THE VIOLINIST'S BESTIARY: CHARACTERIZING BOWING PARAMETERS OF TECHNICAL BOW STROKES

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ABSTRACT

In violin playing, the properties of the sound are shaped continuously through the control of three main bowing parameters that are the bow force, the bow velocity, and the bow-bridge distance. The mastering of the range and the time evolution of these bowing parameters in different playing situations is one of the main challenges of the violinist's education and training. Furthermore, playing violin also requires the mastering of different bowing techniques like staccato, or spiccato, which are very dynamical and short bow strokes.

Technologies like motion capture and sensors allow measuring the effective bowing parameters used by the performer in real performances. These measurements can be analysed in order to characterise playing techniques and differences among musicians. In this paper, we will present measurements of control parameters for basic classes of bowing patterns (sautillé and martelé), whose performance is mainly based on reproduction of well-practiced motor behaviour, more than on conscious control in real-time. Because a proper performance of these bow strokes requires extensive practicing under a long period of time, they exhibit characteristic and reproducible bowing parameter patterns. The time evolution of the bowing parameters was modelled by analytical functions, which allowed to describe and characterise bow strokes by a limited set of control parameters.

1. INTRODUCTION

Musical performance and the control of musical instruments can be studied from the point of view of control parameters, i.e. the description of the action of the musician on the instrument. In some instruments like the piano or some drums, the interaction between the player and the instrument is limited in time and the musician's action for each note can be described by a limited set of parameters (force and position of the impact for the drums, key velocity for the piano, for example). However, the case of continuously excited instruments like bowed string or wind instruments is more difficult to deal with, because the action varies along time. For example, in violin playing, the time evolution of the sound is shaped through the control of three main bowing parameters that are the bow force, the bow velocity, and the bow-bridge distance. The magnitude and the relative variation of these parameters along time offer an almost unlimited space to explore in order to obtain different sounds and different dynamical shape of the sound, which make the expressive richness of these instruments. In this case, the control and the performance cannot be directly described by a set of discrete parameters, one for each note, and it is necessary to reduce the problem by finding a set of pertinent parameters describing the time evolution of the bowing parameters.

In the past, the problem has been mainly approached for sound synthesis purposes, in order to produce adequate bowing parameters from musical scores. For instance, sound synthesis based on physical modelling requires a description of the control parameters representing the action of the player. Pioneer works have been presented by Chafe [1], Jaffe and Smith [3] or Rank [2]. In a recent work by Maestre et al [4], the time evolution of the bowing parameters are represented as a sequence a short segments, each segment being modelled using Beziers cubic curves. After analysis of real performances, the authors constructed a database of classes representing different playing situations and they were able to synthesise bowing parameters from different musical scores.

Violin performance is based, for a great part, on different bowing techniques that have been practiced and improved during years of education. A first class is made of bow strokes during which the player steadily draws the bow across the string in order to maintain a continuous vibration of the string (Helmholtz motion). For instance, for notes played *détaché* or *legato*, the player continuously controls the motion of the string in order to obtain the adequate vibration and specific sound properties depending on the musical context (sound colour, variation in dynamic). More importantly, he receives an immediate feedback from the instrument which allows him to adapt his control and make corrections while executing a given note.

A second class of bowing patterns consists of short or quick strokes, during which the player cannot have a conscious control in real time. It can be assumed that the performance of such bow strokes is mainly based on reproduction of well-practiced motor behaviour and, to some extent, these bow strokes could be considered as ballistic movements. Examples of bow strokes belonging to this class are *martelé*, *spiccato*, *sautillé*, and *tremolo*.

In our approach, we will not try to have an extensive description of all possible playing situations. Instead, we will focus on the later class, i. e. short and highly dynamical bow strokes. Because the proper performance of these bow strokes requires extensive practicing under a long period of time, we can assume them to exhibit characteristic and reproducible bowing patterns. For each of these bow strokes, we used simple mathematical functions (mainly sine functions) in order to reproduce the time evolution of bowing parameters measured with a system combining optical motion capture and sensors attached on the bow [5]. In contrast with the approach in [4], our goal was to build representations described by a limited set of parameters that could be easily understood and interpreted, and we wanted each model to be sufficiently general to allow extrapolation capabilities (i.e. some related bow strokes could be obtained easily by changing only a few parameters in the model). As a consequence, a compromise had to be fund in each case between the simplicity of the mathematical expression, the pertinence of the parameters, the fidelity to the original measurements, and the extrapolation capabilities of the models.

In this paper, measurements and the modelling of different bowing techniques are shown and discussed. Sect. 2 is concerned with bouncing bow strokes, and Sect. 3 presents dynamical and accentuated bow strokes belonging to the class of martelé bow strokes.

