Sensor Based Measurements of Musicians' Synchronization Issues

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ABSTRACT

From a technical point of view, instrumental music making involves audible, visible and hidden playing parameters. Hidden parameters like force, pressure and fast movements, happening within milliseconds are particularly difficult to capture. Here, we present data focusing on movement coordination parameters of the left hand fingers with the bow hand in violinists and between two violinists in group playing. Data was recorded with different position sensors, a micro camcorder fixed on a violin and an acceleration sensor placed on the bow. Sensor measurements were obtained at a high sampling rate, gathering the data with a small microcontroller unit, connected with a laptop computer. To capture bow's position, rotation and angle directly on the bow to string contact point, the micro camcorder was fixed near the bridge. Main focuses of interest were the changes of the left hand finger, the temporal synchronization between left hand fingers with the right hand, the close up view to the bow to string contact point and the contact of the left hand finger and/or string to the fingerboard. Seven violinists, from beginners to master class students played scales in different rhythms, speeds and bowings and music excerpts of free choice while being recorded. One measurement with 2 violinists was made to see the time differences between two musicians while playing together. For simple integration of a conventional violin into electronic music environments, left hand sensor data were exemplary converted to MIDI and OSC.

Keywords

Strings, violin, coordination, left, finger, right, hand

1. INTRODUCTION

Today, several technologies for motion and gestures' detection during instrumental musical playing exist. Diverse works by e.g. Maestre [6] presented several approaches to objectively capture gestures, particularly those associated to the bowing of string instruments. The most used measuring methods are based on the use of acceleration sensors and gyroscopes. Among others, the first sensors applied to violins, bow and violin gestures were the acceleration sensor on the bow by Bevilaqua et al. [2] and Rasamimanana et al. [8], left hand pressure and position sensor by Grosshauser et al. in [3] and [4]. Several Hyperinstruments with similar technologies exist (see Machover et al. in[5] and the commercially available K bow by McMillen. Also several vision based approaches are explored, e.g. the one described by Ng [7]. Nevertheless, sensing of the left hand is clearly underrepresented in the literature. In this paper, different methods for left hand sensing are introduced. In addition, while a left-right-hand investigation with marker based video tracking as been done by Baader [1], we show here an alternative set-up by using a small DV camcorder fixed to the violin near the bow to string contact point. In so doing, a useful view to the usage of the bow can be obtained. The sensors presented here are used for the recognition of position of left hand fingers and for synchronization measurements of left-fingering and right-bowing hands. The set up allows precise measurements of the coordination between left-hand finger changes and right-hand bowing movements of one and more musicians while playing together. To accomplish this, several pretests were made to particularly proof the synchronization between two different measurement setups, and to assess bow movement and acoustic output of the violin as well. The setup was evaluated with test subjects ranging from amateur violinists up to master class students. Several scales and music pieces with different tempi and bowing types were played. In addition, to proof the measurement concept for coordination measurements during group music making, another test with two musicians playing together was performed. We show that the present setup works with a high temporal resolution and can be used in the field of string players, from beginners up to professionals alike. To support musicians and music teachers in daily exercising, particularly during their technical training, here, different sensors are used to show parameters, difficult to detect but meaningful for music making. Thus, our goal is to test and provide systems for data acquisition in fields not explored so far and to develop measurement methods for playing parameters, which are often discussed among musicians, but which are difficult -if not impossible- to see with the naked eye. Furthermore, we give some visions for practical use in teaching and exercising string instruments. Last but not least, we discuss integration possibilities of the final set-up presented here into electronic music scenarios and new playing techniques, all of which becomes possible by using this sensor types. In this study, we further developed previous sensor setups, e.g. a left hand and bow sensor on two violins, combined with a synchronization method for accurate measurements during group music making.

2. TECHNICAL DESCRIPTION OF THE BASIC SETUP

All setups, described in the following sections consist of a microcontroller board, an acceleration sensor placed on the frog of the bow, a mini DV camcorder for audio and video recording, a pickup and diverse left-hand sensors further described in detail below. Due to latency issues, all setups are realized with wire-based data transfer. This allows for higher data transfer rates without dropouts. Synchronization during testing with two musical instruments was done with several electronical cues presented during each recording. Every single measurement unit, namely the micro-controller board and the DV camcorder generate a time stamp for simplified data alignment.

