The vBow: Haptic Feedback and Sound Synthesis of a Virtual Violin Bow Controller

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Abstract

How an instrument feels to a performer, or the haptic feedback of the instrument, is key to how the player responds to the instrument. The vBow is a first attempt at building an electronic musical controller that, in addition to generating sound, produces a haptic response similar to the force-feedback of a bow acting on an acoustic violin string.

The vBow design is based on a single servomotor and cable system. The servo is secured to a housing, which was machined from acrylic and is fastened to a violin-shaped base. A capstan, which was turned from an aluminum rod, is attached to the shaft of the motor. The cable, which is terminated at the frog and tip of the virtual bow, passes through guide holes in the acrylic housing, and wraps around the capstan. The frog and tip are attached to a fiberglass rod, which serves as the stick of the virtual bow. As the player draws the vBow, the stick passes through a linear bearing, which is screwed to the housing, and the cable spins the capstan on the shaft of the motor.

A digital encoder on the servo reads the number of counts per revolution of the motor shaft, which is decoded by a data acquisition and servo control card, installed in a personal computer. The sampled encoder reading is used as input to the bow velocity parameter of a bowed string physical model, controlling the timbre of the sound synthesis. The control software also responds to the encoder reading, by periodically sending servo control messages, through the card, to the servomotor of the vBow. As the control software rapidly engages the motor, the capstan on the motor shaft seizes the cable, which moves the shaft of the vBow, producing a vibration on the virtual bow.

The instrument serves as a tool for experimenting with the haptic feedback a performer responds to when drawing a bow across a violin string, and for testing the responsiveness of a bowed string physical model. Future developments of the vBow will also make it useful as an expressive musical controller for composers and performers.

Motivation

As a composer and performer I have tried to use a MIDI violin as a musical controller, but have found the instrument to be unresponsive and prone to error. The delay between when the string is bowed, and when the vibration is translated into MIDI pitch and velocity information is substantial, causing a disconnect between the performance gesture and the resultant sound. Often, rapid changes in bow direction, such as tremolo, or in pitch, such as trills, are lost in the translation, due to this latency. The translation of the physical vibration into discreet MIDI data is also prone to error. Pitches can be transposed, due to sympathetic vibration or frequency cancellation.

My initial goal was to build a violin controller which did not depend on the serial MIDI protocol for its sound synthesis, but rather used parallel data streams from multiple sensors to simultaneously feed data to synthesis parameters in computer programming. The idea was to avoid the latency and error of translating a physical vibration into MIDI, by directly sampling performance gesture using a faster sampling rate and more direct data input.

Around the same time that I started designing the vBow, I became aware of the need for an instrument to test the playability of the bowed string physical model under development at CCRMA. Previous research had used a graphics tablet as an input device for the synthesis parameters of the bowed string physical model (Serafin, Dudas, Wanderley, and Rodet, 1999), but range of motion was restrictive, and there was limited gestural similarity between using the graphics tablet and drawing a bow across a string.

I also became interested in the studies researchers were conducting at CCRMA, which showed a reliance by performers on the haptic or force feedback response of an instrument, in addition to their dependence on the auditory response, when assessing their performance. Their research shows a strong correlation between the ability of a performer to control their gesture and the haptic response of the system (O'Modhrain and Chafe, 2000). They also show that simulating these tactile cues adds to the playability of a bowed string physical model (O'Modhrain, Serafin, Chafe, and Smith, 2000).

The vBow was designed with these three uses in mind. It is an expressive instrument for performing music, and a tool for testing the expressivity of the bowed string physical model and experimenting with simulations of the haptic feedback from the interaction between the acoustic violin bow and string.

