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The Semi-Virtual Violin – A Perception Tool

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ABSTRACT

In this paper, a semi-virtual violin is presented which has been developed in the context of a research project on desirable violin sound properties. The method used here focuses on musicians' perception of spectral components rather than on physical modeling properties. A silent violin which has been designed with particular emphasis on authentic haptic and visual properties is used as interface between musician and virtual body. Binaural transfer functions of real violins measured at the violinist's hearing position serve as initial sound references for further spectral modifications. A filtering software enables highly-detailed modifications in the frequency domain, changing individual resonances or resonance areas while leaving other resonances unaffected. Implementation on an external signal processor provides for real-time sound processing. An application example demonstrates the tools capability: The presented tool can be used, inter alia, to manipulate the vowel quality in violin tones by modifying specific formant properties.

1. INTRODUCTION

String instruments in general and violins in particular have been of scientific interest for a long time. The complexity of the sound generation process in combination with the fascinating sound itself is very attractive for many researchers in different scientific fields. However, there still remains the question of a comprehensive explanation of what is essential for an instrument's quality. In the course of their research works, many violin researchers and luthiers focus on the resonance profile, i.e. the acoustic fingerprint of an instrument or more precisely, of an instrument's resonance body [1], [2], [3]. The idea behind this approach is that the body is mainly responsible for the specific sound character of an instrument and can approximately be considered as a linear and time invariant system (LTI system). The source-filter separation allows for a complete description of the body properties on the basis of its impulse response or frequency response (Fig. 1). The so called resonance profile is the magnitude spectrum of the frequency response:

$$H(j\omega) = \frac{Y(j\omega)}{X(j\omega)}, \quad \omega = 2\pi f, \tag{1}$$

where $Y(j\omega)$ and $X(j\omega)$ are the acoustic radiation of the body and the string oscillation, respectively, both in frequency domain.

Scientists and violin makers nowadays infer physical properties from instruments' resonance profiles [4], [5], [6] but there is also a rising interest for synthesizing violin sounds, e.g. in [7], [8]. Virtual modeling of specific body properties allows—depending on the modeling technique used—a kind of backward reasoning which, in turn, can be helpful for a better understanding of the sound process, or for building instruments. This is the approach on which the present paper is based on. In order to identify the acoustic impact of modified resonance constellations an electronic platform has been developed. Therefore, similar to an approach of Mathews et. al in the 1970s [9] and other attempts, e.g. [10], [11], and [12], the sound process of a violin has been divided into two components: the excitation signal or string signal (source) and the resonance body (filter). Here, the excitation signal is generated with a specially designed silent violin and the resonance body is realized virtually [13].

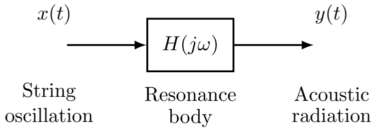

Figure 1: The violin body treated as an LTI system.

Due to a strict focus on authentic acoustical, visual and haptic properties the presented platform has been designed for the dialog with violinists and investigations of luthiers. Besides the reason mentioned above, the separation of string excitation and resonance body has been chosen to enable an authentic playing situation for musicians. This fact is necessary for drawing reliable conclusions from playing tests.

In the following section, the main components of the violin model are described, including the methods for achieving high level quality source signals, binaural HRTFs, and the process for virtually modeling the violin body. Also, the software interface and the implementation on an external DSP board will be briefly explained. Afterwards, a specific application example is described: the presented tool can be used to manipulate the vowel quality of violin tones by specifically changing formant properties. In concurrent research work, the authors seek for a relationship between perceptible vowel properties in violin tones and the instruments' quality [14].

2. METHOD

Fig. 2 shows the signal chain of the violin platform. The dashed box includes the computer-based elements, mainly the synthesized body and a standard room reverberation effect. The acoustic feedback path is realized with closed headphones. Fig. 3 shows the complete violin tool.

