The *Hyperbow*: A Precision Violin Interface

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Abstract

This paper addresses the need to utilize precision measurement techniques in the the creation of new performance instruments and interfaces. Discussed within is the design and construction of a new violin interface, the Hyperbow, which serves as a first demonstration of how a violin bow might be made capable of measuring the most intricate aspects of violin technique–the subtle elements of physical gesture that immediately and directly impact the sound of the instrument while playing. In order to provide this insight into the subtleties of bow articulation, a sensing system has been integrated into a commercial carbon fiber bow to measure changes in position, acceleration, and the downward and lateral strains on the bow stick. These sensors were fashioned using an electromagnetic field sensing technique, commercial MEMS accelerometers, and foil strain gauges. The measurement techniques used in this work were found to be quite sensitive and yielded sensors that were easily controllable by a player using traditional right hand bowing technique.

1 Introduction

Though a great deal of progress has been made in the fields of audio analysis and synthesis, and software tools for musicians continue to quickly increase, there is comparatively little advancement in the area of performance instrument design and development, especially for accomplished players. Certainly, there is a great need for the development of new musical interfaces that may respond to the smallest and most subtle gesture of an accomplished musician. Not only may much be learned from accessing this level of description of musical technique, but by using this data we may begin to delve into new kinds of musical expression, building upon traditional methods of manipulating sound. Of course, care must be taken not to reduce the playability of the instrument in the development of such an interface. As in the study of a violin bow interface described here, when beginning with a traditional acoustic instrument as a model, this issue is of extreme importance.

The violin (and its accompanying bow) is a prime candidate for study and evolution. Traditional violin repertoire and technique require extremely subtle articulations and sophisticated coordination of gesture, most of which is not easily understood by non-players. For these reasons, the violin is a source of inspiration for new music controllers.

The problem of how to develop a new musical interface for an experienced string player in order to create new methods of musical expression was addressed in the *Hypercello* and subsequent *Hyperinstruments* work at the M.I.T. Media Lab (Paradiso and Gershenfeld 1997; Machover 1992). Later, projects such as the *bossa* (Princeton) were developed (Trueman and Cook 1999). These endeavors used measurements such as bow position, pressure on the bow stick, and acceleration of the bow to alter the sound produced by the bowed string.

The *Hyperbow* project discussed in this paper is a music controller similar to those mentioned above, as the sensing system on which the controller is based includes sensors for bow position and acceleration (Young 2001). However, in order to provide greater insight into the subtlety of gesture demanded of and used by violinists, different types of strain in the bow stick are also measured. The downward and lateral strains on the bow stick are closely related both to the experience of a violinist while playing and to the immediate changes in the sound produced by the string when bowed. The three sensing subsystems–position, acceleration, and strain–were grafted onto a carbon fiber bow to enable (directly or indirectly) the *Hyperbow* to collect and transmit data reflecting bow position, speed, acceleration, downward force, and angle of the bow.

This paper describes the implementation and design considerations of the *Hyperbow* project, applications, and future advancements.

2 Design and Implementation of the *Hyperbow*

2.1 Position Sensing

The method of sensing the position of the bow (relative to the bridge of the violin) presented in this paper is an adaptation of the system used in the development of the *Hypercello* (Paradiso and Gershenfeld 1997).

In this method, two square wave signals of different frequencies are produced. The signals are connected to opposite ends of a resistive strip that spans the length of the bow. A simple electrode antenna is placed behind the bridge of the violin. This antenna is connected

Figure 1: The electrode antenna is mounted behind the bridge of a Jensen electric violin.

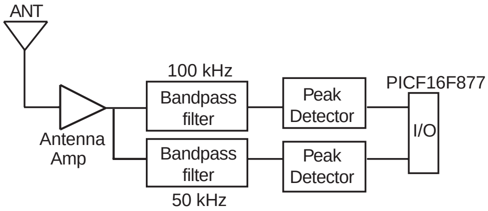

Figure 2: The amplified signal from the antenna board on the violin combines two signals sent from the bow. To determine the position of the bow, the combined signal first must be separated into two signals once again. This function is performed by directing the combined signal into two bandpass filters, one at 50KHz at 100KHz. The filter outputs are converted to DC by two peak detectors and sent to the PIC16F877.

to a circuit that amplifies the combined signal and is sent via a cable to a remotely mounted board, whose task is to separate the two signals from each other and measure their varying strengths. Bow position is then determined from this data in software on a computer receiving the output of the board.

For the *Hyperbow*, the implementation of the position sensor is completed with as little alteration to the rest of the existing sensing system as possible. So as to add a minimal number of hardware components to the small board mounted on the bow, the two square wave signals are generated by the PIC16LF877 manufactured by Microchip Technology, Inc. The board that receives the signal from the antenna consists of two bandpass filters that have been designed to separate the two different signals of different frequencies from each other. Peak detectors convert the signals to analog DC voltages equal to the signal amplitudes and a PIC16F877 microprocessor with a built-in 10-bit A/D converter receives these voltages and sends them to a PC workstation as serial data (see Fig. 2).

