Towards complete physical modelling synthesis of performance characteristics in the violin.

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Abstract. *This paper discusses the need for total performance capabilities of a playable physically modeled violin by means of precise left-hand finger interaction within the system. The paper describes the design of a violin physical model, in which the computational need for adjacent string fingering performance of playing is minimized. The main focus of this paper is on the principles of developing a convincing physical model for the complete tonal range of sound synthesis of the violin. The realistic tonal beaviour of modelled strings compared to adjacent strings of a real instrument, and multiple-stopping performance techniques (e.g. when a 4-pitch chord is played using "quadruple-stop"). This enables the interaction of the string with the left-hand fingering. The artistic performance using physical modelling synthesis is shown to be feasible by using only two string models. The system also considers symphatetic coupling between different parts of modelled instruments in connection to expressive performance of the violin.*

1. Introduction

The playing techniques of bowed string instruments have remained almost unchanged for the past few centuries. There are certain rules and expressive notations for every playable technique. In this paper, the left-hand fingering of chords is investigated by means of physical modelling synthesis of violin playing. The principal focus is on various *"stopping"* techniques, commonly used in string music (Adler 1989). This places certain demands for the simultaneous act of both hands of the player, i.e. synchronization of finger and bow techniques.

Physical modeling of musical instruments makes it possible to simulate various aspects of sound generation in considerable detaile (McIntyre, Schumacher, Woodhouse 1983). In the field of violin physical modelling, a great deal of work has been done by McIntyre, Schumacher and Woodhouse (McIntyre, Woodhouse 1979; Schumacher 1979; (see also the excellent collection by Hutchins (Hutchins 1997))). The mechanical and dynamic principles may be seen to act on both acoustics and human-interaction in playing the instrument.

The basis of the bowed-string instrument model herein is on digital waveguide techniques (Smith 1993). A digital waveguide string is excited by the friction of bow and the actual length of the string is altered in accordance with the left-hand fingering model. The interaction within the strings consists of left-hand fingering damping, bow-string interaction, and the losses in travelling wave propagation. Another key elements, is the resonating body, which is also studied and modelled with satisfactory restuls (Hutchins 1997; Holm, Välimäki 2000). Other notable losses and air-, body-, and string-couplings occurring to the system are also considered.

2. Violin Fingering

The notes played simultaneously on adjacent strings are called double-, triple- and quadruple-stops. In live performance, notes are either played on open strings *or* pitches are stopped. The total range of possible notes played by violin is shown in Fig.1. The bow draws mainly across two of the strings at the any given time. With triple-stops being greater, bow pressure has to be excerted on the middle string of the three or four sounded so that all can sound at the same time, though this may prove technically complicated in some cases. When performing quads, the bow is only capable of sustaining two simultaneous pitches, i.e. the quadruple-stop must be arpeggiated. For attacks, the notes are accomplished with a greater dynamic (*f* or *mf*). The shape of the bow has changed since its first inception. A significant difference is the inward curve of the wood in the modern bow (Adler 1989). This has affects the attack of the real bowing. Some notation examples of possible and impossible stopping techniques by means of tonal range is shown in Fig. 2.

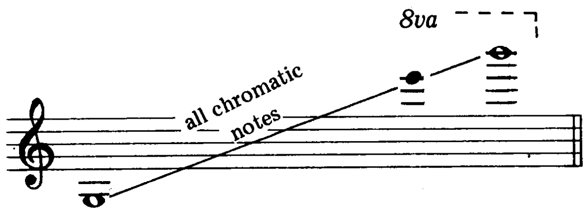

Figure 1. The total playable range of the violin (Adler 1989).

* Both pitches are on the same string.

Figure 2. Some examples of chords playable on the violin with different stopping techniques. Few fingerings are shown to be impossible (Adler 1989).

3. Violin Model

The digital waveguides acts as the main building blocks of the string within a modelled instrument (Smith 1993). The main elements and couplings evident in bowed string instruments are shown in Fig. 3. The physical model used in this work consists of the digital waveguide strings in a real violin manner, so that the physical properties of a real string have been implemented in each of the string models. These properties include the various wave impedances (transverse and torsional) of the strings (McIntyre, Woodhouse 1979; Schumacher 1979; McIntyre, Schumacher, Woodhouse 1983; Hutchins 1997). The body coupled strings may also interact with each other through *"so called"* symphatetic vibrations. The couplings of stringed musical instruments is discussed in detail by Smith (Smith 2001). The violin body is a very intricate resonator and is a fundamental factor in the production of the rich sound expected by the listener. This may be implemented by a resonator filter bank simulating the main modes of resonance together with a conventional filter of varying size for the remainder of the body. Also multi-rate properties may be added to the body's filter design. The violin body implementation is discussed in greater detail in (Holm, Välimäki 2000).

