Classification of Common Violin Bowing Techniques Using Gesture Data from a Playable Measurement System

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ABSTRACT

This paper presents the results of a recent study of common violin bowing techniques using a newly designed measurement system. This measurement system comprises force, inertial, and position sensors installed on a carbon fiber violin bow and electric violin, and enables recording of real player bowing gesture under normal playing conditions. Using this system, performances of six different common bowing techniques (*accented détaché*, *détaché lancé*, *louré*, *martelé*, *staccato*, and *spiccato*) by each of eight violinists were recorded. Using a subset of the gesture data collected, the task of classifying these data by bowing technique was undertaken. Toward this goal, singular value decompostion (SVD) was used to compute the principal components of the data set, and then a k-nearest-neighbor (k-NN) classifier was employed, using the principal components as inputs. The results of this analysis are presented below.

Keywords

bowing, gesture, playing technique, principal component analysis, classification

1. INTRODUCTION

Physical bowing technique is a topic of keen interest in research communities, due to the complexity of the bow-string interaction and the expressive potential of bowing gesture. Areas of interest include virtual instrument development [18], interactive performance [17, 2, 13, 8], and pedagogy [7]. For many applications, reliable recognition of the individual bowing techniques that comprise right-hand bowing technique would be a great benefit.

Prior art on classification of violin bowing technique in particular includes the CyberViolin project [9]. In this work, features are extracted from position data produced by an electromagnetic motion tracking system. A decision tree takes these features as inputs in order to classify up to seven different bowing techniques in realtime.

Recently, the task of classifying individual violin bowing techniques was undertaken using gesture data from the Augmented Violin, another playable sensing system [11]. In this work, three bowing techniques (*détaché*, *martelé*, and *spiccato*) were classified using minimum and maximum bow acceleration in one dimension as inputs to a k-nearest-neighbor (k-NN) algorithm.

In the study presented in this paper, a similar approach was taken to classify violin bowing techniques. However, here, the analysis incorporated a greater diversity of gesture data, i.e., more data channels, to classify six different bowing techniques. Also, although a k-NN classifier was also used, in contrast to the research described above, the inputs to this classifier were determined by a dimensionality reduction technique using all of the gesture data. That is, the data reduction technique itself determines most salient features of the data.

The data for this experiment was captured using a new measurement system for violin bowing [16]. Based on the earlier Hyperbow designs [15], this system includes force (downward and lateral bow force), inertial (3D acceleration and 3D angular velocity), and position sensors installed on a carbon fiber violin bow and electric violin, and enables recording of real player bowing gesture under normal playing conditions.

2. BOWING TECHNIQUE STUDY

The primary goal of the bowing technique study was to investigate the potential of using the new bowing measurement system described above to capture the disctintions between common bowing techniques. In this study, the gesture and audio data generated by eight violinists performing six different bowing techniques on each of the four violin strings were recorded for later analysis. The details of the study protocol, experimental setup, and participants are discussed below.

2.1 Study Protocol

In this study each of the eight participants was asked to perform repetitions of a specific bowing technique originating from the Western “classical” music tradition. To help communicate the kind of bowstroke desired, a musical excerpt (from a work of the standard violin repertoire) featuring each bowing technique was provided from [1]. In addition, an audio example of the bowing technique for each of the four requested pitches was provided to the player. The bowing technique was notated clearly on a score, specifying the pitch and string, tempo, as well as any relevant articulation markings, for each set of the recordings.

Two different tempi were taken for each of the bowing techniques (on each pitch). First, trials were conducted using a characteristic tempo for each individual bowing technique. Immediately following these, trials were conducted using one common tempo. Though the target trials were actually those that were conducted with the same tempo across all of the bowing techniques, it was found early on that requesting performances using the characteristic tempo first enabled the players to perform at the common tempo with greater ease.

