An Expressive Synthesis Model for Bowed String Instruments

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Abstract

The paper describes our recently developed model of physical sound generation and playing of bowed string instruments. We apply the waveguide string model and the friction bow-string interaction model for sound synthesis, parameterization of bowing styles, and a special notation for interpretation and expressive playing. Previous results are developed further in three aspects: interaction of the string with the left hand fingers, physically-based modeling of the bow motion, and the notational expression of bowing styles in addition to MIDI data. In order to faithfully reproduce both stationary and transient vibrations, we use a digital waveguide model for sound synthesis. Unlike previous models of bowed strings, we apply at the fingerboard a second scattering junction with moving position and varying impedance. This allows more realistic pitch transitions in legato playing and position changes, as well as production of flautato sounds and other dampening effects by the left hand finger. We simulate the various bowing styles (detache, martele, staccato, spiccato, salutato, etc.) by modulating the bow force and velocity with different envelopes, generated dynamically by a simple physical model of the bow, that partly takes into account the elasticity of the bow and dynamics of the player’s right hand.

1 Introduction

Bowed string instruments have for long been a great undefeated challenge to the research and development of sound synthesis algorithms. One reason for the difficulty is that their sound is continuously affected by the bow motion, and the resulting time-varying articulation and intonation are characteristic to the instrument. This is why simple sampling or abstract FM techniques have not been successful. Physical modeling with appropriate control devices have shown promise with woodwind instruments, but bowed strings are still an open area for further research.

Basically the physics of vibrating strings and the bow-string interaction, as well as the violin body as a resonating radiator, are quite well studied (see the excellent article collection by Hutchins [1997] for reference). A signal processing solution, as presented by Smith [1986], is based on a digital waveguide string excited by the bow friction and followed by the body resonator (fig.1).

To enhance efficiency for real-time applications, a commuted model has been used for plucked instruments, such that the computationally expensive resonating filter has been replaced by the body’s impulse response as an input signal to the string model. For bowed strings this has been applied as a dense train of input pulses convoluted with the body response [Jaffe and Smith 1995]. However, the approach is problematic, since it does not account for non-linear transient effects at the bow-string junction.

Fig.1. System overview with main control parameters.
Fig. 2. The friction model: force exerted to the string vs. relative velocity of string and the bow.

A physical model of the bow interaction is based on the alternating sticking and slipping of string with respect to the bow hairs. This follows roughly the curve of figure 2 [McIntyre and Woodhouse 1979]. This model has recently been refined by Serafin et al. [1999a]. With friction applied, the signal processing scheme becomes as in [Smith 1999], from which our model is developed by adding the finger as another scattering junction (fig. 3). Playing this model is effectively the control of three parameters: velocity and force of the bow, and lengths of the waveguides (with fractional delays applied for tuning).

From the musical point of view, however, we should not only model the violin but the violinist as well [Weinreich 1993]. One approach is to make interactive controllers with enough degrees of freedom [Serafin et al. 1999b]. Our purpose of research, however, is to make an automatic system – partly for understanding the phenomenon of violin playing, partly for applications with virtual musicians.

Various bowing styles used for different articulations can be represented as parametric models. The most direct physical parameters are the bow velocity and force against the string. Their variation in time can be represented as characteristic envelopes for each bowing style [Jaffe and Smith 1993]. Moreover, these envelopes can be produced by higher level control functions taking their input from expressive annotations attached to the music, and fed to the synthesis program along with MIDI commands. This approach was previously used for guitar [Laurson et al. 1999] and is here reworked for instruments of the violin family.

2 Extended violin model

In order to faithfully reproduce special effects of violin playing, we extended the previous model in two ways: first with a model of left-hand finger effects, and second with time-dependent control functions for different bowing styles. Both are necessary since transitions and other spectral changes are the most important features determining the character of an instrument.