Construction

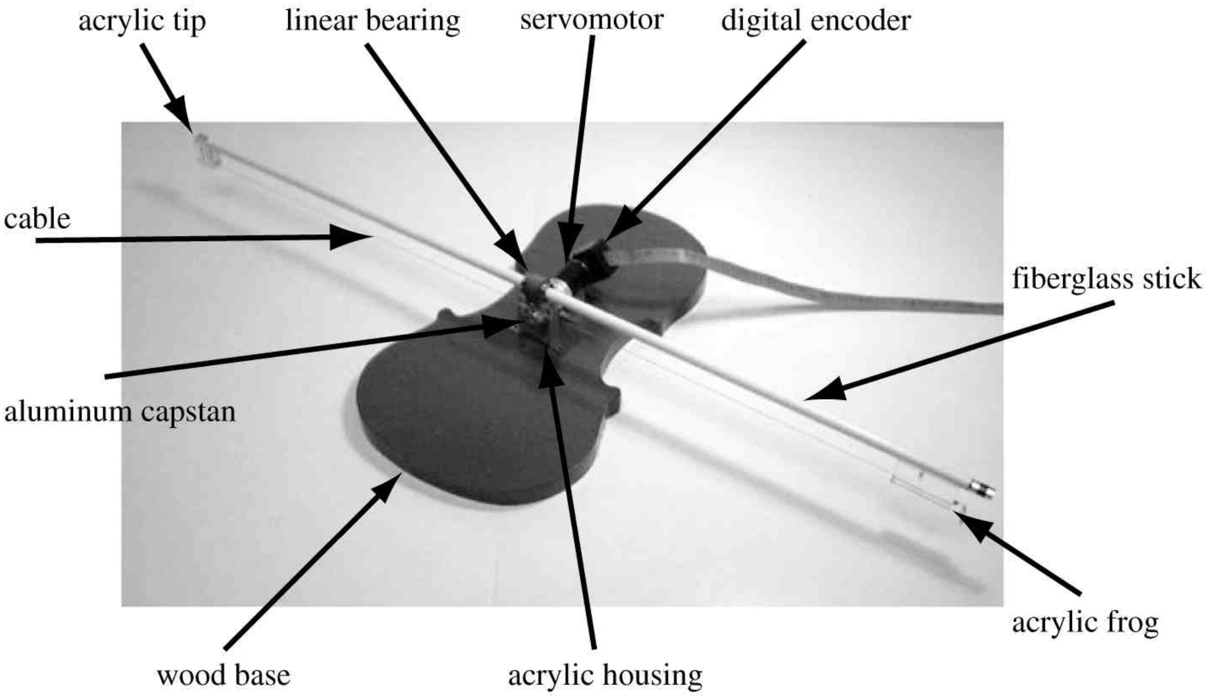
The construction of the vBow is designed around a single Maxon Precision Motors servomotor with a rare earth magnet, precious metal brushes, and digital encoder. The servo was selected for its stall torque, which can withstand the maximum bowing force possible, and operating range, which can handle spikes in force due to forceful or percussive bow strokes. The digital encoder, able to read a total of two thousand counts per turn, was selected for its precision.

Fastened to the servo is a capstan, turned from an aluminum rod. A hole drilled through the length of the capstan fits over the shaft of the servo, while a hole drilled through the radius holds a set screw, which secures the capstan to the servo shaft. A groove, cut into the side of the capstan, serves as a guide slot for the cable, and is cut so that the interior radius, along with the stall torque of the servo, provides the optimal steady-state force. A Sava Industries stainless steel cable, which is nylon coated for adhesive friction, wraps around the capstan within the groove.