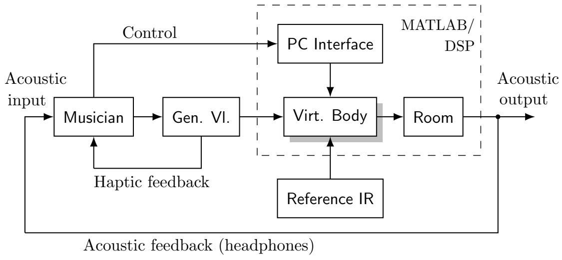

Figure 2: Main components of the semi-virtual violin platform.

Figure 3: Silent generator violin, DSP platform, power supply unit for the built-in impedance converter, and software interface.

The virtual body bases on binaural impulse responses of real violins. These reference impulse responses are generated with a special technique [15], [16]: the damped strings are pulled aside by means of a thin copper wire until the wire breaks. A near-field dummy head microphone placed at the playing position records the instruments' acoustic radiation in an anechoic chamber (Fig. 4). This high reproducible impulse excitation is closer to the natural instrument excitation than conventional impulse response methods, e.g. the impact hammer method.

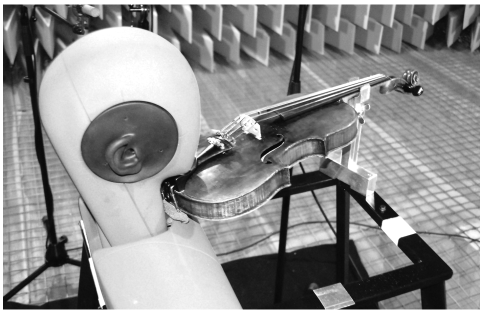

Figure 4: Dummy head microphone at the playing position in an anechoic chamber for impulse response measurements.

For modifying the virtual resonance profile, a MATLAB-based control software has been developed which enables resonance modifications with arbitrary high resolution. Modifications, for instance, can be shifting, boosting, attenuating, broadening, etc. of individual resonances or resonance areas. The filter technique is based on a recursive peak filter system [13].

The string signals for the excitation of the virtual body are generated on a special silent violin, hereafter called generator violin. Tests with violinists have shown that musicians clearly prefer a familiar responsiveness which is often not given by a common silent violin [17]. So the instrument designed here has similar haptic and visual properties like conventional violins and is nearly silent as it features no own wood or air resonances. These properties are achieved by damping with light polyurethane foam and silicone. The string signals are recorded via a piezo pickup integrated in the bridge (Fig. 5) and routed to an impedance converter within the body (Fig. 6).

Figure 5: Bridge of the silent violin featured with piezo-electric sensors.

Figure 6: Phantom-powered built-in impedance converter.

Even though body resonances are strongly damped, the generator violin still reveals some specific admittance behavior. So the undesirably remaining modes have to be compensated for. Due to the damped body, the duration of the impulse response of the generator violin—measured with an accelerometer at the side of the bridge—is very short (of about 1.5 ms). Thus, it is possible to equalize the admittance curve (Fig. 7) applying a simple inverse filtering process without taking account of a reverberation part. The implemented equalization filtering process also involves some other compensation steps. Fig. 8 shows the signal chain of the tool beginning with the string oscillation of the generator violin and ending with the violinist's perception. Some of the blocks shown here represent individual transfer functions, e.g. headphones, and therefore have to be compensated for. The complete magnitude frequency response of the equalization process can be written as

$$\left|H(e^{j\Omega})\right| = \frac{\left|H_{BP}\left(e^{j\Omega}\right)\right|}{\left|G\left(e^{j\Omega}\right)\right| \cdot \left|E_{DH}\left(e^{j\Omega}\right)\right| \cdot \left|A\left(e^{j\Omega}\right)\right|}, \qquad (2)$$

where $H_{BP}(e^{j\Omega})$ is a band pass filter curve, $G(e^{j\Omega})$ is the admittance function of the generator violin, $E_{DH}(e^{j\Omega})$ is the dummy head auditory canal frequency response, and $A(e^{j\Omega})$ is the frequency response of the headphones (see also Fig. 8 and Fig. 9). Here the equalization frequency response $H(e^{j\Omega})$ is realized by means of an 256 tap FIR filter which has been designed using the frequency sampling method.

