Low Force Pressure Measurement: Pressure Sensor Matrices for Gesture Analysis, Stiffness Recognition and Augmented Instruments

Tobias Grosshauser

IRCAM/ ReactiveS.net
1, Place Igor Stravinsky, Paris

ReactiveS Lab, Munich
+49- 176- 242 99 241

Tobias@Grosshauser.de

ABSTRACT

The described project is a new approach to use highly sensitive low force pressure sensor matrices for malposition, cramping and tension of hands and fingers, gesture and keystroke analysis and for new musical expression. In the latter, sensors are used as additional touch sensitive switches and keys. In pedagogical issues, new ways of technology enhanced teaching, self teaching and exercising are described. The used sensors are custom made in collaboration with the ReactiveS Sensorlab.

Keywords

Pressure Measurement, Force, Sensor, Finger, Violin, Strings, Piano, Left Hand, Right Hand, Time Line, Cramping, Gesture and Posture Analysis.

1. INTRODUCTION

Many audio and gesture parameters have already been explored and described in exercising, teaching and performing of musical instruments. The suggested method in this paper extends the approved practices. Basic technology is a high sensitive pressure sensor. The line up of several of these extremely light weighted sensors in arrays allows a broad field of applications. A combination in matrices allows 3-dimensional representation of the linearised data with position and pressure visualisation. The position, pressure/ force and the data representation with for instance time line alignement shows the change of the overall energy and is visualised graphically. Alongside the time axis the change of the applicated force respectivly the pressure can be observed.

Many different visualisation, recording, sonification and feedback tools are programmed in PD and MaxMSP or similar software environments and can be applied for the generated data.

All in all, the target group is from beginners up to professional musicians in the areas of teaching, performance, composition and posture and gesture analysis.

In music and art, sensors can be an alternative or an enahncement for traditional interfaces like computer keyboard, monitor, mouse and camera in man-machine interaction. Position, pressure or force sensing is a possibility to translate the haptic reality to the digital world. There is already a great choice of high performance motion and position tracking systems, but techniques for pressure recording are still under-represented. Besides the expenses, this is due to the complicated measurement technology needed for the mostly high capacitance of the industrial sensors and the complicated and damageable mechanical setup. After the first development period of the pressure sensors, the main goals, high sensitivity and low weight, were achieved. Later, also the following additional requirements:

- cheap and stable, "live-performance-proof"
- easy to use and to install
- no distraction of gesture or movements
- usable in performances with and without computer, "stand-alone system"
- every sensor can be detected autonomously
- high resolution AD-conversion, but also
- compatibility to standards like MIDI

2. STATE OF THE ART OF RESEARCH IN GESTURE, PRESSURE AND POSITION RECOGNITION

Poepel shows a summarisation of the extended violins, playing with ASDSS sounds, playing with expanded existing instruments and playing with new gestures [1]. Askenfelt already measures bow motion and force with custom electronic devices [2]. A thin resistor wire is among the bow hairs to get position data and bow bridge distance with electrified strings. Paradiso uses the first wireless measurement system, two oscillators on the bow and an antenna combined with a receiver [3]. Also pressure of the forefinger and between the hair and wood. Young received pressure data from a foil strain placed in the middle of the bow [4]. Demoucron attaches accelerometers to the bow and measures

the complete pressure of the bow with sensors connected to the bow hair [5].

Maestre presents a gesture tracking system based on a commercial EMF device [6]. One Sensor is glued on the bottom near the neck of the violin, a second one on the bow. Data of position, pressure by deforming the bow and relating data to this capturing can be calculated. A lot more systems exist, but mostly combined with a camera, which does not seem to be stable and reliable enough for performances and everyday use.

A different approach is developed at IRCAM by Bevilaqua [7]. The sensing capabilities are added to the bow and measure the bow acceleration in realtime. A software based recognition system detects different bowing styles.

Guaus measures the bow pressure over all [8] and not each finger, which cause the pressure on the bow. Sensors are fixed on the hairs of the bow on the tip and the frog. This means additional weight on the tip, which could influence professional violin playing, because of the leverage effect.