Both tempi required for each bowing technique were provided by a metronome. In some cases, a dynamics marking was written in the musical example, but the participants were instructed to perform all of the bowstrokes at a dynamic level of *mezzo forte*. Participants were instructed to take as much time as they required to either play through the musical example and/or practice the technique before the start of the recordings to ensure that the performances would be as consistent as possible.

Three performances of each bowing technique, comprising one trial, were requested on each of the four pitches (one on each string). During the first preliminary set of recording sessions, which were conducted in order to refine the experimental procedure, participants were asked to perform these bowing techniques on the open strings. The rationale for this instruction was that the current measurement system does not capture any information concerning the left hand gestures. It was observed, however, that players do not play as comfortably and naturally on open strings as when they finger pitches with the left hand. Therefore, in the subsequent recording sessions that comprise the actual technique study, the participants were asked to perform the bowing techniques on the fingered fourth interval above the open string pitch, with no vibrato.

The bowing techniques that comprised this study were *accented détaché*, *détaché lancé*, *louré*, *martelé*, *staccato*, and *spiccato*. Brief descriptions of these techniques may be found in the Appendix.

2.2 Experimental Setup

In each trial of the bowing technique study, the physical gesture data were recorded simultaneously with the audio data produced in the performances of each technique. The experimental setup, depicted in Figure 1, was simple: the custom violin bowing measurement system installed on a CodaBow® Conservatory™ violin bow [3] and the Yamaha SV-200 Silent Violin [14]; headphones (through which the participants heard all pre-recorded test stimuli and real-time sound of the test violin); M-Audio Fast Track USB audio interface [4]; and Apple MacBook with a 2 GHz Intel Core Duo processor (OS X) running PureData (Pd) version 0.40.0-test08 [10].

The audio and the gesture data were recorded to file by means of a PD patch (shown in Figure 1), which encoded the gesture data as multi-channel audio in order to properly "sync" all of the data together. Each file was recorded with a trial number, repetition number, and time and date stamp. The Pure Data (Pd) patch also allowed for easy playback of recorded files used as test stimuli.

The recordings took place in the Center for Interdisciplinary Research in Music Media and Technology (CIRMMT) of McGill University. Care was taken to create as quiet and natural a playing environment as possible.

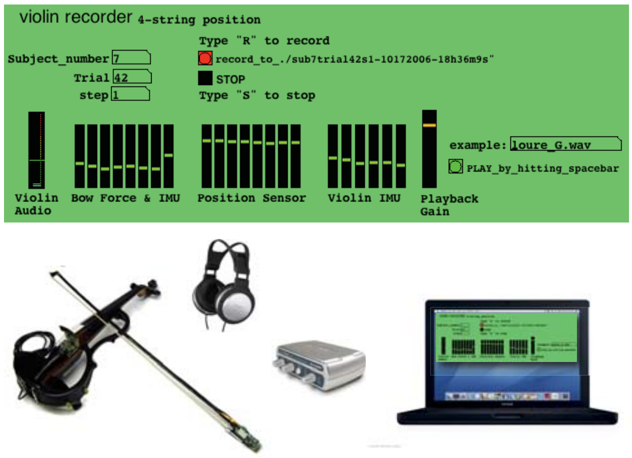

Figure 1: This figure describes the experimental setup used in the recording sessions for the bowing technique study. The top half of the figure shows the interface for the Pd recording patch, and the lower half shows the individual elements of the setup. From left to right, they are the custom violin bowing measurement system installed on a Yamaha SV-200 Silent Violin and a CodaBow® Conservatory™ violin bow; headphones; M-Audio Fast Track USB audio interface; and an Apple MacBook with a 2 GHz Intel Core Duo processor (OS X).

