Visualization of bowing gestures for feedback: The Hodgson plot

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Abstract

A set of displays is proposed for the visualization of bowing gestures measured using motion capture techniques. The main displays (Hodgson plots) show the spatial trajectory followed by the bow frog in time in two different projections. The bridge and the strings of the instrument are shown in the background, forming a functional context for the displayed bowing gestures. The main purpose of the visualizations is to provide informative feedback to players regarding their use of the bow, making them suitable for pedagogical use.

1. Introduction

Motion capture (MoCap) techniques have been proven useful for the analysis of bowing gestures in bowed-string instrument playing. The obtained data is charactarized by a high temporal and spatial resolution allowing for detailed analysis of timing and coordination [1, 2], extraction of bowing parameters such as bow speed and bow-bridge distance [3, 4], and the study of the kinematics and kinetics of players in relation with the development of injuries [5, 6, 7].

As is well known the player of a bowed-string instrument exerts direct control over the produced sound with the bow, mainly by varying bow speed, bow-bridge distance and bow force (i.e., the normal force exerted by the bow on the string). The production of a good tone under voluntary control of the player requires a subtle coordination of these bowing parameters. The creation and maintenance of a regular string vibration (Helmholtz motion) imposes physical constraints on the possible combinations of bowing parameters [8, 9]. Furthermore, the serial execution of bow strokes in the context of a musical piece requires planning ahead to optimize bow distribution, not to mention the wide variety of different bowing techniques the player has to master. Gaining control over the bow is therefore one of the major goals in learning to play a bowed-string instrument.

In the light of the previous the possibilities offered by MoCap are potentially interesting for bowed-string instrument teaching to provide feedback to the player on his/her use of the bow. The most obvious way to achieve that is by means of visualization. The cyclographs made by Hodgson [10] represent – as far as known by the author – the first photographic images of bow motion during violin performance used for pedagogical purposes. More recently, visual displays of quantitatively measured bowing gestures have been developed by Ho [11], Rabbath & Sturm [12], and Ng et al. [13]. These contributions show clearly the potential of the use of technology in instrumental teaching. However, most of these approaches are based on a rather implicit notion of feedback, assuming that what is shown will somehow have the desired effect. What still fails is a vision of how the feedback can be understood and utilized by students, and related to their playing skills.

In this paper visualization methods of bowing gestures recorded using MoCap and/or other quantitative sensing techniques are proposed. During the design special effort was made to make the displays as accessible and informative as possible to enhance the communication of feedback to the student.

2. Visualization of bowing gestures

2.1. Measurement of bowing gestures

The proposed visualization methods require an accurate measurement of position and orientation (6 degrees-of-freedom) of both the bow and the instrument. In addition, the positions of important landmarks on the bow and the violin (bridge, strings, hair ribbon) must be known, either via direct measurement or reconstruction. The visualization methods can in principle be applied on data obtained via different measurement techniques (e.g., [3, 4, 13,

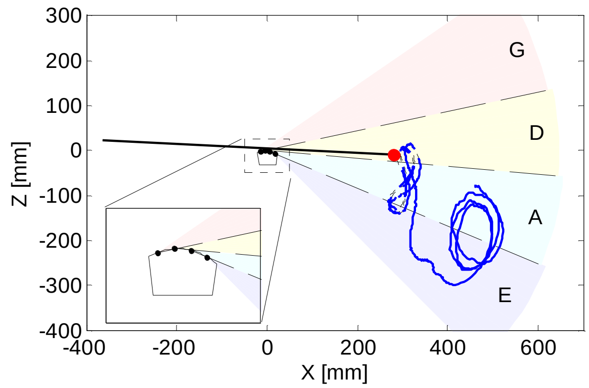

Figure 1. Hodgson plot in orthographic back projection (xz-plane). The red dot indicates the position of the frog at the "present" moment (i.e., at the end of the selected time interval). The solid black line corresponds approximately to the bow-hair ribbon from the frog to the tip, ignoring the bending of the hair at the bow-string contact point. The trajectory history of the bow frog is indicated by a blue line, shown as solid and fat when the bow was in contact with the string, thin and dotted otherwise. In the background, the bridge, string positions and string crossing angles are shown (see close-up for more detail), forming the functional context of the displayed bowing gestures. The string crossing angles (dashed lines) subdivide the space into 4 angular zones associated with the bowing of the different strings. The zones are indicated with different pastel colors: blue (E string), green (A string), yellow (D string) and red (G string).

