NON-IMPULSIVE SIGNAL DECONVOLUTION FOR COMPUTATION OF VIOLIN IMPULSE RESPONSES

Andrés Bucci, Alfonso Pérez, Jordi Bonada

Universitat Pompeu Fabra

ABSTRACT

This work presents a method to compute violin body impulse responses (BIR) of acoustic violins that are adapted to the signal captured with an electric violin (a violin with a transducer measuring vibration). The computed BIRs correspond to the transfer function that maps the pickup signal of the electric violin to the radiated acoustic sound of the acoustic violins. By convolution of the pickup signal with the corresponding BIR, we pretend to simulate the radiated sound of the acoustic violin by playing the electric one. The method to obtain the BIRs is based on signal deconvolution between a recorded audio signal of an acoustic violin and the signal coming from an electric violin's pickup. The recorded signals consist of glissandi performed with a violin-playing machine enhanced with motion sensors that provide the bowing parameters (bowing position, velocity and force). By controlling the bowing parameters and analyzing the fundamental frequency of each frame we perform the deconvolution on equivalent frames and obtain the desired impulse response between the two instruments. A user survey consisting of violinists and non-violinists was performed to evaluate the obtained results with respect to the original pickup signal.

***Index Terms*—** Deconvolution, Violin, Bowing

1. INTRODUCTION

It is a very common issue the use of acoustic instruments in performances that require sound amplification. In many cases this amplification is not feasible due to sound feedback and other artifacts and thus an electric instrument must be chosen even when the sound of an acoustic instrument is preferred over the one produced by its electrical counterpart.

Since the timbre characteristics of both instruments differ significantly, when a player wants to imitate the sound of an acoustic instrument, the signal coming from the pickup of the electric instrument is usually altered by means of manually combining equalization and reverberation units. These techniques, however, are not sufficient to simulate the radiated sound from an acoustic instrument.

In the particular case of the violin, a solution is reported [1, 2] based on a deconvolution algorithm that computes violin body impulse responses (BIR), which correspond to the transfer function from the signal captured with a transducer built into the bridge and the acoustic sound radiated. In the referred work, the violin is excited by human-bowing and the estimated BIR can be convolved with the signal captured by the same transducer in order to simulate an acoustic sound. The requisite is that both signals (acoustic and transducer's) have to be recorded at the same time in order to ensure the use of the exactly the same bowing parameters in both.

In this work we present a new method based on the latter approach, for obtaining BIR from any acoustic violin adapted to any electric violin. This implies that different acoustic recordings and measurements from different transducers are not necessarily carried out at the same time and therefore, we need for a procedure to compute BIRs of recordings that may have different bowing parameters.

The proposed method is based on a newly designed violin playing machine, which can automatically bow a violin in an almost repeatable way and it is also equipped with a measuring system capable of acquiring the bowing parameters (i.e. bowing position, velocity and pressure). The non-repeatability is solved by a frame-based deconvolution algorithm that matches frames in two recordings with equal bowing parameters and pitch.

2. PREVIOUS WORK

When trying to model the violin body with computational tools it is usually treated as a LTI system [3, 4, 5]. The way this is approached is by measuring the response of the violin body to a known excitation signal and calculating its body impulse response (BIR). However, the method for obtaining them can fall into two main categories, direct and reciprocal. Direct methods can be further subdivided according to the characteristics of their excitation signal, which can be either impulsive or continuous.

This process has been tried in different instruments such as the guitar [6], where they approximate the radiated sound using the vibration signal coming from a bridge vibration pickup using a single digital filter; for this purposes the crucial aspect is to excite the guitar bridge with a rich frequency content signal.

In the specific case of the violin, mainly impulse hammer or maximum length sequences (MLS) were used to determine the impulse response of the body. In [7] the difference between direct and reciprocal methods was also studied. Reciprocal methods use excitation of the sound field with a known volume and measuring the velocity of the bridge to calculate the impulse response of the body, but it is mentioned that the reciprocal methods yield inferior results than the direct ones. In [8], it is mentioned that for violin sound radiation, a steady-state bowing method is favored because it is closer to human performance; although the focus of that study was not violin body modelling, it helps raise the question that other methods could be developed to obtain the transfer function between the body excitation and its radiated sound.

In [6, 1] two similar methods are reported in order to obtain BIRs of the guitar and violin respectively. These methods are based on exciting the instruments by playing (plucking for the guitar and bowing for the violin) and doing a deconvolution of two non-impulsive measured signals. The first one is captured with a transducer attached to the body of the instrument and the second one consists of an acoustic recording using a microphone. The drawback of this method is that both signals must be recorded at the same time, so it is not possible to combine the estimated BIR of an acoustic violin with a different electric violin, because it would not yield the desired acoustic sound.

