Playability Evaluation of a Virtual Bowed String Instrument

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ABSTRACT

Driving a bowed string physical model using a bow controller, we explore the potentials of using the real gestures of a violinist to simulate violin sound using a virtual instrument. After a description of the software and hardware developed, preliminary results and future work are discussed.

1. INTRODUCTION

One of the aspects that makes the family of bowed string instruments successful is the incredible degree of nuance and expressivity that a player can obtain with a bow. In building virtual bowed string instruments, the same expressivity is a desirable characteristic. The issue of expressivity in synthetic bowed string research is well known in the computer music field. The importance of controlling a bowed string physical model with input parameters that simulate a physical gesture was first underlined in the work of Chafe [2] and Jaffe and Smith [5]. In this research the combination of the input parameters of a bowed string physical model was used to reproduce different bow strokes such as detaché, legato and spiccato.

Although the goal was to reproduce a particular sound specific to a certain performer's gesture, no real-time input controller was used. To our knowledge, one of the first attempts to control a bowed string physical model using devices other than the traditional mouse and keyboard was proposed in the early 90s by Cadoz and his colleagues at ACROE. Using a device capable of providing tactile feedback the player was able to feel the synthetic bowed string. Recent results of this research are detailed in [3].

Recently, an increasing interest has been shown in controllers for virtual bowed strings developed using physical models.

Preliminary experiments using a Wacom tablet to control a real-time waveguide bowed string model developed in the Max/MPS environment were performed at IRCAM and described in [10]. The Wacom tablet allows a straightforward mapping of the parameters of the bowed string physical model, since it is able to capture the pressure and two axis position of the pen provided with the tablet itself; these values can be easily mapped to the bow pressure, velocity and bow-bridge distance. Moreover, the tablet is able to detect the horizontal and vertical tilt angle of the pen. This immediately shows an advantage of the Wacom tablet versus more traditional input devices such as a mouse and a keyboard, i.e. the possibility of having the same degrees of freedom as a bow in contact with a string. The tablet, however, shows limitations that are mainly illustrated by the difficulties of using it as a performance instrument. These are due also to the lack of tactile feedback (because of the lack of elasticity of the tablet compared to the bow hair) and the dramatic difference between its ergonomics and that of a traditional violin bow.

This lack of force feedback was compensated for when controlling the same bowed string physical model using the Moose, a device built by Sile O'Modhrain and Brent Gillespie. Experiments show that the playability of the bowed string physical model greatly increases when tactile feedback is provided [7]. Researchers simulated the friction of the bowed string using the Moose, thereby providing force feedback associated with bowing gesture.

In order to introduce both force feedback and ergonomics that are reminiscent of a traditional violin interface, Charles Nichols built the vBow [6], a haptic feedback controller. The goal of the vBow is to be able to introduce a new violin interface that addresses the prior limitations of MIDI violins as well as to provide a controller that can also play other real-time synthesis tools.

In this paper, we extend the previous research by proposing an evaluation of the playability of a virtual bowed string instrument when driven by a bow controller that has the same ergonomics of a traditional violin bow.

2. ASPECTS OF PLAYABILITY

In virtual musical instruments and musical acoustics, the word *playability* has different definitions. While in this paper we focus on playability of virtual bowed strings, the same issues can be applied also to all other expressive virtual instruments.

According to Jim Woodhouse [14], playability of virtual instruments means that the acoustical analysis of the waveforms produced by the model fall within the region of the multidimensional space given by the parameters of the model. This is the region where *good tone* is obtained. In the case of the bowed string. *good tone* refers to the Helmholtz motion, i.e. the ideal motion of a bowed string that each player is trying to achieve. The Helmholtz motion is given by an alternation of stick-slip-stick-slip, in which the string sticks to the bow hair for the longest part of its period, slipping just once. Experiments show that simulated bowed strings have the same playability as real bowed strings as calculated by Schelleng [9].

Further experiments also show that the playability of virtual bowed strings increases when accurate friction models that account for the thermodynamical properties of rosin are taken into account [12].

This above mentioned definition of playability is interesting from a musical acoustician's point of view but does not

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reflect performance issues. In these experiments, in fact, the input parameters that drive the bowed string model corresponding to the right hand of the player are kept constant for each simulation. This is a situation that is clearly not the same as that which occurs in violin performances, as in performance it is the continuous evolution of the input parameters that constitutes the nuances that are the characteristics of an expressive performance. In order to address this issue, Askenfelt [1] studied the contribution of bowing parameters in different bow strokes, trying to determine the physical limits of the input parameters in order to achieve a specific stroke. He determined the maximal duration of the pre-Helmholtz attack allowed in order to judge a particular stroke as acceptable.

