Finger Position and Pressure Sensing Techniques for String and Keyboard Instruments

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ABSTRACT

Several new technologies to capture motion, gesture and forces for musical instrument players' analyses have been developed in the last years. In research and for augmented instruments one parameter is underrepresented so far. It is finger position and pressure measurement, applied by the musician while playing the musical instrument. In this paper we show a flexible linear-potentiometer and force-sensitive-resistor (FSR) based solution for position, pressure and force sensing between the contact point of the fingers and the musical instrument. A flexible matrix printed circuit board (PCB) is fixed on a piano key. We further introduce linear potentiometer based left hand finger position sensing for string instruments, integrated into a violin and a guitar finger board. Several calibration and measurement scenarios are shown. The violin sensor was evaluated with 13 music students regarding playability and robustness of the system. Main focus was a the integration of the sensors into these two traditional musical instruments as unobtrusively as possible to keep natural haptic playing sensation. The musicians playing the violin in different performance situations stated good playability and no differences in the haptic sensation while playing. The piano sensor is rated, due to interviews after testing it in a conventional keyboard quite unobtrusive, too, but still evokes a different haptic sensation.

Keywords

Sensor, Piano, Violin, Guitar, Position, Pressure, Keyboard

1. INTRODUCTION

Following the last years in musical instrument performance capturing, two main fields in capturing technologies in musical instruments can be distinguished: External systems like optical and electromagnetic field sensing and sensor based, pervasive systems. In this paper we investigate in sensor based systems for pressure, force and position measurements based on FSR technologies for traditional musical instruments.

In string instrument sensing this means linear potentiometers (working principle see in Fig. 2) integrated into the fingerboard (see Fig. 1), for left hand finger position sensing. In piano playing, FSRs for pressure only and FSR matrices for pressure and position of the fingers on the piano keys (see Fig. 10) are introduced. The sensors are custom made by different manufacturers and can be installed on any keyboard and string instrument. The sensor hardware communicates via USB to a host computer, which uses the Open Sound Control (OSC) protocol or MIDI to transmit finger position, pressure and touch area. These data can be used for performance analysis, music medicine, music pedagogy or connected to any sound synthesis program.

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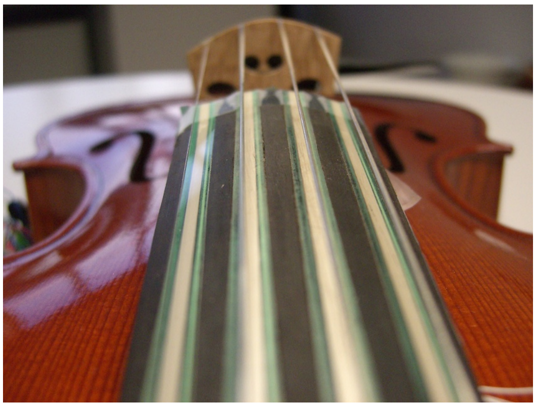

Figure 1: The final violin fingerboard with the integrated position sensors. Due to haptic influence while playing, the right ratio between ebony wood and flexible linear-potentiometers' plastic surface had to be evaluated.

2. RELATED WORK

Research into motion, position and posture sensing has been ongoing for many years. The following sections summarize related research in finger position sensing.

2.1 String Instrument Sensing

Today, several technologies for motion and gestures' detection during instrumental musical playing exist. Diverse works by e.g. Maestre [10] 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 video, optical tracking techniques, acceleration sensors and gyroscopes. Among others, the first sensors applied to pianos, violins and bows were the acceleration sensor on the bow by Bevilaqua et al. [1]. FSR based measurement on string instruments for performance analysis was introduced by Grosshauser et al. in [3] and for finger pressure and position measurements on the bow. in [4]. Also several vision based approaches are explored, mostly VICON technology, e.g. described by Ng [14].

He detected several bowing related like bow to string angle or bowing speed.

On the other side, several Hyperinstruments with similar position sensing technologies (see Machover et al. in[9] or new sensor technologies are built e.g. by Overholt described in [15]. Guaus et al. in [5] use capacitive touch sensing to measure a guitarist's fingering on the fretboard.

