LISTENING TO THE DIRECT SOUND OF MUSICAL INSTRUMENTS IN FREELY ADJUSTABLE SURROUNDING DIRECTIONS

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ABSTRACT

This contribution demonstrates a piece of software named *vMIC* (virtual microphone) that processes sound-radiation data from musical instruments. *vMIC* uses 64 channel recordings taken by a surrounding spherical microphone array. The 64 microphones of this arrangement capture the direct sound of the recorded instrument at 64 discrete directions of radiation hence represent a nearly complete acoustic image of the instrument. Instead of graphical analysis of the directional sound radiation, we consider listening to the recordings directly. For this purpose, *vMIC* uses a controllable "virtual microphone" position for which the direct sound of the instrument is computed by hyperinterpolation in real-time. Spherical harmonics hyperinterpolation provides seamless interpolation between the discrete directions of the microphone array, yielding the audio signal of the "virtual microphone" carrying the matter of our interest: a timbre and loudness depending on the direction. To maintain a geometric overview, *vMIC* renders a graphical output of the construction of the recording layout including symbols for the instrument, the musician, and the virtual microphone position.

1. INTRODUCTION

Audio engineers frequently require lots of experience to know or to find the good places to put a microphone for recording well-balanced direct sound from a musical instrument. Instruments usually do not radiate their sound omnidirectionally. In fact, it is of great importance to find a suitable microphone position as to preserve a frequency spectrum of the instrument that is perceived as desirable or natural and which does not attenuate or exaggerate its timbral properties. There has been quite important research illuminating the frequency dependent behavior of musical instrument directivity in the past, cf. [1, 2, 3], that show up some main features of different instrument groups. And with some practice in hearing, these scientific findings help the audio-engineer to get this experience faster. Recently, another interesting way of scientific data-mining has been established at a few institutions [4, 5]. Spherical arrays of microphones can be arranged to entirely surround a musical instrument, and hereby simultaneously capture musical sounds or phrases at several locations, i.e. an entire acoustic image.

To observe this acoustic image, there are several feasible ways. For instance, spectral analysis can be employed to observe radiation patterns. However, the interpretation of hereby obtained data requires a good notion of spectrally decomposed sounds. In particular, it needs experience to imagine the directional dependency of the musical sound from directivity diagrams. Instead of a graphical analysis as done in previous works, this paper attempts to make accessible an easier interpretation of the data, by listening to the recorded signals.

In principle, one can listen to the discrete microphone signals of the spherical array, i.e. a set of discrete directions of sound-radiation, and switch between them to hear the differences. Given the first surrounding array that uses 64 microphone positions suitable for hyperinterpolation, our demo goes beyond that and applies hyperinterpolation to interpolate sound-radiation between the microphone points. Hereby the user can freely choose any direction of radiation to listen to in real-time. Moreover, hyperinterpolation is most efficient in terms of hardware effort and perfectly reconstructs the sound signals at the microphone locations [6], preserving the highest possible angular resolution.

The virtual microphone position is adjustable and adapts the point of the interpolated play-back (or transmitted live) in real-time. While we may present the audible outcome of *vMIC* in the symposium lecture, this paper includes some information about *vMIC* and the spherical microphone array setup.

2. HYPERINTERPOLATION

In the presented application, hyperinterpolation is employed, which offers a precise representation of the recorded signals at the L microphone positions $\{\boldsymbol{\theta}_l\}$ and performs angularly band-limited interpolation between the positions. Using the discretized spherical harmonics $Y_n^m(\boldsymbol{\theta})$ of the orders $0 \leq n \leq \mathrm{N}$ at the microphone locations, the approach is formulated as

$$\boldsymbol{x}(t) = \boldsymbol{Y}_\mathrm{N}\, \boldsymbol{\xi}(t), \tag{1}$$

$$\boldsymbol{Y}_\mathrm{N} = \begin{pmatrix} Y_0^0(\boldsymbol{\theta}_1) & Y_1^{-1}(\boldsymbol{\theta}_1) & \dots & Y_\mathrm{N}^\mathrm{N}(\boldsymbol{\theta}_1) \\ Y_0^0(\boldsymbol{\theta}_2) & Y_1^{-1}(\boldsymbol{\theta}_2) & \dots & Y_\mathrm{N}^\mathrm{N}(\boldsymbol{\theta}_2) \\ \vdots & \vdots & \ddots & \vdots \\ Y_0^0(\boldsymbol{\theta}_\mathrm{L}) & Y_1^{-1}(\boldsymbol{\theta}_\mathrm{L}) & \dots & Y_\mathrm{N}^\mathrm{N}(\boldsymbol{\theta}_\mathrm{L}) \end{pmatrix}, \tag{2}$$

$$\Rightarrow \boldsymbol{\xi}(t) = \boldsymbol{Y}_\mathrm{N}^{-1}\, \boldsymbol{x}(t). \tag{3}$$