2.1 Attachment to the Violin

All electronics were affixed to the shoulder rest. This allows fast removal and easy transportation. Only the pickup and the finger sensor itself were directly attached to the violin corpus, reducing the influence on the violin's sound and the playing of it.

2.2 Acceleration Sensor on the Bow

The bow acceleration sensor was fixed, according to similar existing designs (see Young in [9]) on the inner side of the frog of the bow. The ADXL330 from InvenSense sensor fixed on a small outbreak printed circuit board (PCB) is used. It is a small, lightweight and complete x-, y-, and z-axis accelerometer. A very lightweight cable for data transfer to the microcontroller unit was used to allow unhindered musicians' motion performance.

2.3 Mini DV Camcorder on the Violin Corpus

A small DV Camcorder PMDV80 was fixed on the violin (see Fig. 1). Video resolution is 720 x 480, 1,3 mega-pixel, frame rate is 30 fps, and the size is 52x18x8 mm. Although not necessary for the measurements, its use is of great support in aligning and analyzing the recorded sensor data. As additional gain, the CV camcorder provides a particularly interesting view to the bow-to-string contact point. It shows clearly the usage and the motion of the bow during playing activity. Relevant points of interest within this specific scenario are (a) contact point of bow and string (e.g. the area between bridge and finger board), (b) angle of bow to string (which should be around 90°, but it can vary in certain situations) and (c) the approximate amount of bow hairs used during playing (an often discussed issue among violin teachers, which is hard to see during live performances).

2.4 Pickup on the Violin Bridge

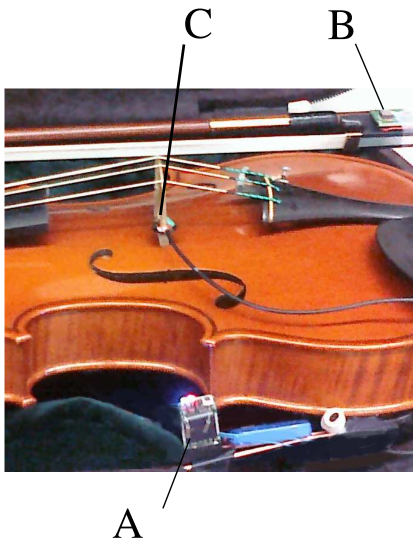

Figure 1: Sensors fixed on the violin: A: small DV camcorder, B: acceleration sensor fixed on the bow and C: pickup fixed in the bridge.

The pickup attached to the bridge is mainly to support data alignment. Both, the pickup's audio signal and the DV camcorder are also used for video and sensor data synchronization.

3. DEVELOPMENT OF THE LEFT HAND FINGER SENSOR

The main challenge of the measurement setup presented here is the development of the left hand sensor. Nowadays, several approaches exist with wires along or crossing the strings. Here, several designs for left hand finger position sensing were developed, built and tested. Each design presented particular advantages and disadvantages that will be described in the following section. Due to the characteristics of measurements on coordination, a good time resolution is needed. In our setup, the time resolution is 2.5 ms.

3.1 Switch Matrix Finger Board Sensor

The first design tested was a switching matrix (see Fig. 2). The sensor is flexible PCB with contact points at each finger. A voltage of 3 V is successively applied to each string separately. Depressing a string closes the contact to the conductive areas on the fingerboard. The areas are read out one after the other at a high sampling rate. Every closed contact means a "high" respectively a binary "1" on the IOs of the microcontroller. The first tests showed the following ad- and disadvantages of this left hand sensor type:

Figure 2: Switch matrix sensor for left hand finger position sensing. A flexible PCB is mounted on the violin finger board. The contact areas are coated with gold.

Advantages:

1. A fast readout is possible, with an estimated sampling frequency around 500 Hz.
2. Easy to install.

Disadvantages:

1. There is no contact between string and fingerboard in higher finger positions. In this case, the contact is only with the highly resistive skin.
2. No contact or high resistance at the contact point of the E-string and the sensor surface. The resistance between the depressed E-String (even by using a new gold string) is in the range of some mOhms or not measurable. This is a very high value compared to around 2-10 Ohms of the other string to sensor contact points. In common violin playing, the data loss, due to missing electrical contact was too high.
3. Amplitude of the "free swinging" string leads to uncontrolled contact with the fingerboard, especially during loud playing.
4. Bad tactile perception on the fingertip while playing. If the covered area on the fingerboard is too large, the missing contact between finger and the wood disturbs the tactile experience during playing. Further experiments have shown, that a free, uncovered area of more than 50% between the contacts improves the haptic perception. The musicians have still a similar sensation as playing on a common fingerboard.

