WIRELESS SENSOR SYSTEM FOR MEASUREMENT OF VIOLIN BOWING PARAMETERS

Diana S. Young

Media Lab
Massachusetts Institute of Technology
Cambridge, MA, USA
diana@media.mit.edu

ABSTRACT

We present a new system to measure the position and force parameters most relevant to violin bowing technique. It is stable and reliable, and as it allows players to perform without impediment and consists of minimal equipment, it is also suitable for use in professional performance settings. This measurement system, implemented on a carbon fiber bow, relies on an electromagnetic field sensing technique for detecting both transverse bow position and bow-bridge distance and foil strain gauges for downward force measurement. The position data is collected using an antenna that is located behind the bridge and mounted from the tailpiece of an acoustic violin. The strain gauges are permanently mounted around the midpoint of the bow stick, and the force data is collected and sent to a remote computer via a wireless transmitter mounted at the frog. The resultant bow remains wireless, and the placement of the sensors and electronics ensures a balance point that remains within the normal range for traditional bows. We describe several experiments illustrating the usefulness of this system for continued studies of bowing parameters, as well as inspection of musical performance style and pedagogical applications.

1. INTRODUCTION

The measurement system presented in this paper was originally developed as an enhancement of a carbon fiber violin bow to create a new electronic music interface, or controller. Specifically, it was designed for the purpose of measuring various aspects of right hand bowing technique in order to enable real-time control of effects processing and synthesis algorithms in electroacoustic music performances [1]. This work was related to previous projects involving the modification of traditional string instruments to create new electronic music instruments for expert performers [2, 3, 4].

Despite its beginnings as a performance interface, this bow sensing system shows promise for use in scientific studies of bowing parameters. The limits of the bowing parameters of bow force, bow velocity, and bow-bridge distance are discussed in [5, 6, 7]. This work presents the inspection of bowing parameters as a means of understanding distinctions between different musical performances and musical styles. Because the system described here originated as a bow controller suitable for use in performance scenarios and environments, we suggest it as a tool for such studies.

In the following sections we describe the architecture of the sensor system and its operation. A closer inspection of the strain sensor measurement relating to downward force is detailed, which includes details of its range and performance. Finally, downward strain in the stick (corresponding to downward force), position and velocity, and acceleration data is shown for simple *detaché* bowstrokes.

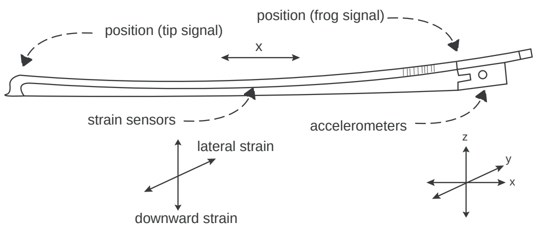

Figure 1: The measurement system for the bow includes accelerometers, mounted at the frog of the bow, to give acceleration data for all three axes of bow movement, two strain sensors, mounted around the middle of the stick, for downward (normal to the strings) and lateral (parallel to the strings) strains, 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.

2. MEASUREMENT SYSTEM

The violin bow measurement system discussed in this paper consists of three kinds of sensors. An electromagnetic field sensor [8] is used to measure bow position (transverse), foil strain gauges are used to detect both downward and lateral strain in the bow stick, and accelerometers are used to measure 3D acceleration.

The accelerometers are housed on an electronics board mounted on the frog, while the strain sensors are mounted directly to the bow stick around the midpoint of the bow. The bow board also sends two square wave signals to either end of a resistive strip that runs the length of the bow stick, acting as an antenna for the position measurement. Figure 1 shows the relative positions of the sensors on the carbon fiber bow.

The basic schematic for the bow board is shown in Figure 2, and the bay station schematic is shown in Figure 3.

The implementation of this sensing system is minimal and maintains the playability of the bow as much as possible. Though the sensors and electronics add a considerable amount of weight (almost 30 g), the balance point is still within the normal range, and the bow remains wireless. Details concerning the hardware design may be found in [1, 9].

