

MEASURING THE BOW PRESSING FORCE IN A REAL VIOLIN PERFORMANCE

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Abstract

In the last few years, many high quality and realistic violin synthesizers appeared. But the quality of the resulting sound is sometimes poorer than promised due to the lack of musical information provided to the system. It is very difficult for composers to deduce and include information like “bow speed”, “pressing force” or “fingering” to a MIDI file while real violinists base their musicality on these parameters, among others. The aim of this work is to present a system to measure the pressing force that the violinist applies to the violin string through the bow. It is based on two strain gages attached to the frog and the tip of the bow that modify the behavior of an electronic circuit. The output of this circuit is attached to a microcontroller to process the data and converts it to MIDI format. This paper will show the details of the system and the calibration.

INTRODUCTION

Music synthesis is one of the most important challenges in the music industry. The benefits it provides are enormous, specially for composers in their creative process. The violin is one of the most difficult instruments to synthesize due to the complexity of its performance. It is not difficult to sample or to synthesize their sound, but it is really difficult to reconstruct all the interpretative details such as articulations, timbres, intensity or vibrato. Furthermore, these parameters are correlated and depend on the musical piece. In summary, the main problem in violin synthesis is not the sound itself but the high amount of parameters to control, parameters that violinists are able to play with.

The main parameters the musician can play to generate a specific color in the sound are controlled by the right hand, using the bow. The left hand is basically used to change the pitch using a specific fingering (different sounds are produced by different fingering/string combination) and the vibrato. With the bow, the player can control the bow velocity, the bow pressing force, the bow-bridge distance, the bow tilt and the inclination (and the string which is played). There is no a direct relationship between these parameters and the resulting sound. Roughly speaking, a major bow velocity or a higher bow pressing force provides louder sounds. But we get more brilliant timbre which is a property also related to the bow-bridge distance. This shows that there is no a specific control for a specific sound quality.

The bow pressing force is one of the most difficult parameters to measure. The force applied by the musician to the string depend on many other parameters such the

bow position or the bow tilt. On the other hand, the main restriction in force measurements is that sensors need to be the less intrusive as possible which means a) low weight and b) no interaction with the Helmholtz motion [Cremer, 1984].

This work has been developed in the context of a violin synthesizer based on Spectral Concatenative Synthesis [Bonada, 2007][Schwarz, 2004. As explained in [Perez, 2007][Maestre, 2007], the overall system uses a Polhemus Liberty 3d-motion to detect the bow position, bow-bridge distance and bow velocity. Data provided by this sensor is used to train a set of neural networks that will decide which samples need to be concatenated to reproduce a musical sound according to a given score and musical articulation. In this process, the bow pressing force information is crucial. This paper will show how the pressing force measurement system is built using strain gages, how the electric signal is conditioned and, finally, how it is converted to MIDI. The calibration procedure will also be exposed.

PREVIOUS WORK

Askenfelt fixed the starting point of measuring the bow motion in string instruments in [Askenfelt, 1986]. He used diverse custom electronic devices attached to both the violin and the bow. The bow transversal position was measured by means of a thin resistance wire inserted among the bow hairs and the bow-bridge distance was measured according to the resistance value provided by the electrified strings. He use strain gages at the frog and the tip to detect the bow pressing force. Paradiso propose a novel wireless method to measure the bow position in [Paradiso, 1997]. He attached a resistive strip to the bow which was driven by an antenna mounted behind the bridge of the cello. For the violin implementation he decides to do the opposite that is building two drivers in the bow and use the antenna in the bridge as a receiver. A measurement relative to the bow pressing force is carried out by using a force-sensitive resistor below the forefinger. The main problem of these systems is how intrusive to the musician they are. The most important advance was made by Young in [Young, 2002] and [Young, 2003]. She measured downward and lateral bow pressure with foil strain gages, while the bow position with respect to the bridge is carried out in a similar way as in [Askenfelt, 1989]. The strain gages 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. In addition to the additional hardware attached to the violin, the highly customized bow imposed its use. Another successful approach was proposed by Rasamimanana in [Rasamimanana, 2003]. He performs wireless measurements of acceleration of the bow by means of accelerometers attached to the bow, and uses force sensitive resistors (FSRs) to obtain the strain of the bow hair as a measure of bow pressure. This system has the advantage that can be easily attached to any bow. Conversely, it needs considerable post-processing in order to obtain motion information, since it is measuring only acceleration. Finally, Demoucron [Demoucron, 2006] propose a system which is the most suitable for our constraints and which serves as the basis of our proposal. He proposes the use of two strain gages, one at the tip and the other on the frog, to detect the bow pressing force as a function of the deformation of the hair ribbons and the bow position.