2.2 Acceleration Sensing

In order to sense the acceleration changes of the bow, ADXL202 accelerometers from Analog Devices, Inc. are employed. This MEMS (Micro-Electromechanical Systems) accelerometer has a measurement range of ±2g and is capable of measuring both static and dynamic acclerations.

Because the ADXL202 is a 2-axis accelerometer, two of these devices, one mounted orthogonal to the plane of the electronics board containing the other, are used in the design in order to attain acceleration data along all three axes. This accelerometer has a digital output for each of its two axes of sensitivity that has a maximum resolution of around 14 bits. The acceleration measured by the accelerometers is encoded in the digital output signal by modulating the duty cycle linearly with the acceleration. The acceleration is thus retrieved by simply counting the duty cycle in a software loop.

2.3 Strain Sensing

Because of its direct effect on the violin string and its close relationship to the experience of a violinist while playing, we developed a technique of measuring the downward and lateral forces on the bow stick. This measurement is similar to that used in the original *Hypercello* project, which employed a force sensitive resistor to indicate the pressure of the right hand index finger on the bow stick. However, in this method we measure the relative changes of the different strains on the carbon fiber material of the bow stick itself. This basic technique was also employed by Askenfelt (Askenfelt 1986; Askenfelt 1989).

Strain Gauge Operation The sensors used in this project are commercial foil strain gauges from Vishay Measurements Group, Inc. The gauges are two-terminal devices that behave as variable resistors. Therefore, the proper operation of the gauges demands that they be securely and permanently affixed to the material that is under strain such that the stretching of the gauge is identical to the stretching of the material. The strain gauges used in this project possess a uniaxial pattern designed to measure strain along one axis (in the direction of the grid lines), as in a bending beam.

Wheatstone Bridge Configuration The strain gauges were arranged in a Wheatstone Bridge configuration with the midpoints of each "leg" of the bridge connected to a differential operational amplifier. So as to allow for the best measurement possible, a full bridge configuration, i.e., two strain gauges in each of the two legs of the bridge, is implemented. The sensor measures the strain at the point located approximately halfway between the two sets of gauges (see Fig. 4). At rest, the resistances of all of the gauges are approximately

Figure 3: These two uniaxial strain gauges (EK-06-250BF-10C) each have nominal resistances of approximately 1000Ω and are 6.35mm long and 3.18mm wide each.

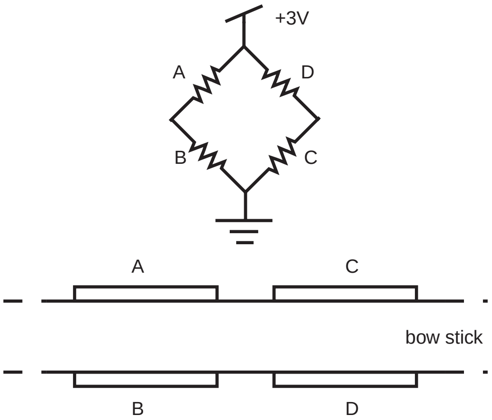

Figure 4: The arrangement of the strain gauges that comprise the Wheatstone Bridge circuit has been designed so that the sensor measures the strain roughly halfway between the two legs of the bridge (A/B and C/D). In the case that a lateral force is applied to the bow, gauges A and C are compressed and therefore decrease in resistance, while gauges B and D expand and therefore increase in resistance.

equal, and so the corresponding voltage values between the midpoints of the bridge and ground are also approximately equal, resulting in a voltage difference of zero at the output of the differential amplifier.

Application and Alignment The accuracy of a strain gauge measurement is highly sensitive to the relative alignment of the group of strain gauges along the bow surface (see Fig. 4). Any difference of the angle made between individual strain gauges and the axis of the test object alters the effective lengths of the strain gauges along the strain axis and therefore affects their relative rest and strained resistances. Discrepancies between the orientations of the individual gauges and how they conform to the surface of the bow contribute to the difference between their nominal resistance values, and this in turn creates problems in the performance of the bridge. Since the measurement taken is really the voltage difference between the two voltages at the midpoints of each leg of the bridge, when the gauges are not closely matched this value at rest is nonzero and the dynamic range of the measurement is impaired.

Figure 5: The *Hyperbow* consists of a modified CodaBow *Conservatory* violin bow enhanced with strain sensors and a resistive strip used for position sensing. A PCB mounted to the frog houses the accelerometer sensors as well as control circuitry for sending data wirelessly to a remote receiver.