14]). Technical details about the measurement methods are therefore out of the scope of this paper.

For the measurements shown in this paper a six-camera Vicon system was used for motion capture. Bow force was measured using a custom-made sensor, developed by Matthias Demoucron (IRCAM). For more details of the methods used the reader is referred to Schoonderwaldt et al. [3].

2.2. Design criteria

The major goal of the visualizations is to provide informative feedback on the use of the bow, as this forms an important element in the practicing process. According to Ericsson et al. [15] three requirements need to be fulfilled for deliberate practice: (1) a well-defined task, (2) informative feedback, and (3) opportunities for repetition and correction of errors. Feedback can hereby be understood as a "process by which an environment returns to individuals a portion of the information in their response output necessary to compare their present strategy with a representation of an ideal strategy" [16]. It has been shown that technology can successfully enhance teaching of complex musical tasks when implemented according to these criteria [17].

For a clear presentation of the feedback the following criteria were taken into account for the design of the visual display. Firstly, the display should be easy to understand for musicians without a scientific background. The visualizations should mainly be self-explanatory and the information should be presented in such a way that the player can easily relate it to his/her actual playing. Secondly, the display should contain relevant information giving the player an idea of how to improve his/her performance. A third criterion was that the display should not be normative in itself. The representation of an ideal strategy (see the above definition of feedback) should arise from comparison with other performers or self-exploration, rather than being imposed via norms and fixed criteria. This should make the display more versatile and easier to integrate in different teaching approaches.

2.3. Hodgson plots

The visual displays proposed in this paper are based on the cyclographs presented in Hodgson's book [10], and will therefore further be referred to as "Hodgson plots." In the current implementation Hodgson plots show basically the spatial trajectory followed by the bow frog during a chosen time span (typically 1 s). This provides a simple representation of bowing gestures with a direct relation to the actions of the right hand of the player.

The acquisition of 3D data using MoCap in combination with calibrated geometrical models of the bow and the violin allows for some important additional features. Firstly, the motion of the bow can be transformed to the reference frame of the violin, showing only the effective bowing gestures related to sound production. Thus, there is no need to constrain the movements of the player, allowing for natural playing conditions. Secondly, different projections can be chosen. This allows for example to show the bowing gestures from the perspective of the player to strengthen the association with his/her own actions. Finally, it is possible to visualize important landmarks on the violin, such as the bridge, the strings and the angles corresponding with string crossings, in order to provide a functional context for the displayed bowing gestures.

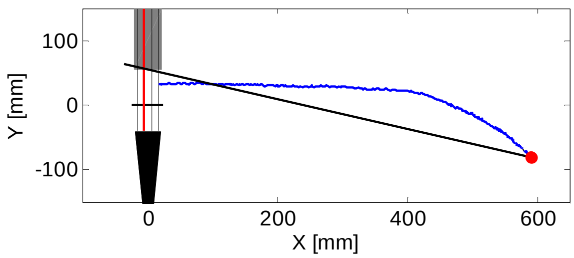

Figure 2. Hodgson plot in orthographic top projection (xy-plane). The bow and the frog trajectory history are shown in a similar way as in Fig. 1. The context is formed by the 4 strings (vertical lines), the bridge (bold horizontal line), the fingerboard (gray rectangle) and the tailpiece (black shape), based on the specific measures of the instrument. To enhance the clarity, the string played at the "present" moment (i.e., the moment the bow is shown) is highlighted in red.

Two types of Hodgson plots are proposed representing different orthographic projections, which together cover the main aspects of the motion of the bow. In the back projection (Fig. 1) the violin is more or less seen from the player's perspective. This projection is especially suited for showing complex bow coordination patterns involving bow changes and string crossings (see Hodgson [10] for an extensive overview of different types of patterns). The fragment shown in Fig. 1 is a selection of about three seconds of a performance of "Praeludium and Allegro" composed by F. Kreisler. It contains two clearly distinguishable coordination patterns: semi-quavers across two strings played détaché (circle-shaped pattern) and semi-quavers across three strings played spiccato (eight-shaped pattern). A wide variety of information can be obtained from the displayed patterns, for example about the bow distribution (bow position, amount of bow used), the regularity of the motion and the efficiency of the string crossings.