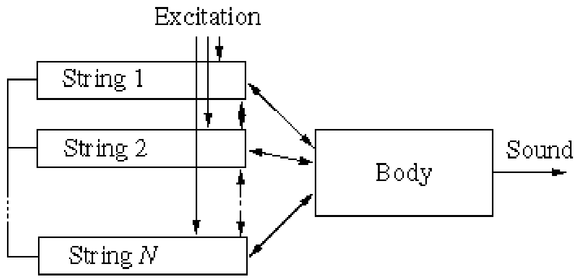

Figure 3. Basic block model for a bowed string instrument. Depicting the excitation of more than one string.

The physical model of the bow-string interaction has already been studied and sucessfully modelled (McIntyre, Woodhouse 1979; Schumacher 1979; McIntyre, Schumacher, Woodhouse 1983; Hutchins 1997), though the problem of taking the width of the bow properly into account is still an undefeated challenge. Some encouraging simulations have been achieved in (Pitteroff, Woodhouse 1998). In this paper only single-point excitation is used including string dependent frictional characteristics.

In this paper a two sided digital waveguide model is used, where the left-hand fingering is modeled with a separate scattering junction. With two-sided waveguide strings, the reasonable behaviour of wave propagation can be obtained when used with present scattering schemes. The damping of finger pressure may be thought as being quite similar for every note pressed, but is implemented separately, since the variety of the performance maintains its richness when tones are parameterized as individual tones. Also, the frequency dependent damping on higher positions of the fingerboard may be added. The finger-damping is implemented with fractional delays (Laakso, Välimäki, Karjalainen, Laine 1994) applied for tuning. Dampening effects, as they occur along a real string are lumped (Fig.4) as parameterized filters, e.g. in bridge filter.

The velocity and force is fed into the nonlinear friction scattering junction as common velocity but separate force, since the pressure during chord playing varies when moving from one stop to another within the modelled strings (Fig.4). The fractional delay interpolation and deinterpolation (Laakso, Välimäki, Karjalainen, Laine 1994) methods are used for fine-positioning of the excitation feed and left-hand fingering on the fingerboard. The other parts of the violin physical model are described in the caption of Fig.4.

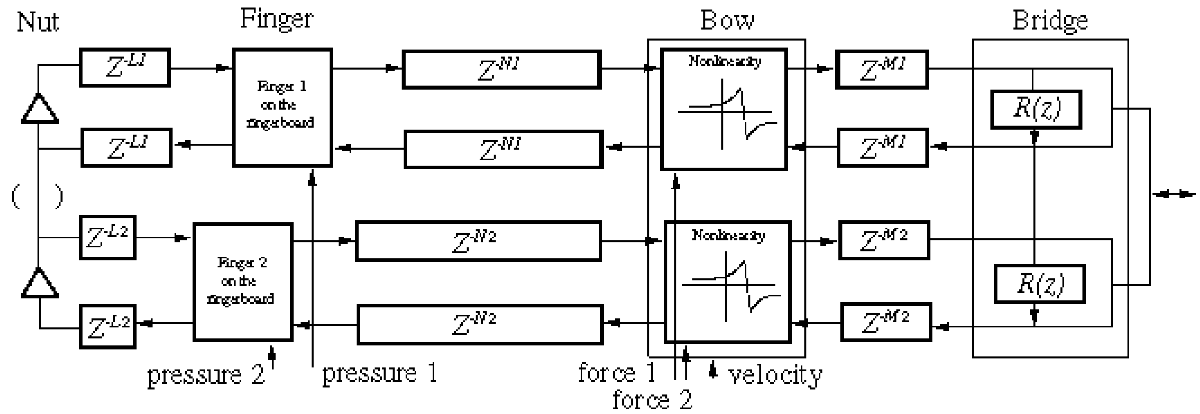

Figure 4. Complete simulation scheme of a waveguide signal processing model for a violin (or a bowed string) used here. The two waveguide string models are parted by variable position scattering junctions for left-hand fingering and the nonlinear bow-string interaction. The string models are parted (Z^{-LN}, Z^{-NN}, Z^{-MN}, N=1,2,3,4) by scattering junctions mentioned. Left hand finger pressures, forces and common velocity distribution are labelled. Connections for couplings are also depicted in the figure.

3.1. Left-hand fingering

Information relating to left-hand fingering position may be included in the synthesis model to achieve a more natural sound. This is important when considering the possibility of playing the same note on strings of different compound properties, and the resulting timbral consequences.

Since the occurrence of open string notes in chords found in violin music is relatively rare (depending on the composer and scale used), compared to the total playabe range, one may heavily rely on the need for only two string models used as each consequent pair (quadruple-stop exhibiting the greatest need, Fig.7). This may be seen as being feasible, since only the vibration of a note played on open strings may be sustained even a short period longer compared to a stopped note, whose vibration will be damped straight after the finger is raised from the board, e.g. the fingering needed for next chord. Note examples of the chords of different stoppings are shown in Figs. 5-7. The diminished occurrence of open string usage is clearly pointed out by means of total tonal range.

