VAT system, whereas this current publication serves to illustrate a range of applications, including recording in virtual acoustics for a commercial release in a multichannel audio format.

2. Recording in active acoustics: the Virtual Haydn

A novel method of live music recording taking place within purposely built virtual acoustic environments was tested and evaluated in the Virtual Haydn Project (McGill, 2009). The Virtual Haydn was a research project conducted by performer/musicologist Tom Beghin, virtual acoustics researcher/architect Wieslaw Woszczyk, and *Tonmeister*/producer Martha DeFrancisco in the Centre for Interdisciplinary Research in Music Media and Technology (CIRMMT) at McGill University (Woszczyk *et al.*, 2009b). Together, they recorded the complete works of Joseph Haydn for solo keyboard in virtual reconstructions of the rooms in which these pieces would have been originally performed, using replicas of the instruments that Haydn and players of his music would have used. Nine virtual rooms were created as faithful multichannel replicas of acoustical environments in which performances and recordings of Haydn's solo keyboard sonatas would be made. Seven replicas of historical instruments were constructed for this project and both the builders and tuners of these instruments who were present at the recording sessions always chose to tune with the virtual room on, indicating lack of any pitch artifacts in virtual rooms. There was an unlimited rehearsal time combined with the adjustability of virtual environment to suit the need of the music and the performer, without constraints on time and availability of the actual space. The Virtual Haydn was recorded in high-definition audio to professional quality standard and was commercially released by Naxos International in the Blu-ray format both in 2.0 stereo and multichannel 5.0 surround sound. The work was nominated in Canada for the prestigious Juno Award in 2011, in the Best Music Video of the Year category.

2.1. Measurement of multichannel impulse response of a room

Historic rooms related to Joseph Haydn had to be measured first in order to capture and prepare impulse responses of these rooms for their subsequent real-time rendering during rehearsal and recording in a laboratory. In each room location we measured 24 responses, 8 responses at each of three heights of the array, at 2 m, 3 m, and 4 m above ground. Four of the microphones are omnidirectional, arranged in Omni-Square with 2 meter spacing, and four microphones are bidirectional arranged as orthogonal spaced-pairs crossing with 90° angle (Fig. 1). The room impulse response is measured using a long logarithmic swept sinewave as the excitation signal. The signal is radiated through multiple loudspeakers distributed on the stage or the area of the room where musician(s) would normally perform. The loudspeakers are arranged to approximate the average radiation from a specific instrument or from an ensemble of complex musical sources producing strong reflections and reverberation.

Fig. 1. Typical layout of eight microphones and mulltiple loudspeakers during the measurement of room impulse response.

Virtual acoustics is generally created from synthesized impulse responses based on geometrical room models, mirror image models, ray or beam tracing methods (Alpkocak, Sis, 2010), or simply using algorithmic synthesis derived from the analysis of sound fields in real spaces (Gołaś, Suder–Dębska, 2009). Active acoustics system already in commercial use do not employ convolution of source signals with measured impulse responses as means for generating acoustic enhancement, according to published sources (Svensson, 1996; Kawakami, Shimizu, 1990), and (Poletti, 2010). The virtual acoustics system presented here is solely based on the low-latency convolution of measured room impulse responses with captured source signals.

2.2. The rendering of virtual rooms in a laboratory

Virtual rooms are rendered in acoustically dry Immersive Presence Laboratory of CIRMMT (Centre for Interdisciplinary Research in Music Media and

Technology) at McGill University. Twenty-four ribbon loudspeakers distributed on a half-sphere around and above the musician produce the selected room response with 10 ms latency allowing for natural interaction of the performer with the virtual room. Recording of the direct sound now proceeds in this laboratory, which is connected to a high-quality surround sound control room (Critical Listening Laboratory) where mixing and monitoring take place. The block diagram of the complete rendering and recording system used for recording The Virtual Haydn is presented in Fig. 2.