As mentioned above, the semi-virtual violin platform is developed for the use with violinists. So, a very low processing latency is required which is achieved by using an external DSP

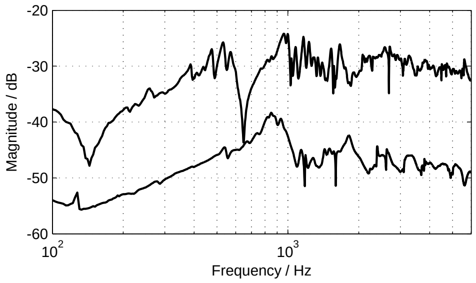

Figure 7: Magnitude spectra of bridge admittance functions; top: conventional violin, bottom: silent violin (separated with a –10 dB offset for a better comparison).

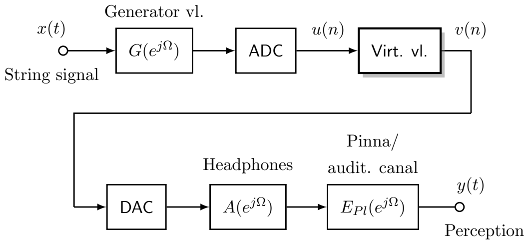

Figure 8: Outer components of the signal chain including the bridge admittance of the generator instrument $G(e^{j\Omega})$, the headphone frequency response $A(e^{j\Omega})$, and the frequency response of the violinist's pinna/auditory canal $E_{PI}(e^{j\Omega})$ (see also description in the text).

board (Texas Instruments TMS320C6416). Due to an overall system latency of less than 5 ms, the platform allows for experiments on perceived sound properties and human-instrument interaction.

3. APPLICATION EXAMPLE

The presented platform can be used as a research tool for various topics. The most obvious application is the manipulation of individual resonances. The impact of modifications on the sound is immediately perceptible while playing the instrument. This allows doing basic violin sound research in a simple, perception-based way. Furthermore, previous studies on optimal resonance constellations or energy distributions in certain frequency bands can be verified.

Here, a further, more specific field of application is briefly introduced which relates to a parallel project of the authors: the vowel quality of violin sounds [14]. Unofficial listening tests have shown that musicians prefer particular vowel sound properties in certain frequency bands. An e-string, for example, sounds more pleasant if its sound character is mainly associated with an [eː]-vowel instead of an [iː]-vowel; IPA (*International Phonetic Alphabet*) notation is used here. Besides, nasally sounding vowels like [æː], [ɛː], and [ɜː] are undesirable. One could state that the vowel quality of an instrument's sound directly correlates with the perceived quality of the instrument.

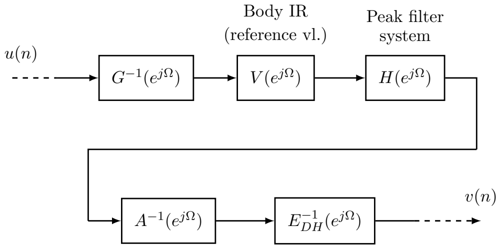

Figure 9: Inner components (implemented in the model) including the compensation frequency responses as well as the reference impulse response $V(e^{j\Omega})$ which contains the dummy head pinna/auditory canal transfer function $E_{DH}(e^{j\Omega})$. $H(e^{j\Omega})$ represents the frequency response of the peak filter system which is used for modifications (see also description in the text).

On the basis of the semi-virtual violin tool, individual resonances can be varied in the context of vowel quality knowledge. While heading towards the desired sound perception, the most promising violin modifications will be identified. Vowel analysis can be done by means of the LPC (*Linear Predictive Coding*) analysis. The location of the roots of the LPC transfer function indicates the formants and therefore the perceived vowel. Fig. 10 shows the LPC spectrum of a bowed violin tone (G#3) which is recorded from the semi-virtual violin. Here, the spectrum and hence the pole locations roughly correspond to an [æː]-vowel. For comparison, the LPC spectrum of a spoken [aː]-vowel (male voice) is shown, too.