As evident, from common knowledge of violin playing as well as the violin literature (e.g. (Adler 1989)), all string triple- and quadruple-stops (Figs. 6 and 7) must be rolled. The modelling of the total performance of chord playing can be shown to be dealt with in the method described above. The symphatetic couplings during each playing case are considered in modelling.

Figure 5. Example of double-stops played on varying pairs of fingering. Every string is used. (Adler 1989)

Figure 6. Example of triple-stops played on varying combinations of fingerings (Adler 1989).

Figure 7. Example of quadruple-stops played on varying combinations of fingerings (Adler 1989).

One intriguing possibility when creating an artificial instrument model as used here, is the opportunity to create a completely new type of instrument. For instance, the fingering performance with the model introduced here opens the potential to play figures that are inconcievable on the original instrument, as depicted in Fig. 2. When a tonally more soft and warm low-string sound is required, the complete chord may be played by string instruments with the violin's E-string characteristic parameterization.

3.2. Right-hand bowing

Bowing techniques may be divided into two sub-sections: *on-the-string-* and *off-the-string* bowings, including the most common bowing styles. In chord playing, a frequently used technique is *détaché* (separate) bowing style. For very heavy and vigorous expression, a series of down-bows may be used. In chord playing a *martelé* (*marcato*) approach is very often used. In bowing it indicates a fast, well-articulated, heavy separate stroke, resembling a sforzando, or pressed accent. Parameterization of one cycle of certain style is shown in Fig.8. The expressive performance of chord in violin music is evident.

In the bow physical model force (bow pressure) and velocity parameters, amongst others, can be fed into the system (Fig.8). This allows the control of the actual bowing technique used. When added into the string model, the total performance on this point is obtained. Some study of bowing performance has been conducted by means of bowing style (Mathews, Pierce 1989; Takala, Hiipakka, Laurson, Välimäki 2000).

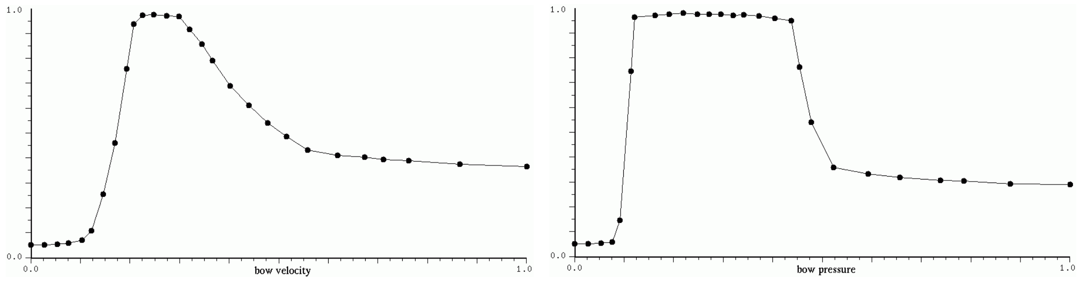

Figure 8. Envelopes of bow force and velocity in martelé (marcato) bowing style of one bowing period as function of time. The figure shows the general form of these parameters for physical modelling synthesis.

4. Results and Conclusion

An extended physical model of the violin is created and tested with various implementations of string models by means of playing performance, especially for the differing left-hand stopping techniques. Left-hand fingering is implemented as separate varying scattering junction for each note played on adjacent strings. Appropriate controls for bow force and velocity are included so as to simulate each of the cases. Computational needs must be considered and balanced against the efficiency of computation. Even the quadruple-stop technique may be found to be tolerable by just using two string modelling elements with varying parameterization, since it corresponds to the behaviour of the real violin performance in certain cases. The model used here has been created by means of investigating the left-hand fingering technique. Finally, it should be stated that the prime objective of this study was not the simulated production of a "perfect" violin sound but rather the demonstration of multiple stopping performance capabilities within artificial violin models.

The complete simulation of the physical model of violin discussed here is programmed by using Matlab in Unix platform. The usage of Matlab is preferred for more analytical implementation, since the vector and matrix operations, with e.g. two sided waveguide, filtering and fractional delays, can be found more lucid and more simple. The variables and interaction parameters for the system are distributed vectors as function of time (e.g. velocity and pressure of the bow) or case dependent coefficients (bowing location, finger locations), so that changes within the system are indicated. Some sound examples are presented. The real-time implementation (C++) is attached in the future plans. See the website (Holm 2001) for more information and examples about the virtual violin project of the author.

5. Acknowledgments

This work is part of post-graduate studies by J.-M. Holm in association with Pythagoras Graduate School of Sound and Music Research. Author would also like to thank Dr. Vesa Välimäki, Helsinki University of Technology, for fruitful discussions and help at the start of authors research on violin.

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