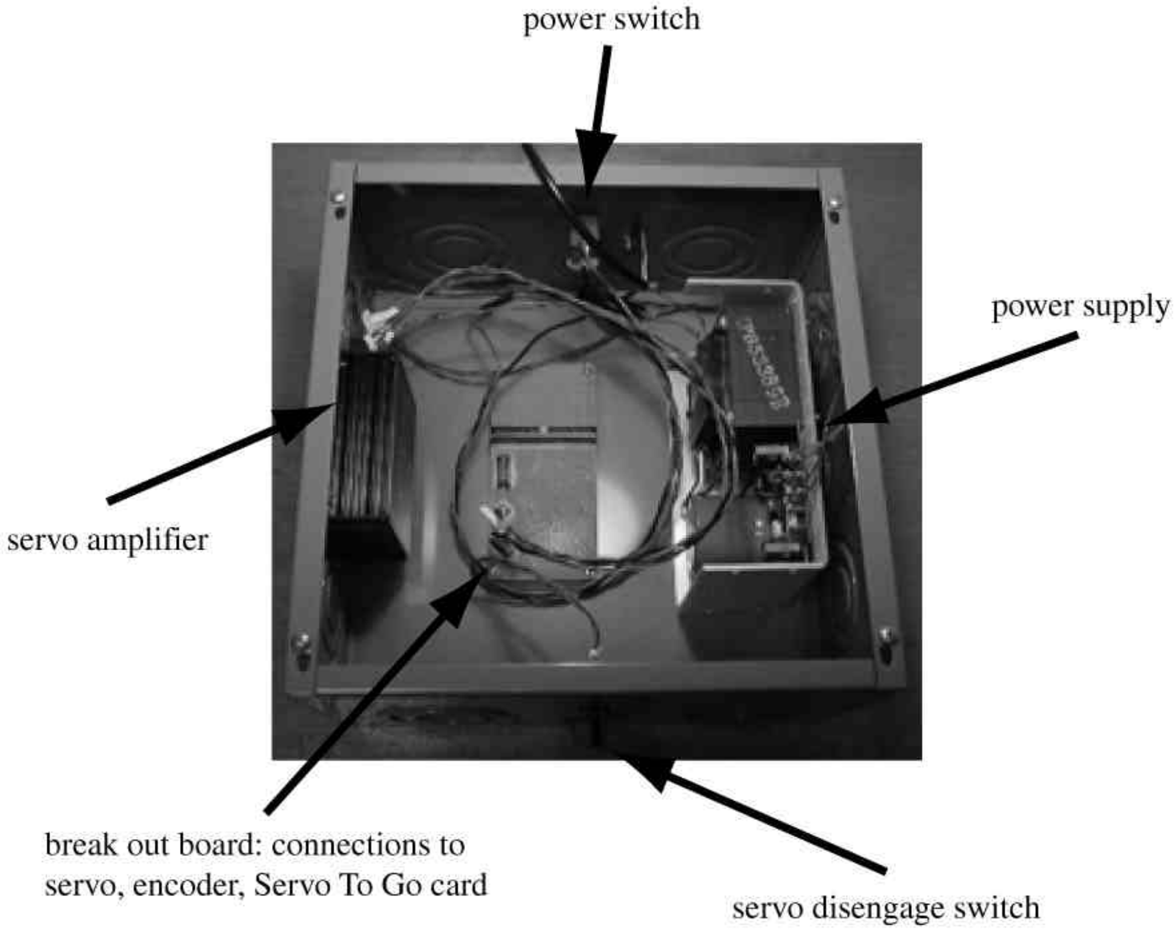
At the heart of the vBow construction is a housing, machined from acrylic, and secured to a violin-shaped wood base, for stability. The dimensions of the housing were based on the height of the point of contact between the bow hair and the violin string, above the violin body. Several holes are drilled through the housing, for screws to secure components of the vBow to the housing, and as guide holes for moving parts. Screws secure the servo to the housing, through holes drilled through the depth, while other screws hold a metal strip, which fastens the linear bearing to the housing. The capstan spins within a hole drilled through the depth of the housing, while the cable passes through a hole drilled through its width. On a shelf, cut at the top of the housing, sits the linear bearing.

A W. M. Berg linear bearing is held to the housing with stainless steel retainer rings, which fit in grooves cut into the outer wall of the bearing. A metal strip fits over the outside of the bearing wall, and is screwed to the top of the acrylic housing, while a strip of craft foam sits between the metal strip and bearing wall, to reduce vibration and increase stability. The linear bearing functions as the guide hole through which the shaft of the vBow passes.