For the purposes of the work in this paper, only the downward strain sensor, and the position sensor are necessary, though transverse acceleration (x) is a convenient indicator of changes in bowing direction. The downward strain sensor is used to reflect

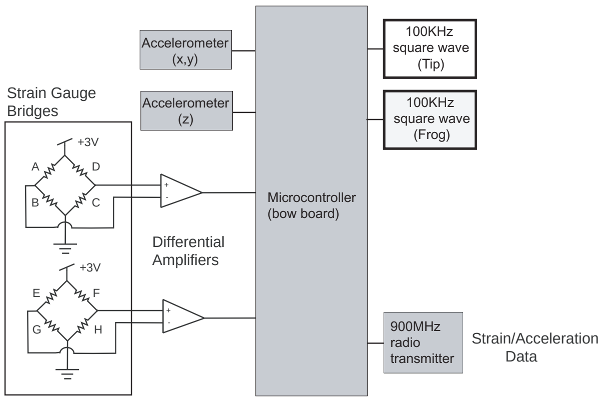

Figure 2: The electronics board mounted to the frog of the bow houses a microcontroller, two 2-axis accelerometers, and an RF transmitter. The microcontroller outputs the two square wave signals for the position measurement and receives the signals from the strain sensors as inputs to its internal A/D converter.

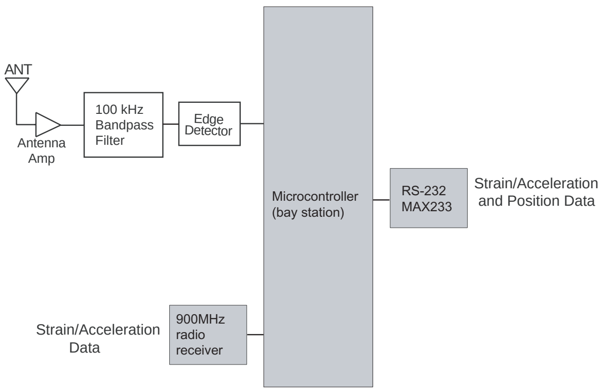

Figure 3: Bay station schematic. Signal radiating from resistive strip on bow received by electrode antenna mounted behind the bridge of the test violin. The signal is then passed through a bandpass filter and edge detector and into the A/D of the microcontroller. The position data values for the tip and the frog ends of the bow are then added to the stream of data carrying the strain sensor and accelerometer information (which is received via an RF module).

bow force, and the position sensor data is used to measure bow velocity and bow-bridge distance.

As depicted in Figure 4, the strain and acceleration data is transmitted from the bow wirelessly to the bay station, and the position sensor data is carried from the antenna mounted on the violin to the board via a cable. The microcontroller in the bay station combines the two data streams and sends the result to the serial port of the computer for analysis. Currently, the sampling rate of the bow data is about 40 Hz.

3. STRAIN SENSOR TESTS

In order to characterize the response of the downward strain sensor, the sensor data was recorded while force was applied directly to the bow stick by an Instron universal testing machine (4400 series). To accomplish this, the bow was secured by a clamp on either end (tip and frog). Unfortunately, this arrangement was not ideal and probably contributed to the error in the measurements, as the

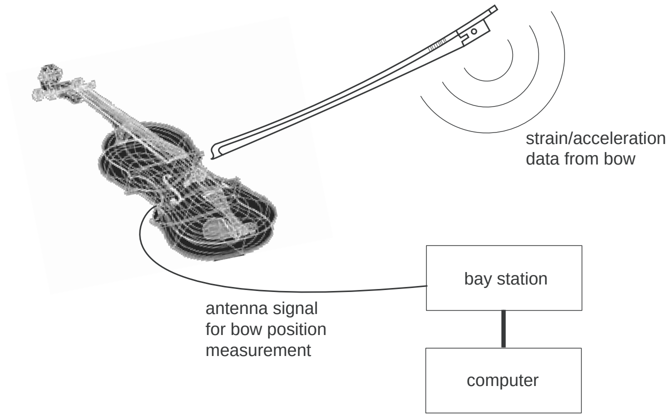

Figure 4: The bay station for the bow measurement system contains an RF receiver that receives the strain and acceleration data from the bow. An antenna cable also carries the position sensor signal to the board, and both data streams are combined into one and sent out of the serial port to the computer for analysis.

bow may have slipped during the experiments. Despite this likelihood, we proceeded with the measurements in order to estimate the range of the strain sensor.