The recent paper of Young [9] describes a data base of bow strokes with many sensor data like 3D acceleration, 2D bow force, and electric field position sensing, again with an over all bow force measurement.

The presented measuring system here shows a setup easy to install, just sticking the less than 1mm thick, flexible sensor on the bow or finger and connecting it with the convertor box. As every single finger itself is measured, besides pressure and force allocation and changes between the fingers at different playing techniques, muscle cramps and wrong finger position can be detected.

3. BASIC SETUP

Each sensor is connected directly with a converter box. If less data is required, fewer sensors can be plugged into the convertor box. Standard stereo jacks are used as plugs, each sensor/ plug has its own control channel. This allows individual and minimized setups and a better overview, if fewer channels are used, especially with younger students. Wireless transmission is partly possible, but not always practicable. The connector box can be worn on a belt. Data transmission is possible either to a computer or directly to synthesizers or other modules via MIDI. The connector box provides a power supply for each sensor and direct MIDI out.

The basic sensor is 5 x 5 x 2 mm, larger dimensions are possible. It weights only some grammes, depending on the dimensions of the surface area. The sensors are usually combined in 2 to 4 rows each consisting of 4 to 8 sensors, sticked on a flexible foil.

The basic setup consists of at least one 16-channel programmable converter and connector box, sensor matrices for shoulder rest, chin rest and bow. Further a computer with MaxMSP, MathLab or common music software to process, record or display the data.

4. PRESSURE AND POSITION MEASUREMENT
4.1 Strings
The basic measurements at the violin (exemplary for strings) are:

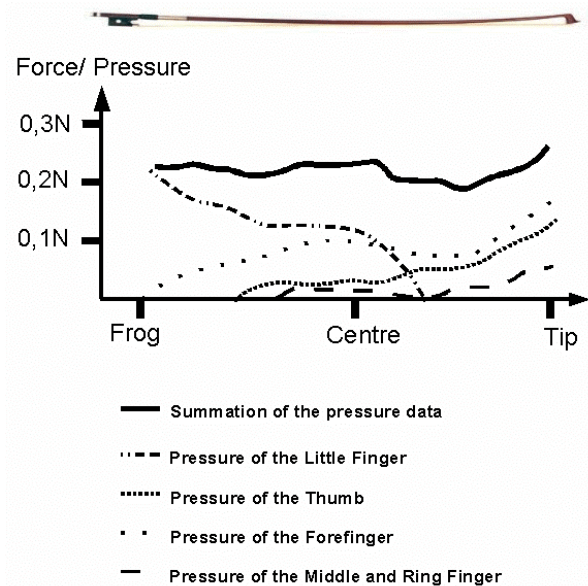### 4.1.1 Pressure and Position of each Finger of the Right Hand

Figure 1. Change of force during one bow stroke

These integrated sensors show when the position and/or pressure changes during the movement of the bow (see figure 1) or over a certain force limit. This limit can be adjusted individually and visual feedback or just data recording is possible. This allows ex post playing analysis of the performed music piece, or just information for beginners. The sensors of the middle and the ring finger can also be used for steering or switching peripheries on/off or for constant sound manipulation.

Figure 2 shows the integration of the sensors into the bow and finger posture of the right hand. Every sensor is installed to the right place, individually adapted to the ergonomical and technical correct position of the musicians' fingers. For beginners, rather in the age over 15 years, this is a simple control for the correctness of the posture, if they exercise alone at home and it detects wrong exposure or stiffness of the hand and fingers, for example too much or wrong directed pressure on the forefinger.

Figure 2. Pressure sensors on the bow

4.1.2 Pressure of the left Hand

This is not an every day solution, because the flexible sensors are sticked on each finger. But for several methodical and technical issues useful information is generated. Not the maximum pressure itself, but how the pressure changes for example at different types of thrills or vibrato and how the pressure is divided between the fingers when double stops are played. In combination with bow position sensor, left- right hand coordination can be explored very accurate.