In interactive performances, other issues related to playability must be considered. Sile O'Modhrain [7], for example, studied the influence of tactile feedback on the playability of virtual bowed strings.

She discovered that haptic feedback greatly increases the playability of virtual instruments. In this context, playability is referred to as the ability of bowed string players to consistently perform different bow strokes that produce violin sounds that are judged as perceptually acceptable by professional bowed string players and also have waveforms that reside within the playability region as defined by [14].

Another important issue in virtual musical instrument playability refers to the precision and accuracy of both the hardware and the software that comprise the virtual instrument itself.

In the situation where a controller is used to drive a synthetic model, we may say that a controller is precise if it allows the player to control subtle variations of the gesture parameters with great care, and we may say that it is accurate if the data collected by the device may be easily correlated to a real physical values of a gesture. Correspondingly, we may say that the model is precise if it reproduces the nuances in the sonorities that are produced by a real instrument, and it is accurate when the physical input/output data can be matched to measurements on real acoustic instruments. An issue of importance in considering both of these aspects is that of latency, which may be adversely affected by limitations of either precision or accuracy. Of course, in musical performance, minimizing latency is a priority.

Obviously, the acceptance level of responsiveness varies according to the instrument played. For example, percussion instruments require a higher responsiveness than woodwind instruments. In general, it is reasonable to assume that transient instruments require a higher level of responsiveness that sustained instruments.

In the case of the bowed string, the issue of responsiveness is crucial when fast bow strokes such as staccato, balzato, martellato are performed.

Another more general definition of playability is the ability of the virtual instrument to be ergonomically playable. That is, the player should be able to physically manipulate the interface freely and with ease.

A chart that summarizes all the playability issues mentioned above is shown in figure 1.

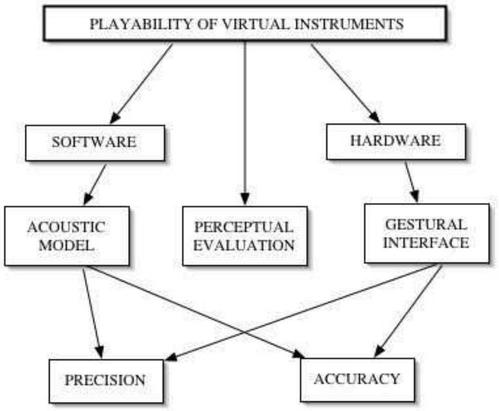

Figure 1: Playability chart of a virtual musical instrument

3. NEW EVALUATION PLAYABILITY

In this paper we are interested in exploring all the previous definitions of playability and extending them by driving a violin bowed string physical model using a bow controller.

Rather than building or adopting an alternate controller or working with a haptic device such as in the examples mentioned above, we are interested in exploring the possibility of reproducing traditional bowing techniques using a bow controller that behaves in a manner as closely related to that of a traditional violin bow as possible.

This allows us to validate both the model and the controller by comparing it to the behavior of the traditional instrument.

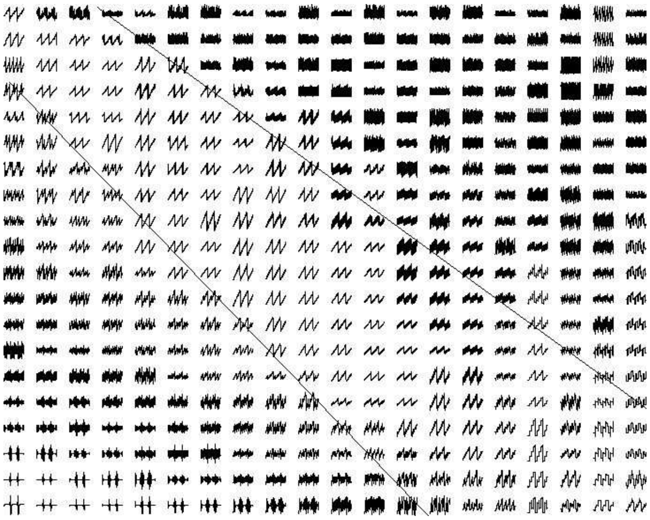

Figure 2: Playability plot obtained by capturing the waveforms after steady-state motion is obtain. Horizontal axis: bow force. Vertical axis: bow position.

3.1 A bowed string physical model

We built a bowed string physical model that combines waveguide synthesis [13] with latest results on bowed string interaction modeling [8].