The participants for the bowing technique study included eight violin students from the Schulich School of Music of McGill University, five of whom had taken part in the preliminary testing sessions and who therefore already had experience with the measurement system and the test recording setup. The participants were recruited by means of an email invitation and "word of mouth", and they were each compensated $15 CAD to take part in the study. All of the players were violin performance majors and had at least one year of conservatory-level training. They were also of the same approximate age.[1]

3. TECHNIQUE STUDY EVALUATION

The main goal of the technique study was to determine whether the gesture data provided by the measurement system would be sufficient to recognize the six different bowing techniques (*accented détaché*, *détaché lancé*, *louré*, *martelé*, *staccato*, and *spiccato*) played by the eight violinists. To begin these classification explorations, only a subset of the gesture data provided by the measurement system was considered for the evaluations. Included in the analyses were data from the eight bow gesture sensors only: the downward and lateral forces; x, y, z acceleration; and angular velocity about the x, y, and z axes.

In order to answer these questions, a simple supervised classification algorithm was used. The k-nearest-neighbor

[1]These studies received approval from the MIT Committee on the Use of Humans as Experimental Subjects (COUHES) [5].

(k-NN) algorithm was chosen because it is simple and robust for well-conditioned data. Because each data point in the time series was included, the dimensionality, 9152 (1144 samples in each time series x 8 gesture channels), of the gesture data vector was very high. Therefore, the dimensionality of the gesture data set was first reduced before being input to the classifier.

3.1 Computing the Principal Components

Principal component analysis (PCA) is a common technique used to reduce the dimensionality of data [12]. PCA is a linear transform that transforms the data set into a new coordinate system such that the variance of the data vectors is maximized along the first coordinate dimension (known as the first principal component). That is, most of the variance is represented, or "explained", by this dimension. Similarly, the second greatest variance is along the second coordinate dimension (the second principal component), the third greatest variance is along the third coordinate dimension (the third principal component), et cetera. Because the variance of the data decreases with increasing coordinate dimension, higher components may be disregarded for similar data vectors, thus resulting in decreased dimensionality of the data set.

In order to reduce the dimensionality of the bowing gesture data in this study, the data were assembled into a matrix and the principal components were computed using the efficient singular value decompositions (SVD) algorithm. For this bowing technique study, there were 576 (8 players x 6 techniques x 4 strings x 3 performances of each) recorded examples produced by the participants, and for each example, 8 channels of the bow gesture data were used. These data were used to form a 576 x 9152 matrix $\mathbf{M}$, which was input to the SVD in order to enable the following analyses.

Before continuing with the classification step, it was informative to illustrate the separability of bowing techniques produced by the individual players. From the matrix $\mathbf{M}$, a smaller matrix composed of those 72 rows corresponding to each violinist (6 techniques x 4 strings x 3 performances of each) was taken and then decomposed using the SVD algorithm to produce the principal components of each individual player's bowing data. A scatter plot was then produced for each player's data, showing the first three principal components corresponding to each bowing technique. Two of these plots are shown in Figures 2 and 3. As can be seen in these examples, clear separability of bowing techniques for individual players was demonstrated using only three dimensions.

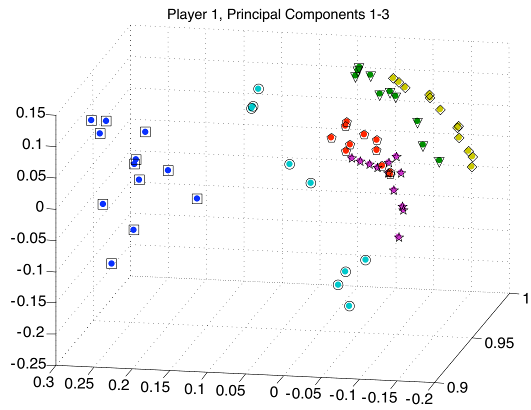

Figure 2: Scatter plot of all six bowing techniques for player 1 (of 8). *Accented détaché* (square), *détaché lancé* (triangle), *louré* (pentagon), *martelé* (circle), *staccato* (star), *spiccato* (diamond). The axes correspond to the first three principal components.