2.4 System Overview

Though we are interested in creating a violin bow with capabilities unlike any other and expect the form of the bow to differ from the traditional as a result, we wanted to maintain certain traits of the physical interface so as to enable a player to use the same posture of the right hand wrist and fingers on the bow. Therefore, the hardware implementation of the *Hyperbow* measurement subsystems was designed so as to provide the performer with an instrument as similar to a traditional bow in size, weight, and weight distribution as possible.

In addition to the requirements of the physical interface of the bow itself, there are several basic requirements for the architecture of the sensing system. Though the printed circuit board on the bow performs the functions necessary to attain and send strain and acceleration data, it acts as only part of the position sensor. The second part of the position sensor is the tail-piece-mounted antenna described below. Because the progress of the position sensing subsystem is separate from that of the rest of the project and the subsystem was designed for use in musical applications different from those of the strain and acceleration sensing subsystems, the hardware to receive position data is isolated from the other subsystems.

A serial protocol is used to carry the combined strain/acceleration data stream and the position data stream to an external computer at 19200 baud. The sampling rate of the position sensing subsystem is $1/7$msec/sample ≈ 142.86samples/sec. and the sampling frequency for the acceleration and strain subsystems is $1/24$msec/sample ≈ 41.67samples/sec.

A crucial design objective was that the bow remain wireless, without power or data cables. The small electronics board mounted to the bow is powered by a lithium battery and sent the sensor data from its transmitter to a receiver on a separate electronics board. This data transfer is performed via a Linx HP-SeriesII RF module, manufactured by Linx Technologies, Inc. This module operates in the 902-928MHz band, is capable of transmitting data for distances up to 1000ft, and has eight selectable channels (making it possible to adapt this sensing system for use in several instruments simultaneously). The antenna for the transmitter is a simple $\frac{1}{4}$ wave whip antenna made from a piece of solid conductor wire cut to the appropriate length.

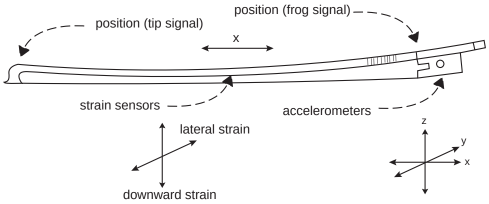

Figure 6: The *Hyperbow* system includes accelerometers, mounted at the frog of the bow, to give acceleration data for all three axes of bow movement, two strain sensors, mounted around the middle of the stick, for downward (normal to the strings) and lateral (parallel to the strings) strains, and the outputs for the two signals necessary for position sensing (parallel to the bridge), located on the stick at the extreme ends of the bow hair.

Weight and Balance Point The overall weight of the *Hyperbow* was increased to 89.751g from the original weight of 60.930g. The balance point was shifted from approximately 25.5cm (measured from the frog end of the bow stick) to about 22cm. Though the weight is considerably increased, the shift in the balance point toward the right hand seems to ameliorate the effect. Though the weight might be reduced in future by finding a suitable battery that is lighter than those currently used (approximately 11g), the play-ability of the *Hyperbow* was found to be adequate by several professional violinists.

3 Applications

The *Hyperbow* has been used in public performances by a professional violinist in January 2002 in Dublin, Ireland and February 2002 in Berlin, Germany where it was included in Tod Machover's *Toy Symphony*. Future performances of this piece will take place in April (Dublin, Ireland), and June (Glasgow, Scotland) of 2002. The *Toy Symphony* piece includes a solo violinist, full orchestra, and a children's chorus.

Though it was designed to be an interface for a virtuoso violinist with a traditional classical music background, the *Hyperbow* is meant to be an alternative for any violinist, or indeed, for any player of a bowed string instrument. By offering possibilities for the real-time alteration of acoustic or electric sound though gestures familiar and learned by the player, the *Hyperbow* offers an endless supply of musical options. The *Hyperbow* enables players to view, inspect, and exploit the subtlety of their bowing.

Also, the possibility of using the *Hyperbow* to play already existing models of bowed strings, or indeed models of altogether different sounds, may be pursued. This might enable a person who has particular skill playing a violin to play other instruments in a style that is somewhat violinistic.

As the *Hyperbow* is a new instrument, with different capabilities than a traditional bow, it is hoped that further experimentation with the *Hyperbow* may lead to altogether new bowing techniques.

4 Future Work

There is much exciting progress to be made in improving the interface of the *Hyperbow* in order to make it more comfortable to play, to reduce the vulnerability of the sensing system, and to better accommodate the technological enhancements within the form of the bow. Perhaps in the future, a new bow may be created whose sensing system is contained completely within the bow stick.

The construction of a custom designed bow that better houses the sensing system may also necessitate the design of custom devices, such as strain sensors (possibly created with MEMS technology), whose form factor and material properties are better suited to this application. Because augmenting a musical instrument like a violin bow offers new challenges in terms of materials, form factors, and precision requirements, it is also possible that progress may be made in sensor and device technologies as a result of this new and rare research.

One might also hope that the design and construction of new bows would inspire the development of new stringed instruments.

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