2.2 Keyboard Instrument Sensing

Moog and Rhea [13] implemented multiply-touch-sensitivity into keyboards. They measured the front-to-back position of the player's finger on the key as well as the vertical position of the key itself. With a custom micro controller interface the data was made available and each key could be used to control up to three independent parameters. Haken Continuum [7] allows recording up to 10 touches in three dimensions.

Capacitive touch sensing was introduced by Paradiso et al. in [16] and McPherson et al. in [11]. Coming from optical sensing, (see McPherson et al. in [12]) sensing continuous key position on the acoustic piano at 600 Hz sampling rate and 10 to 100 points during the brief interval a key is in motion he could record not just the velocity but the shape of each key press. Further dimensions were percussiveness, weight into the keybed, depth, and finger rigidity from each press. In pedagogy, researchers favored isolated finger work with the only inclusion of arm movements for the horizontal displacement of the hand while playing the cembalo, recent studies favored the addition of the contribution of arm segments in the production of playing force (see Hadjakos in [6]. Furuya et al. in [2] have investigated the activation and coordination of several arm segments and fingers while playing.

3. TECHNICAL DESCRIPTION OF THE SENSOR SETUPS

The main challenge of the setup presented here is beside a high measurement accuracy, the integration of additional technology into an existing musical instrument without influencing the musician while playing.

FSR-based pressure measurement for music making is introduced by Koehly et al. in [8]. Pressure measurements of the contact point between musicians and the musical instruments for performance analysis is described by Grosshauser et al. in [3] for violin bowing studies. Flexible FSRs were fixed to the curved surface of the violin bow and chin. Similar technology is used here. All sensors described in this paper can be fixed on every string instrument without frets and any keyboard instrument. But due to glues recommended by musical instrument makers, all sensors can be removed residue-free from the instruments again.

3.1 Technical Description of the Linear Potentiometer Sensors

A linear potentiometer allows position sensing with a variable resistance, depending on the position of the contact pint. The physical layout of the device and a schematic representation of the device are given in Fig. 2 (Circuit drawing partly from Princeton sensor tutorial [1]). The voltage which appears at the contact point 'B' will be proportional to the position RPot of the contact.

3.2 Technical Description of the FSR Sensors

The most basic method of interfacing to an FSR is depicted in Fig. 3. In this configuration a FSR is used as a voltage divider.

[1]http://soundlab.cs.princeton.edu/learning/tutorials/sensors/node17.html

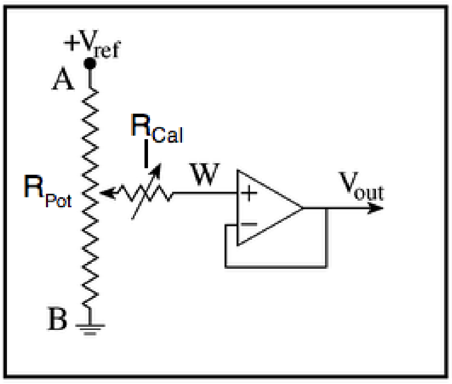

Figure 2: Depicted is a circuit diagram of a voltage divider based on an adjustable reference resistor (RCal) and a resistor (RPot) with a sliding contact (linear potentiometer). RCal is used to adjust the sensitivity of the sensor to the position of the sliding contact. There are four linear potentiometers integrated into the violin, each consisting of this voltage divider/sensor combination.

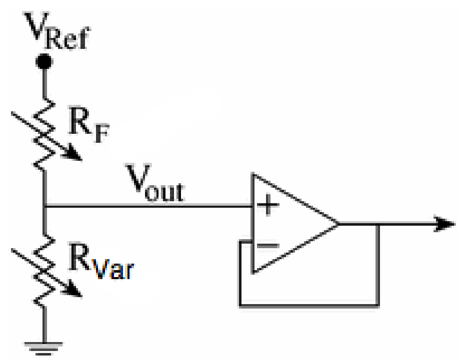

Figure 3: Circuit diagram of a voltage divider based on a adjustable reference resistor (RVar) and a force sensitive resistor (RF). RVar is used to adjust the sensitivity of the sensor to the excerpted pressure on each contact point. There are 4 x 28 measurement points, each consisting of this voltage divider/sensor combination.

In this case RF in Fig. 3 is the force sensing resistor. The force sensor consists of a contact element and a resistive surface. The resistance of the contact varies according to the amount of pressure or force. An increase in force results in a decrease in the value of RF, and change in the output voltage. RVar is a potentiometer to calibrate the sensor and adjust the sensitivity.