DESCRIPTION

Strain Gages

Following the work proposed by Askenfelt in [Askenfelt, 1986], our approach uses of two strain gages which are mounted on the tip and the frog of the bow, as shown in Figure 1.



Figure 1: Strain gage at the frog and tip of the violin bow.

The two gages are configured as a 1-active-gage for measuring bending stress. The gages are attached to a plastic support which follows the deformation of the bow hair in detail and is light enough for our purposes. This plastic support is quite temperature sensitive. It forces to use only one strain gage in the configuration described above instead of the usual 2-active-gages configuration (which provide higher sensitivity and temperature cancellation produced by the thermal effect in the leadwires but does not avoid the physic deformation of the plastic support produced by high temperatures in both sides). We will compensate this effect using calibration.

The gages we use (Graphtec N11FA812023) acts as an electrical resistor. We use a Wheatstone bridge to amplify the signal from the gage and it is sent to an Op. Amp. At the output of the amplifier we have a continuous tension (0..5V) according to the bending of the bow hairs. This tension is proportional to a specific pressing force, as we will in the following sections. The schematics of this conditioning circuit are shown in Figure 2 and the welded main board is shown in Figure 3.

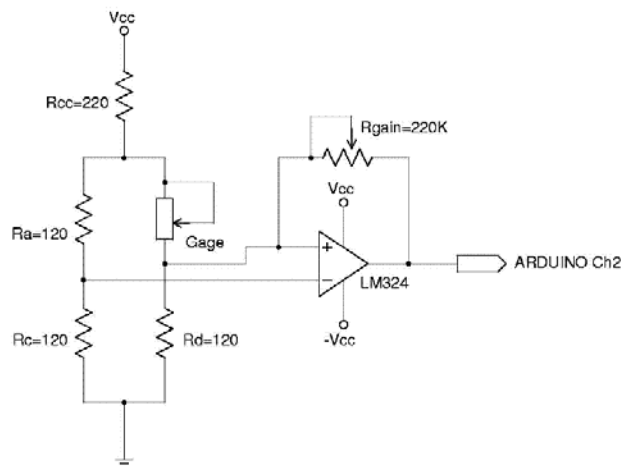


Figure 2: Conditioning circuit for a strain gage.

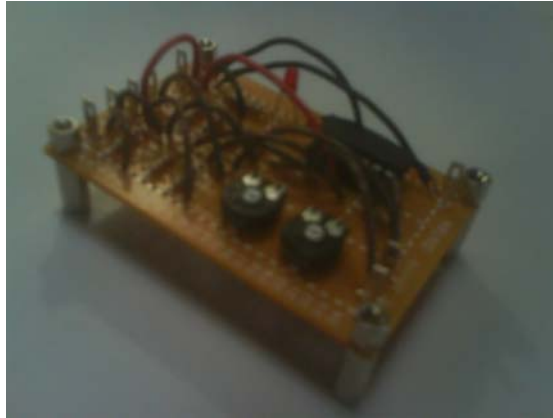


Figure 3: Main board of the welded conditioning circuit for the two gages.

The cable used from the gages in the bow to the conditioning circuit is thin enough to avoid the system being intrusive to the musician and coaxial to avoid interferences from the other sensors that can be attached to the bow or the violin.

MIDI conversion

From now on, we have an instrumented bow and the conditioning circuit. The output voltage has to be recorded in perfect synchronization with audio data given by the microphones in the recording studio. The easiest option is to convert the output information from the gages to MIDI format. In our first approach we use Doepfer-PocketElectronics analog to MIDI converter, but the sampling rate of analog inputs was too low for our purposes (www.doepfer.de/pe.htm). The second option was to use the Arduino which is an open-source physical computing platform based on a simple I/O board, and a development environment for writing Arduino software (www.arduino.cc). Figure 4 shows the two converters we have used.

