EXPRESSIVE CONTROLLERS FOR BOWED STRING PHYSICAL MODELS.

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ABSTRACT

In this paper we propose different approaches to control a real-time physical model of a bowed string instrument. Starting from a commercially available device, we show how to improve the gestural control of the model.

1. INTRODUCTION

Real-time physical models of musical instruments become interesting when played using expressive controllers that allow for exploration of all the sonorities and nuances that the models can create.

In this paper we examine the behavior of different controllers when used to drive a real-time waveguide physical model of a bowed string instrument.

The physical model is driven mainly by the parameters that a bowed string player can control with his right hand i.e. bow velocity, bow position and bow force, plus pitch variations obtained by changing the length of the delay lines in the digital waveguide simulation of the strings.

We furthermore extended the model in order to create sonorities that cannot be obtained with a real instrument. This allows us to simultaneously increase the number of parameters that the controller is able to manipulate, and to create interesting sonorities, especially in the case of the Metasaxophone, as described in details below.

2. CONTROLLING THE MODEL USING A GRAPHICAL TABLET

Our first attempt to drive the model in real-time consisted of using a graphical tablet provided by Wacom. The tablet has some nice properties, like the fact that the pen provided has roughly the same degrees of freedom as the bow in contact with the string. The tablet, in fact, is able to detect the horizontal and vertical position of the pen, which we mapped to bow velocity and position respectively, and the pressure of the pen which we mapped to bow pressure. It is also possible to use two transducers at the same time on the tablet, which also allowed us to control the left hand of the player, responsible mainly of pitch changes, vibrato, and glissando. The pen provided with the tablet, however, lacks an important characteristic of expressive musical controllers, i.e. force feedback. As shown in [3], force feedback controllers greatly increase playability of virtual instruments such as bowed strings.

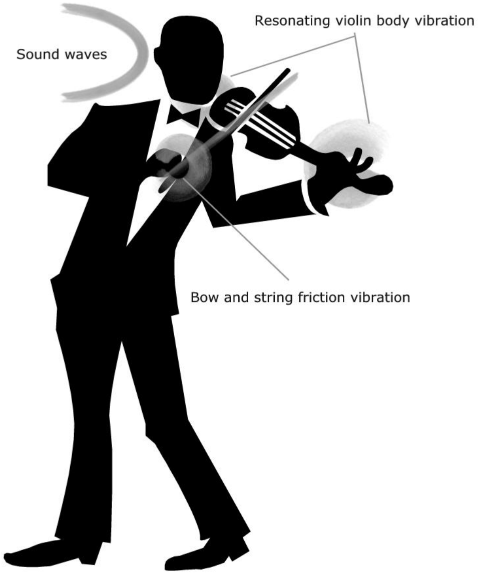

Figure 1: Auditory and tactile feedback for a violinist.

3. A HAPTIC FEEDBACK CONTROLLER FOR THE VIRTUAL BOWED STRING

The term ”haptic,” derived from the Greek word ”haptesta” (to touch), refers to combined feedback from tactile sensors in the skin and kinesthetic sensors in muscles and joints. Though spread throughout our bodies, tactile and kinesthetic sensors are most concentrated in our hands and lips. It is no accident, therefore, that musicians are acutely aware of an instrument's “feel”, since the actions of blowing, bowing, plucking, pressing, and tapping used to play most instruments are carried out by hands and lips. By incorporating haptic feedback into the controller for the virtual bowed string, we aimed to take advantage of the player's existing sensitivity to the relationship between their instrument's feel and its sound in order to create a wider range of parameters that can be sensed and controlled during performance. In the following section, we address the implications of adding real-time haptic feedback to musical instrument controllers in general, and to our bowed string model in particular.

3.1. Hardware Considerations for Haptic Feedback Music Controllers

Haptic feedback devices are most often configured as closed-loop devices, sensing the position of the operator's hand in the workspace and relaying forces based on this position back to the operator. The rate at which forces must be computed and updated is determined by our ability to sense the granularity in feedback and is accepted to be around 1kHz [2]. Given that devices need to be servoed at this rate, two configurations for incorporating haptic feedback into simulated environments currently exist. Either

1. control parameters derived from sensors in the haptic display device are fed at an appropriate sampling rate (usually 1KHz) to a central servo loop which generates force output based on these parameters, or
2. haptic feedback is computed on a separate processor, usually embedded in the device itself, which communicates with a control computer via an isochronous protocol.

Both approaches have advantages and disadvantages for music controollers. In the first case, the tight coupling between sound and touch provides the potential for a single physically based model of the instrument to drive both auditory and haptic feedback. Thus the frictional forces for a haptic rendering of bow-string interaction could be computed from the coefficient of friction generated as part of the audio model. Since movement is sampled at 1kHz, it is also possible to create an instrument that is responsive to tiny gestural nuances, giving the performer a sense of connection to the audio model that is lacking in existing control protocols such as MIDI. Currently, this approach is limited to very simple instruments, because the computational resources required to support both haptic and audio output from a single physical model are not readily available. Moreover, this approach requires haptic and auditory responses to be uniquely designed for each instantiation of the instrument, since they are highly dependent on each other.