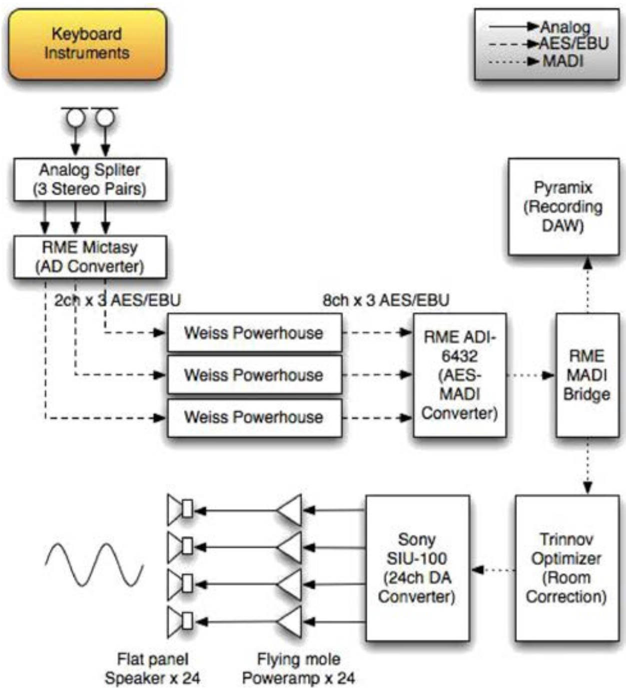

Fig. 2. Block diagram of the virtual acoustics rendering system used for rehearsing and recording of the Virtual Haydn Project in the Immersive Presence Laboratory of CIRMMT. The sound of a keyboard instrument is captured with microphones and recorded on a Pyramix workstation in the control room. Simultaneously, low-latency rendering of virtual room is carried out "live" in the recording room using 24 channels of convolution via 24 flat-panel ribbon loudspeakers distributed around the performer who is able to hear and interact with the virtual room during recording.

3. Virtual acoustics in concert performance

Further use of this technology includes rendering of virtual acoustics in larger spaces in order to include the audience in sharing the simulated acoustics produced for the artist or the ensemble. One critical benefit of active architecture is the controlled variability of acoustics. McGill's Virtual Acoustic Technology (VAT) system has been described in the Archives of Acoustics (Woszczyk, 2011) as it offers new solutions in the key areas of performance by focusing on the electroacoustic coupling between the existing room acoustics and the simulation acoustics. The system has enabled an audience to experience The Virtual Haydn "live". Our ongoing research aims to broaden the use of virtual acoustics in large spaces by serving chamber, orchestral and choral ensembles in rehearsing, performing and recording of music.

To flexibly control various aspects of the aural architecture, we have developed a worstation called Space Builder "Live", presented in a block diagram in Fig. 3. The convolution based Space Builder employs temporally defined segments of impulse responses to construct flexible spatial designs using an intuitive graphic interface (Woszczyk *et al.*, 2010). The system has multiple low-latency convolution engines loading data from a library of multi-channel impulse responses, a 128-channel MADI router and mixer operating at 24/96 resolution and a MIDI controller. The controller reveals different levels of complexity depending on the needs and expertise of the user. Space Builder is built upon a library of high-resolution, multi-channel impulse responses (IR's) collected from churches, recording studios, scoring stages and performance halls across North America and Europe. Space Builder's three separate temporal segments (early, mid, late) allow for independent positioning of certain portions of reflected energy in different areas around the listener. This effect is most pronounced in the placement of the early reflections.

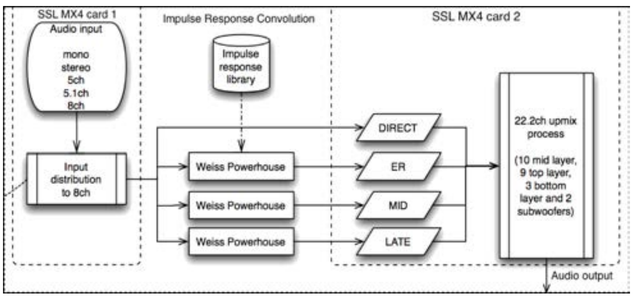

Fig. 3. Block diagram of the Space Builder "Live", the virtual acoustics rendering system used for enhancing the acoustic environment during live music performance in the MultiMedia Room of the Schulich School of Music at McGill University. Two SSL MX4 cards provide routing, distribution and mixing of input and output signals, with up to eight microphone inputs and twenty four loudspeaker outputs available. The low-latency response of virtual rooms is generated by three eight-channel custom-built convolution engines (Powerhouse) using measured room data from the impulse response library.