A schematic representation of the model is shown in figure 3. In this model, the bow excites the string in a finite number of points, which represent the bow width. The frictional interaction between the bow and the string is modeled considering the thermodynamical properties of rosin [12]. The bow width is modeled by discretizing the region of the string in contact with the bow using finite differences and calculating the coupling between the waves propagating along the string and the frictional interaction between the bow and the string at each point. Once the velocity of the string at the contact point has been calculated, the waves propagating along the string are modeled using digital waveguides. More precisely, transversal and torsional waves propagating toward the bridge and the fingerboard are modeled as pairs of one dimensional digital waveguides.

The outgoing velocity at the bridge is filtered through the violin body's resonances and corresponds to the output waveforms perceived by the listener.

For a detailed description of the physical model see, for example, [11].

The input parameters of the model corresponding to the right hand of the player are bow position relative to the bridge (normalized between 0 and 1, where 0 corresponds to the bridge, 1 corresponds to the nut, 0.5 corresponds to the middle of the string), bow pressure, bow velocity, and amount of bow hair in contact with the string. The model has been implemented as an external object in the Max/MSP environment.

Figure 2 shows the waveforms obtained by running the model with a constant bow velocity of 0.05 m/s, and varying the bow force and bow position between 0 and 5 N and 0.01 and 0.4 respectively. The waveforms are captured after a steady-state motion is achieved. Inside the two straight lines appears the playability region as measured by Schelleng with the same parameter configuration. Note how the synthetic model and the real instrument are in good agreement concerning the playability region's results.

3.2 The bow controller

The bow controller provides three different types of measurement that reflect the nuances of gesture that may be observed in traditional string instrument bowing technique. The controller's sensing system employs commercial MEMS accelerometers to measure three axes of acceleration, electric field sensing to track bow position and bridge distance from the bowing point, and foil strain gauges to detect changes in the downward strain of the bow stick as well as in the orthogonal direction (toward the scroll).

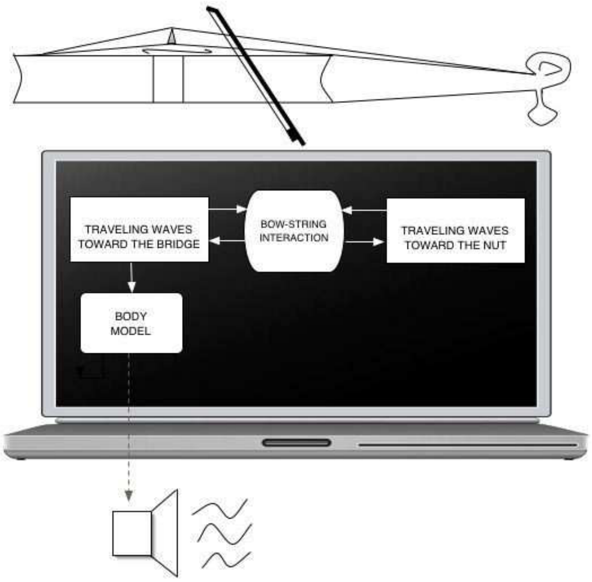

Figure 3: A bowed string instrument and the corresponding simplfied block diagram of its model.

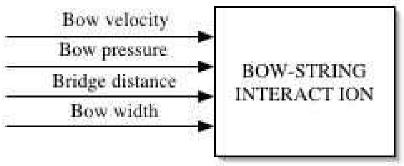

Figure 4: Input parameters of the bowed string physical model.

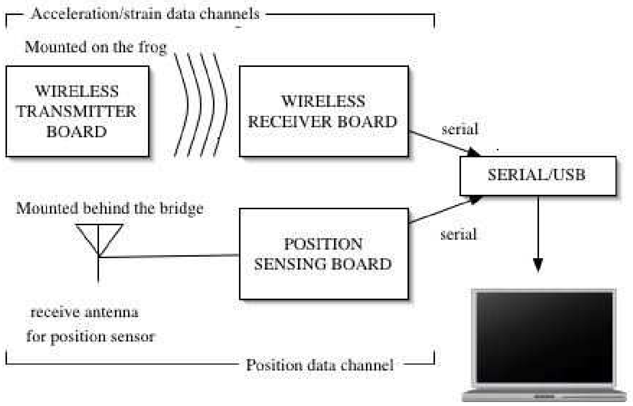

Figure 5: Data flow for the violin controller.

These sensors were chosen so as to offer a player and composer the ability to capture data concerning all of the parameters of bowing that contribute to the interaction between the bow and the string: bow speed and bowing point (from the position tracking), downward force and bow width (both reflected by strain sensors). Additionally, the accelerometers were included as a means of observing with great precision changes in bowing direction as well as the differences in characteristics of various kinds of string attacks.