3. DATA ADQUISITION SYSTEM

The main idea behind building the violin playing machine is to perform the same excitation in two different violins, in a way that is nearly impossible for a human to do. This excitation consists of slowly increasing glissandi covering one octave of the lowest string of the violin. The machine then must move the bow across the string at a constant rate and change the pitch of the violin continuously. We will explain each of these aspects individually, since when designing this machine such actions were considered to be uncorrelated from one another.

For the string excitation of the violins, from here on referred to as the bowing arm of the machine, a scotch-yoke mechanism was used to move a standard violin bow across the desired string; this mechanism consists of a rotating disk with an eccentric pivot that slides between a straight guide, thus converting the rotational motion of a motor to the linear motion required to move the violin bow across the strings.

This mechanism was chosen in part for simplicity of construction, since it involves very few moving parts; its major drawback, which is friction between the pivot and the guide was ignored because of the slow speed in which the bow motion is performed. The other main reason why this mechanism was chosen is due to the fact that positive and negative displacements of the bow with respect to its center can be obtained without changing the direction of the motor. This avoids the necessary breaking and starting forces to change the bow direction, but rather we obtain a stable oscillation from constantly spinning the motor in one direction. We decided to move the bow approximately half of its total dimension, therefore the disk has a radius of 320 mm.

For the alteration of pitch a different kind of mechanism was needed since the movement had to follow the violin strings and slight imperfections in construction would influence the repeatability of the task negatively; for this reason, a commercial linear actuator was chosen. The length of one octave in a modern violin is around 150mm depending on the manufacturer, so, the length of the actuator was chosen to be 200 mm to leave some margin for the different scroll shapes that exist in electric and acoustic violins. Both the bowing and fingering arms are controlled by a PIC 8-bit microcontroller 16F690. A more detailed description of the violin playing machine and the design considerations can be found in [9].

With the machine in a recording studio we recorded a glissando with each violin, attaching position trackers on the violin and its bow, using the same system as explained in [10] to measure bow position, velocity and force and its distance to the bridge.

The audio from the glissandi was recorded with a sampling frequency of $f_s = 48000$Hz, which differs from the sampling frequency for the position tracker of $f_{spos} = 240$.

4. DECONVOLUTION ALGORITHM

After the recordings of both violins were performed, we obtained the necessary excitation signals for the deconvolution process to be performed. The method presented in [2] performs well because the signals coming from the microphone and the pickup are synchronized since the recordings were performed on a single acoustic violin with transducers embedded in the bridge. The only difference that must be accounted for in this method is the time delay from the microphone signal, which can be calculated from the distance between the microphone and the instrument itself; after this compensation is performed the two signals can be deconvolved sequentially.

This algorithm had to be modified to fit our purposes since we have two different recordings performed at different times, and furthermore our violin playing machine has some limitations in both precision and repeatability, so the recorded excitation signals are not exactly the same. This modification depends on both recordings having a high number of analyzed pitches within the octave and that the bowing gestures are comparable.

Therefore, before performing the deconvolution there is a preprocessing stage where the YIN algorithm [11] and the bow displacement curve are computed for every time instant. The reason why we only used the bow displacement curve is that both the distance to the bridge and the force used to press the bow against the strings remained constant for a given bow displacement, since they are determined by the bowing mechanism.

A block diagram of the modified algorithm can be seen in figure 1. Since the bowing parameters are crucial to the sound produced by the violin, we chose to use only a portion of the bow consisting of 3cm around its center, where these parameters are constant between different bow strokes; this ensures that we can attribute the changes in the spectrum to the resonant body of the violin. In figure 2 a section of the fundamental frequency curves of both recordings where the bow position meets the necessary constraints.

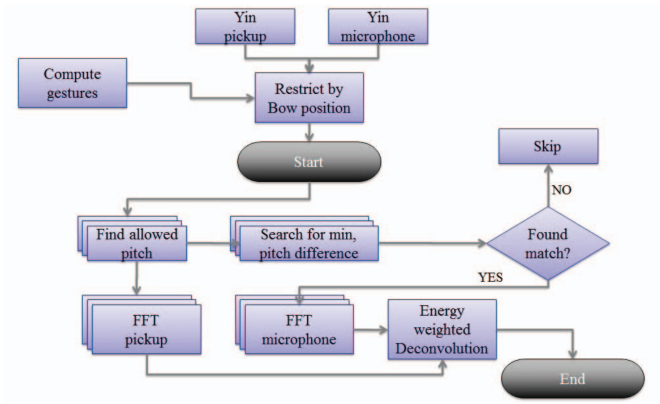

Fig. 1. Deconvolution algorithm block diagram.