In this equation $\boldsymbol{x}(t)$ are the L microphone signals and $\boldsymbol{\xi}(t)$ are $(\mathrm{N}+1)^2 = \mathrm{L}$ signals after decomposition into spherical harmonics. The interpolated signal at the variable location $\boldsymbol{\theta}$ on the sphere is calculated as

$$\hat{x}(t,\boldsymbol{\theta}) = \Big(Y_0^0(\boldsymbol{\theta}),\ Y_1^{-1}(\boldsymbol{\theta}),\ \dots,\ Y_\mathrm{N}^\mathrm{N}(\boldsymbol{\theta})\Big)\ \boldsymbol{\xi}(t). \tag{4}$$

Figure 1: Surrounding microphone array (Hohl [7]) with 64 channels.

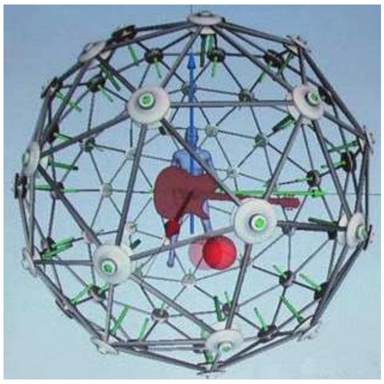

Figure 2: Graphical output of the direct-sound of *vMIC* 0.9.

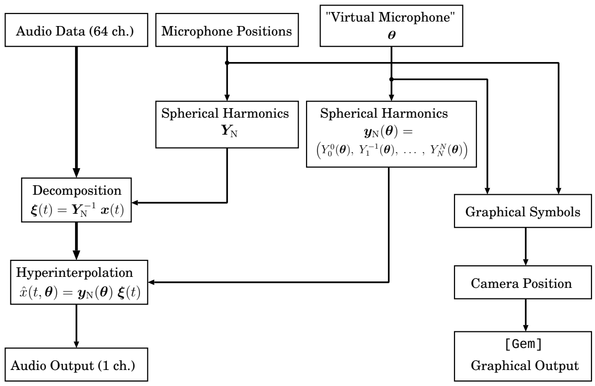

Figure 3: Block-Diagram of *vMIC*.

3. SURROUNDING SPHERICAL MICROPHONE ARRAY

The array employed was constructed [7] using the 64 extremal points for hyperinterpolation with $\mathrm{N} = 7$ as published by Womersley and Sloan, available at [8]. The hardware consists of 64 Behringer ECM8000 at a radius of 1.2m (measured at the capsules), 8 Behringer Pro-ADA-800, an RME ADI-648, and a PC with RME HDSP MADI interface. All microphone levels were digitally adjusted by a Cirrus CR511E 1kHz calibrator. The 64 channel recordings have been taken on a linux-PC using Pure Data, a graphical programming language for computer-music and real-time signal-processing [9]. Note that our recording room is not an entirely anechoic chamber. Nevertheless, acoustic reflections and modes that might occur have been neglected in the presented considerations.

4. THE SOFTWARE VMIC

vMIC uses the Pure Data external `[iemmatrix]` [10] to implement the matrix eqs. (3)(4) in real-time. $\hat{x}(t,\boldsymbol{\theta})$ is sent to the audio output for listening. The angular position $\boldsymbol{\theta}$ of the virtual microphone (angle of the radiated sound) can be controlled by the user in real-time. Simultaneously, *vMIC* renders a graphical output to provide a visual aid to orientation and a geometric overview of the recording scene using `[Gem]` [11].

The building blocks of the audio and graphics signal processing of *vMIC* are depicted in fig. 3. A short video has been rendered using *vMIC* which is available at the website `http://sh.toningenieur.at`.

5. CONCLUSIONS AND OUTLOOK

We have presented a tool in this paper, which allows to empirically experience sound radiation from a musical instrument by listening. The raw data for this tool were recordings taken by the first surrounding spherical microphone array that supports hyperinterpolation. The tool *vMIC* computes the sound signal of the instrument radiated to one direction that can be adjusted in real-time.

vMIC might serve prospect audio-engineers and music performers as a helpful tool in learning about sound-radiation of musical instruments.

As a potential application of the proposed audio signal-processing, comparison to known directivity analyses can be made, as attempted in [12].

Using holographic extrapolation of the wave-field, the virtual monitoring position in *vMIC* could also be controlled with respect to radius, or be rendered for any microphone characteristics. However, holography requires a perfectly anechoic measurement chamber, a high signal to noise ratio at low frequencies, and recordings free of spatial aliasing. Tentatively, holography has been excluded from the considerations in this work and remains subject to future investigations.

Despite shortcomings when regarding the data as acoustic measurements, the data still have been taken in a superior environment for sound recording. Our new exciting tool is easy to handle and it conveys the influence of the directivity of musical instruments on the timbre of their direct sound by simply listening.

6. ACKNOWLEDGMENT

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