4. VIOLIN LEFT HAND FINGER SENSOR

In the following sections, the evaluation of the left hand violin-fingerboard sensor is described.

4.1 Unobtrusive Finger Board Integration of the Sensors

The main challenge of the setup presented here is the integration into an existing musical instrument without influencing the tactile sensation of the musician while playing (example plot of a performance see Fig. 5). Nowadays, several approaches exist with wires along or crossing the strings, altering the friction and tactile sensation of the surface of the instrument. We integrated the flexible linear-potentiometers under each string, keeping as much ebony between the strings as possible for a similar friction between finger and the wood. The flexible sensors are custom made, based on flexible conductive foils. They are self-adhesive and can easily be fixed on the finger board. To reach unhindered playing, the gaps between the sensor stripes have to be filled up with ebony stripes the same material as the finger board. These completed fixation is shown in Fig. 1. Therefore the right ratio between wood to the plastic surface of the sensor is needed. The integration of the sensors into the fingerboard is easily manufacturable together with violin makers and into every standard string instrument. A micro controller unit is used to read out the sensors and a PCB with potentiometers to calibrate the four used measurement channels. An integrated USB port enables connectivity to any laptop or host computer (see Fig. 4).

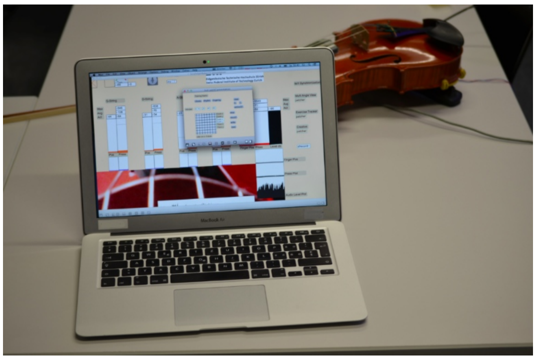

Figure 4: The data are transferred to a laptop computer and visualized and recorded with Max.

The sampling rate is around but not limited to 300 Hz. Given good contact conditions, the resolution of position measurement of the finger on each string is 0.5 mm. Due to latency and robustness issues, the setup is realized with wire-based data transfer. This allows for higher data transfer rates without dropouts and lower delay times for real-time feedback or sound synthesis. The used instrument is a new master violin (fecit 2010) by the awarded violin maker Hildegard Dodel, Cremona, Italy.

4.1.1 Measurements and Results

An evaluation regarding the haptic integration and the data aggregation were made. 13 students were asked to play on the instrument in different situations like daily practicing, tuition and concert situations. All sessions were recorded to prove the stageworthiness and robustness of the system. The participants were between 19 and 38 years old, four male and nine female students. They all were advanced violinists with at least 10 years of playing experience. Three of them stated an influence of the sensors, but one of them further explained, it was more caused by the unknown violin. The other two mainly were distracted by the cables attached to the violin. Students were asked to suggest improvements or design changes. The answers mainly criticized the small cables from the finger board to the shoulder rest, where the micro controller unit is fixed. The violin in this evaluation was played more than 100 hours and after that, no defects were recognizable.

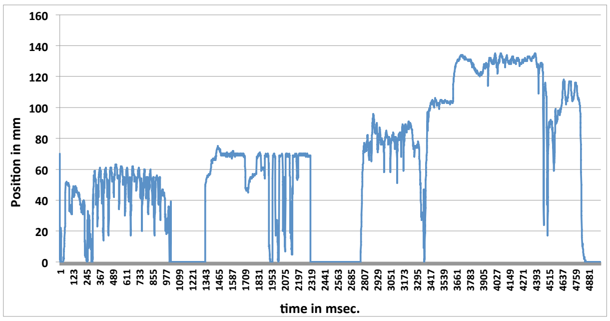

Figure 5: A plot of the left hand finger positions of a short excerpt of Tzigane for violin and orchestra is shown. The "0" values are open strings. Differences in string to finger board contact quality and different vibrato styles are measured.

5. GUITAR LEFT HAND FINGER AND PICKING SENSOR

The same technology was applied to a classical guitar. Guaus et al. in [5] use capacitive sensing to capture the guitarists' movements. In our approach we integrated linear potentiometers on the fret board to capture the position of the left hand fingers (see Fig. 6). Additionally we fixed a MPU6050 sensor on a plectrum to capture the picking movements of the right hand (see Fig. 7).

