Digital Equalization of the electric violin:
Method for obtaining violin body impulse response based on machine bowing

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Chapter 1

Introduction

The violin has been for many years and from many different points of view a recurring subject of study, however there is still a fascination in understanding how the instrument produces sound and how to improve its quality. With the use of technology this is no longer an exclusive task of violin makers, or luthiers, but also a continuous research field for many scientific contexts; its mechanical behavior, radiation patterns and the effect of its different parts in sound quality are all still developing lines of work. In the last decades, specially in modern music ensembles with different amplified instruments it is not uncommon to find electric violins. These violins on the contrary, and the crucial aspects regarding the quality of their sound, have not been studied so thoroughly, at least in a scientific context.

In this chapter we will provide a brief explanation of the relevant concepts of this work, its motivation and goals. In Chapter 2 we will discuss previous and related work, the specific methods that we plan to use, as well as its implications on the implementation. In Chapter 3 we will present the specific details of our implementation. in Chapter 4 we analyze the performance of the obtained sound and finally, in Chapter 5 we provide the conclusions obtained from this analysis and point towards future directions in which this work can be expanded or improved.

1.1 General Context and Objectives

1.1.1 Motivation

Equalization and amplification of instruments in musical performances is a known issue. For many musical applications, the sound of an acoustic instrument is preferred over the one produced by its electrical version; however it may not always be feasible to use such instruments due to certain sound level requirements, and thus its electric counterpart must be chosen.

Much of the differences from acoustic and electric instruments can be found in the way they are built; in acoustical stringed instruments, the resonance box or body of the instrument is the main element that provides amplification from the excitation of the strings, and the interaction between both elements and the air enclosed alter the timbre of the instrument by enhancing or reducing certain frequencies. In the case of electric instruments, amplification is done in a separate element, the amplifier, which takes an input signal coming from a transducer embedded in the instrument, increases its amplitude and then transforms this amplified version into sound pressure by means of loudspeakers; transducers and amplifiers mainly account for the timbre of the electric instrument, since audio amplifiers are rarely designed to provide linear signal gain, and often include controls to alter the timbre.

Since the timbral characteristics of both instruments may 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 alter specific parts of the spectrum of the incoming signals and the perception of distance from the listener to the source or the space in which the instrument is played [26]. These techniques, however, are still not sufficient to simulate the radiated sound from an acoustic instrument. Since the methods of generating sound are so different, they produce very distinguishable timbral qualities, and as mentioned before, this may not always be desirable.

In recent years and mainly since the 1980's, researchers have tried different methods to understand and alter the signals coming from the pickups of the electro acoustic stringed instruments to match their acoustic counterparts. These techniques mainly include physical modelling and digital signal processing techniques or some sort of combination between both. Impulse responses are also widely used in commercial reverberation units, when trying to obtain characteristic room reverberation, for example in the Space Designer plugin for Logic Studio[1] and IR1 parametric convolution reverb from Waves [2]. For pickup instruments we found the BodiLizer[3] plugin available for electro-acoustic guitars, and none specifically made for electric violins.

In the particular case of the violin an approach using body impulse responses (BIR) has shown promising results in conveying a more realistic sound in violin synthesis, therefore we can use a similar method to convey the acoustic violin sound from an electric one [21].

1.1.2 Goals

The goal of this project is to develop new algorithms and a methodology to produce more acoustic-like sounds from an electric violin, to reduce the timbre difference between both instruments; in order to do so we must study which are the main influencing factors in both instruments and the most successful methods that have been used to change this timbre in the desired way. The resonating body of the instrument is the main difference in the construction of electric and acoustic violins; since it has been shown to have the largest impact in the timbre of many acoustic instruments [5, 14] and being one of the main contributions in perceptual violin quality evaluation [8]; we will try to find a transfer function from the signal coming from the electric violin to the radiated sound of an acoustic one, because the body of the electric instruments has no important acoustical function [31]. In order to achieve this we must also build a mechanical bowing machine that can excite a violin in a controlled and repeatable manner, since this will be the basis of the method that we propose to use. The specifications of this machine as well as the method will be explained with more detail in the following chapters.

[1] http://testtone.com/developers/apple/space-designer
[2] http://www.waves.com/Content.aspx?id=250
[3] http://www.ijdata.com/products.html

1.2 Main Elements of the Violin

The essential parts of the violin are: the strings, which are steel, gut or nylon (wound with silver, aluminium or steel); they are tuned to G_3, D_4, G_4 and E_5[7]. They run from the scroll to the tailpiece. The top plate or belly is curved and it has two orifices at each side that are mirrored images of each other, these are named after their shape, "f-holes". Underneath it and running longitudinally there is the bass bar and a sound post attached to the back plate. Above the top plate there is the bridge; its function is to separate the strings from the fingerboard, and to transfer the vibration coming from the strings to the resonating structure. The fingerboard sits on top of the neck, where the violin is held by the performer at one end, while at the other it is pressed between the shoulder and the chin, in the chin rest. Figure 1.1 and 1.2 show all these parts, in an exploded diagram and as they would be observed on a standard violin.

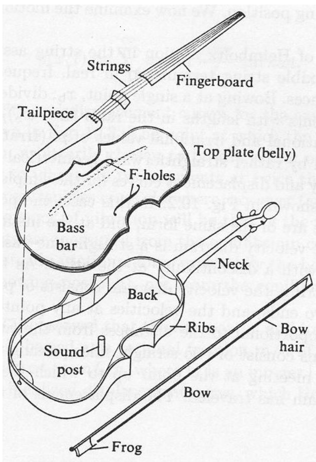

Figure 1.1: Different parts of the violin, from [7]

1.2.1 Importance of the Violin Body in Sound Quality

As discussed previously, the violin body is one of the most determinant factors of the timbral qualities of the instrument; it is responsible in shaping the spectrum in an fixed way, analogous to the effect of the vocal tract in speech[25]. The characteristics of these modifications share some similarities,

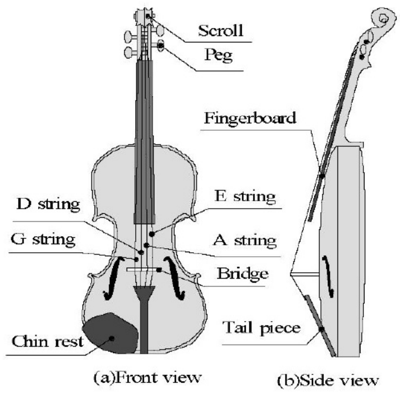

Figure 1.2: Different parts of the violin, from [23]

since the size of the violin and its f-holes are very standard at least in modern day violins and they don't change or deform over time. Nevertheless violinist and violin makers are very sensitive to slight variations in construction that would yield a preferable sound according to their own taste or musical styles.

The response of the violin body is characterized by its resonances or modes. The nomenclature for these modes described in [10] has become a standard in the field; and is as follows:

- A modes, caused by the motion of enclosed air. When the body is vibrating, the volume of the body is changing and air is pressed out and sucked into. The A0 resonance corresponds with the resonant frequency of the whole volume resonator.
- B modes, are motion modes of the back plate.
- T or P modes, are due to motion primarily of the top plate.
- C modes, refer to bending and flexing modes of the "corpus" or body.
- N mode, is the resonance of the neck.
- BH is the frequently called bridge hill, and represents the resonances of the bridge, which overlap and form the shape of a smoothed hill (not a peak).

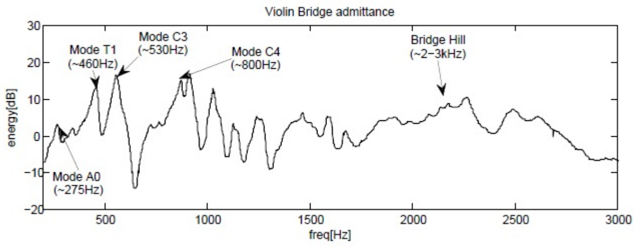

Figure 1.3: Bridge input admittance curve to show the main violin resonances. From [21]

These main resonances can be observed in Figure 1.3 The air resonance(A0),around 270Hz, T1 between 400 and 500 Hz, C3 between 500 and 600 Hz and BH (Bridge hill) between 2 and 3kHz.

In [15] there already existed some measurements of how these specific resonances of the violin body affect the perceived quality of the instrument, by means of subjective testing. The modifications in certain regions of the spectrum by means of parametric equalization proved to work to some extent.

Other studies, such as [1] have compared averaged magnitude spectra of old and new violins that are considered to be of excellent quality, to observe if specific parts of the spectrum can differentiate one violin from another. They observed that as expected, violins of the same era share some common features in their spectra, and that the modern violins have less variation between them. They identify certain regions of interest in which these differences are noticed and the parts where they are similar.

In [9] the perceptual threshold of changes in these specific resonances was quantitatively measured in a set of musically trained and untrained subjects. They observed that the threshold for the musicians was significantly lower than for the non trained subjects, and for the former group to be in the order of 3 to 6 dB in amplitude and 1.5 to 20% in frequency shift.

In the paper by [19] the discussion is taken to a different element in the violin body. He proposes that since the bridge of the violin has specific resonances that produce a form of filtering which is critical to the quality of the perceived overall sound, and those resonances depend on the material properties and geometric configuration of it, then certain modifications to this element will be very influential in the overall sound of the instrument.

1.3 Source-Radiator Separation

The violin is a very complex system that behaves differently according to the instrumental controls articulated by the performer. In [2] we find an appropriate definition:

In a simplified model of violin sound production, we can consider all the elements of sound transmission from the bridge to the listener as linear and the sound pressure that arrives to our ears to be proportional to the transversal force exerted by the string vibration on its anchorage on the bridge.

Using this definition we can attribute the non-linearity to the bow and string interaction, and treat the body of the instrument as a linear system. This will be fully explained in section 2.3, but it's important to know that this separation is not unique, it depends heavily on the properties of the violin that want to be studied and in the measurement techniques employed in analyzing it.