While the sampling frequency of around 500 Hz of the left-hand finger position detection was confirmed, the disadvantages mentioned above led to unsatisfying measurement results. Therefore, this design was improved.

3.2 A Final Hybrid Sensor Setup

The final hybrid sensor is a combination of resistive sensing with a switching matrix. Thin, pairwise copper wires were fixed on the fingerboard on each finger position. Between the two wires, there is a small gap. The gap is closed either with the fingers pads or with the strings meaning that the two copper wire alias two electrical poles are connected either with the fingers or the strings. While the finger connection is highly resistive, the string connection is highly conductive.

A voltage divider was used with a 680 kOhm resistor in series to each contact point on the fingerboard. The resistive difference, for example the difference between the skin and the string closing the gap effects a different voltage which is read in at the analog ports of the microcontroller board. The microcontroller unit is an Arduino Nano with an improved boot loader.

Following advantages of this setup are:

1. Differentiation between finger or string to fingerboard contact.
2. Good tactile feeling due to the very small contact area of the finger and the copper wires. The finger to wood contact area is roughly more than 50%.
3. High temporal resolution, around 2.5 ms, due to high sampling frequency of 400 Hz.
4. Wires can be fixed near the neck of the violin and below the violin corpus.

Disadvantages:

1. More time-consuming to install
2. Less robust, than the PCB version, because the contacts detach more easily from the fingerboard.

This sensor setup fulfilled our most important system requirements, a) differentiation between finger and/or string on the fingerboard, by a high sampling frequency and a good haptic feeling mandatory for unhindered instrumental playing.

4. PRE- TESTS FOR THE UNDERLYING ASSUMPTIONS

4.1 Bow Motion to Acoustic Sound Propagation Test

Two questions were of relevance here: Is there a delay between the movement of the bow and the sound output of the violin? Or, and, is there a delay between the sound and the data from the acceleration sensor?

To assess these questions, a simple setup was built. Several bow strokes were made by a professional violinist on a violin equipped with a pickup attached to the bridge and an accelerometer attached to the frog of the bow. The bow changes were examined, to seem if there is a delay between bow movement and acoustic output. The signals of the accelerometer and the pickup were measured with an oscilloscope whereby the time delay between the out put of the bow and the pickup during bow changes was below one millisecond. Based on these results, only the acceleration data is used for synchronization examination. The signal from the pickup was only used for later data alignment.

4.2 A Synchronization Method for two and more Instruments

To record two or more musicians, a simple and stable synchronization method is needed. To keep the complexity low, all involved microcontroller boards of each violin are coupled via a cable. This cable connects all boards to a 5 V source, when the switch is turned on and sets an input high. This is done several times within one recording to detect data loses or other delays. The resulting synchronization time cues are easy to find in the recorded data helping to the data alignment of the data arising from the different instruments.

5. EVALUATION OF THE FINAL SETUP WITH THE VIOLINISTS

Seven violinists (6 females, mean age 24.3, SD 3.0), all but one with more than 10 years of playing the violin participated in the study. Four considered themselves advanced, 1 considered himself a beginner. Three were students of performing arts at a master level in a Swiss music conservatory and can be considered professional (See table 1 and 2). All participants gave their written informed consent prior to study begin.

5.1 Measurements

All measurements were performed on a new master violin (fecit 2010) by the awarded violin maker Hildegard Dodel, Cremona, Italy. The violin bow was a Hill bow. Prior to measurements, volunteers were allowed to warm-up in their preferred way for a brief period of time (range 5-10 min) and to adapt to the instrument they had to play. An acoustical metronome paced playing speed. All the segments played were placed on a music stand. All participants performed standing.

ID	Female	Male	Age	< 10 years	> 10 years
Tv-01	1		23		1
Tv-02		1	28	1	
Tv-03	1		22		1
Tv-04	1		26		1
Tv-05	1		24		1
Tv-06	1		28		1
Tv-07		1	19		1

Table 1: Data of the subjects, participated in the study.

ID	Beginner	Advanced	Violin Student	Profess.
Tv-01			1	
Tv-02	1			
Tv-03		1		
Tv-04		1		
Tv-05		1		
Tv-06		1		
Tv-07			1	

Table 2: Data of the subjects, participated in the study.

