CALIBRATION METHOD TO MEASURE ACCURATE BOW FORCE FOR REAL VIOLIN PERFORMANCES

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ABSTRACT

In this paper, we present a procedure to predict bow pressing force in a violin from data acquired in real recordings. We focus on the calibration procedure that must be robust to the bow tension changes in long recordings and fast enough to not disturb the recording session. Because of this last limitation, the calibration method here proposed does not exhaustively cover all the possible bow conditions that potentially may appear in the recording. We propose the use of Support Vector Regression to predict all these missing scenarios and compute the predicted force. On the other hand, bow tension variations in long recordings produce decalibrations on the acquisition system. After analyzing their behavior, we propose a solution to compensate this effect based on post processing and a specific behavior of the performer at the beginning and the end of each phrase.

1. INTRODUCTION

Acquisition of bowing parameters in a violin is not a new topic of research. Askenfelt[1, 2] presented a method for measuring bow motion and bow force using diverse custom electronic devices attached to the violin and the bow. Paradiso[5] proposed to measure the bow force by using a force-sensitive resistor below the forefinger. More recently, Young[9, 10] measured downward and lateral bow pressure with foil strain gages using the Hyperbow controller. Rasamimanana[6] used force sensitive resistors (FSRs) to obtain the strain of the bow hair as a measure of bow pressure. Finally, Demoucron[4] and Schoonderwaldt[7] presented, in their PhD theses, an exhaustive and complete study on gesture acquisition and bow parameterization, respectively. Let us remark that the bow sensors we implemented are based on their studies and recommendations.

Most of the state of the art acquisition systems here presented have not been tested in a long real performance environment focused on the audio quality instead of the obtention of the bow motion parameters. Mechanical properties of the bow may vary on time: temperature and humidity are, among others, the most important extern parameters that affect the ribbon hair tension and, as a consequence, the bow force applied to the strings. This paper describes the full process to obtain real force values (in Newtons) for long recordings in a studio. The process is clearly divided in three parts. First, we describe the sensors and the corresponding signal conditioning. Second, we describe the calibration process and, finally, we show the post processing operations to compensate the bow tension deviations

2. SENSING SYSTEM

Bow force acquisition is a very specific part in our violin synthesizer design process. There exists many restrictions imposed by the other blocks that can be summarized as follows: a) Non intrusive to the player (dimensions and weight); b) Synchronized with other sensors; c) Focused on audio quality instead of motion capture; d) Time restrictions; e) Allow changes in bow tension by the performer; f) Robust to intrinsic bow tension variations; g) Capture all of the possible scenarios presented in the score using a short calibration procedure.

2.1. Motion Acquisition

Violin body and bow motions are recorded using the Polhemus Liberty system. It is a six degrees of freedom electromagnetic tracker that provides information on localization and orientation of a sensor with respect to a source. We use two sensors, one attached to the bow and the other one attached to the violin, in order to obtain a complete representation of their relative movement.

2.2. Strain Gages

Our sensing system for bow force prediction is based on the work of Demoucron[4]. We mounted a dual strain gage system attached to a steel foil ($0.9x5cm$), at the frog of the bow. In order to capture the deformation of the ribbon hairs, the steel foil is forced to an initial bending with no force applied, and this bending tends to zero as the

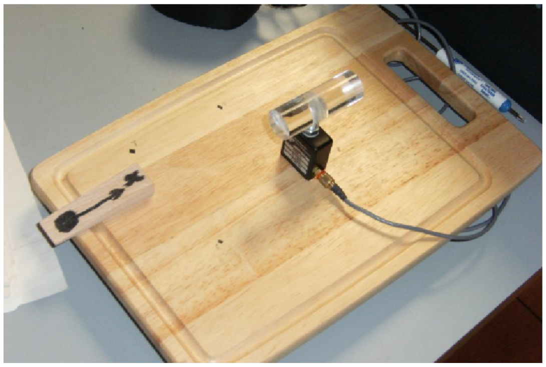

Figure 1. Load cell TransducerTechniques MDB-5 with the methacrylate virtual string and wood support.

applied bow pressing force increases. This deformation is assumed to be proportional to the bow pressing force, and it is function of the bow distance, the tilt, the initial tension provided to the bow, among others. Because of playability constrains, we could not mount another dual gage system at the tip because of: a) The long cord may create interferences to the Polhemus sensor and b) The weight and the center of gravity of the bow change drastically.The metallic piece has been glued to the frog via a wood piece that provides the gages a constant initial bending for increasing the dynamic range.