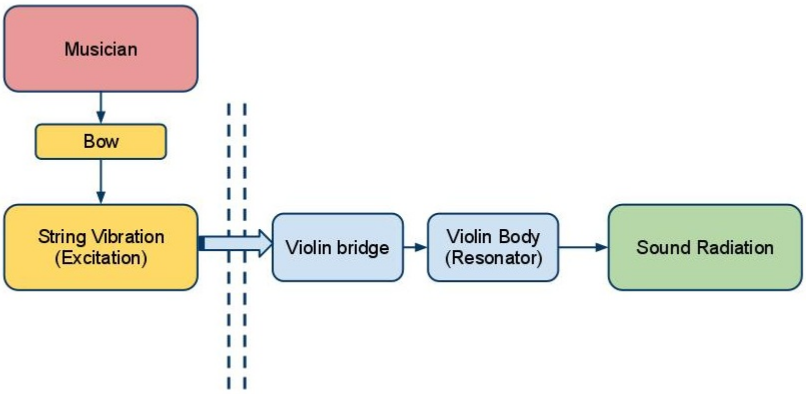

Figure 1.4: Block diagram showing the different elements that affect the violin sound. Dotted lines show the usual separation between the non-linear and linear parts

Chapter 2

Literature Review

2.1 Overview

In this chapter we want to describe the relevant literature regarding models of the violin body and the necessary techniques that are used to measure them; we attempt to provide a description of the main elements we want to consider in our implementation and the benefits and disadvantages of the different approaches. Another concern is to review the existing violin playing machines reported in the literature so we can observe what has been proved successful in the past to come up with the specifications for our own machine, as mentioned in section 1.1.2.

2.2 Signal Deconvolution

The use of deconvolution has a very clear application when an undesired source of noise affects our original signal. This can also be explained by saying that the original signal has been *convolved* with the noise. Deconvolution in this context is a process done to remove this source of noise and recreate the signal before it was affected; if we can know the spectral representation of this noise, then we can apply deconvolution to restore the signal to its original form. The problem of obtaining the original signal without knowing the spectral representation of the noise is called blind deconvolution.[26].

Another application where deconvolution has been proved very useful, is to characterize a system. If we can measure a signal before entering the system, and afterwards, then we can perform deconvolution of the two signals to obtain its impulse response; for any LTI system, this is enough to fully describe it. When we convolve any input to the system with its impulse response, we obtain the output of the system to that signal. These operations are often carried out in the frequency domain, since convolution in the time domain is analogous to multiplication in the frequency domain. Equations 2.1 and 2.2 can help us obtain the mentioned impulse response $h(t)$. If

$$y(t) = x(t) * h(t) \tag{2.1}$$

then we can obtain $h(t)$ by the inverse Fourier transform of $H(\omega)$, where $X(\omega)$ and $Y(\omega)$ are the Fourier transforms of the signal before entering the system and after being affected by it, respectively.

$$H(\omega) = \frac{Y(\omega)}{X(\omega)} \tag{2.2}$$

In this research we will propose a novel deconvolution algorithm to find transfer functions from the electric signal coming from an electric violin to the sound radiated by an acoustic one.

2.3 Obtaining Violin Body Impulse Responses

When trying to model the violin body with computational tools it is usually treated as a LTI system [25, 13, 28] because the displacement of the plates is small[15]. 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 [14] and it is mentioned that can be used in other instruments as well, since the process of measuring excitation and response signals is independent of the instrument that is used. Their goal is to approximate the radiated sound from the guitar using the vibration signal coming from a bridge vibration pickup using a single digital filter. They compare two different methods for computing the BIR, both of them being direct methods. The crucial aspect is to excite the guitar bridge with a rich frequency content signal; in their first approach the guitar is hit with an impact hammer, with the strings damped with absorptive material between them and the fretboard and its response is measured in an anechoic chamber. The impulse hammer signal and the response from the guitar can be observed in figure 2.1

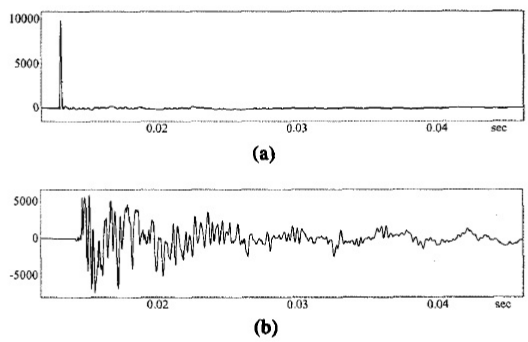

Figure 2.1: Recorded responses to impulse hammer excitation of the guitar bridge. a) From electret pickup b) From microphone placed at 1m facing sound hole [14]

For the other approach they excite the guitar by playing the instrument. For this to work, the excitation signal has to contain sufficient energy in all audible frequencies. It is mentioned that when done properly, the results obtained are more useful that with the impact hammer method.

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 [6] 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; these methods state that if the body resonates at the desired frequencies then the vibration measured will increase also when responding to the external source. However, for practical purposes the direct method is said to yield superior performances than the reciprocal, due to linearity of the transducers and greater signal-to-noise ratio, this is also confirmed in [29].In [30], it is mentioned that for exciting the violin, a steady-state bowing method is favored because it's closer to human performance;

although the focus of that study was sound radiation and not strictly 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, rather than the mechanical transfer function obtained by previous methods.

In [21] the proposed method for obtaining BIR from a normally played violin is approached by excitation and response measurements, like in [14]; surprisingly, this method was not studied previously in obtaining violin impulse responses. Since bowing does not interfere with measuring the response from the instrument and is the natural way of exciting the instrument the only condition for this method to work is to provide a signal that is rich in frequency content. For this purpose they experimented with a performer playing different exercises: glissandi and notes with different lengths, velocities, dynamics, in one or more strings, muted or freely vibrating and with different pitch ranges. They evaluated the spectral content of these signals by performing a histogram of the energy contribution to each spectral bin.

As expected, each of the parameters affected the obtained response of the instrument and after performing several tests, they came up with the following configuration: 1 octave glissando played on the G string of around 50 seconds in total length, played forte. They built a structure to prevent the violin from moving, since its orientation and position will definitely affect the properties of the recorded sound; for their purposes it was important that the player held the instrument, since the goal of this work was highly realistic synthesis. The main difference between this and the previous methods is that for an impulsive signal, all frequencies get excited in a very short timeframe, whereas with this method the energy contribution of the frequencies is different for each instant, so an average of the energy must be performed to minimize the noise obtained in the desired transfer function.

The method then performs the frame by frame deconvolution of the two signals, the excitation measured by a pickup embedded in the bridge of the violin and the response from a microphone, after being aligned properly for compensating acoustic delay and expressed in the frequency domain. Once this is done, then an average of all the frames is performed taking into account the effect of the windows applied to the signals, thus frames that are mainly affected by the window sidelobes give less influence to the average. Maximum bin resolution and stability of the sinusoids in each frame are also critical in this method.

For the magnitude estimation, the equation 2.3 was used, where i is the frame number, N is the number of frames, k is the spectral bin number being estimated and $w_i(k)$ is the weight being applied, which corresponds to the energy of the bin k for the frame i

$$|IR(k)| = \frac{\sum_{i=1}^{N} w_i(k) \frac{out(i,k)}{in(i,k)}}{\sum_{i=1}^{N} w_i(k)} \tag{2.3}$$

Regarding the phase, due to its cyclic behavior, carrying out a classical weighted average would not provide good estimations. As a first attempt, a method based on constructing a histogram of the phase values estimated for each spectral bin, weighted by their corresponding energy was tried. However, the resulting BIR was not causal, so a minimum phase BIR from the estimated magnitudes by using the cepstrum and converting anti-causal exponentials to causal exponentials was used [20]. The length of the obtained BIR was reported to have a duration of 0.74 s.

The trend of exciting the violin in a more natural manner is the more current approach, in [27] another method for computing BIR is mentioned, also derived from previous methods used in the guitar. In their approach they want to generate an impulse that not only excites the body in the plane of the violin bridge but also in the longitudinal direction, since torsional vibrations occur due to string deflection in the normal violin playing. It is mentioned that these vibrations do not decisively influence body radiation, but result in an acoustic radiation of the bridge itself and arguably affect the perceived brilliance of the violin sound and therefore must be considered in a realistic model.

The method consists in automatically pulling the E string sideways using a thin copper wire at the bowing position until the wire breaks with the rest of the strings damped; that makes the fundamental frequency of this 'plucked' string appear beyond 10 kHz and is filtered out by a subsequent lowpass filter; since the copper wire is designed to break at a specific stress level, this excitation signal is highly repeatable. The response is measured using a dummy head microphone to obtain a binaural model of the body and is intended to work with headphones.

2.4 Body impulse response and filter implementation

A signal produced by an electric violin can be processed in order to obtain an acoustic like sound by convolution of the signal with a BIR. Another approach that will be implemented is to filter the source signal with a model of the body, since sometimes the computational cost of performing this convolution can be too high. The initial approach when trying to design a filter is to implement a finite impulse response filter (FIR), using the measured or computed impulse response samples as N taps in the filter[13]; if N is larger than the impulse response duration it can yield a full accuracy body model. The difference equation for the FIR filter can be seen in equation 2.4, where b_i are the weighting coefficients for the respective taps.

$$h[n] = \sum_{i=0}^{N} b_i \delta[n-i] \tag{2.4}$$

We can observe that the problem with this implementation is that to capture the low-frequency details the order of the filter needs to be very large, so they are almost never used in the linear frequency scale. Another way that has been proved successful is to use a *warped* frequency scale called the *Bark frequency scale*[24]; this scale is based on psychoacoustic experiments and by representing spectral energy (in dB) in it we can mimic the process done by the human ear. The most useful filters for modelling instrument bodies have used this technique to lower the filter order but keep the stability of FIR nonrecursive filters. In [13] and in [24] a reduction in filter order of 5 to 10 was obtained using this technique without compromising audible quality. For illustrative purposes, in figure 2.2 a 12th order filter with and without frequency warping is compared to a desired magnitude spectrum.

Recursive filters or Infinite Impulse Response (IIR) filters are also implemented to model the impulse response as a filter, although more careful consideration must be taken into account because of the stability of these kinds of filters.