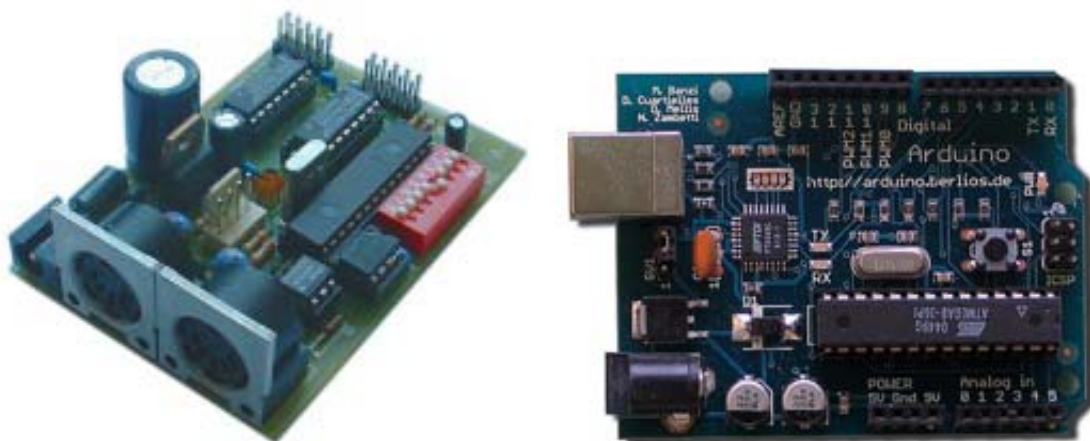


Figure 4: Pocket Electronics and Arduino boards.

The Arduino hardware is programmed to convert the analog input to a digital output according to the MIDI protocol. It uses a *baud rate*=32125Hz. The main loop search for data in the analog inputs and send the information in a NOTE ON message (always the same pitch) as VELOCITY information. A NOTE OFF message is sent

after each NOTE ON. Data from gage on the frog is sent in MIDI channel 2 and data from the gage in the tip is sent on MIDI channel 3 (see Code 1).

```
#define BAUDRATE 31250                // Typical MIDI baud rate
#define NOTE_CH2 0x64                 // E3
#define NOTE_CH3 0x67                 // G3
#define STATUS_NOTEON_CH2 0x91        // 145 Dec -> 91 Hex
#define STATUS_NOTEON_CH3 0x92        // 146 Dec -> 92 Hex
#define STATUS_NOTEOFF_CH2 0x81       // 129 Dec -> 81 Hex
#define STATUS_NOTEOFF_CH3 0x82       // 130 Dec -> 82 Hex

void loop(void)
{
  gage1 = gage1Value/8;
  gage2 = gage2Value/8;
  sendMIDI(STATUS_NOTEON_CH2,NOTE_CH2,gage1);
  sendMIDI(STATUS_NOTEON_CH3,NOTE_CH3,gage2);
  sendMIDI(STATUS_NOTEOFF_CH2,NOTE_CH2,0x00);
  sendMIDI(STATUS_NOTEOFF_CH3,NOTE_CH3,0x00);
}
```

Code 1: Excerpt of the definitions and main loop in the Arduino program.

The digital output from the Arduino is adapted to a MIDI OUT connector using a resistor ($R=220\Omega$) according to the MIDI Standards.

Noise Reduction

All the electronics (conditioning circuit and Arduino board) have been fixed in a metallic box to avoid interferences from the other sensors (see Figure 5).



Figure 5: Metallic box to avoid interferences.

CALIBRATION

The pressing force that the bow provides to the string is not directly related to the force that the violinist provides to the bow. It depends on the bow tilt and the bow position, between others. In this section we will describe the calibration procedure that translates the MIDI output to an input force (in Newtons). All the calibration measurements have been done with the hair ribbons stressed in a fixed position, according to our violinist criteria.

Dynamic Range

As explained above, the strain gages are mounted in a 1-active-gage for measuring bending stress configuration. This configuration forces the amplifier to work with high amplification values. The output of the OpAmp's don't use the whole available dynamic range between 0 and 5V. The expansion of the signal to fulfill the 5V range is carried out by the Arduino applying a function with an initial offset number and a linear expansion function. All these values are set manually according to the normal working conditions of the bow (see Code 2 for details).

```
#define GAGE1_CAL 76      // Calibration value for gage 1 (output at NULL input)
#define GAGE1_AMP 9       // Digital amplification for gage 1
#define GAGE2_CAL 102     // Calibration value for gage 2 (output at NULL input)
#define GAGE2_AMP 9       // Digital amplification for gage 2

void loop(void)
{
  ...
  gage1Value = (analogRead(1)-8*GAGE1_CAL)*GAGE1_AMP;
  gage1 = gage1Value/8;
  gage2Value = (1024-analogRead(2)-8*GAGE2_CAL)*GAGE2_AMP;
  gage2 = gage2Value/8;
  ...
}
```

Code 2: Calibration code for expansion of the dynamic range.