The placement of the sensors and the accompanying electronics were carefully designed so as to provide good results in measurement, while also maintaining as completely as possible the balance, weight, and feel of the bow. Also a priority in this implementation is the protection of the hardware itself and robustness of the overall system, as the interface was intended for use in live performance and rig-

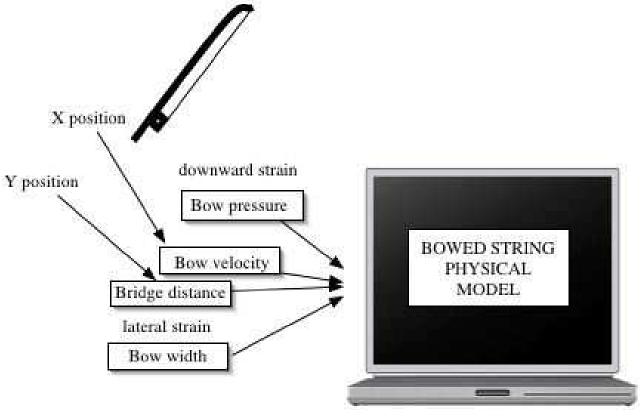

Figure 6: One to one mapping of the bow controller to the bowed string physical model.

orous laboratory experiments.

The strain sensors are effectively integrated onto the composite material of the bow, as they are permanently adhered around the midpoint of the stick. They are protected from wear by a thin layer of flexible tubing, and their connecting wires run down the lower length of the bow to the electronics board mounted on the frog (while still allowing the frog to slide freely in order to adjust the tension of the bow hair). This electronics board houses the accelerometers, the microcontroller, and the wireless transmitter, which sends the acceleration and strain data to a remote receiver board containing a serial port. This board also sends two separate signals to either end of a resistive strip that runs the length of the bow stick, acting as an antenna for the position measurement. The resultant mixed signal is received by an antenna mounted behind the bridge of the violin, and this signal is connected to another electronics board that determines the different amplitudes of the two received signals.

The mechanical layout of the electronics on the bow allows the player to use traditional right hand bowing technique, while keeping the hardware out of harm's way from the players hands and the strings of the violin. The electronics add about 30g of weight to the original carbon bow, but because of the careful distribution of the weight along the length of the bow the balance point of the bow is still well within the normal range for a traditional violin bow. In addition, the remote electronics boards are small and light, and the bow is wireless and runs on a camera-style battery with a lifetime of over 20 hours, and so the interface is highly portable.

The data from the bow controller is carried by two separate serial buses: one for the acceleration and strain data and one for the position data. In this experiment, a commercial serial/USB converter is used to connect the two serial lines with the input of a Macintosh computer [15].

4. MAPPINGS

In order to build an expressive virtual musical instrument, the capture of the gesture of the performance is as important as the manner in which the mapping of gestural data onto synthesis parameters is done. In the case of physical modeling synthesis, a one-to-one mapping approach of control values to synthesis parameters makes sense, due to the fact that the relation between gesture input and sound production is often hard-coded inside the synthesis model [4]. Because both the physical model and the bow controller are developed according to physical input and output parameters, the mapping between the two is straightforward. Figure 6 shows how the data sent by the bow controller is mapped to the input parameters of the physical model. Downward bow strain of the controller is directly mapped into bow force in the physical model. Bow velocity and bow-bridge distance are captured by measuring the horizontal and vertical position of the bow respectively. Moreover, lateral strain sensors are mapped into the amount of bow hair in contact with the bow.

5. PRELIMINARY EXPERIMENTS

The first experiments completed to begin the integration between the bow controller and the violin physical model were encouraging. With the model parameters of bow-bridge distance, bow velocity, and bow width for a fixed frequency held constant, we mapped the downward strain data from the bow controller to the downward force parameter. While applying pressure on the strings of our test violin (without actually drawing the bow across the strings) using the bow controller, we were able to quickly produce sonorities from the model that sounded appropriate for the amount of pressure we applied to the bow.

We also experimented by drawing the bow across damped strings to determine the response for changes in downward force that occur during different bow strokes. Again, the response of the model and the feel of this simple mapping produced a satisfying interaction and was interpreted by us as extremely promising for continued work.

6. CONCLUSION

The initial experiments for this research project yielded positive results. Players were able to produce bow strokes that felt natural and were judged as acceptable from bowed string players. Furthermore, the mapping between the amount of force and the change in amplitude of the sound seemed intuitive.

Mapping each of the remaining input parameters of the physical model to the appropriate sensor data and aim to iteratively build a convincing link between physical controller and virtual violin. This allows us to evaluate each component of the system as well as the overall system by examining all aspects of playability discussed.

Using this methodology we are able to validate not only the acoustical properties of our system, but also the performance capabilities, issues which are often treated separately.

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