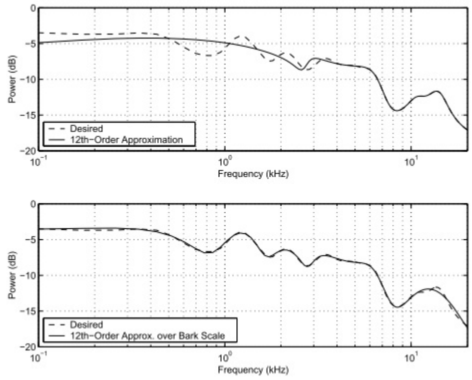

Figure 2.2: Comparisson of 12th-order filter a) without frequency warping b) using the Bark bilinear transform frequency warping, from [24]

2.5 Bowing machines

In the literature we can find different kinds of machines that attempt to produce sound out of a standard or modified violin by controlling bow motion and fingering using different actuators and sensors. These machines fall under three main categories:

- Anthropomorphic robot arms that attempt to mimic the way a human player performs a musical piece on the violin, mainly focusing on expressivity[23].
- Score followers or mechanical playback devices that are fed a sequence of notes in a standard format, and repeat the sequence by bowing and fingering the violin accordingly[11][12].
- Parameter extraction machines, which attempt to play the violin in a repeatable and deterministic manner that would be impossible for a human performer, in order to study the behavior of the violin as a system. [3][17][30].

The use of these machines is not new, since by 1937[18], they were employed to analyze bowing movements, estimate constraints for violin sound based on bowing and particular resonance modes of the violin body. In these areas machines are preferred over humans because of their ability to execute certain movements in a repeated and deterministic fashion; that allows the possibility of examining the violin as a system, minimizing the human factor in violin playing.

One of the key aspects among the different mechanisms is the way they excite the violin. This excitation is made mainly using three different methods.

- Controlling an actual violin bow and moving it across the strings to produce sound.
- Creating an "infinite bow", this is a mechanism that rotates and makes a single point of contact with the violin strings. The speed of the rotation and the force applied at this point excites them to produce sound.
- Exciting the strings without contact, using a form of magnetic oscillator known as the ebow[1].

From the fingering point of view, there are basically two ways to alter the pitch played by the instrument, either by having dedicated actuators fixed on the notes that we want the violin to make, or by sliding and pressing the actuator to the desired position. They depend heavily on the purpose of the machine and the amount of complexity of the pieces that are going to be played.

[1]://www.ebow.com/home.php

Chapter 3

Methodology

3.1 Overview

In this chapter we will explain in detail the methods that we used in order to extract and process the data to obtain the violin body impulse responses; first we will discuss the generation of data, and the specific details of the bowing machine construction responsible for it; then we will discuss the signal processing techniques applied to improve the performance of the deconvolution algorithm and our analysis parameters.

3.2 Violin Playing Machine

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, as mentioned in chapter 2 consists of slowly increasing glissandi covering one octave of the lowest string of the violin. The machine then must perform the following actions:

- Move the bow across the string at a constant rate.
- 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.

3.2.1 Bowing Mechanism

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 strings; this mechanism consists of a rotating disk with an eccentric pivot that slides between a straight guide, as illustrated in figure 3.1, 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 considered to be performed. The equations for the motion of the bow can be derived, using the nomenclature observed in figure 3.1, discarding the radius of the pivot and the width of the guide.

If P is the point where we attach the bow to the mechanism, located at a distance l from the guide in the mechanism, which is at a distance R from the center of the rotating disk, then the displacement of this point can be described by the movement of the pivot in the x-axis, as

$$P = R \cdot cos(\theta) + l \tag{3.1}$$

The velocity can be obtained by taking the time derivative of the displacement function

$$\frac{dP}{dt} = Vp = -R \cdot sin(\theta) \cdot \frac{d\theta}{dt} \Longrightarrow Vp = -R \cdot \omega \cdot sin(\theta) \tag{3.2}$$

where $\frac{d\theta}{dt} = \omega$ is the angular velocity provided by the motor. We can observe that the maximum displacement depends only on the radius of the disk in the mechanism, since the distance l is a constant offset from the center

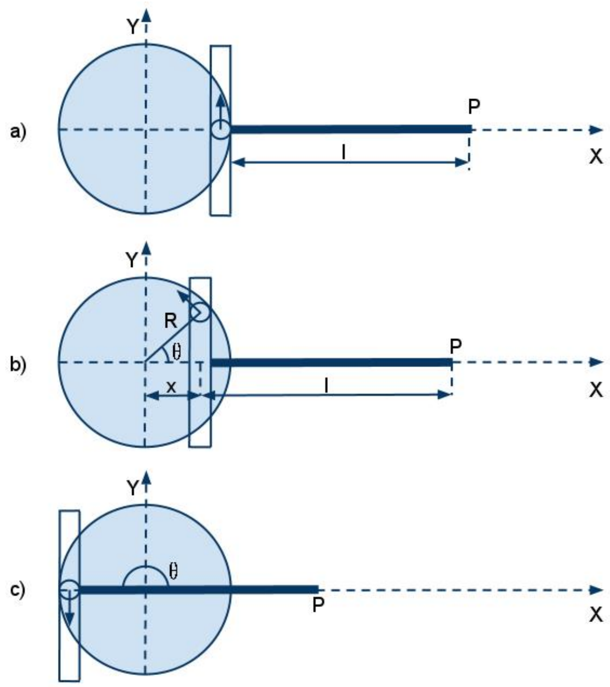

Figure 3.1: Scotch-Yoke mechanism design considerations. The figure shows three different positions of the mechanism: a) Maximum displacement, where $\theta = 0$ b) interemediate point where $\theta > 0 < \frac{\pi}{2}$ and c) Minimum displacement, where $\theta = \pi$.

of the disk. The maximum displacement occurs at $\theta = 0$ and the minimum displacement in $\theta = \pi$. From equation 3.2 we can observe that where these displacement maxima occur, the velocity is 0 and the velocity sign changes. Since it is a sinusoidal displacement function, this behavior is expected.

However, the distance from the center of the disk to the attachment point of the bow heavily influences the torque needed for the motor to move the violin bow, since it is also proportional to it. All of these considerations must be taken into account when designing the mechanism.

In our case we decided to move the bow approximately half of its total dimension, therefore the disk has a radius of 320 mm and that is the maximum displacement that can be obtained, minus the radius of the pivot.

The other main reason why this mechanism was chosen can be seen in equation 3.1; since positive and negative displacements of the bow with respect to its center can be obtained without changing the direction of the motor. This avoids breaking and starting again and dealing with the necessary forces to change the bow direction, but rather obtain a stable oscillation that would be more repeatable for both violins.

3.2.1.1 Bowing motor

To achieve the motion of the whole bowing mechanism, we chose a standard servo motor attached to the center of the disk from the opposite side of the mechanism. A servo motor is just a DC motor coupled to a gear train, a control circuit that make them move to a specified position and some mechanical stops at both ends of the motion range, to prevent it from exceeding it; servo motors are commonly used in robotics and other electronic projects because they offer a high torque with respect to their size and weight, and the interface is very straightforward: Pulse-width modulation signals with a fixed period, and a duty cycle that is proportional to the amount of degrees the servo is desired to rotate. For most RC servo motors, the duty cycles range from 1-2ms and the period is 20ms. This can be observed in figure 3.2.

Since the rotor of the motor is mechanically attached to a potentiometer, it can determine the position of the rotor by means of the control circuit. The error between the current position and the desired position produces the proportional voltage needed for the motor to turn; when this error reaches zero, the motor stops.

Since for our application we were not interested in position control but rather in speed control, certain modifications were done to the servo motor to fill our needs. First the position sensor was removed, and an equivalent set of resistors was placed so that it always produces a signal that corresponds to the center position of the servo (90 °). The mechanical stops were then removed to allow full and continuous rotation as long as the control pulses stay constant; since the control circuit now produces a constant output, then the difference represents a proportional speed and direction in which it has to turn. Pulses that are in the 1-1.5ms range will make the motor turn in a counterclockwise direction, and pulses in the 1.5-2ms range make it move in a clockwise direction.

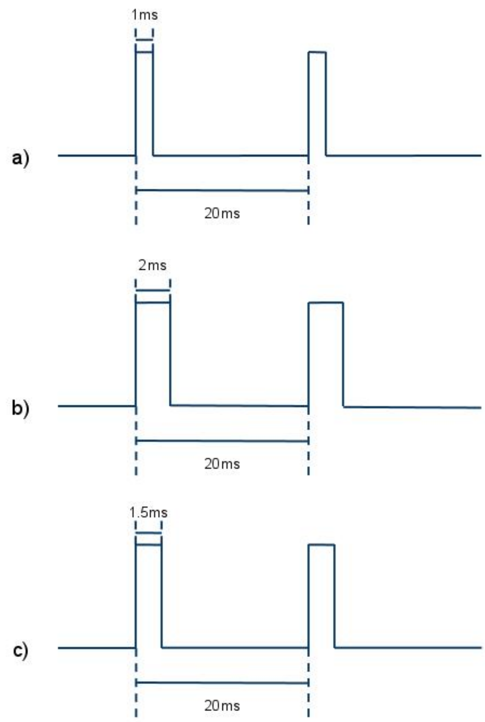

Figure 3.2: PWM input for the servo motor showing three different commands: a) Move to 0 degrees b) Move to 180 degrees and c) Move to 90 degrees

The servo motor chosen for this project is BMS-620MG, its specifications can be found in the manufacturer's website.[1] It was chosen mainly because of its torque of 9.1kg-cm at 4.8V. The no-load speed specifications say it covers 60 ° in 0.15s, thus our maximum angular velocity is 6.9813 rad/s; that would make our maximum horizontal velocity for the bow, as specified in section 3.2.1 of 209.439cm/s. This value will be decreased substantially once the load has been applied to the mechanism, but we can observe that is fast enough to excite the strings of the violin.

[1] http://www.blue-bird-model.com/en/servos/bms-620mg.html

3.2.2 Fingering Mechanism

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 two main parameters to consider in this part of the design are then the maximum distance that the actuator can achieve, called stroke length, and the maximum force that it can push or pull an object, since there is a certain force that the end point of the actuator has to apply to the string to make the desired note on the instrument; other relevant although less significant parameters are the speed of the desired movement and the noise level of the actuator.