4.1.3 Areal Distribution of Pressure and Position of the Chin on the Chin Rest

First measurements of chinrest pressure in violin playing were done by M. Okner [10]. Five dependent variables were evaluated: peak pressure, maximum force, pressure/time integral and force/time integral, and total contact area. Similar variables are studied in our measurements and shown in figure 3.
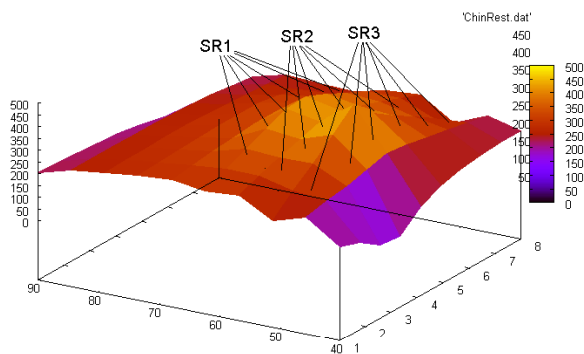

Figure 3. Pressure Allocation Chin Rest

Figure 3 shows the chin rest pressure and force sensor matrix measurements data in a 3-axis coordinate system. This optical representation of the force and pressure data seems to be a pratical way of showing the measruement results.

The sensor matrix enables the detection of the pressure distribution over the whole area, compared to the pressure measurement in one point only. Both, position changing and muscle cramping is detectable and could prevent pain of back and neck of beginners and malposition, especially in long-lasting exercising situations or general inattentiveness.
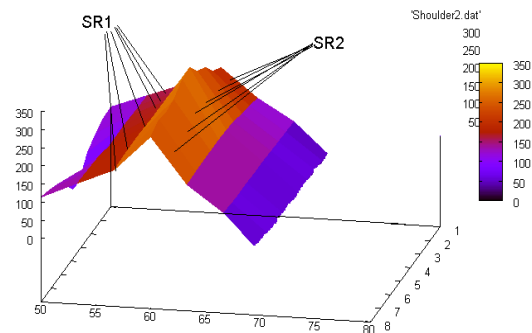

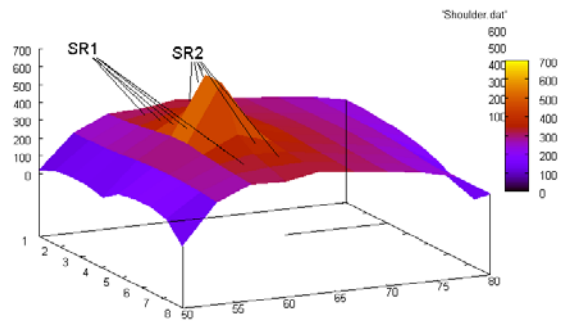**Figure 4. Shoulder Rest Pressure Allocation, SR1 and SR2 Sensor Array**

Figure 5. Shoulder Rest Malposition, SR1 and SR2 Sensorposition

Similar to the above-mentioned chin rest solution, the shoulder rest matrix (see figure 4) detects malposition and false posture, often caused by disposition of the shoulder. In figure 5, SR2 shows an incorrect pressure allocation on the shoulder rest, compared to SR2 in figure 4. Correct violin position is a basic condition precedent to learn the further playing techniques. This issue concerns mainly beginners, for advanced musicians it is possible to use for example a defined pressure raise of the chin or shoulder for switching and steering interactions. (Besides a bad positioned shoulder rest, backache can be avoided by good shoulder and neck posture.)

4.1.4 Comparison Shoulder-Chin Rest Pressure and Position

Figure 6 shows the pressure allocation of chin and shoulder in one coordinate system. The upper area is the chin pressure, the lower area the shoulder rest pressure allocation area. The optical representation is important for a simple every day use. In this case wrong posture or mal position would appear in a brighter colour or inhomogeneous shape of the 2 areas.