Figure 6: Close-up of the FSR integrated into a guitar fingerboard. The frets are fixed on the FSR and in the wood.

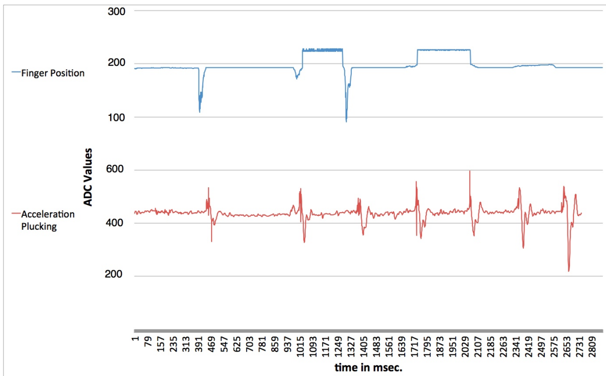

Figure 7: A plot of the left hand finger positions of guitar left hand finger changes (blue line) and right hand finger picking (red line) is shown. Further the left hand finger and right hand coordination is illustrated.

6. PIANO SETUP

In the following sections, the calibration and first evaluations of the piano sensor are described.

6.1 K6D Multi-Axes Based Calibration of the Piano Pressure Sensors

Although only the pressure distribution between and physical stress of the fingers is considered in all of our experiments, we did a calibration to get an idea of the absolute pressure values in Newton.

Figure 8: Setup with a K6D Force sensor for the piano key pressure sensor calibration. A black and white off-the-shelf piano key is used to calibrate the FSR sensors

The multi-axis sensor K6D (see Fig. 8) is suitable for the force and torque measurements in three mutually perpendicular axes. It is adjustable with a self-developed mount attached to the grand piano. The maximum specified measuring range of the 6-axes force-torque sensor is: We use the GSV–1A8USB 8-channel strain gauge amplifier, suitable for full, half and quarter bridges.

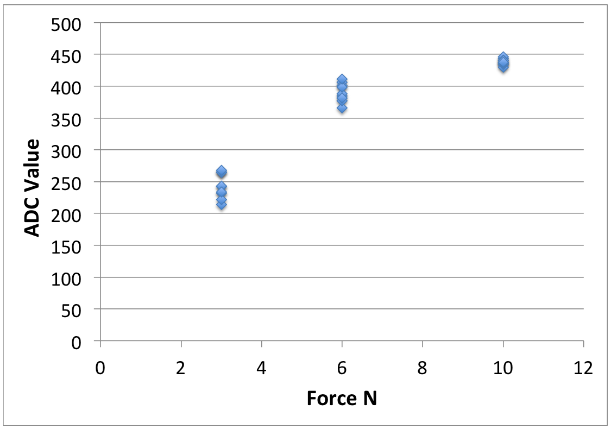

Figure 9: ADC value drift caused by inaccuracy of FSR sensors in repetition tests. Participants of the study had to perform increasing pressure on the key with their second finger (forefinger). Especially if low pressure is exerted, the repetition accuracy differs around 20%. The higher the pressure, the lower the deviation.

Several invited piano students performed the calibration. They increased finger pressure onto the K6D sensor several times and if a certain value was achieved, the ADC value of the micro controller unit was recorded. The measurement point were 2.5, 6 and $10N$. The were asked to perform like on a virtual piano, to get a realistic finger angle. The results a shown in Fig. 9.

6.1.1 *Measurements*

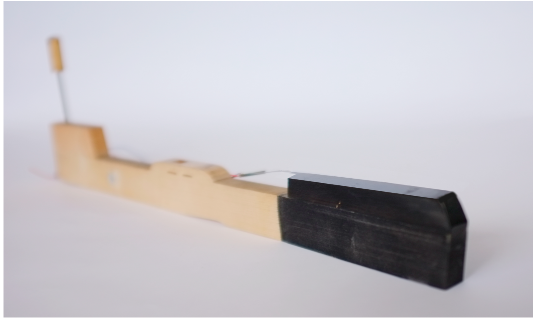

Figure 10: Black piano key with a FSR on top. This sensor key was used to calibrate and measure the forces.