The length of one octave in a modern violin is around 150mm depending on the manufacturer, so, the stroke 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. The Firgelli automations mini actuator model FA-MS-8-12-8" was chosen, since it meets the above mentioned specifications, which can be found in table 3.1, from the manufacturer's website[2].

Model	FA-MS-8-12-8"
Input voltage	12 VDC
Load Capacity	8 lbs
Static Load	2 x Max. load capacity
Stroke length	12"
Speed at no load	1.5"/sec
Size	1" x 1.25"
Clevis ends	0.22" diameter
Screw	ACME
Gear ratio	5:1
Duty cycle	20%
Operation temperature range	$-26\,^{\circ}\mathrm{C} \sim 65\,^{\circ}\mathrm{C}$
Limit switch	Built-in (Factory Preset) Not movable
IP Grade	IP54 (dust and splash proof)

Table 3.1: Specifications for the linear actuator

[2] http://www.firgelliauto.com/miniactuator.pdf

3.2.2.1 Fingering motor

In the case of the fingering mechanism, the motor is encapsulated inside the actuator. From the specifications we can observe that the Speed at no load is of 38.1mm/s. We require a continuous displacement that shouldn't exceed 4mm/s so that the glissando is slow enough for our purposes. To accomplish this we will again Supply the motor with a PWM signal instead of a constant voltage, thus turning the actuator for 10% of the time, at full power (12VDC). The reason why this was chosen is that PWM signals are easy to generate from a microcontroller output, and can be synchronized with the bowing mechanism control signals with just one timing reference.

3.2.3 Control Circuit

In order to perform the necessary excitation for the deconvolution process both the bowing and the fingering mechanisms must be controlled in a deterministic fashion, or at least as deterministic as possible, taking into account that certain approximations were considered. This is accomplished by the use of an 8-bit PIC microcontroller 16F690. The specifications for this part can also be found at the manufacturer's website[3]. The microcontroller provides the system timing, proper control signals to the different motors and digital inputs necessary for resetting to the initial conditions of the test.

A diagram of the algorithm performed by the microcontroller can be observed in figure 3.3. When the device is turned on, the machine starts bowing to establish a constant velocity in the bowing arm, and starts a total time counter, that gets increased every $100\mu s$. This is our time resolution for the whole machine, the minimum amount of time we can change timing controls or system outputs; for the first 800ms it performs it at full speed clockwise rotation, to generate a transient in the audio data, then it changes the bowing controls to establish a constant velocity and waits for 15s so that the mechanism behaves steadily. The value for this initial delay was determined empirically by observing how much time the machine takes to reach this steady state, and then providing some extra margin.

Once this is accomplished, the fingering actuator begins moving at an almost constant rate, provided that the alignment of the string and the ac-

[3] http://ww1.microchip.com/downloads/en/DeviceDoc/41262E.pdf

tuator is parallel, and the force doesn't exceed the maximum load capacity provided in the specifications. It is worth mentioning that this maximum load capacity in the linear actuator is also reduced by a certain amount when less than 12VDC is supplied to it, but these specifications were not provided by the manufacturer.

When the time reaches 150s both the bowing and fingering mechanisms are stopped. In this time the whole octave of the violin must be covered.

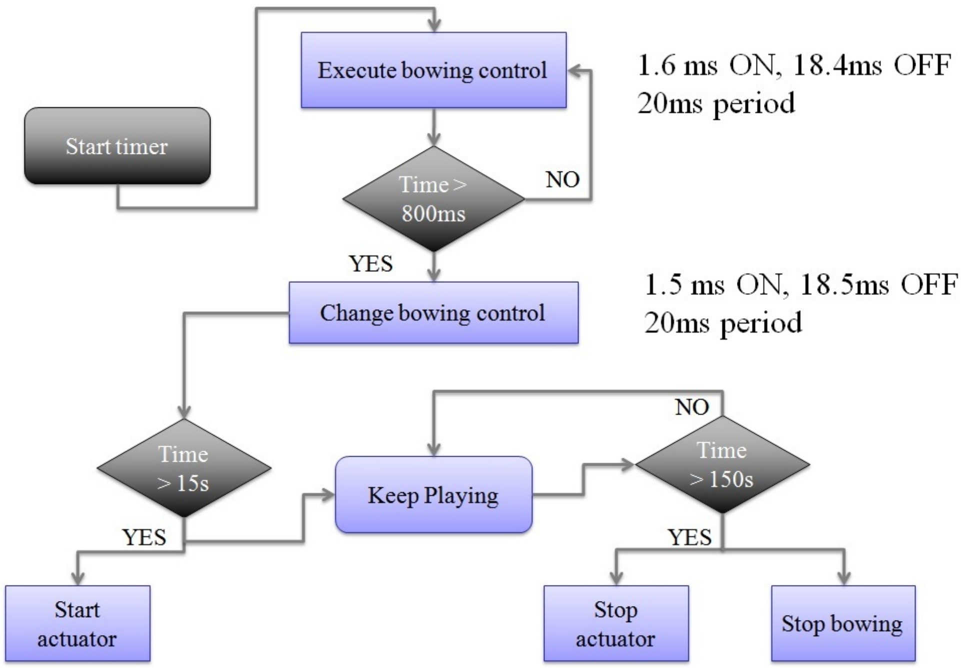

Figure 3.3: PIC16F690 algorithm for controlling the violin playing machine

It is important to mention that the supply voltage for this part, hence the maximum voltage that the microcontroller is able to generate as an output to the different motors is 5VDC. For the linear actuator supply voltage to be achieved, a driver stage consisting of an H-bridge circuit must be placed between the output of the microcontroller and the input of the linear actuator.

The H-bridge is a circuit that enables a certain voltage to be applied to a load, in this case our fingering actuator, with reversible polarity. The integrated circuit L293B allows a maximum current of 1A to be supplied to the motor, at the specified 12VDC. It can also change the polarity across the motor with a logic input; this enables us to move the actuator forwards and backwards.

A diagram showing all the necessary components of the violin playing machine can be seen in figure 3.4. The full schematic diagram can be observed in figure 3.5.

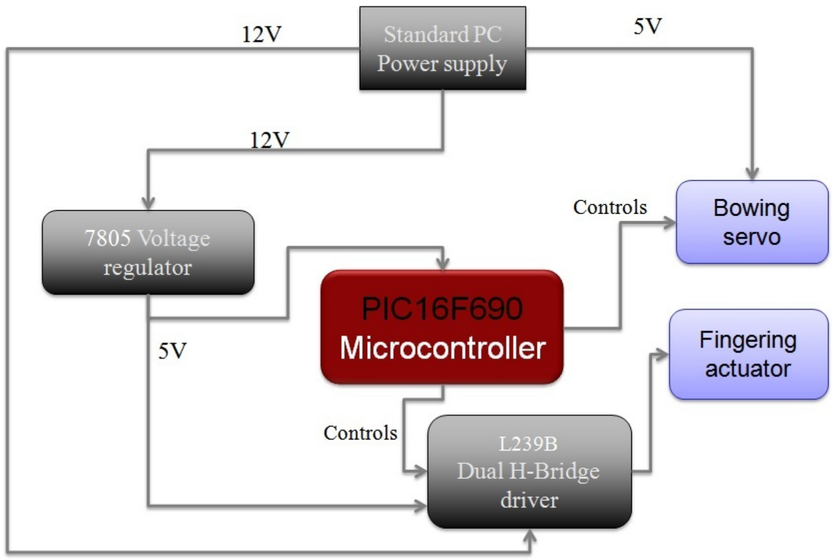

Figure 3.4: Block diagram showing the different components of the violin playing machine

The final construction of the machine as well as the studio recording setup can be seen in figures 3.6, 3.7 and 3.8, with an acoustic violin. The support for the violin was a commercial violin stand fixed to an aluminium profile for stability, since one of the design considerations was that the machine should not occupy a large volume to minimize the sound reflections from the machine to be captured by the microphone. The microphone used for the acoustic violin was a condenser microphone, model AKG-414 in the cardioid pattern configuration; it was positioned it so that the back of the microphone pointed towards the bowing mechanism so that its noise would be also reduced.