Postion changes of the violin itself can be detected while playing. This enables the musician or teacher to analyse besides pressure and force changes, changes of the violin position. Evaluation and

studies about expressive gestures during a live performance or practising situations are possible.
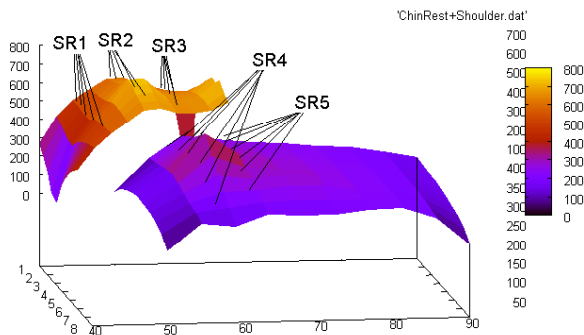

Figure 6. Comparison Shoulder-Chin Rest Pressure and Position

4.1.5 Stiffness Recognition

A common problem in teaching, especially in beginners' lessons, is too much tension or stiffness in the bow hand. Besides wrong posture of the hand, elbow and fingers, often force is applied to the wrong fingers, sometimes because of the impression, the bow could fall down. The wrong applied force can be detected by the sensors. Most of the times, too much pressure is applied to fingers, where usually nearly no force is needed. In this example on the violin bow the middle and the ring finger. A visualisation tool (figure 7) was programmed in PD and MaxMSP. A blue ball reacts to the pressure of the ring finger. If there is too much pressure, it moves to the right (figure 8) and the color and shape changes. Besides that, a sonification is implemented; the more force, the louder and more distorted sound is generated. When the opposite appears, the ball reacts into the other direction.

Basically all sensor data can be visualised and sonified with this tool, but every student reacts individually to technology in teaching situations. First practical experience shows quite good acceptance and feedback, even from the younger pupils.
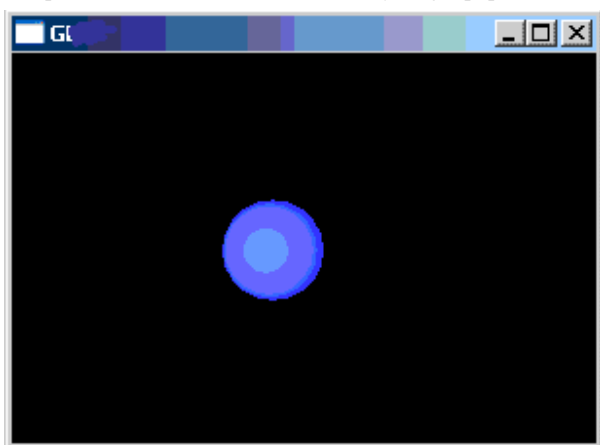

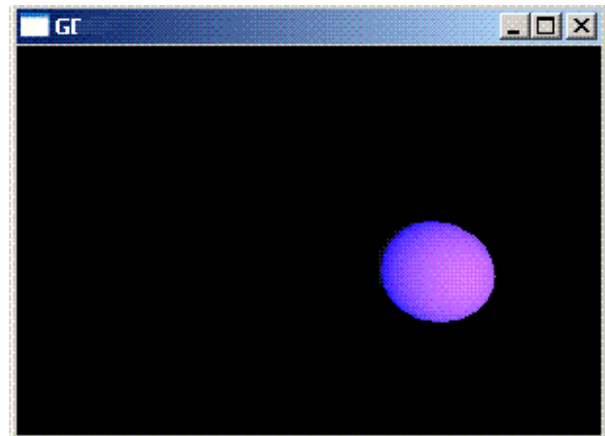**Figure 7. Visualisation of 3rd Finger, "Stiffness Control"**

Figure 8. Visualisation of 3rd Finger, "Stiffness Control", too much force/pressure

4.1.6 Pedagogical Issues

The core application right now is the posture and tension control for stundents older than 15 years. Usually they like this feedback tool and are used to work with computers. A playful approach always is important and technical experimentation often ends up in long exercising periods. This kind of motivation is not always working, but the other positive results like remembering the posture learned in the last lesson and being able to record data besides music is interesting.