2. BOUNCING BOW STROKES

2.1. Description

Bouncing bow strokes are started from the air and finish off the string. The string is excited during a rather short contact time, set by the rebound of the bow. Because the bow leaves the string, the string is then free to vibrate with a decaying oscillation. This principle of driving the string is shared by several bowing patterns that differ essentially in the technique that is used for controlling the rebound, according to Galamian [6]: in spiccato, "the bow is thrown down on the string for every single note and (at least for the longer strokes), lifted up again", while the sautillé uses the natural rebound of the bow for performing several notes with the same impulse, and the bow comes off the string because of the elasticity of the bow.

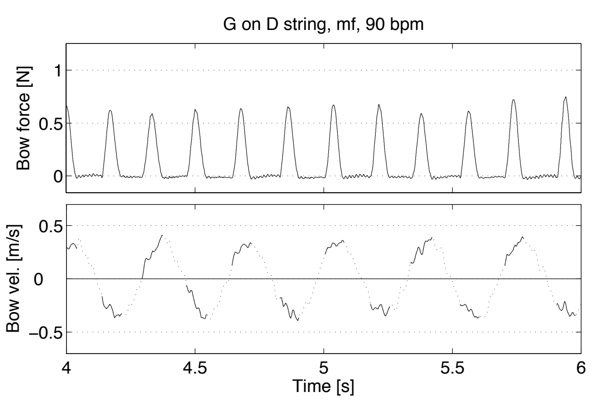

Figure 1: Illustration of bowing parameters measured during sautillé. From top: Bow force, bow velocity and bow-bridge distance. The bow velocity is displayed in solid line when the bow and the string are in contact.

In Figure 1, bowing parameters measured during sautillé are illustrated. Roughly, the force shows regular impulses corresponding to the rebound of the bow on the string. Each individual bow force pattern exhibits a bell-like shape mainly characterized by the maximal force that is reached (around 0.74 N here). Furthermore, the synchronisation between the rebounds and the velocity changes is of primary importance in order to obtain well performed sautillé, as noticed by Guettler and Askenfelt [7].

2.2. Modelling bowing parameters

All variations of bouncing bowing patterns share the same feature, which is the rebound of the bow on the string. The time evolution of the bow force during the rebound can therefore be considered as the most prominent feature for the perception of the rebound. The model used to reproduce the bell-like shape of the bow force is illustrated in Fig. 2. Two successive cosine functions are used, before and after the force maximum.

Each function is defined by three parameters (frequencies f_1 and f_2, amplitudes A_1 and A_2, offset O_1 and O_2), but these parameters can be changed in more intuitive and relevant parameters such as the force maximum during the stroke F_{max},

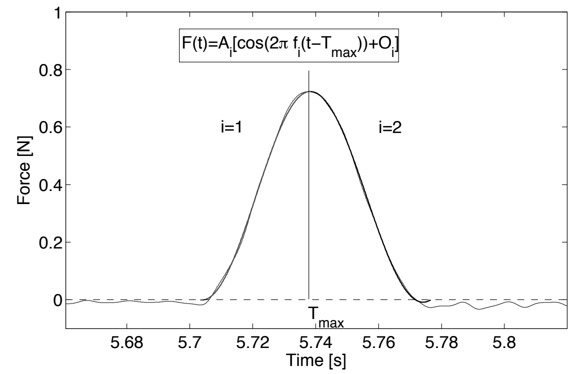

Figure 2: Double cosine model used for fitting the bow force during the rebound in sautillé

the duration T of the contact, the asymmetry of the shape A, and the slope at the beginning and the end. Fig. 2 shows that the model fits well on real measurements: no difference can be seen between the measured and the fitted curve.

In sautillé playing, the bow bounces only once on the string while performing a short to-and-fro movement. The simplest representation of the to-and-for motion of the bow consists in using a half sine curve per bow stroke for the bow velocity. Fig. 3 shows such a model, with real data in grey and a fitted sine in black. The duration T_{bs} of the stroke is determined by the positions where the velocity crosses zero. The amplitude of the sine must be fitted to data.

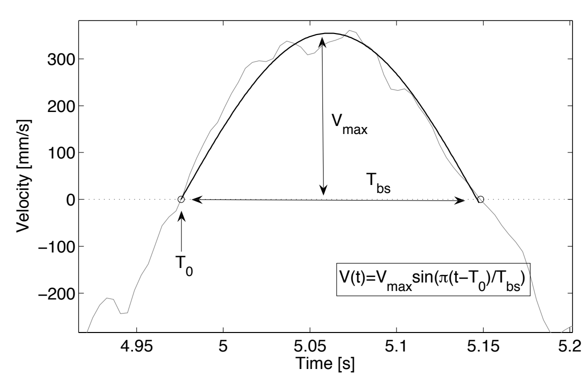

Figure 3: Simple sine model used for fitting the bow velocity in sautillé.