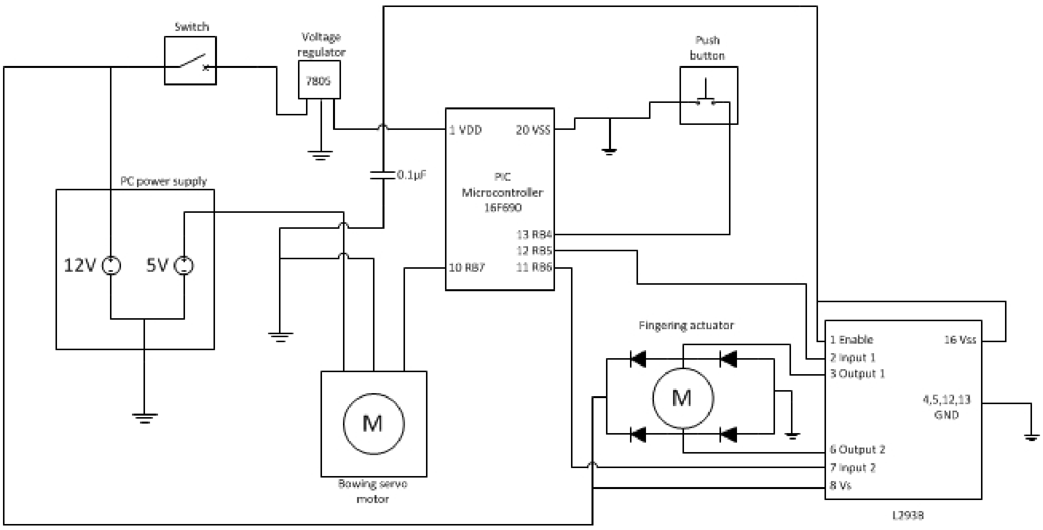

Figure 3.5: Schematic of the violin playing machine

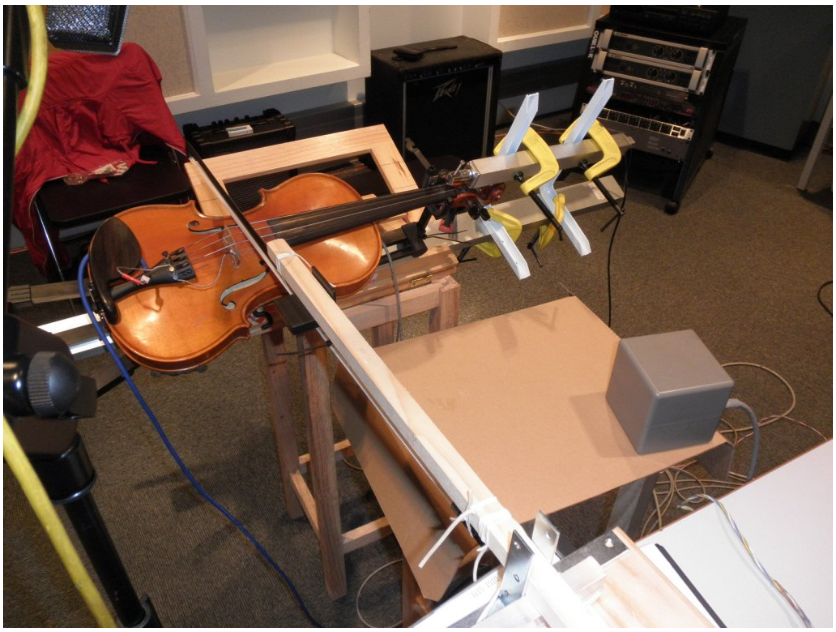

Figure 3.6: Image of the violin playing machine

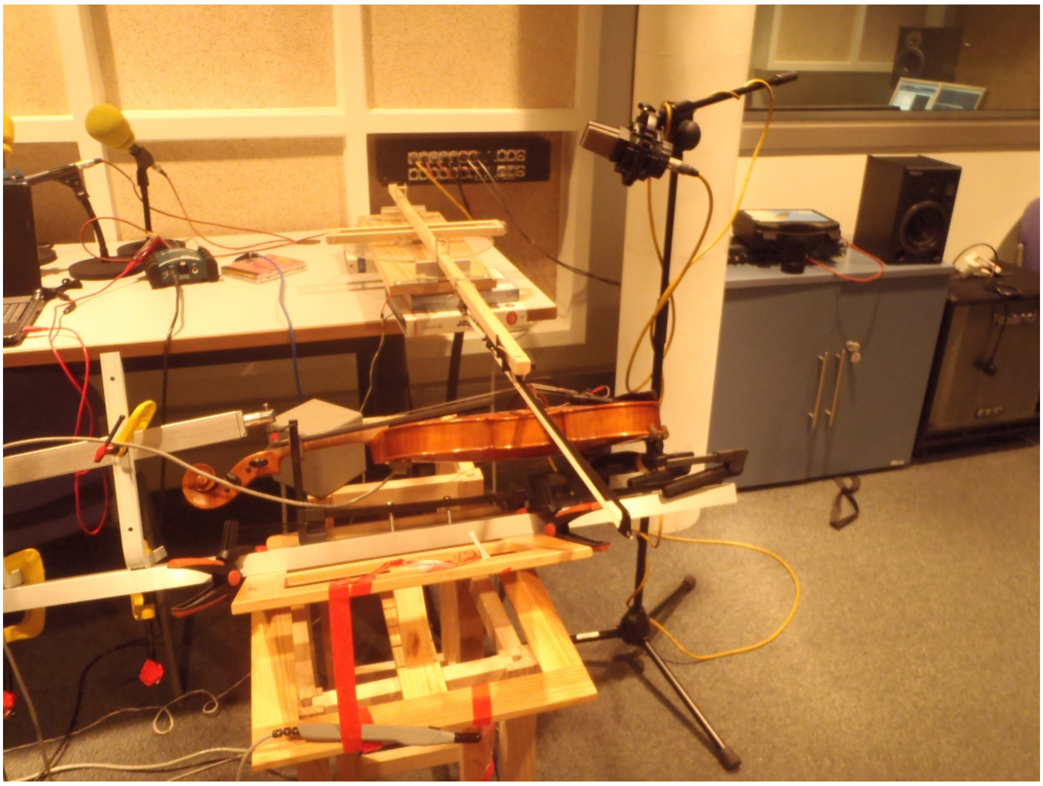

Figure 3.7: Studio recording setup

Figure 3.8: Detail of the fingering mechanism

3.3 Initial Conditions and Repeatability

As mentioned before, the main goal of the violin playing machine is that it must generate the same excitation signal for two different violins, one electric and one acoustic, so we can obtain the transfer function from the excitation at the electric pickup to the measured sound pressure captured by a microphone from the acoustic one. In order to guarantee the initial conditions for these two signals, a sensing system capable of measuring relative bow position, velocity and force based on the Polhemus [4] motion tracking system was used and calibrated according to [16].

By placing certain trackers on the violin and its bow, we can obtain data from the movement of the bow and measure its distance from the bridge, which will be the two main parameters that we observed. We must first place the violins at the same initial conditions, since our machine cannot change bow position in more than one axis. We registered the values for bow position and bow-bridge distance both at the minimum and maximum displacements that were going to be produced by the machine, and did several recordings to measure the difference in setting these initial conditions.

The initial conditions from six different recordings performed in different moments, as measured by the position tracker can be seen in table 3.2. It is important to mention that although there are differences between them, once the machine is installed and calibrated, the initial conditions for both violins can be manually set to be equal. In the current state of the machine this procedure must be performed before any recordings are done, to ensure that the bowing parameters for the glissandi are equal. Table 3.3 shows the initial conditions for the bow-bridge distance.

[4] http://www.polhemus.com/?page=Motion_Liberty

Test Number	Minimum bow position (cm)	Maximum bow position (cm)	Total displacement (cm)
Test 1	44.732	16.740	27.992
Test 2	44.732	16.730	28.002
Test 3	44.726	16.731	27.995
Test 4	43.230	14.532	28.698
Test 5	42.800	15.000	27.800
Test 6	43.190	14.536	28.654

Table 3.2: Initial conditions for six different recordings

Test Number	Minimum bow-bridge distance (cm)	Maximum bow-bridge distance (cm)	Total displacement(cm)
Test 1	1.441	2.396	0.955
Test 2	1.579	2.393	0.814
Test 3	1.479	2.476	0.997
Test 4	0.850	1.367	0.517
Test 5	0.900	1.245	0.345
Test 6	0.938	1.377	0.439

Table 3.3: Initial conditions for six different recordings

3.4 Signal Deconvolution

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 [22] 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. The two main aspects of the sound that need to be preserved in order to compare two different spectra and attribute these changes only to the resonating body of the violin are:

- Every pitch within the covered glissando octave must be present in both recordings.
- The bowing parameters that produce the sound must also be matched.

Therefore before performing the deconvolution we ran a pitch detection algorithm to the audio recordings and computed the bow displacement curve using the position tracker to obtain the relative position of the bow at every time instant. The reason why we only used the bow displacement curve is that, unlike humans, the violin playing machine cannot choose freely which parameter to control; in fact it only controls the speed of the movement, both the distance to the bridge and the force used to press the bow against the strings are determined by the bowing mechanism. We observed that for every bow displacement point in the curve the velocity, the force and the distance to the bridge are all fixed and don't change over time. This can be observed in figure 3.9. For simple comparison purposes we also plotted the gestures of a human performer playing the same task as the machine to further illustrate this point. The human glissandi can be observed in figure 3.10.

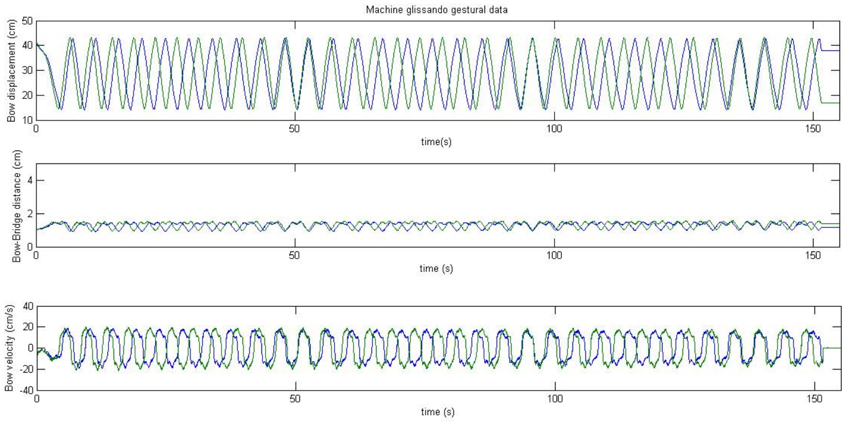

Figure 3.9: Violin playing machine performing two different glissandi: a) Bow displacement curve. b) Bow-bridge distance curve. c) Bow velocity curve

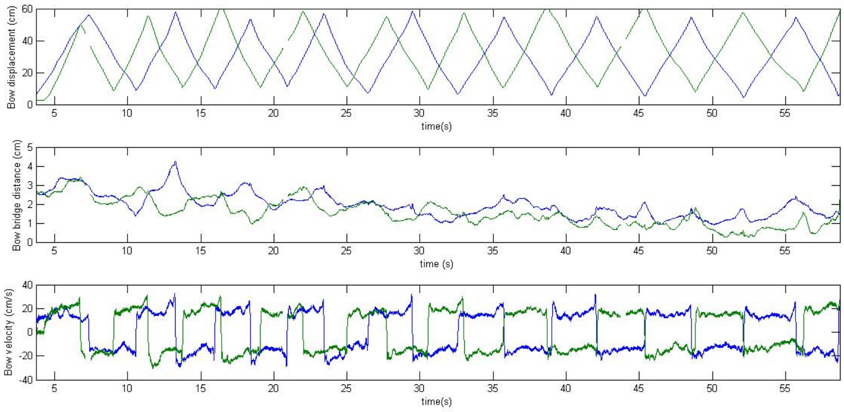

Figure 3.10: Violinist performing two different glissandi: a) Bow displacement curve. b) Bow-bridge distance curve. c) Bow velocity curve

A block diagram of the modified algorithm can be seen in figure 3.11. There is a preprocessing stage where the YIN algorithm [4] and the bow displacement curve are computed. 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 equivalent between different bow strokes, since at the ends of the bow the mechanism starts decreasing and increasing its speed in a non-linear manner, as mentioned in section 3.2.1; this ensures that the bowing gestures are also constant between different recordings so we can attribute the changes in the spectrum to the resonant body of the violin.