Figure 5 shows plots of strain data taken for force applied at three different points along the length of the bow. Each plot shows the curve corresponding to increasing force on the stick, as well as decreasing force. Clearly, these measurements indicate definite hysteresis in the sensor. However, it is likely that hysteresis in the bow itself may be a large contributing factor to this behavior, as it is easy to observe that the stick is slow to recover to its original position after being held in a flexed position.

The experiment was repeated at the location around the midpoint of the bow for a smaller range in applied force, corresponding to the normal range of bow force discussed in [5, 6]. Figure 5(d) shows that for this smaller measurement range the hysteresis is significantly reduced.

Though the results of these experiments are limited, the data shown clearly indicates that the downward strain sensor is capable of reflected the full range of downward force used in normal violin playing.

Further tests should be done in order to correctly calibrate the stain sensor to properly reflect changes in downward bow force. Clearly, the setup used here was insufficient, due to the manner in which the bow was secured for data collection. Not only was the bow not held tightly enough during the experiment, but these measurements should be taken while the bow is held only at the frog. Therefore, we hope to repeat a series of similar experiments using a computer-controlled bowing machine. After doing so, a calibration curve relating the strain data to downward bow force for different bowing points should be attained.

4. POSITION SENSOR TESTS

Gesture data for simple bow strokes was recorded in order to illustrate the performance of the position sensor. As discussed in [8], the amplitudes of the signals emitted from the tip and frog may be use to determine the transverse bow position and bow-bridge distance. Bow position is found to be equal to the difference of the two values divided by the sum of the two values. In Figure 6, the bow position is plotted for bowstrokes of about 30 cm in length around the midpoint of the bow. The plot of the acceleration in this direction is also included to indicate the changes in bow direction.

These results are encouraging, as they indicate that the position sensor is quite linear in its response. Though the strain sensor data does not yet indicate illustrate the downward force parameter, its plot shows consistency and repeatability in the measurement.

Bow-bridge distance is not depicted here, but depends on the same data as the position measurement. In future, much more testing will be done to correlate the gesture data measured by the bow system with different strokes in order to further investigate the performance of the sensors.

5. CONCLUSIONS AND FUTURE WORK

We have presented a new kind of measurement system for bowing parameters that is suitable for use in performance scenarios and environments. Such a system could facilitate studies of musical style and may even be useful for pedagogical applications in which the monitoring of bowing parameters is used for training purposes.

Experiments were described that indicate that the downward strain sensor located around the middle of the bow stick is capable of reflecting the range of downward force used in normal violin playing. Also, the data from the position sensor was shown to be consistent and linear.

There is a great deal of work yet to be done toward a full characterization of the sensor system presented here, which should include experiments using a computer-controlled bowing machine. A thorough study of different bow strokes and musical performances should follow.