2.3. Fitting model parameters to measurements

The model parameters used to synthesise the bow velocity and bow force patterns don't have the same importance. Intuitively, we expect the maximum bow force, the velocity amplitude, the duration of the stroke and the phase between bow force and bow velocity to have the strongest effect on the synthesised sound. In contrast, the asymmetry factor can be used to change the balance between the landing and lifting of the bow.
A more complete discussion about the fitting and the values of the model parameters can be found in [8]. As an illustration, Fig. 4 shows the force maximum and the velocity amplitude for the model fitted to real measurements, for three dynamic levels (p, mf, f) and two tempos (90 and 150 bpm).

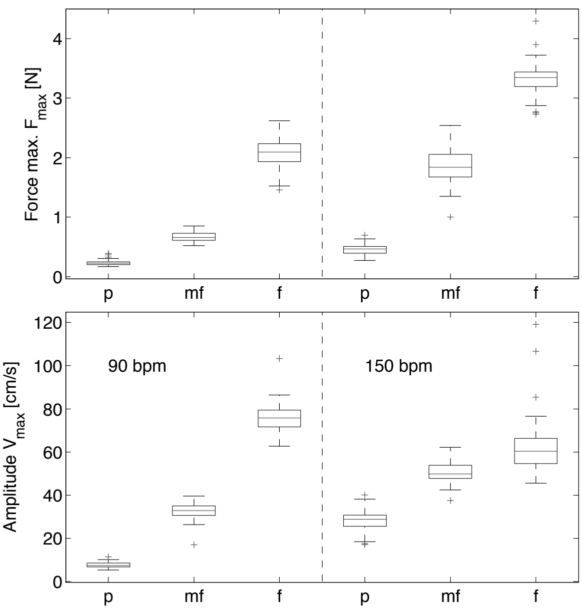

Figure 4: Example of model parameters fitted to real measurements, for three dynamic levels (p, mf, f) and two tempos (90 and 150 bpm). Top: Force maximum. Bottom: Velocity amplitude.

As expected, the force maximum (Fig. 4, top) is found to increase with increasing dynamic level and the values range from around 0.5 N in piano to more than 3 N in forte. It is interesting to compare the resulting trends with the velocity amplitude presented in Fig. 4, bottom. At 150 bpm it was found that the increase in velocity was not as clear as for the slower tempo. In contrast, we can notice that the increase in force is still very clear for rapid sautillé. An explanation could be that rapid motions of the bow constrain the gesture of the player in such a way he cannot control the velocity as freely as when the motion is slower.

3. FAST MARTELÉ

3.1. Description

The fast martelé is one of the three fundamental types of bow strokes together with détaché and spiccato, according to Menuhin. It is a fast, accented bow stroke that requires a good control of the bow for obtaining precise variations of the bow force.
According to Galamian [6]: "The martelé is decidely a percussive stroke with consonnant type of sharp accent at the beginning of each note and always a rest between strokes. The accent in this stroke requires preparation in the form of a preliminary pressure: the bow has to "pinch" the string before starting to move. This pinching is a pressure stronger than the stroke itself will require, and it has to last just long enough to produce the necessary accentuation at the beginning of the tone. The pressure is then immediately lessened to the degree required. If this preparatory pressure is released too soon, there will not be any accent; if it is released too late, there will be a scratch."

This description is illustrated in Fig. 5, which shows measurements of bow force and bow velocity during the performance of three fast martelé strokes. During the stroke, the bow force if rapidly decreased from about 1.5 N to less than 0.5 N. During intermediate periods of rest (shaded parts), the

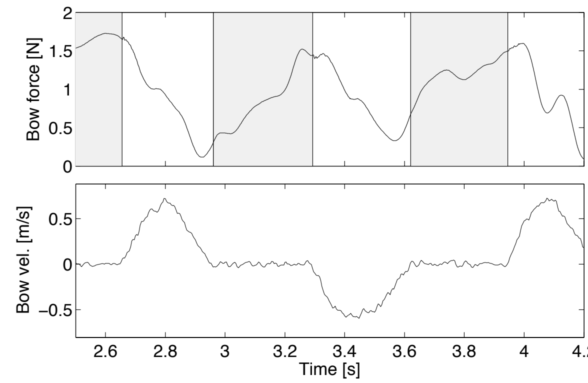

Figure 5: Illustration of fast martelé. Top: Bow force. The periods when the bow is at rest are shown shaded. Bottom: Bow velocity. The direction of the bow was down-u-down.

force is increased to the high initial value in preparation of the next stroke.