The great number of channels used in the Space Builder requires an advanced, flexible multi-channel software mixer to sum, distribute and route the incoming signals and the outgoing reverberation. Each of the three convolution engines is loaded with a separate temporal IR segment, creating the possibility of mixing and matching parts of different rooms within a single reverberation scheme. For example, early-reflections could be taken from a measured studio, mid-reverberation from a theatre, and late-reverberation from a church. Combining simulated rooms and sections of impulse responses allows for the creation of "designer spaces", based upon the work presented earlier in (Woszczyk *et al.*, 2009a). They incorporate the best aural features of multiple rooms, creating a virtual space that does not and probably could not exist in the acoustic reality domain. The distribution of segments also affords the operator the ability to alter the frequency content and overall level of each individual temporal element independent of the others, providing options that are not available in traditional single-IR reverberators, adding an array of creative options to the system.

One of such options is a rather straightforward creation of coupled active spaces that interact electroacoustically with the physical space. Each convolution block generates 8 individual convolutions from impulse responses (IR's) of any length, therefore with 3 available blocks it is possible to generate three different simulated spaces each having eight IR's. The acoustic coupling of virtual rooms with the actual room is amplified by employing spherical radiation pattern loudspeakers and mildly directional microphones. The outcome is an integrated ambient response that contains features from simulations and from the physical room all blended together by the aural architect. Figure 4 shows the loudspeakers of the McGill Virtual Acoustics Technology system mounted on the motorized grid in the performance space of the MultiMedia Room at the Schulich School of Music.

Fig. 4. The Virtual Acoustics Technology rendering system in the concert space of the MultiMedia Room of the Schulich School of Music at McGill University.

The new wireless touch-screen user control interface has been added to enable adjustments from any seat on the stage and in the audience. Thus, the aural architect can control the balances in the Space Builder workstation using an iPad and audition them from seat to seat while making any required adjustments. It is also feasible to give the balance control to a performer who may want to adjust aspects of virtual acoustics during rehearsal or performance. This in itself provides additional creative possibilities of matching the repertoire and the style of interpretation to the acoustics. Figure 5 shows the page of graphic user interface (GUI) hand held touch-screen interface for the Space Builder, designed for an iPad.

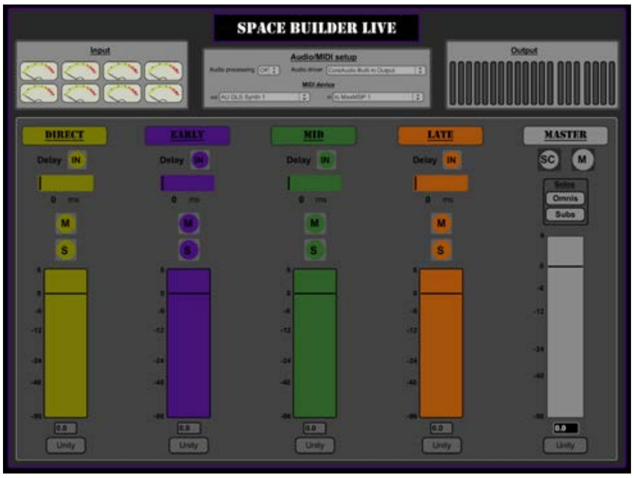

Fig. 5. The GUI page provided on a wireless iPad touch-screen as a user control interface for the Space Builder "Live".

4. Conclusions

The key design aspects of the presented above Virtual Acoustics Technology developed at McGill University are: the comprehensive library of carefully measured room impulse responses, the low-latency (10 ms) response of the Space Builder system, full control of the ambient design through temporal IR segmentation, enhanced natural coupling of the acoustic and electroacoustic systems, and intuitive wireless touch-screen user interface. The performance of the system has been tested by instrumental and vocal musicians who enjoyed the experience and offered valuable feedback. There is an ongoing development to further simplify the operation of the system for a variety of users including rock musicians. The technology has been tested within highly regarded projects, such as The Virtual Haydn, proving that virtual acoustics offers a desirable working flexibility and refined sonic quality. Currently, in cooperation with the NHK, Space Builder "Studio" system is being developed to become the ambiance design tool of choice for mixing 22.2 ch audio in ultra high definition television productions. Further refinements of this technology will generate additional creative and technical applications in audio and multimedia productions, not necessarily requiring low-latency, as is often the case in post-production.

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