The top projection (Fig. 2) shows the violin from above. This projection gives a good sense of the bow-bridge distance and the skewness of the bow. The frog trajectories might also illuminate details of changes in bowing direction, which according to empirical findings follow curved rather than straight paths [10, 18, 19]. The example shown in Fig. 2 represents a long decrescendo note played down bow. It can be seen that at the end of the bow stroke the bowing was far from perpendicular to the string. This should, however, not be considered as a fault as it has been demonstrated that the skewness of the bow can be utilized to change the bow-bridge distance dynamically during the bow stroke [3]. In this particular case the skewness of the bow was used to drive the bow towards the fingerboard in order to accomplish a diminuendo note.

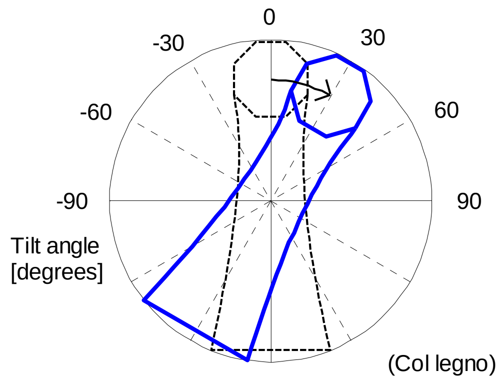

Figure 3. Visual display for bow tilt. The keyhole-like shape represents the bow frog when looking at it along the direction of the stick. Tilt is shown as a rotation of the frog in a clock-like display. When the stick is turned away from the player (as during normal playing), this is shown as a clockwise rotation (30 degrees in this example). For col legno playing tilt angles of 90 degrees or more are employed, clockwise or anti-clockwise depending on the preference of the player.

The above described projections allow for an effective visualization of the inclination and the skewness of the bow. For the visualization of bow tilt, another important bow control parameter, a third projection is added showing the rotation of the bow frog relative to the string played in a clock-like context (Fig. 3). During normal playing, the bow is often tilted so that the stick is turned slightly away from the player. This corresponds to a clockwise rotation in the tilt display. The tilt angle is easily quantifiable, realizing that an angle of 30 degrees corresponds with 5 minutes on the clock (in pp playing close to the frog bow tilt can reach up to about 45 degrees).

2.4. Additional displays and animations

The Hodgson plots described in the previous section provide a clear insight in the positioning and angling of the bow. This information is, however, not yet complete from an acoustical point of view, bearing in mind that tone production is mainly governed by bow speed, bow force and relative bow-bridge distance at the bow-string contact point. During the attack bow acceleration is also an important parameter. For a more