2.3. Load Cell

As suggested by Schoonderwaldt[7], we use the Transducer Techniques MDB-5 load cell for calibration. As shown in Figure 1, it has been mounted on a wood support and we attached a methacrylate piece over the sensor to simulate the string. By playing with the bow over this virtual string, we obtain the relationship between the real applied force and the deformation measured by the gages. During the calibration process, the Polhemus sensors are active so, we are also recording the information about bow position, tilt and inclination, for that specific initial tension (manually fixed by the performer). The calibration process using the load cell will capture and compensate all the playing scenarios, i.e. the force is not distributed across the width of the bow hair, different bow positions, bow tensions, etc.

2.4. Signal Conditioning

The signal from the gages is connected to a Transducer Techniques TM0-1 instrumentation amplifier through a wheatstone bridge mounted on a small board. The load cell is directly attached to another TM0-1 instrumentation amplifier whose output is also connected to the input of the A/D converter. For the A/D conversion, we use the Arduino prototyping platform. All the potentiometers are manually fixed to use the maximum dynamic range of the Arduino.

3. CALIBRATION

3.1. Load Cell Calibration

The first step is to establish a relationship between the output of the load cell and the conditioning circuit TM0-1 and force units (Newtons). Because of the load cell is designed to measure both compression and depression forces, we use only one half of its dynamic range. The output of the conditioning circuit is captured by the Arduino. We decided to calibrate the load cell using a set of precision weights and to compute the force produced by these weights to the load cell according to the Newton's second law $\sum F = M \cdot g$, with $g = 9.8m/s^2$, and extend the measured values using a linear regression ($y = ax + b$, being $a = 101.498$ and $b = 1.675$). These parameters must remain unaltered for the rest of the recording.

3.2. Setting Up the Bow

The measured value from the gages at the output of the Arduino depends on the following parameters: a) Bow position: the maximum deformation of the ribbon hairs is obtained when playing near the middle of the bow. Playing near the frog produces moderate deformations and playing near the tip produces low deformations; b) Bow tilt: maximum deformation is obtained for *perpendicular* playing; c) Inclination: in low pressing force conditions, the strain gages and their support produce a small deformation of the normal shape of the ribbon hairs which depends on the vertical inclination; d) Bow tension: the performer will adjust the bow tension according to their own preferences; e) Amplifier: position of the potentiometers.

The bow position, tilt and inclination are acquired by Polhemus sensors. The amplifier is adjusted to provide maximum dynamic range for all the normal playing conditions, including dynamics (from *pp* to *ff*) and bow tensions adjusted by the performer. Finally, the bow tension is, from now on, assumed to be constant for all the recordings. In Section 4 we show how to compensate time deviations on this parameter.

3.3. Recording Calibrations

According to the restrictions mentioned in Section 2, the calibration procedure must be short (it must not take more than two or three minutes) and complete (it must cover all the bowing conditions that potentially occur in the real recording). For that, we play with the instrumented

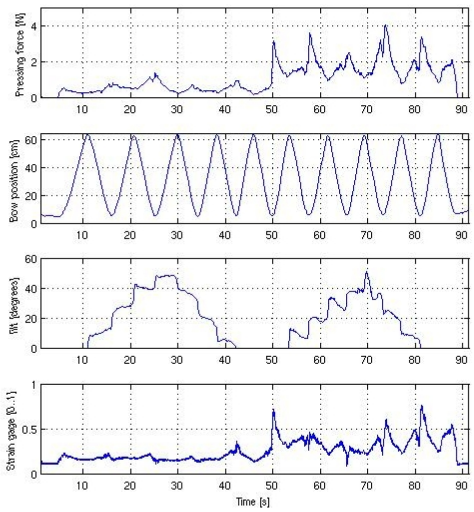

Figure 2. Recorded data from calibration: a) Pressing force measured at the load cell [N], b) Bow position [cm], c) Tilt [degrees] and d) Strain gages [0..1].

bow over the methacrylate piece, as if it were a string, covering all the possible scenarios (tilt, bow position and pressing force; after some initial experiments, the inclination is not taken into account because it only affects when the applied force is zero, i.e., the performer is not playing). Figure 2 shows an example of recorded data for a real calibration. We use a specially developed software to synchronously record all data. To extend the stored information to all the possible scenarios, we train a Support Vector Regression (SVR) algorithm which will be able to predict the real pressing force (in Newtons) from the other parameters. The Support Vector machine was developed at AT&T Bell Laboratories by Vapnik et al.[3] and good performances in regression and prediction applications emerged soon (See [8] for a detailed explanation on this technique). Using 10-fold cross validation on training data from callibrations, we got *squared correlation factors* > 0.95.