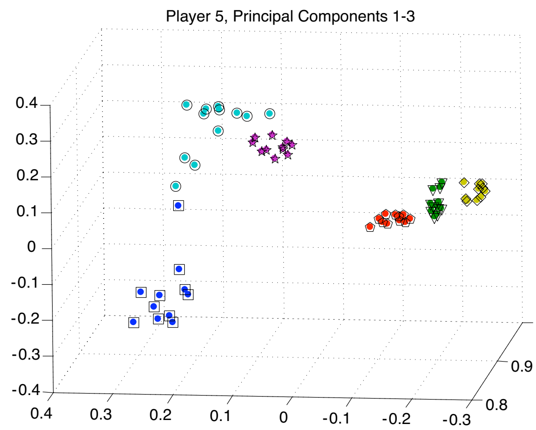

Figure 3: Scatter plot of all six bowing techniques for player 5 (of 8). *Accented détaché* (square), *détaché lancé* (triangle), *louré* (pentagon), *martelé* (circle), *staccato* (star), *spiccato* (diamond). The axes correspond to the first three principal components.

3.2 k-NN Classification

After computing the principal components produced by the SVD method, the challenge of classifying the data was undertaken using the full data matrix (including all players data together). Toward this goal, a k-nearest-neighbor classifier was used. Specifically, Nabney's matlab implementation [6] was employed. In this case, a subset of the data contributed by *all of the players* was used to train the k-NN algorithm in order to classify the remaining data from all of the players by technique.

In each case, the principal components of the training data set were first computed using the SVD method. The remaining data (to be classified) were then projected into the eigenspace determined by this exercise. Some number of the principal components corresponding to the training data were input to the k-NN algorithm, enabling the remaining data to be classified according to technique. For each case, a three-fold cross-validation procedure was obeyed, as this process was repeated as the training data (and the data to be classified) were rotated. The final classification rate estimates were taken as the mean and standard deviation of the classification rates of the cross-validation trials.

The effect on the overall classification rate of the number of principal components is clearly illustrated by Figure 4. As seen in Table 1, using 7 principal components enables classification of 6 bowing techniques of over $95.3 \pm 2.6\%$ of the remaining data.

class. actual	acc. detaché	det. lanceé	louré	martelé	staccato	spiccato
acc. det.	**0.938**	0.010	0.010	0.042	0.000	0.000
det. lancé	0.000	**0.917**	0.000	0.010	0.021	0.052
louré	0.000	0.000	**0.979**	0.000	0.021	0.000
martelé	0.042	0.021	0.000	**0.938**	0.000	0.000
staccato	0.000	0.010	0.010	0.000	**0.979**	0.000
spiccato	0.000	0.031	0.000	0.000	0.000	**0.969**

Table 1: Training on two-thirds of the data from each of the eight players, predicting the remain third of each player's data (with overall prediction of 95.3 ± 2.6%) with seven principal components.

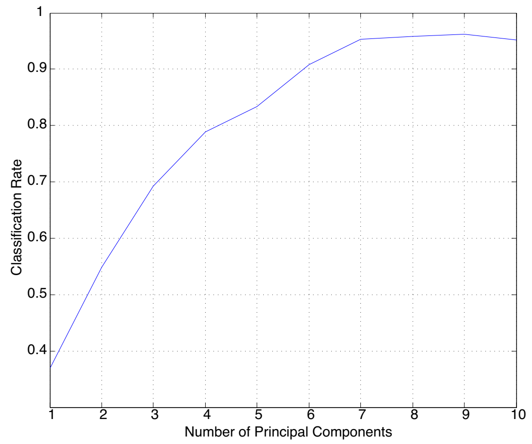

Figure 4: Mean prediction rates produced by k-NN using two-thirds of the data from each of the eight players to predict the remaining one-third of all player data and increasing principal components from one to ten.