3.2. Modelling bowing parameters

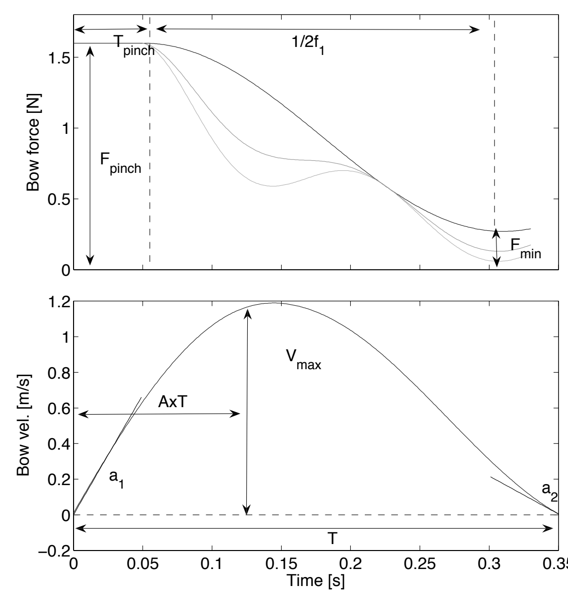

Figure 6: Model used for fitting the bowing parameters of fast martelé. Top: A short constant part followed by a simple sine used for simulating the bow force decrease (dark line) A second sine with higher frequency is used to reproduce the damped oscillations of the bow due to the sudden relaxation of the bow force at the beginning of the stroke. Bottom: The cos-cos model described for the bow force during sautillé is used for reproducing the time evolution of the velocity.

As the bow velocity patterns are rather similar to the bow force evolution that was observed during rebounds of the bow (bell-shape profile), the same model will be used (cos-cos model). The resulting pattern and the parametrisation is illustrated in Fig. 6 (Bottom). The observed decrease in force can be modelled by a sinusoidal decrease. To enable a control of the time during which the string is "pinched", we add a constant part at the beginning. The force profile and definition of the parameters are shown in Fig. 6 (Top). This modelling provides a good description of the overall shape of the bow force. However, some more or less pronounced oscillations around a frequency of 13 Hz can be observed as well, which are probably due to the response of the bow when the finger force on the stick is suddenly decreased at the start of the motion. These ripples can be modelled with a second damped sinusoid with a higher frequency.

3.3. Extending the models

The gesture models are described by a few parameters that can be changed in order to obtain different time evolutions of the bowing parameters. Some of these parameters such as the maximum velocity or the value of the initial pinching have a great influence on the simulated sound, while others such as the ripples in the bow force, or the initial and ending slope of the bow velocity, will only have a slight influence on the simulated strokes. The important point is that the models are not restricted to the exact reproduction of the strokes they are inspired from, but they have extrapolation capabilities. By changing the parameters, it is possible to obtain different qualities for the bowing patterns (well performed or not), and we can also move away from these standard cases in order to reproduce related bow strokes such as flying staccato, and collé, for example.

As an illustration, different qualities of the fast martelé will be produced if the initial pressure of the bow on the string is too high, or if the force is decreased too late. In this case, the resulting sound will be scratchy during the attack or part of the stroke. Similarly, a scratchy sound is produced when the bow pressure restored to its initial value too early at the end of the stroke, when stopping the bow, which can be simulated by making the period for the decrease such as the minimum of the force is well before the end of the stroke.

The flying staccato ”is performed with the same motion as the solid staccato, except that the pressure is lightened and the bow is permitted and encourage to leave the string after each note” [6]. In order to simulate this stroke, the model for the martelé is used, with a force decreasing below zero in order to imitate the release of the bow from the string. However, in the case of the flying staccato, the bow force must become positive again and damp the free oscillation of the string before the start of the next stroke. The collé is very similar, but the time of preparation is reduced to minimum, and the string is encouraged to oscillate freely between successive strokes.

4. CONCLUSION

We have illustrated the modelling of bowing parameters for two important bowing patterns in this paper: bouncing bow strokes sautillé and spiccato, followed by fast martelé and related bow strokes. We have presented representative bowing parameters, measured during real performance, and, from analyses of the measurements, we have empirically deduced simple models that reproduce the time evolution of the bowing parameters well.

The bowing parameters models can be used to control a physical model of the bowed string, for example. With adequate parametrisation, the gesture models produce very satisfying sound synthesis. Special care was taken to obtain an intuitive parametrisation of the models, because we wanted the model parameters to be relevant and as understandable as possible from a string player's and a naive user's point of view. In the design of the models, choices were made in order to permit extrapolation to related types of bow strokes by simply modifying relevant parameters.

The models described here can be considered as basic bricks of a musical discourse. The model parameters for each bow stroke provide a faithful description of isolated strokes, and could be also used to analyse a musical performance.

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