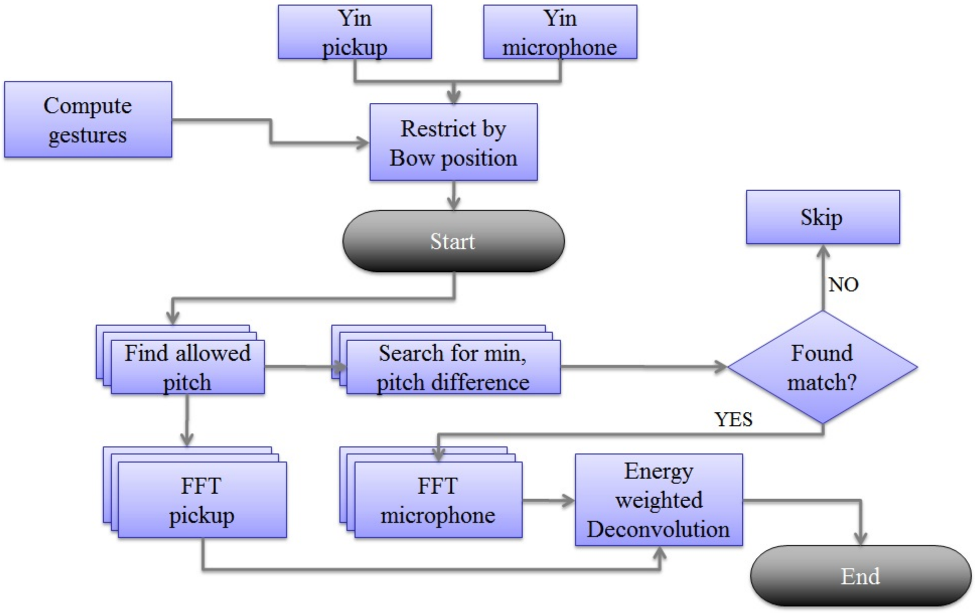

Figure 3.11: Deconvolution algorithm with its modifications

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 $f_{sp} = 240$Hz and also from the output of the YIN algorithm, that produces one pitch sample every 128 samples of audio, so the sampling frequency for the pitch is $f_{sy} = 375$Hz. Since both audio and pitch are already related we performed linear interpolation on the position curve to match the sampling frequency of the pitch curve.

The recording from the pickup is considered to be the reference and the microphone recording the target one, and we don't include the pitches that fall outside 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 same pitch in the other recording, and performs the FFT in the target recording. Finally, it divides the two magnitude spectra in order to perform the deconvolution; 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.

A comparison of one frame containing the magnitude spectrum of the pickup in the electric violin, the magnitude spectrum of the acoustic violin with the matching pitch, and the energy-weighed deconvolution can be seen in figure 3.12. It is important to mention that when dividing the two spectra, a limit is imposed on them to avoid division by zero, so the minimum value for the deconvolution is set to -200dB.

The phase of the frequency response was obtained from the magnitude spectrum in the same way as in [21] by computing the minimum phase transfer function in order to make our impulse response causal.

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. The resulting waveform decays over time, showing the typical impulse response shape; due to our analysis parameters, it has a duration of half a window size (0.683s), although most of the energy is concentrated around the first 100ms of the response. In figure 3.13 we can observe the resulting impulse response.

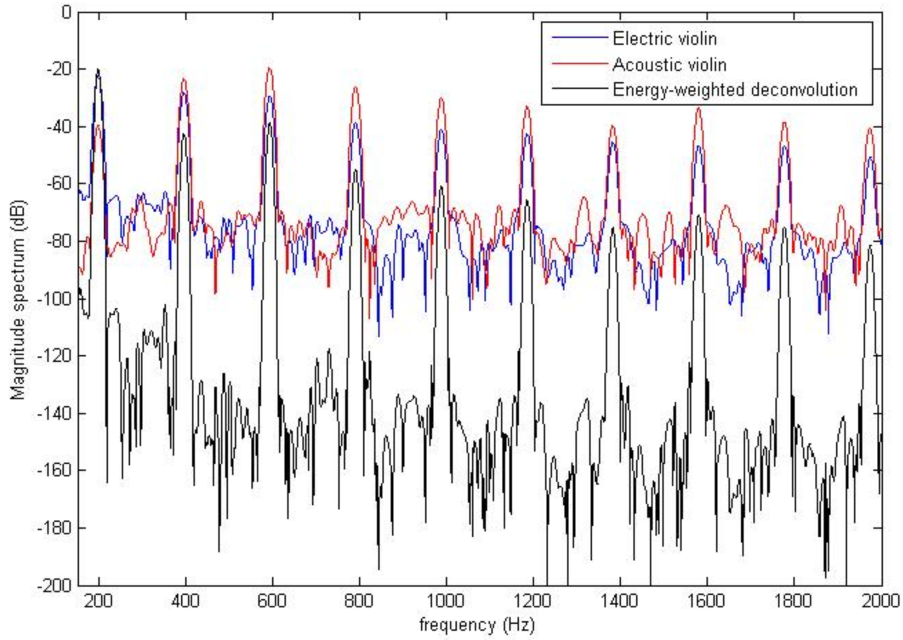

Figure 3.12: Magnitude spectrum and energy weighted deconvolution one frame of the compared pitches and the first 9 harmonics

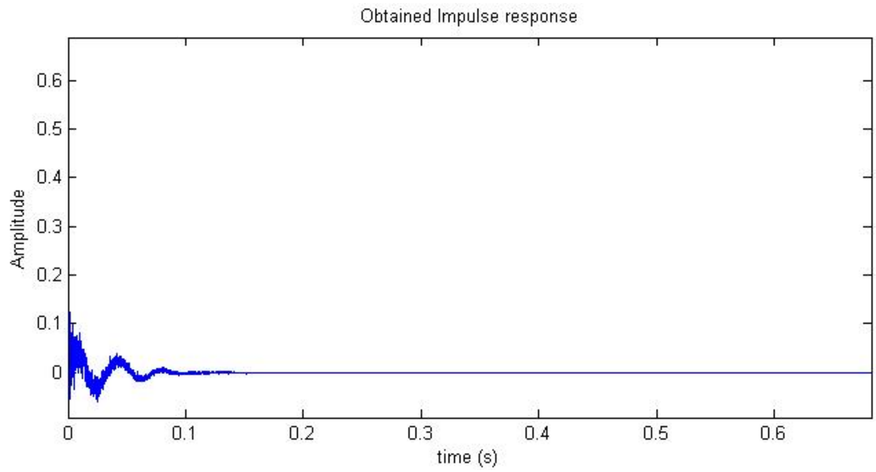

Figure 3.13: Obtained impulse response waveform

3.4.1 Final Modifications

After initial listening tests by convolving an input signal with the impulse response shown in figure 3.13 the resulting waveform showed some over-emphasized frequencies; since the algorithm explained in section 3.4 assumed that we could obtain every possible pitch inside the glissando octave range; however, after performing the bow position restriction in the recordings with both violins we observed that although the speed of the glissandi was indeed performed very slowly, we could not obtain every possible pitch within the glissando octave that also met the the bow restriction condition. In figure 3.14 we can observe some of the audio frames that have a fundamental frequency between 244Hz and 265Hz and are within the bow displacement constraints. It is also worth mentioning that if the algorithm does not find a pitch difference of 0.05Hz between these two recordings, these frames will be also skipped, further reducing the amount of analyzed frames that are effectively used in the computation of the impulse response.

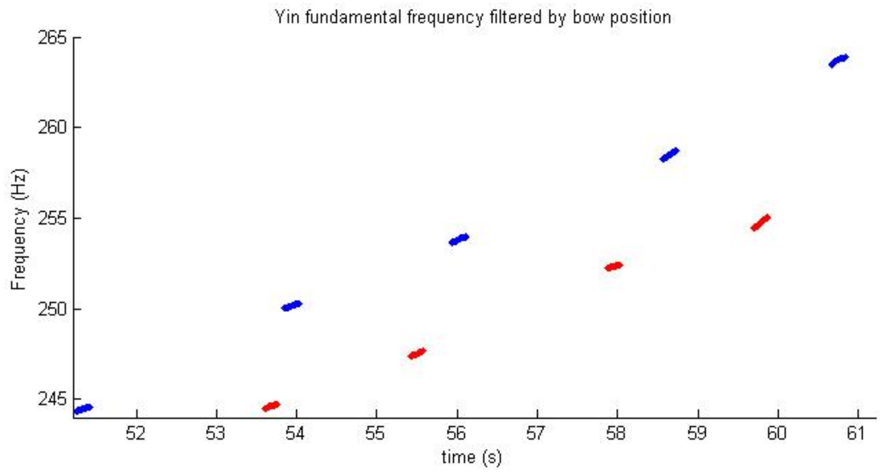

Figure 3.14: Detected fundamental frequency that also meets the bow restriction condition. The graph shows a portion of the octave ranging from 244Hz to 265Hz.

In order to compensate for this effect, the overall speed of the fingering mechanism was decreased to cover the whole octave in 1200s instead of 150s, while keeping the bow movement at the same rate of motion. This allowed us to have much more samples of any specific frequency that met the bow restriction conditions, since the fingering mechanism turns on for 100ms every 3s. This change allowed us to increase the amount of frames that met the bow position restriction and also ensure that the closest frames from the two different recordings were deconvolved, since their difference in fundamental frequency would be smaller than 0.05Hz.