4. DISCUSSION

The results of this bowing technique study are encouraging. Using a relatively small number of principal components, the k-NN classification yielded over 95% average classification of the six bowing techniques produced by the eight participants. Some of the error of this result can be understood from Table 1. This confusion matrix shows that *accented détaché* is most often mis-classified as *martelé*, which is not surprising as these two techniques are somewhat similar in execution. Interestingly, there was considerable error from mis-classifying *détaché lancé* as *spiccato.* Although these two techniques are quite diffferent from each other, Figure 5 implies they were confused by one of the participants. This discrepancy alone explains much of the error in classifying these two techniques.

Of course, there is much to be done to build on the work begun here. The analysis described here involved the classification of six different bowing techniques in which each trial was actually comprised of a repetition of one of these techniques. An immediate next step is to analyze the same data set using individual bowstrokes. Also, only a subset of the gesture channels captured by the bowing measurement system was used for this study. For future studies that may include more techniques and players, the benefit of the remaining channels should be explored.

The SVD and k-NN algorithms were chosen for this experiment partly for ease of implementation. Other techniques, however, should be evaluated in pursuit of robustness and higher classification rates.

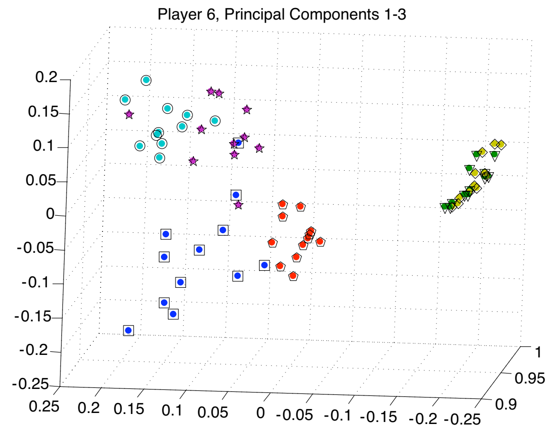

Figure 5: Scatter plot of all six bowing techniques for player 6. *Accented détaché* (square), *détaché lancé* (triangle), *louré* (pentagon), *martelé* (circle), *staccato* (star), *spiccato* (diamond). The axes correspond to the first three principal components. As can be seen here, the *détaché lancé* and *spiccato* techniques are not separable in three dimensions.

Finally, more vigorous classification of bowing techniques should include qualitative listening evaluations of the bowing audio to complement the quantitative evaluation of the bowing gesture data.

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6. APPENDIX

Descriptions, taken from [1], of the six bowing techniques featured in this study are included below.

- ***accented détaché*** A percussive attack, produced by great initial bow speed and pressure, characterizes this stroke. In contrast to the *martelé*, the *accented détaché* is basically a non-*staccato* articulation and can be performed at greater speeds than the *martelé.*
- **détaché** Comprises a family of bowstrokes, played on-the-string, which share in common a change of bowing direction with the articulation of each note. *Détaché* strokes may be sharply accentuated or unaccentuated, *legato* (only in the sense that no rest occurs between strokes), or very slightly *staccato*, with small rests separating strokes.
- ***détaché lancé*** "Darting" *détaché.* Characteristically, a short unaccented *détaché* bowstroke with some *staccato* separation of strokes.

- ***legato*** Bound together (literally, "tied"). Without interruption between the notes; smoothly connected, whether in one or several bowstrokes.
- ***louré*** A short series of gently pulsed, slurred, *legato* notes. Varying degrees of articulation may be employed. The *legato* connection between notes may not be disrupted at all, but minimal separation may be employed.
- ***martelé*** Hammered; a sharply accentuated, *staccato* bowing. To produce the attack, pressure is applied an instant before bow motion begins. *Martelé* differs from *accented détaché* in that the latter has primarily no *staccato* separation between strokes and can be performed at faster speeds.
- ***staccato*** Used as a generic term, *staccato* means a non-*legato martelé* type of short bowstroke played with a stop. The effect is to shorten the written note value with an unwritten rest.
- ***spiccato*** A slow to moderate speed bouncing stroke. Every degree of crispness is possible in the *spiccato*, ranging from gently brushed to percussively dry.

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