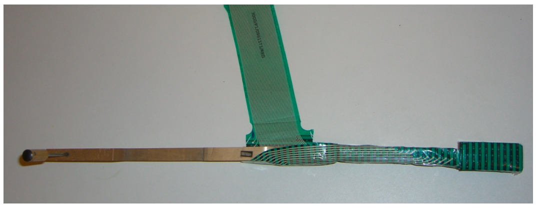

Figure 11: Prototype of a flexible PCB based FSR, 4 x 28 matrix sensor attached to the top of a piano key. The sensitivity is around $40gr$ and the sampling frequency is $100Hz$.

The basic construction of the sensor key is shown in Fig. 11. A custom made flexible PCB with a FSR based pressure sensor matrix is wrapped around a white and black standard key of a piano keyboard. The resolution of the matrix is around 5 x 5 mm. and the sensitivity is around $40gr$ overall pressure with a fingertip, which will be improved with the next version. The 'finger prints' of a touched key are shown in Fig. 12. The sampling frequency is around $100Hz$.

We invited 10 piano students with the age between 19 and 28. We used a simple keyboard with weighted keys. One key of this keyboard was prepared with the flexible sensor matrix (see Fig. 13). The students played some scales and pieces of their own choice. The haptic sensation of the sensor key was different for all participants, but not distracting. Due to this results, the haptics will be changed and refined in the next version.

The finger position data allow low-latency position and pressure recognition and open many possibilities in performance analysis and data to sound mapping. This is crucial in electronic music. The responsiveness of the sensors of this instrument allows new possibilities in performance analysis, electronic and digital sound generation, and many more application fields.

7. CONCLUSIONS

A new interface which augments the violin and the keyboard with multiple touch sensitivity is presented. The sensors integrated into keyboard and string instruments open many possibilities in combination with interactive software tools or any other controls. Finger pressure and position sensitivity can substantially enhance the expressivity of the traditional instruments by adding new parameters, up to now not available at all or still hard to detect. The improved capturing technologies further open up many new possibilities in teaching and understanding complex playing parameter better. Based on this information, the development of

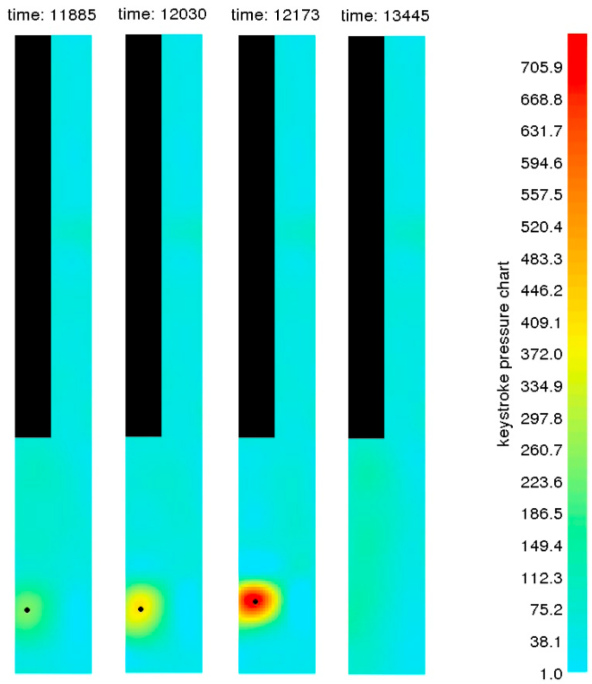

Figure 12: Heat map visualization of the prototype FSR pressure sensor matrix on a piano key indicating pressure, position and contact area. The key stroke was played in 'staccato forte'.

Figure 13: Fexible pcb based FSR, 4 x 28 matrix sensor attached to the top of a piano keyboard for usability tests with piano players.

alternative exercises might be attempted, which can be in turn objectively evaluated regarding their efficiency by using one of the introduced setups. The next steps will also include the simplification of the present setup and its refinement to still enhance its already high acceptability among musicians. Building a complete piano keyboard with the introduced technology is hopefully realized, soon. There are some data processing problems to be solved, caused by the combination of many channels and high sampling frequencies if many sensor matrices are fixed on each key e.g. on a grand piano keyboard.

8. ACKNOWLEDGMENTS

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