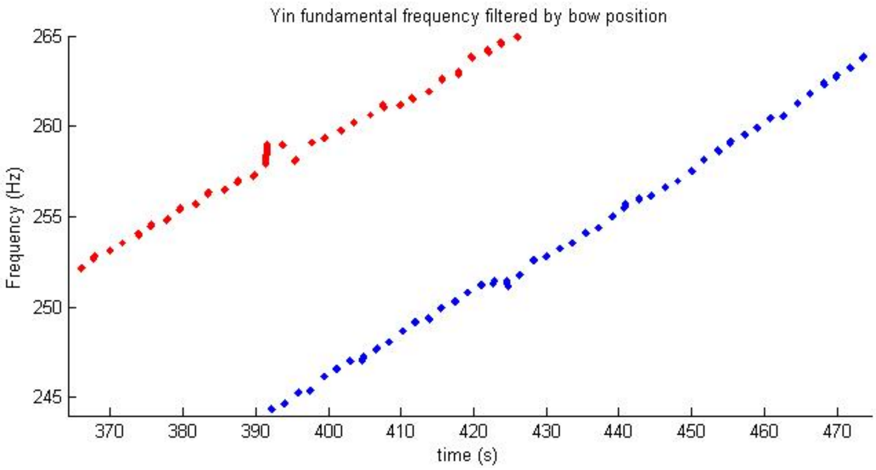

Figure 3.15: Detected fundamental frequency after the modification. For comparison purposes the range is maintained from figure 3.14.

A comparison of both transfer functions can be observed in figure 3.16. For visualization purposes the frequency axis is limited to 5kHz; here we can observe that the resonances are better resolved and smoothed after the modification was implemented. In the lower frequencies the increased number of processed frames and the spacing between them make up for the gaps in the previous transfer function that transform into noise in the time domain signal. Also it is noticeable that the overall gain of the transfer function was reduced, and the overemphasis of certain frequencies was minimized.

After transforming the new transfer function into a time domain impulse response, we observed that it resembles the typical impulse response waveform seen in rooms and other reverberant spaces, much more than the one observed in 3.13. In figure 3.17 the final impulse response can be observed.

This method is heavily dependent on the characteristics of the violins used, so it finds a unique BIR for a specific pickup in the electric violin. This is not the case with the acoustic violin recordings; one could obtain a reference recording of a high quality acoustic violin in a anechoic chamber and use it as the desired sound that will be produced by convolving the electric violin signal with the obtained BIR.

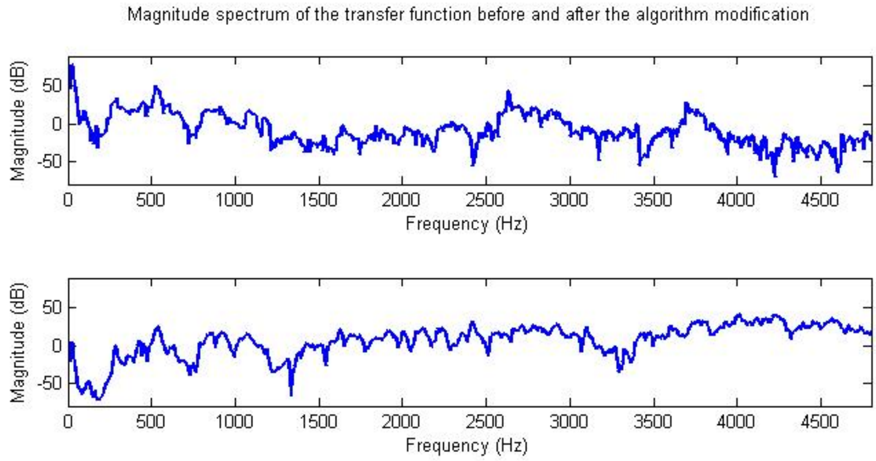

Figure 3.16: Comparison of the obtained transfer function before and after the algorithm modification.

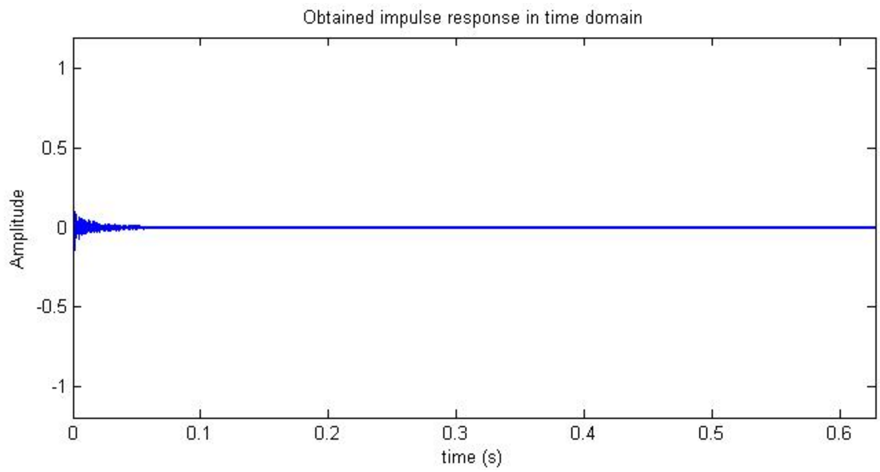

Figure 3.17: Obtained impulse response waveform after modification of the algorithm.

Chapter 4

Discussion and Evaluation of the Results

4.1 Overview

In this chapter the results obtained after the transfer function and its corresponding impulse response will be discussed. By performing a survey with the original sounds and the processed ones we will compare them in quality and in the way the processed sound perceptually approaches the radiated sound coming from an acoustic violin. In the final part of this chapter we will compare the filter approximation to the BIR with the obtained impulse response and its main differences, to see how well it can be emulated by it.

4.2 User Evaluation Survey

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 sound quality differences between the electric and the processed sound, to see if any improvement has been made.

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. The ideal case consists that our processed sound can be marked as acoustic and we obtain higher levels of quality ranking than the sound coming directly from the electric instrument's pickup, but also to measure the difference in quality that is perceived can be a great advantage for further research in this area, specially if the results coming from the violin players match the ones coming from average listeners. The survey form can be found in Appendix A with links to the used test sounds.

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. The reported experience for every test subject can be observed in figure 4.1.

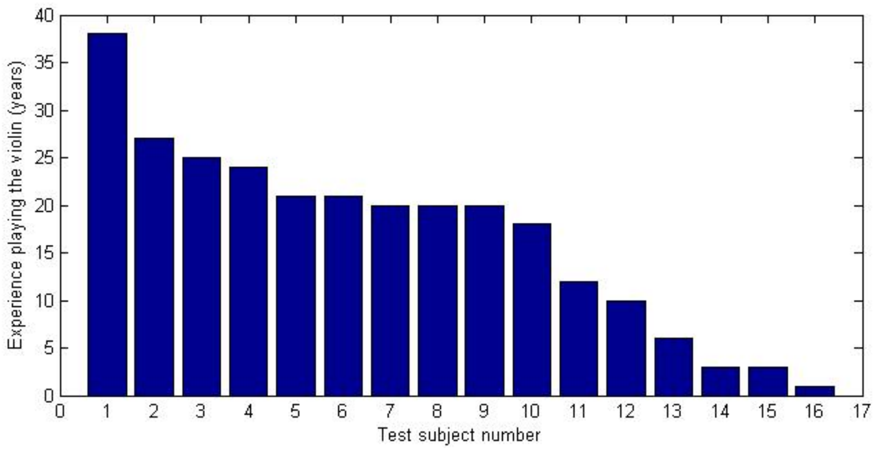

Figure 4.1: Reported experience in violin playing from the survey, in descending order

Overall, the expected results confirmed our expectations, with 67.143% of the subjects stating that our processed sound comes from an acoustic violin, 10% labelling it as an electric violin sound and 22.857% were not able to identify the source of the sound. Compared to the sound coming directly from the pickup of the electric violin, 15.714% stated that it came from an acoustic violin, 60% of the subjects labelled it as an electric violin sound and 24.286% were not able to identify the source.

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 4.1: Comparative results Between violin players and Non-violinists in source identification

From these overall results certain trends can be observed. First of all the majority of the test subjects identified the source of the processed sound as an acoustic violin and the direct sound from the pickup as an electric one; although in the overall results the percentage of subjects who cannot identify the source is comparable, it is still slightly higher in the electric violin sound, which could indicate that people are not usually trained to listen to this sound.

If we separate the subjects into two different groups with respect to their experience with the instrument, a similar trend than the overall results can be found for non violinists. On the contrary, if we only look at the results coming from the violin players, 87.500% of the subjects labelled the processed audio sample as an acoustic violin, 6.250% as an electric violin sound and 6.250% indicated that they couldn't identify the source. In the case of the original electric violin sound 6.250% of them reported it to come from an acoustic violin, 81.250% as an electric and 12.500% couldn't identify the source of the sound. These results show that the majority of the violin players agree in their choices in the questions regarding the source of the sound; it also shows that the level of expertise with the instrument is a determining factor in distinguishing between electric and acoustic violins. In table 4.1 we can compare the results for the two groups.

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. As this survey was filled online we had no control over the quality of the speakers in which the test was performed, but it was recommended to use headphones; the other aspect in which we have no control is if the users are ranking the sound or the execution of the performer. For the processed sound the overall quality ranking 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 most frequent value or the mode of the quality of the processed sound was 8 and for the original sound was 6.

As seen in figure 4.2 the distribution of the overall votes is also more narrow for the processed sound than for the original signal, this maybe mainly because listening to the timbre of the electric violin is less usual. As in the previous case, we separated the population into the trained violinists and the non violin players and we noticed that on average, the trained violinists tend to give less quality for both sounds than the untrained subjects, because, as mentioned before, their criteria for evaluating violin sounds is developed by their practice on different instruments and overall more exposure to violin sounds, and our process heavily depends on the quality of the acoustic violin recordings as well as on the limitations of the method.