A finger model is needed, because the mere change of string length alone does not create appropriate note transitions in legato play. Even more important it is for flautato sounds, played by slightly touching the string at a node of vibration, thus dampening the basic frequency and leaving only higher harmonics.

Physically the finger acts like a damper attached to the vibrating string. In signal processing terms, it is implemented as yet another scattering junction with variable position and coupling to the waveguide (fig. 3), similarly to the modeling of finger holes in woodwinds [Välimäki et al. 1993].

For defining appropriate playing parameters for each note, we applied the Expressive Notation Package (ENP) originally developed for guitar [Laurson et al. 1999], and modified it to accommodate different bowing styles. What each style means in terms of physical control parameters, was inferred partly from recorded sound examples, partly from the educational knowledge of how the player's muscles are used and how the bow moves while playing [Garam 1972, for example]. As result, we get envelopes of control parameters, similarly to that by Jaffe and Smith [1995].

Fig. 3. Bowed string as a waveguide signal processing scheme.
Below are listed some of the most important bowing styles, with explanations of how they are produced. Respectively, the diagrams in figure 5 show envelopes for bow force and velocity. The envelopes were derived from a physical mass-spring-damper model of the bow (fig.4), which produces elastic bouncing of bow against the string. Figure 6 demonstrates transition effects due to the interaction of fingers with the string.

- **detache** — The bow moves steadily back and forth with relatively constant force. While changing direction, the bow velocity quickly (but not abruptly) goes to zero and then accelerates again.

- **martele** — The bow starts from rest with quite strong force, which is quickly released after the bow starts to move. At the same time, velocity accelerates towards constant.

- **staccato** — Is played by a rotating wrist movement as a series of notes drawn in the same direction. Thus the bow velocity and force roughly follow a cycloid curve, synchronized as in the diagram.

- **saltato** — This style is like a fast detache, utilizing natural resonance of the bow. Like in staccato, the periodic force and alternating velocity are synchronized to make an attack force before the velocity starts to grow.

- **spiccato** — This is a bouncing bow style, like detache but letting the string to vibrate freely after each note. Roughly the force and velocity curves are like clipped sine curves.

- **ricoche and arpeggio** — Another bouncing style, utilizing the bow resonance, and making a series of notes in each direction. Effectively, the bow force behaves like a bouncing ball. Arpeggio is similar, but changing string for each note.

- **pizzicato** — Plucking the string with finger can be modeled basically as an impulse excitation. Due to the softness of the finger, however, a gradually releasing damping effect is applied at the finger position [Cuzzucoli and Lombardo 1999].

Fig.4. Physical model of the bow motion.

Fig.5. Envelopes of force and velocity in various bowing styles, along with resulting sounds (above: staccato, below: ricoche).

3 Implementation and results

Our first implementation was a waveguide mesh which, although computationally not optimal, allows easy experimentation of various physical effects. With this model we tuned the material and control parameters to correspond with experimentally recorded data.

From this model, we turned on to the more efficient delay-line model, developing parameterized filters that lump together all dampening effects along the string. Fine-tuning the finger and bow positions was realized by fractional-delay filters [Laakso et al 1996].
As our main interest was in modeling the articulation, and not to make a perfect violin, we used a simple feedback delay network for the instrument body, similar to those used for room reverberation [Jot 1992].

Fig.6. Transition signals generated by the model (above: evolution from open string to flautato, below: beginning of pizzicato, showing slight frictional effect of the finger).

Conclusions

We have developed extensions to previous violin models with promising audible results. Our additions include the left hand finger as another scattering junction to the waveguide, and procedural controls for the bow force and velocity to simulate different bowing styles. These controls are partly physical (bow elasticity) and partly based on our expressive notation package.

The extended model brings better understanding of the mechanisms of articulation and intonation of bowed strings. The results can be useful at developing more natural high level controls for physically based synthesizers. Also the model can be utilized as an automated virtual musician in rehearsals, or performing passages impossible for a human player.

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References