The possibilities to provide a simple visualisation tool to get objective data for self studies or practising scenarios are manifold. Some useful scenarios are:

- Early detecting of too much muscle tension, caused by wrong finger position or fatigue

- Easy feedback for beginners, if their posture of the right hand is OK

- Avoiding of lasting and time consuming postural corrections

With professional violinists, interesting tests are made. After long exercising or job-related playing periods, physical fatigue can be measured by posture or pressure changes. In exercising situations, a visual feedback could inform the student and suggest a short recreation phase.

4.2 Keyboard Instruments

Several basic measurements are applied in piano playing. The main goals are mal position of the hands of fingers and too much muscle tension or cramping of the fingers, hands and elbow.

Furthermore the force of single keystrokes and attacks were measured and visualised for analysing.

With these sensor arrays, augmented pianos are possible and new ways of playing techniques and expressions could be found.

4.2.1 Pressure/ Keystroke and Fingertip Position of each Finger of the left and right Hand

There are two possibilities of keystroke and fingertip position recognition. First, sticking the sensor onto the keys (difficult to play), second fixing one sensor on each fingertip. Only the result of the second variation were useful.

Keystroke recognition is explored by R. Möller [11] with „High-speed-camera Recording of Pulp Deformation while Playing Piano or Clavichord". Different sensor types are discussed, but in laboratory conditions with precise but usually unaffordable equipment and only one playing mode. The low cost system described here is fast enough to detect the maximum forces and the gradient of each finger in different playing modes, like thrills or fast scales.

Common key stroke recognition works with two measure points and the delay between them with every stroke (See Figure 9). Guido Van den Berghe describes the system in [12] and mentions the unsatisfying possibilities to create differentiated key strokes on electric pianos. He also developed a force measurement system in combination with a high speed camera: But no easy to use and an external tool, where no connections in or on the piano, no sensors or fixed parts are needed. Even if there are better systems existing now, there is no "force-detection" interface except someteimes the MIDI-attack recognition for piano or keyboards, to connect to a fine grain and high resolution force and pressure measurement.
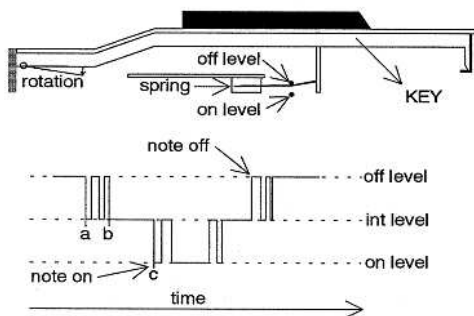

Figure 9. Key velocity measurement system in an electric piano [10]

4.2.2 Pedagogical Issues, Stiffness Recognition

In Figure 10, the changes of the force of slow keystrokes with different attacks are shown.

Figure 10. Piano Key Strokes, from "piano" to "forte", Sensors sticked on the finger tips

Explanations about key strokes could be assisted with this tool. Self studies at home could be compared to the recorded data in the music lesson or from other musicians. Several basic pedagogical problems were explored. The non-releasing of the keys, a common beginner's fault can be detected and visualised. Fatigue and cramping are other reasons for this manner, even at advanced pupils or professionals.

Many examples could be given, one more is the problem of rhythmical and dynamical irregularity. Time line, score and audio alignment of the data with adjustable time resolutions can show clearly the problem, which might be difficult to hear. In these cases, basic visualizations can simplify long-winded explanations.

4.2.3 Further Analysis

First experiments with further combined measurements are made. For example: Food pedal usage and pressure measurement. Two aspects of this measurement are useful. Seeing how and when, for example a professional player uses the pedals. This could be recorded in a commonly used audio software and analysed with the sensor data aligned to an audio recording. Self recording helps to explore the own usage, or the change of the usage of the pedal during a longer exercising period.

4.3 Extended Music, Enhanced Scores and Augmented Instruments

Figure 11 shows a score with additional fingerings with the thumb. The Zero before the conventional fingering is the left hand thumb on the violin. It is used like an additional finger.The second number next to the "0" gives the position of the thumb, if the sensor allows more than one active area. In this case three sensitive areas are used and in each the pressure of the thumb is detected. This allows not only switching effects on and off, even more, adjusting the amount of data or sound manipulation. Extended playing techniques, data or sound manipulation and more voices are feasible.