6. ACKNOWLEDGEMENTS

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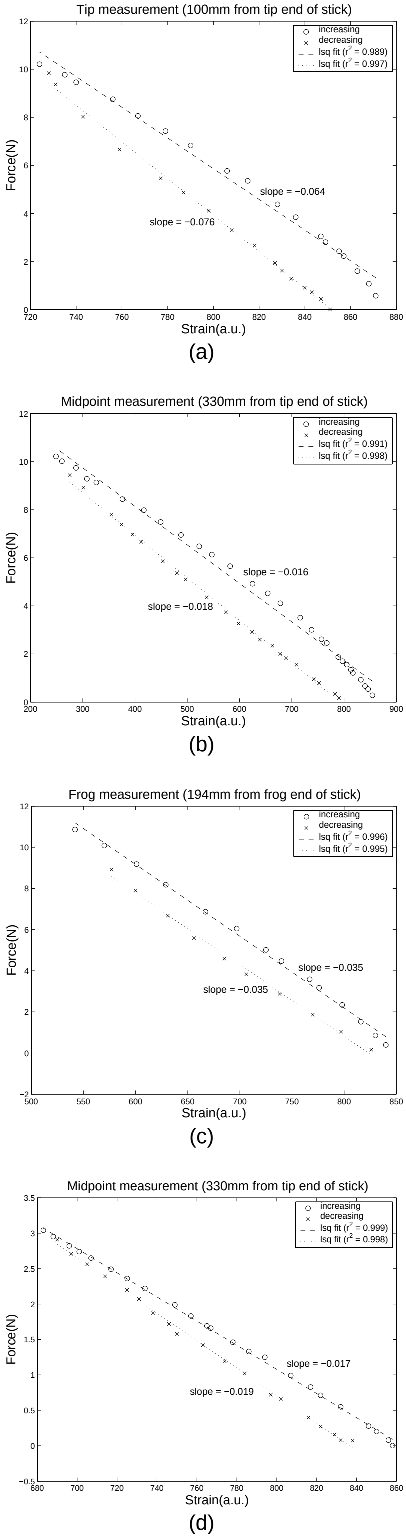

Figure 5: In order to calibrate the downward strain sensor, a force was applied directly to the bow as the sensor data was recorded. Data was taken for an increasing force of approximately 0–10 N, and then a force decreasing to zero. The exercise was performed for three points along the length of the bow at (a) 100 mm from tip, (b) 330 mm from tip, and (c) 194 mm from frog end. The measurement reveals a significant hysteresis effect. (d) The force calibration exercise was repeated for the midpoint position for a range of 0–3 N. It can be seen that the hysteresis observed in the previous plots is smaller for the lower range of applied force.

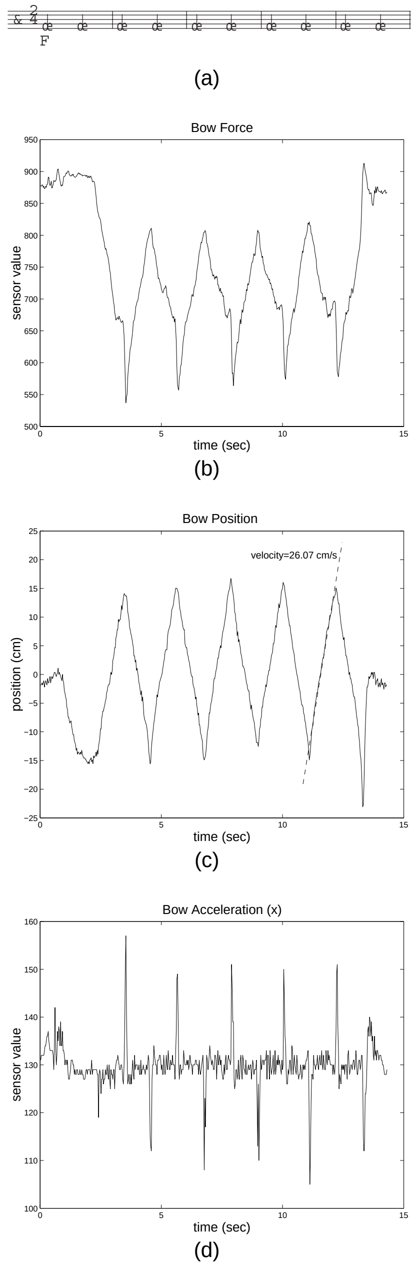

Figure 6: Gesture data was taken for a series of *detaché* bowstrokes, played on the open D string of the test violin. The figure shows (a) repeated strokes on the open D string, played at a steady *mf* dynamic level; (b) downward bow force reflected by the strain sensor measurement; (c) bow position over a range of about 30 cm around the midpoint of the bow stick, as well as the bow velocity indicated by the slope of the graph; and (d) data from the accelerometer indicating the changes in bow direction.