For the virtual bowed string, therefore, we turned to the second approach and computed haptic and audio output on separate processors which communicated via MIDI. Here we were able to take advantage of MIDI's existing control protocol to communicate with the physical model of the bowed string. For our first prototype, we coupled our existing haptic display, the Moose [1], to a bowed string physical model ([4]), and simulated both the normal and frictional components of the "feel" of bowing a string [3].

The position and velocity of the haptic display's puck were used to generate both bow force and bow velocity which were passed, via MIDI, to the audio model.

Because of the substantial difference in the sampling rate for the audio and haptic models, values for normal and frictional forces for the haptic model were not derived directly from the parameters of the physical model, but were generated locally using a simple Dahl friction model for pre-sliding displacement, and approximating normal force as the displacement of a linear spring. Moreover, because position and velocity parameters, which were sampled from the Moose at 1kHz, had to be subsampled to be transmitted via MIDI so that the violin model was only updated every 200msec. This process inevitably introduced a small amount of latency, which experienced players could easily detect.

The most advantageous approach is therefore a hybrid approach in which haptic and auditory models can communicate at a rate of 1kHz, either by inter-process communication on a single machine or by high-speed hardware communication. This approach leverages both a high-bandwidth connection to capture nuances of gesture and a modular design to allow for redesign or substitution of either part of the model. With this design, haptic controllers can be thought of as gestural controllers, generating sampled signals that can either operate on synthesis parameters directly or can be analyzed and parsed into events. In the following section, we introduce the vBow, the second-generation haptic controller for the bowed string, designed to address some of the issues raised here.

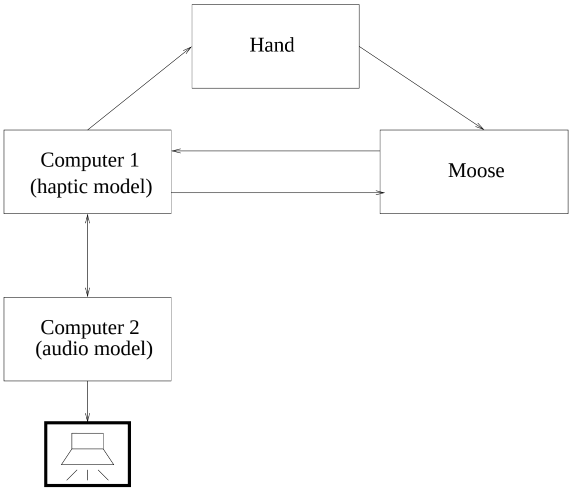

Figure 2: Virtual bowed string experiment.

4. THE VBOW

In response to the success of the experiments described in [3], using the Moose to enrich the experience of playing the physical model by adding the haptic feedback of a friction model, Nichols developed two versions of a new musical controller. The vBow is a virtual violin bow controller which provides the haptic feedback of a friction and vibration model, in addition to driving the bowed-string physical model.

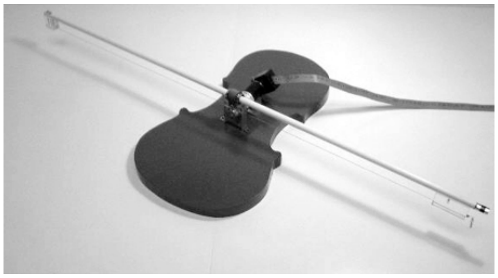

Figure 3: The vBow version 1

The first version uses a single servomotor and cable system, to sense the performer's bow stroke direction and velocity, and to produce a vibration as the performer draws the vBow. The cable is stretched between the frog and tip of the vBow, like the hair of a violin bow, and wraps around a capstan attached to the shaft of a servomotor.

The servomotor uses a digital encoder to read the shaft rotations, as the cable spins the capstan, while the performer draws the vBow. These encoder readings are used as bow direction and velocity data for the physical model, and as triggers for the friction model.

If the vBow is drawn quickly, a thin violin timbre rich in high partials is produced by the physical model, emulating a flautando sound. When the vBow is drawn slowly, the physical model produces a scratching sound, similar to the sound of a bow moving across a string too slowly to produce a steady-state vibration. If the vBow is drawn at an optimal speed, the physical model produces a clear violin timbre.

When the encoder reads a set number of transitions from the digital encoder, the software initiates a vibration, by sending rapid control messages to the servomotor. These control messages are varied randomly, to add to the realism of the vibration. The consequent vibration additionally provides a friction drag on the vBow. The second version of the vBow builds on what was learned from experiments with the first version, providing additional degrees of freedom for the performer, sensing more movement and producing additional haptic cues.