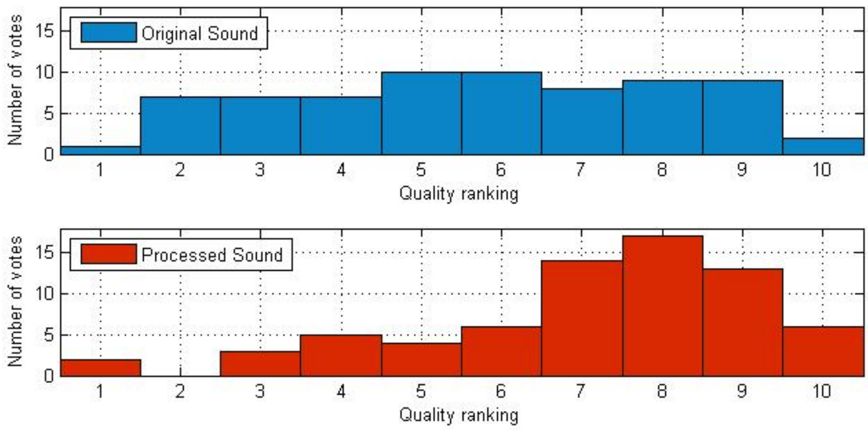

Figure 4.2: Histograms of the user survey quality ranking, both for the original and processed sound

The mean vote for the violin players is 5.563 for the quality of the processed sound and of 4.188 for the original sound of the electric violin, so even if the quality rankings are lower, there is still an improvement in quality ranking after the method is applied. For comparison purposes the histogram of the violin player's answers is shown in figure 4.3; in this case the modes were 5 and 3, respectively.

In table 4.2 the results can be seen separated according to the different

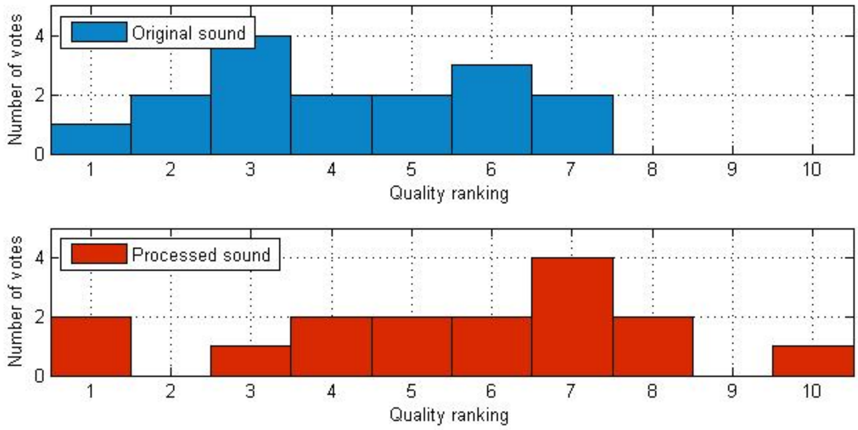

Figure 4.3: Results for the trained violin player subjects

populations. Even though there is a difference in the numerical values we can observe that the increase in quality ranking is almost constant regardless of the violin playing experience.

Sound	Quality Ranking	Violin players	Non-Violinists
Processed Sound	Mean	5.563	7.574
	Standard deviation	2.502	1.766
	Mode	7	8
	Median	6	8
Original Sound	Mean	4.188	6.222
	Standard deviation	1.870	2.328
	Mode	3	9
	Median	4	6

Table 4.2: Comparative results Between violin players and Non-violinists in quality ranking

Finally, in order to verify that the votes were not randomly guessed, we counted both the number of votes that rank our processed sound to be better than the original sound and the number of votes that were considered equal or worse than the original sound. In table 4.3 these results are shown. We obtained a positive difference for 75% of the violinists and 64.81% of the non-violinist populations; these results include the subjects who couldn't identify the source as an acoustic sound but yet an improvement in subjective quality was observed. Assuming that the sample of the population follows a binomial distribution, we can conclude with a confindence of 99.72% that this mean value did not happen by chance but rather confirming that there is a preference for the processed sound.

	Improvement	Violin players	Non-Violinists	Overall
Sound quality difference	Positive	12	35	47
	Equal or negative	4	19	23

Table 4.3: Sound quality improvement votes for violin players and non-violinists

Chapter 5

Conclusions and Future Work

5.1 Contributions

After analyzing the obtained results we can mention that the main contributions of this work are the prototype of a violin playing machine that can be used to obtain the instrument's body impulse response in order to convey more acoustic-like sound coming from an electric violin without the need of a human performer and the methodology that can be followed in order to obtain it, by comparing recordings coming from different instruments and performing spectral domain deconvolution in a non-sequential manner.

We also obtained experimental data coming from average listeners and experienced violin players that may be useful for further research in this field, as well as to support our claims that the sound of the electric violin after performing the method described in this work is improved by making it sound closer to an acoustic violin, which was shown to be preferred in the survey, and can be used to verify further improvements on the method.

5.1.1 Violin Playing Machine

In the aspect of the violin playing machine, certain conclusions were reached. The most significant findings from the outcome of this work are:

- A violin playing machine can be employed in order to obtain a transfer function between electric and acoustic instruments.
- Signal processing techniques can help in overcoming the physical limitations of the machine and still produce convincing results.
- A bowing mechanism limits the bowing motion in a way that a human performer cannot imitate.

However, there is still much room for improvement from this prototype to obtain closely matched excitation signals. The most important modifications that can be performed are:

- Perform closed-loop control to the motors of the machine, to dynamically compensate for the errors caused mainly by frictional losses.
- Provide for controlled adjustments in the positioning of the instrument, to cope with different sizes and shapes while maintaining alignment between them.
- Increase the sound isolation from the motors to the recording microphone without decreasing motor torque.

5.1.2 Method for obtaining violin body impulse responses

In the method described in this work we can also mention certain conclusions after the analysis of the results:

- The modifications made to the previous deconvolution algorithm allow for certain variations in the excitation and response signal to be present without losing too much significant information.
- The use of a position tracker information allowed us to determine the bowing parameters of the machine, and to limit them so that two different spectra coming from different instruments could be regarded as equivalent.

- In comparison with a human performer, the glissandi had to be significantly slower in the case of the violin playing machine; each violin recording in our method took more than 15min to cover the required octave with the necessary resolution to provide good quality results.

- This method is highly dependant on the quality of the acoustic violin recordings, the position, type and orientation of the microphone used and the type of pickup of the electric violin. Thus, for every different combination the process must be repeated to obtain one specific impulse response.

5.2 Future Work

This research has shown interesting results in developing a method that can be used to obtain an impulse response of the resonating body of an acoustic violin; some points that can be addressed to as extensions or complements of this work are the following:

- The violin playing machine is still in the prototype stage. Further refinements made in the hardware and the available control parameters could yield better performance in the obtained body impulse response.

- A real-time implementation of the convolution between the input signal from the electric violin with the impulse response of the violin body could be useful for violinists to encourage them to use their electric instruments in a live performance scenario.

- Even though we presented some quantitative data for the emulation of an acoustic violin sound, more extensive experiments are needed to investigate the perceptual differences between the timbre of the two instruments, and to determine the threshold in which listeners are able to distinguish them.

- Performing reference recordings with the machine in an anechoic chamber with multiple high quality microphones could be very useful, since the electric violins can be recorded without room reverberation or background noise.

- Perform tests with filter approximations of the impulse response which could also be perceptually evaluated to determine the different elements that affect the impulse response to be perceived as an acoustic violin.

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Appendix A

Violin comparison test

The purpose of this test is to compare the quality of two different violin sounds. If you are taking this test on a laptop, please use headphones instead of the laptop speakers when you hear the test sounds. Also try not to have too much background noise.

The form is in English and Spanish, separated by " – ". Please choose your language of preference.

Items with (*) are required fields.

Thank you for your time.

El propósito de esta encuesta es comparar dos sonidos diferentes procedentes de un violín. Si está haciendo la encuesta en un portátil, por favor utilice auriculares y no los altavoces del portátil cuando escuche los sonidos. Evite hacer la encuesta si existe mucho ruido en el ambiente.

La encuesta se encuentra en Inglés y en Castellano, separado por " – ". Utilice el lenguaje de su preferencia.

Los elementos marcados con asterisco (*) son obligatorios.

Gracias por su tiempo.

Are you a violin player? – ¿Es Ud. violinista? *

Yes – Sí
No – No

How many years have you been playing the violin? – ¿Cuántos años tiene tocando el Violín? If you answered no to the previous question, feel free to skip this one – Si respondió no a la pregunta anterior, por favor salte esta pregunta

Answer :

Please copy this link and paste it into a new browser window – Por favor copie el siguiente enlace y colóquelo en una ventana nueva de su navegador

`http://soundcloud.com/jinkoandres/violin1`

Listen to the audio file and rate the quality of the sound. You can repeat the sound as many times as you want – Escuche el archivo e indique la calidad del sonido. Puede repetir el sonido tantas veces como desee

1. Very Bad – Muy Mala.

10 Excellent – Excelente.

Can you tell if this sound is coming from an electric or an acoustic violin? – ¿Puede decir de que instrumento proviene este sonido?
*
Please choose only one – Por favor seleccione una sola opción

1. Acoustic Violin – Violín Acústico.
2. Electric Violin – Violín Eléctrico.
3. I can't tell – No puedo diferenciarlo.

4. Neither of the two – Ninguno de los anteriores.

Now copy this link and paste it into a new browser window – A continuación copie el siguiente enlace y colóquelo en una ventana nueva de su navegador

http://soundcloud.com/jinkoandres/violin2

Please rate the quality of the second sound. Again, you can listen to the sound as many times as you want – Indique la calidad del segundo sonido. Nuevamente, el sonido puede ser escuchado tantas veces como desee *

1. Very Bad – Muy Mala.

10 Excellent – Excelente.

Can you tell if this sound is coming from an electric or an acoustic violin? – ¿Puede decir de que instrumento proviene este sonido? *
Please choose only one – Por favor seleccione una sola opción

1. Acoustic Violin – Violín Acústico.
2. Electric Violin – Violín Eléctrico.
3. I can't tell – No puedo diferenciarlo.
4. Neither of the two – Ninguno de los anteriores.

Thank you for your time, once you are happy with your choices, click submit – Gracias por su tiempo. Una vez que este satisfecho con sus opciones, presione el botón para terminar.