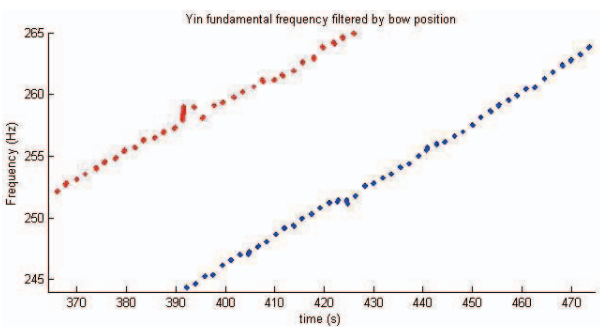

Fig. 2. Fundamental frequency vs time for an electric and an acoustic violin.

The recording from the pickup is considered to be the reference and the microphone recording the target one, including only pitches that fall inside of the allowed bow range. The algorithm then selects one allowed pitch from the reference recording and performs the Fast-Fourier Transform (FFT) on the block of audio that corresponds to the desired pitch; it then searches for the corresponding pitch in the target recording, and performs the FFT in the target recording only if the absolute difference between the two pitches is less than 0.05Hz. If this pitch is found, it divides the two magnitude spectra in order to perform the deconvolution, with a minimum value limit of -200dB; the result is then multiplied by the energy of the frame in the reference recording and accumulated to be averaged at the end of the analysis stage.

The spectral analysis parameters were chosen to optimize for frequency resolution and low side lobe effects, so a Blackman-Harris window of 8192 samples with a zero-padding factor of 8 (yielding an FFT size of 65536 samples) with a 50% window overlap, which gives us a bin resolution around 0.732Hz; but the pitch should be kept constant at least for 0.683s in order to provide reliable results, since for one single frame we are considering that just one pitch exists.

The phase of the frequency response was obtained from the magnitude spectrum by computing the minimum phase transfer function in order to make our impulse response causal[12].

After all the allowed pitches have been analyzed, the resulting transfer function is converted to an impulse response by performing an Inverse Fast-Fourier Transform of the complex spectrum; due to our analysis parameters, the impulse response has a duration of half a window size (0.683s), although most of the energy is concentrated around the first 100ms.

5. EVALUATION

With the purpose of quantitatively evaluating the obtained sound after performing the convolution with the impulse response we performed a survey to determine two main questions, how accurate is our algorithm in conveying an acoustic-like sound from an electric violin, and what are the perceived sound quality differences between the electric and the processed sound.

The users are given two music excerpts and are told that they come from different instruments. After listening to both examples they must rank their quality and choose which instrument is producing the sound; we obtained 70 responses, out of which 22.857% reported that they were violin players and 77.143% stated otherwise. The average experience for the violin players was 16.813 years, which should indicate even though there is not a high percentage of violinists, they can be regarded as expert listeners, since they are used to hear and compare different violin sounds.

Overall the obtained results confirmed our expectations, with the majority of the users labelling our sound as an acoustic sound and the original signal as an electric one. These results can be observed in table 1; it is worth mentioning that the violinists show less confusion in this source identification, as expected.

Sound	Answers	Violin players (%)	Non-Violinists (%)
Processed Sound	Acoustic Violin	87.50	62.96
	Electric violin	6.25	9.26
	I can't tell	6.25	27.78
Original Sound	Acoustic Violin	6.25	18.52
	Electric violin	81.25	53.70
	I can't tell	12.50	27.78

Table 1. Comparative results Between violin players and Non-violinists in source identification

Regarding the quality evaluation of the perceived sounds we gave the users a scale of 1 to 10, where 1 meant very bad quality and 10 meant excellent quality to indicate their subjective opinion of the sound. For the processed sound the overall quality ranking mean was 7.114 and for the original sound coming from the electric violin pickup it was 5.757; this also confirms our hypothesis that there is an overall preference for the acoustic violin sound than the raw signal coming from an electric violin, although this cannot be generalized for every musical context; the results for the individual populations are shown in table 2. Overall we obtained 47 positive evaluations against 23 negative or equal, but is hard to determine if the sound is the only thing being evaluated or also the performer.

Sound	Quality Ranking	Violin players	Non-Violinists
Processed Sound	Mean	5.563	7.574
	Standard deviation	2.502	1.766
Original Sound	Mean	4.188	6.222
	Standard deviation	1.870	2.328

Table 2. Comparative results Between violin players and Non-violinists in quality ranking

6. CONCLUSION

In this work we presented a procedure to measure violin body impulse responses (BIR) by exciting the instruments with a newly designed violin-playing machine enhanced with motion sensors, which are able to track the bowing parameters (bow position, velocity and pressure). The system is used to obtain the BIR corresponding to the transfer function of the signal captured with an electric violin to the acoustic radiation of an acoustic violin. The obtained BIRs are convolved with the signal of an electric violin in order to simulate the acoustic one. Listening test have been carried out on experts (violinist) and non-experts in order to evaluate the simulations resulting in very good evaluations of the synthetic sound being considered to be very close to an acoustic violin.

7. REFERENCES

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