In the second version, the single servomotor and cable system of the first version is suspended from a robotic arm. Three additional servomotor and cable systems on the robotic arm allow for rotation across, vertical motion above and pressure into, and longitudinal motion along multiple virtual strings.

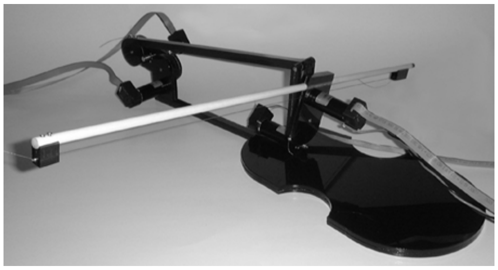

Figure 4: The vBow version 2

With the additional encoders, the vBow senses more aspects of the violinist's bowing gesture, and drives more parameters of the bowed-string physical model. In addition to allowing for various bow attacks, the second version provides longitudinal position along the virtual string in relation to the virtual bridge and bow pressure data to the physical model.

Along with adding enhanced gestural sensing, the second version also provides more haptic feedback to the performer. The same servomotor with the encoder which senses bow rotation provides detents as the vBow comes into contact with virtual strings. The servomotor with the encoder which senses vertical position provides haptic cues of string elasticity and resistance, when the vBow lands or pushes into the virtual strings. And, the servomotor with the encoder which senses the longitudinal position of the virtual bow provides additional friction as the vBow slides along the virtual strings.

5. THE METASAXOPHONE

Recent work has involved exploring extended techniques for physical models using instrumental controller subsititution (see Burtner, Serafin, 2000 and 2001). Instrumental controller substitution utilizes the virtually disembodied nature of physical models as a means of exploring their unique acoustic nature. The decoupling of the instrumental controller and the audio synthesis is used as a compositional opportunity to expand the musical possibilities of physical models. In this work a non-string instrument interface, the saxophone, is used as a controller for the string physical model. We built a new expressive computer controller, the metasaxophone, shown in figure 5.

Figure 5: The metasaxophone

The metasaxophone allows the force feedback from the keys of an acoustic saxophone to act as individual controllers for the parameters of the bowed string model. The metasaxophone is a Selmer tenor saxophone with an on-board computer microprocessor located on the bell, communicating with an array of force sensing resistors (FSR) that capture continuously changing finger pressure from each of the front six keys and the two thumb rests. The microprocessor converts the performance data into a continuous MIDI control message that is sent from the saxophone to a Max/MSP interface containing the physical model string.

The input parameters of the physical model, the bow pressure, bow force, bow position, the string inharmonicity, frictional properties, center frequency, and microtonal frequency variation are each controlled by a different FSR on the metasaxophone. By assigning each finger of the saxophone to a different parameter of the model, the bowing action is broken into a series of isolated tasks. This creates a reallocation of the parameters of a complex expressive action – the bowing – to another complex action – the fingering of keys. The keys of the acoustic saxophone offer a high level of force feedback to the performer. The saxophonist can sense the spring mechanism of the key as it is gradually depressed, can feel the key pad contact the tone hole, and then can sense the increasing pressure as the hole is fully closed and more pressure is applied. The saxophone keying action provides feedback to nerves in the fingers when light pressure is applied, and to the muscles and joints as the key is closed and after-touch pressure is applied. Under normal playing conditions this haptic information is not used by the performer who is simply required to accomplish a complete closing of the key pad over the tone hole. The traditional saxophone key configuration offers only ”open” or ”closed” control. On the metasaxophone, the haptic response from each key is used as a continuous control parameter for the complex bowing action. The performer is aware of the exact position of the key and the pressure of each finger, and uses this forced feedback as a means of controlling the physical model. We experimented with varying logarithmic data mappings, applying different exponential pressure curves to the audio parameters of the physical model.

Instrumental controller substitution opens new paradigms for compositional timbral exploration using physical models. Rather than evaluating the musical effectiveness of the physical model in terms of its acoustic real-world counterpart, the virtual instrument is explored for its own complex and unique properties. Similarly, the instrumental controller when coupled with the physical model can be evaluated independently from its acoustic basis, solely as a controller for the redefined digital instrument. Through this work we seek to occupy a new timbrally rich musical space in which a dialectic is established between control parameters and sonic parameters. This type of coupling is natural with all musical instruments but instrumental controller substitution opens the possibility of potentially unlimited hybrid electroacoustic instruments.

6. CONCLUSIONS

In this paper we described different approaches to control a real-time physical model of a bowed string. We proved how force feedback greatly imcreases the playability of the model. We furthermore extended the capabilities of the model by playing it with an alternate controller, the Metasaxophone.

7. REFERENCES

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