4. BOW TENSION'S TIME DEVIATION

4.1. Calibrations

At this point, the system is assumed to be calibrated. But depending on the score, the time lapse between calibrations and the temperature of the strain gages, the bow tension and the measured values change for each recorded phrase. It is difficult to quantify these deviations but the error induced in the predicted force may be about $1[N]$. To solve this problem, we propose to perform two calibrations for each group of recordings, one

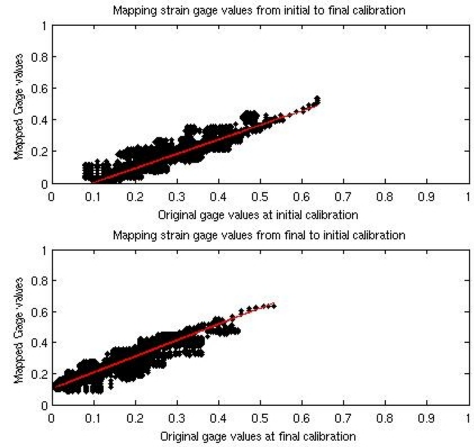

Figure 3. Mapping of measured values in similar scenarios for two calibrations: a) Mapping from initial to final calibration; b) Mapping from final to initial calibration.

at the beginning and other at the end. The time lag between these two calibrations may be up to $45'$. Both calibrations have different bow tensions. As we have the motion and real force data, we can map the strain gages value in a specific context (similar measured forces, bow positions, tilts and inclinations) from the initial calibration to the final calibration, and viceversa. Each black point in the upper graphic on Figure 3 represents a specific scenario in the original calibration file that is also represented in the final calibration. The lower graphic represents the specific scenarios in the final calibration that are also represented in the initial calibration. Assuming these mapping functions are linear, we deduce that small changes in bow tension linearly affects the deformation of the ribbon hairs and the value provided by the strain gages. The mapped strain gage values can be used to train the SVR: we can compute the bow force from one of the calibrations *as if it were played* in the same bow tension conditions of the other calibration. After training, we have four SVR models for each group of recordings: a) SVR model from initial calibration; b) SVR model from initial calibration as if it were played using final calibration conditions; c) SVR model from final calibration; d) SVR model from final calibration as if it were played using initial calibration conditions.

4.2. Recordings

We can compute linear mapping functions between calibrations because we acquired real force data. In real recordings, such information is not available, so, how can we deduce the mapping function? Our intention is to apply a mapping function from the strain gage mea-

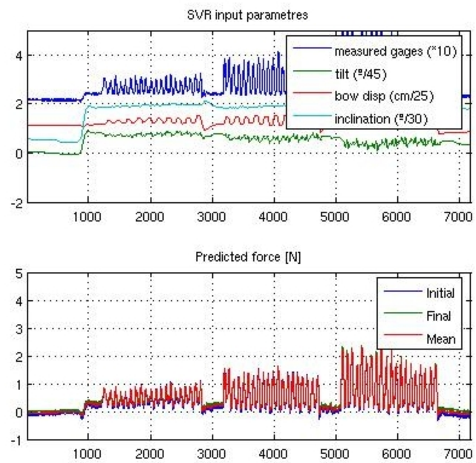

Figure 4. Example of measured parameters and predicted forces: a) measured values that will feed the trained SVR models and b) predicted forces by converting the the gage values

sured values to the initial and final calibrations, compute the real force for each case using their respective SVR model and compare that both results are (theoretically) the same. For that, we asked the performer to start and finish each phrase with the bow in a *relaxed* position, that is 0^o for inclination and tilt, and $0N$ of applied force. Then, we can study the time evolution of the gage values on these equal conditions, and deduce the mapping function from that. This procedure is fast (about $1s$ before and after each phrase) and non intrusive to the performer.

Figure 4 shows an example of the measured parametres and predicted forces of a recorded phrase. Note how the two predictions are quite close. This means that the linearity hypotheses assumed in Section 4.1 can be accepted.

5. CONCLUSIONS

In this paper, we presented a procedure to predict the bow pressing force in a violin bow from data acquired in real recordings. The work focuses on the calibration procedure that compensates the changes in the bow tension in a long session. This calibration method accomplishes the requirements imposed by real recordings in which time is limited and the sensing system has to be non intrusive to the performer. Because of these restrictions, calibration data is not complete and we use Support Vector Regression to expand the measured data to all the possible bow conditions that potentially may occur in the recording. We also show the proposed methodology to compensate bow tension variations.

6. ACKNOWLEDGEMENTS

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