A fiberglass shaft, selected for its smooth surface and rigid length serves as the stick of the virtual bow. A tip and frog, machined from acrylic, are fastened to the stick at either end. The cable passes through holes drilled through the length of the tip and frog, and is terminated at both ends with a stainless steel ball and shank. A standard bow tightener eyelet is screwed into the top of the frog, and fits in a slot cut into the length of the fiberglass shaft. A standard bow tightener screw fits into a hole drilled through the length of the fiberglass shaft, and through the threaded eyelet. The bow tightener screw and eyelet are used as the tensioner for the cable system.



The electronics for the vBow system are comprised of a Maxon Precision Motors linear servo amplifier, single output power supply, and a Servo To Go servo control and data acquisition card installed in a personal computer running the Windows 98 operating system. The servo amplifier, powered by the power supply, amplifies the control signal from the Servo To Go card, for the servomotor. The power for and data from the digital encoder, are provided and decoded by the Servo To Go card.



As the fiberglass shaft moves smoothly through the linear bearing, the cable, which is terminated at the tip and frog on either end of the shaft, spins the capstan, and in turn the shaft of the servomotor. The shaft rotations are read by the encoder, the encoder data is decoded by the Servo To Go card, and the bow direction and velocity are used by the sound synthesis software, to drive a bowed string physical model. The encoder data is also used by the control software, to generate the friction and vibration model, which is sent through the digital-to-analog converters of the Servo To Go card, to the servo amplifier, which engages the servomotor. As the servo moves, it engages the cable, which is wrapped around the capstan, and produces the vibration and friction haptic feedback on the virtual bow.

Application

This first version of the vBow senses bow direction and velocity, which is used to drive a bowed string physical model, generating the sound synthesis for the instrument. The sampled encoder count is used by the software to determine bow velocity for the bowed string physical model. The sampled encoder count of a bow stroke is divided by the maximum encoder count possible within a single bow stroke, and the resulting value is used as the bow velocity for the model. The bowed string physical model responds expressively to the vBow stroke as a violin string would to a bow. A normal bow stroke produces a clear violin timbre. If the bow stroke is very fast, the higher partials are exaggerated, producing a flautando timbre, and if the bow stroke is too slow, the model produces noise similar to the scratching of a bow moving across a string too slowly to produce a steady state vibration.

In addition to sensing the performer's bow stroke, the first version of the vBow simulates the force-feedback of the vibration and friction of a violin bow moving across a string, providing the haptic feedback for the instrument. The friction and vibration model is based on the random distribution of microscopic hooks on the violin bow hair. When the sampled encoder count reaches a limit varied by a random count, the software sends control messages through the Servo To Go card and servo amplifier to the servomotor. If the bow stroke is a down bow, then the encoder count is positive, and the control messages engage the motor forward, backward, and forward, simulating a vibration on the bow, and causing friction. If the bow stroke is an up bow, the encoder count is negative, and the control messages engage the motor in the opposite direction. Each control message is delayed by a duration of milliseconds varied by a random amount, making the vibration feel more realistic.

Improvement

I have designed and am currently building the second version of the vBow, which suspends the housing of the first version from an articulated robotic arm, which is anchored at the far end of the neck of a new acrylic violin-shaped base. This version will use four servomotors with digital encoders to sense the bowing gestures of the performer and provide the force feedback for the system.

In addition to sensing bow direction and velocity, this second version will read rotation of string crossings across four virtual strings, vertical bow position above and bow pressure into the virtual string, and longitudinal motion along the length of the string, moving toward and away from the virtual bridge. The rotation across virtual strings will determine which of four bowed string physical models will be played, each with a different open-string fundamental frequency, while the vertical position will determine the value for the force parameter of the physical model. The longitudinal motion will be used to simulate sul ponticello and sul tasto effects in the physical model.

This version will also simulate the multiple vibrations caused by playing double and triple stops, and provide detents for when the vBow crosses each virtual string. It will also supply elastic resistance when the vBow makes contact with and exerts force into the virtual string, and simulate additional friction as the vBow moves longitudinally along the length of the virtual string.

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