After the expansion, a residual MIDI Volume of 25 is obtained when the bow is relaxed and a maximum of 120..125 is provided by the bow at maximum pressing force.

Static temperature fluctuations

It is well known that the strain gages are very sensitive to the temperature but, in most of the cases, it can be compensated via the appropriate circuit. As mentioned above we have to deal with a simple gage configuration due to our requirements. A study of the deviation of values provided by the system across the time is shown in Fig. 6. It shows that the system is more stable after 15 or 20 minutes, but this stability is no absolute. We recommend measuring the values with no input force before each performance (see Figure 6).

Force calibration

In this section we will explain the procedure we use to obtain the correspondence between the output MIDI value (0..127) and the input force (in N). We have used a dynamometer to apply different known force values (in steps of 0.5N) to the hair ribbons, at different lengths from the bow (in steps of 2.5cm). Figure 7 shows de setup of the calibration procedure.

In the process of calibration it is possible, specially in those positions close to the frog or to the tip, that MIDI data is over 127 due to the excessive force applied. This situation will not occur in real working conditions of the bow. We decide to fix these results with a 127 MIDI value. On the other hand, the points far from the frog and the

tip of the bow it is possible to apply a force that produces the hair ribbons touch the wood stick. We decide to fix these results with the MIDI value obtained in the last valid measurement. Results are shown in Figure 8.

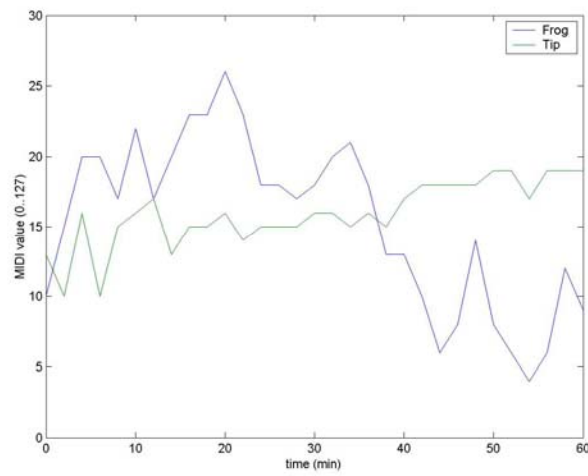


Figure 6: Evolution of the output of the gages during 1 hour with no presence of input force.



Figure 7: Force to MIDI calibration procedure.

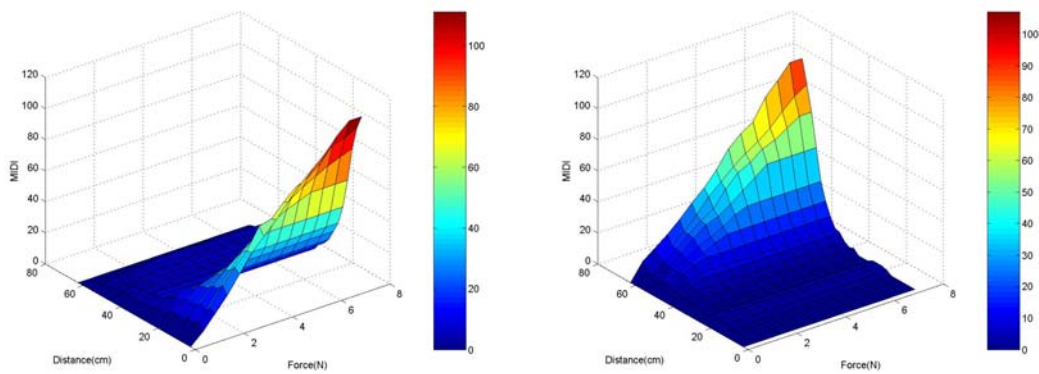


Figure 8: Results of the force calibration.

As mentioned above, the Polhemus sensors provide information of the bow position. Using this information, we are able to deduce the force (in Newtons) applied to the string. When the information from the two gages differs, the mean of these two values is applied.

CONCLUSIONS

In this paper, we showed a bow pressing force system that is able to record data in a real time performance. The sensors we use are not intrusive to the performer and data is transformed to MIDI format to provide a precise synchronization with audio data. The conditioning electronics are shown in detail as well as the method to convert data to MIDI format using the Arduino hardware. The calibration procedure and values are also shown in detail. The force values have been used in the concatenative synthesis algorithm with successful results. Actually, the whole process is implemented in a non real-time architecture. In a near future, we will implement a VST plug-in that automatically provide force information to the user while playing.

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