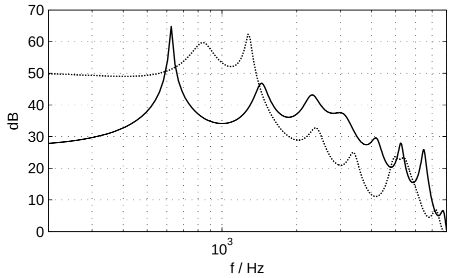

Figure 10: LCP spectrum of order $p = 47$ of a bowed violin tone (G#3) which has been recorded from the semi-virtual violin and LPC spectrum of a spoken [aː]-vowel (male voice); black: violin, dotted: voice.

Here, this voice LPC spectrum exemplarily serves as reference vowel spectrum for the bowed violin tone. Using the body modification software for shifting, attenuating or boosting certain resonances in an iterative process leads to a slightly changed resonance profile. The associated modified timbre can interactively be checked against the perceptional target. The difference spectrum of both the semi-virtual violin LPC spectrum and the voice LPC spectrum serves as a starting point for modifications. Fig. 11 shows the difference spectrum. Moreover, the figure shows the result of the spectral modifications which have been made to change the vowel sound characteristics from [æː] to [aː]. Here, only the first two formants have been taken into consideration. Fig. 12 shows the new LPC spectrum of the violin tone compared to that of the voice signal. The modifications have been made with emphasis on minimal changes. This tentative attempt allows for deriving useful knowledge on desirable sound properties and specific suggestions for modifications on real instruments. Fig. 13 shows both the original resonance profile of the semi-virtual violin and the modified resonance profile.

4. SUMMARY

A perception tool has been developed which allows detailed modifications of violin resonance profiles. The semi-virtual violin is designed for the use by professional musicians. In the future, it will be applied to identify desirable violin sound properties. Real-time capability, natural haptic properties of

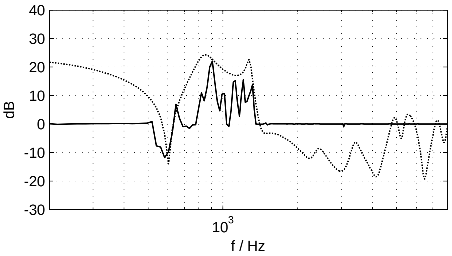

Figure 11: Difference spectrum of spoken vowel and bowed violin tone LPC spectra as initial reference for resonance profile modifications (dotted). Black: difference between original resonance profile and modified resonance profile.

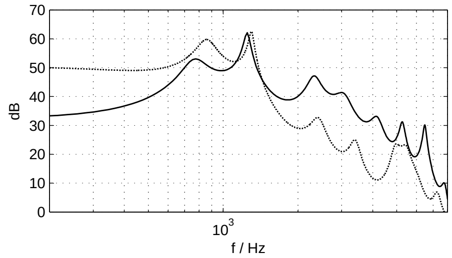

Figure 12: LCP spectrum of order $p = 47$ of a bowed violin tone (G#3) which results from a modified resonance profile of the semi-virtual violin compared to the LPC spectrum of a spoken [aː]-vowel (male voice); black: violin, dotted: voice.

the generator violin and binaural reference impulse responses are designed to work with the violinists' perception. Besides studies on the impact of changing specific resonance constellations, the tool can be used for several research tasks regarding violin sound properties. In this paper, an application has been introduced with which resonance profiles can systematically be modified in order to achieve more vowel related sounds. In upcoming playing and listening tests, the semi-virtual violin tool will be used to identify the relationship between the musicians' perception and instrument properties.

5. ACKNOWLEDGEMENTS

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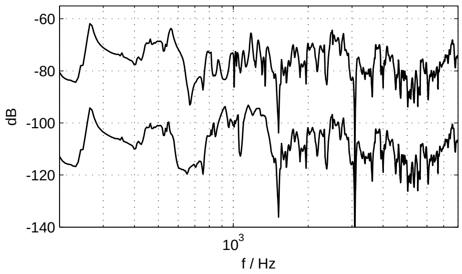

Figure 13: Original resonance profile of the semi-virtual violin (top) and modified resonance profile, separated with a –30 dB offset for a better comparison.