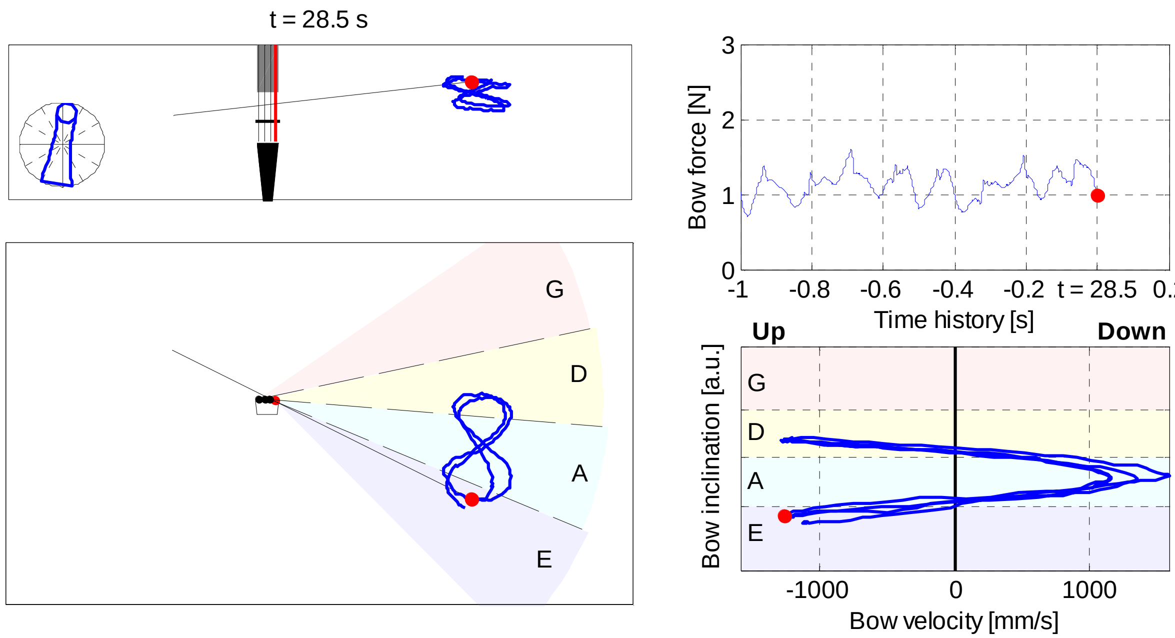

Figure 4. Feedback display showing a combination of aspects of the use of the bow. The panels on the left side show the Hodgson plots in the two projections, as well as bow tilt. The two panels on the right side show additional information on the use of the bow. Depending on the purpose of the exercise different bowing parameters might be displayed here. In this example bow force versus time (present moment and history) is shown in the top-right panel, and a phase-like representation of bow inclination versus bow velocity is shown in the down-right panel. The background colors used in the latter are meant to strengthen the association with the Hodgson plot in the down-left panel.

adequate feedback on tone production additional visualizations are needed to present this information to the player.

In Fig. 4 a total of five panels are combined for a more complete representation of the use of the bow. The example shows the beginning of the arpeggio part from “Preludio” of the third Partita for solo violin by J.S. Bach, played legato across three strings. As in the first example an eight-shaped bowing pattern can clearly be seen in the Hodgson plot (back projection). In the down-right panel the inclination of the bow is plotted versus bow velocity. This display contains more explicit information related to sound production, for example regarding the coordination between bow changes and string crossings. It can be seen that the bow speed in this fast passage reached rather high values of more than 1 m/s in order to obtain a loud sound. The bow force (upper-right panel) was rather constant, varying about 1 N.

Even if the static displays carry a lot of information, they do not yet provide a direct link with the sound. This can be achieved by animating the displays with synchronized sound. This was done making use of the QuickTime tools for Matlab by Slaney [20]. The resulting movies give players the possibility to analyze their bowing by repeatedly playing them back, paying attention to the different aspects of bowing. The movies also allow the players to scroll through their performances and search for different passages. Another advantage is that the movies can be played using a standard media player, which makes the prepared visualizations more accessible for players and teachers.

3. Discussion

The Hodgson plots, in combination with other types of displays, have the potential to provide informative feedback to the player. However, it should be realized that the way they are implemented in teaching and/or practicing is of vital importance for a successful pedagogical application. Further field studies are needed for the development of dedicated exercises and a database of reference performances, as well as an assessment of the usability. Moreover, little is known about expert bowing skills in musical performance as most quantitative studies of bowing are limited to relatively simple tasks. The details shown in this type of displays might be in conflict with popular beliefs in bowed-string pedagogy, as was for example the case with Hodgson's cyclographs [18].

Another interesting possibility would be to show the visualizations in real time serving as an enhanced mirror for the player as for example envisioned by Fober [21] and Ng et al. [13]. This might further strengthen the association with the player's own actions and allow for a more explorative use.

An important limitation is that an accurate measurement of bowing gestures is rather tedious and confined to the lab due to the need for expensive equipment. This forms an obstacle for a widespread use of this technique. However, the current state-of-the-art of the technology would allow for the implementation of this kind of technologies in a school environment as for example realized for piano pedagogy [22].

4. Conclusions

A set of displays is proposed for visualization of bowing gestures measured using motion capture techniques. The main displays shows the spatial trajectory of the frog in time, and are named after Percival Hodgson, who was the first to show photographic images of frog trajectories in violin playing. The proposed displays are mainly an extension of Hodgson's visualizations, showing the motion of the bow in the functional context of the violin. The presence of the context makes these plots both easier to understand and more informative to the player.

Different projections can be chosen to show different aspects of bowing. In the back projection (quasi player's perspective) the motion of the bow and the trajectory of the frog are shown in the context of the specific string crossing angles of the violin. This projection is especially suited for showing complex bow coordination patterns involving bow changes and string crossings. In the top projection bow-bridge distance and skewness of the bow can be clearly observed.

It is believed that Hodgson plots can provide informative feedback to violin and other bowed-string instrument players on their use of the bow. Especially when animated or shown in real time Hodgson plots - in combination with other visual displays of bowing parameters – can be used to illuminate the relationship between bowing gestures and the produced sound, allowing players to analyze their bowing technique and compare different strategies. The visualization methods could form an interesting tool for music education and could – due to their non-normative character – easily be adopted in different pedagogical approaches.

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