5.2 Study Design

Total measurement set up lasted for 20 min. All participants played a G- Major scale (2 octaves) and an e- minor scale (1 octave). Played tempo was 60 bpm in 4, 8, 16 and 32 subdivisions as fast as possible. Bowing tasks were Détaché, Spiccatto and Sautilié with 1 and 2 bindings each octave whereby 2 octaves were played with one binding. Requested rhythmical articulation was dotted, double dotted and 2 bounded notes. All participants played the Kreutzer study Nr. 2, bars 1 to 4. In addition, a 30 sec. to 1 min. segment of a piece at free choice, one fast and one slow were played. After the measurement the subjects filled a form with some questions regarding the experiment and asked for further comments.

6. UNEXPECTED RESULTS OF THE SENSOR SETUPS

In the following sections, findings are described, which have an impact to daily teaching and exercising. The results are also based on the used sensor setup and described in short, although it does not directly affect the synchronization question.

6.1 Detection of "unused" Fingers on the Board

The final hybrid sensor setup indicates the position of all fingers, including the ones not in the highest position of the played string. In most methods for violin playing, these "unused" fingers should not depress the string and their fingertips' position should be a little bit above the string. This fact is hard to see for the teacher and easily forgotten by the student. This technical advice can be easily overseen by the pupil and also the teacher concerned with other aspects of the performance. The position sensor presented here allows to investigate this question based on the measured data.

6.2 Direct View onto the Bow Movement

While at the beginning, the mini DV camcorder was installed to simplify data alignment, during data inspection it became clear that the video allowed a clear view of the bow. Based on this fact, several questions, regarding the individual bow usage of each player can be observed.

6.3 Bow Inclination: "Approximate Amount of Hairs on the String"

The pictures taken allow a visually estimate on the amount of bow hairs used during playing (see Fig. 3). This fact appears particularly important, as this is an essential question regarding playing efficiency and quality of sound.

6.4 The Bow to String Angle

Although, the angle has not to be 90° all the time, the bow to string angle is an important parameter for musical expression (see Fig. 3). It is possible to learn many differing angles during several playing situations. While bow angulation is until now a largely theoretical thought, with the present setup it is possible to practically see the different angulations. This can help to understand and use different angulations in the context of sound production by oneself. Fig. 4 shows a bow to string angle, deviating from 90°.

Figure 3: Direct view onto the bow. Bow angle to the string and approximate amount of hairs on the string is easy to see.

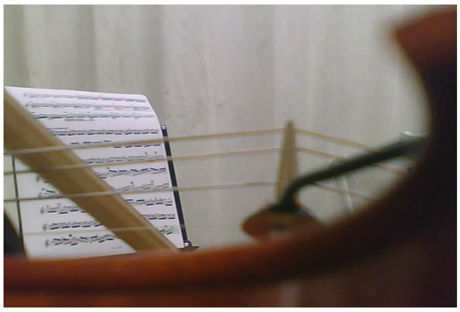

Figure 4: A further direct view onto the bow. Bow angle to the string and approximate amount of hairs on the string is easy to see. Here the bow to string angle is not correct, it deviates from 90°.

7. RESULTS OF THE SYNCHRONIZATION OF THE LEFT HAND FINGER AND THE RIGHT BOWING HAND

According to the audio recording of the subjects, playing quality showed certain differences among study participants. These differences cannot be only interpreted as the result of too long or too unstable synchronization. Indeed, the synchronization between the left-hand fingers and the bow seems to be one of several significant parameters contributing to the observed differences.

The recorded data of left hand fingering and bow acceleration measurements revealed a pattern in which master class students show a shorter average difference between left-finger and right-bow onset. This difference ranged from

1	2	3	4	5
Tv-01	-24ms	61ms	80ms	14ms
Tv-02	-60ms	89ms	149ms	24.1ms
Tv-03	-51ms	38ms	89ms	29.6ms
Tv-04	-61ms	32ms	93ms	16.5ms
Tv-05	-24ms	48ms	72ms	16ms
Tv-06				
Tv-07	-25ms	55ms	80ms	89ms

Table 3: Column number 1: ID, 2: Maximum value "too early", bow change before finger change, 3: Maximum value of bow change after finger change, 4: Maximum deviation value, 5: Average of all absolute values. The data of TV-06 were corrupted.