The goal was the integration of sensors in common playing modes and gestures. On the one hand thumb-steered real-time interaction with electronic peripheries like computers and synthesizers, on the other hand switching, manipulating and mixing of sound effects, accompaniment and 3d-spatial sound position with integrated sensors besides the fingerboard, in the range of the thumb.

Similar methods could be applied to the right hand sensors, but it is quite difficult to change the pressure without influencing the sound too much.

Figure 11. Extended Score

This extended score is a part of the piece "concertare" from Tobias Grosshauser [13].

For keyboard instruments for instance modulation is possible, just by changing the finger pressure after the key is already stroken. This new playing technique allows new ways of articulation, even when the key is already pressed and sound effects like vibrato on the piano or keyboard instruments.

4.4 Further Scenarios and Research

Further research will be observed with finger pressure measurements on wind instruments and drums. In combination with position recognition and acceleration sensors, most important parameters are detected.

This pressure and force sensors provide more and more possibilities for new music compositions in combination with extended scores and simplified real time interaction within electronic environments.

Concerning pedagogic issues, the systems and methods will be more and more accurate and user friendly for a wider range of usage and target audience.

The combination of traditional instruments, computer and high tech tools like new sensors could motivate a new generation of young musicians to learn with new methods they like and they are more and more used to. Cheap and easy to use sensor systems would support this development. Also if teaching and pedagogy would be more of an adventure and research for new possibilities and "unknown terrain", making music, learning and playing a musical instrument and pracitising could be more fascinating.

5. REFERENCES

[1] C. Poepel, D. Overholt. *Recent Developments in Violin-related Digital Musical Instruments: Where Are We and Where Are We Going?* NIME06, 6th International Conference on New Interfaces for Musical Expression, 2006.

[2] A. Askenfelt. *Measurement of bow motion and bow force in violin playing,* Journal of Acoustical Society of America, 80, 1986.

[3] J. A. Paradiso and N. A. Gershenfeld. *Musical applications of electric field sensing,* Computer Music Journal, 21:2, S 69-89, MIT Press, Cambridge, Massachusetts, 1997.

[4] D. S. Young. *Wireless sensor system for measurment of violin bowing parameters,* Stockholm Music Acoustics Conference, 2003.

[5] M. Demoucron, R. Caussé. *Sound synthesis of bowed string instrumnets using a gesture based control of a physical model,* International Conference on Noise & Vibration Engineering, 2007.

[6] E. Maestre, J. Janer, A. R. Jensenius and J. Malloch. *Extending gdif for instrumental gestures: the case of violin performance*, International Computer Music Conference, Submitted, 2007.

[7] F. Bevilaqua, N. Rasamimanana, E. Flety, S. Lemouton, F. Baschet. *The augmented violin project: research, composition and performance report*, NIME06, 6th International Conference on New Interfaces for Musical Expression, 2006.

[8] E. Guaus, J. Bonada, A. Perez, E. Maestre, M. Blaauw. *Measuring the bow pressure force in a real violin performance*, International Conference on Noise & Vibration Engineering, 2007.

[9] D. Young, A. Deshmane, *Bowstroke Database: A Web-Accessible Archive of Violin Bowing Data,* NIME07, 7th International Conference on New Interfaces for Musical Expression, 2007

[10] M. Okner, T. Kernozek, *Chinrest pressure in violin playing: type of music, chin rest, and shoulder pad as possible mediators*, Clin Biomech (Bristol, Avon)., 12(3):S12-S13, 1997-04

[11] R. Möller, Wentorf, *High-speed-camera Recording of Pulp Deformation while Playing Piano or Clavichord.* Musikphysiologie und Musikermedizin, 2004, 11. Jg., Nr. 4,

[12] Guido Van den Berghe, Bart De Moor; Willem Minten, *Modeling a Grand Piano Key Action*, Computer Music Journal, Vol. 19, No. 2. (Summer, 1995), pp. 15-22, The MIT Press

[13] T. Grosshauser, *Concertare,* www.extendedmusic.net, click "concertare"