14-16 ms for students, 16-29 ms for advanced and 24 ms for the beginner. In addition, and in congruence with the expected pattern of left-before-right movement onset, in 4 out of 6 participants left finger movement preceded right, bow-hand movements (see table 3). It is important to note, that due to the low number of participants and the technical characteristic of the present report, only descriptive statistic of the data are meaningful. Summarizing, deviations from synchronicity within one playing task was larger for beginners than for advanced players (see table 3). One data set was corrupted and could not be used.

7.1 Results of the Questionnaire

The acceptance of the hybrid setup was relatively high among musicians. Four violinists declared the set up was not having any influence on their playing. One violinist found the setup "a little bit distracting" regarding the fingerboard, one felt the shoulder rest wiring and the shoulder rest in general were distracting, and another one considered the bow sometimes "strange to control". In addition, all participants felt the hybrid set-up could be of use for their musical training, and were willing to participate in a new run of such measurements. More over, participants vastly concurred with the asked questions on bow position and finger positions and movements.

7.2 Synchronization Between two Musicians

This evaluation was done by measuring two violinists playing a duo in C-Major composed by I. Pleyel. This piece of music is considered to be easy to perform, particularly for two master class violin players.

The measurements seem to allow precise data analysis in terms of synchronization. The results show, that the delay time between the starting time of bowings is 28ms. This seems to be a quite high value, but on the other hand compared to the left to right hand deviations of one single person, it is close to the double delay time of 14-16 ms.

7.3 New Interface for Musical Expression Based on Left and Right Hand Sensing

The presented sensor setup offers new opportunities to further steps to implement an USB-MIDI violin. Implementation of MIDI and OSC directly into the PCB on the violin allows easy integration into electronic music environments. Such a code would be easy to implement for the present setup. Due to the big form factor of standard DIN plugs, a DIN to MINI USB adapter cable is developed. This cable is lightweight and does not influence the player. To avoid potential confusion with conventional USB connectors it is recommendable to perform a plug modification whereby a new pin is added.

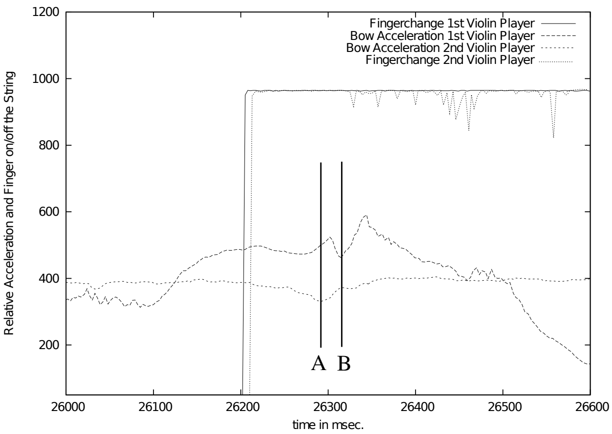

Figure 5: Synchronisation of bow and finger change of two musicians playing a Duo in C-Major from I. Pleyel. The finger synchronisation of both players is accidentally nearly at the same time, important here is the starting point of the bow of each player at position A and B.

8. CONCLUSION AND FUTURE WORK

The described setup represents a further step to gathering objective data in instrumental music making. Furthermore, the work represents a new step towards novel measurement setups to quantify usually hidden parameters pivotal to music making, which are hard to hear and difficult to be objectively shown. While usually the individual impression of "uncoordinated" playing may be right, its objective depiction and quantifying is a challenge. By using the presented measurement setup and sensors it is possible to measure parameters like delays and irregularities of fingers of the left hand as well as left-right movement (de-)synchronization. A potential next step will be the implementation of real-time feedback and the objective evaluation of exercises supposed to enhance left-finger to bow-hand coordination. Based on this information, the development of alternative exercises might be attempted, which can be in turn objectively evaluated regarding their efficiency by using a comparable setup. The next steps will also include the simplification of the present setup and its refinement to still enhance its already high acceptability among musicians. In addition, other relevant parameters not included here should be observed, also in combination with diverse existing technologies. Easy understandable real-time feedback modalities, and the use of the sensor setup in other types of musical instruments will be a long-term goal. This may ultimately contribute to the development of new methods of instrumental training.

9. ACKNOWLEDGMENTS

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