The Elbow Piano: Sonification of Piano Playing Movements

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ABSTRACT
The Elbow Piano distinguishes two types of piano touch: a touch with movement in the elbow joint and a touch without. A played note is first mapped to the left or right hand by visual tracking. Custom-built goniometers attached to the player's arms are used to detect the type of touch. The two different types of touches are sonified by different instrument sounds. This gives the player an increased awareness of his elbow movements, which is considered valuable for piano education. We have implemented the system and evaluated it with a group of music students.

Keywords
Piano, education, sonification, feedback, gesture.

1. INTRODUCTION
A pianist can use different combinations of movements in different joints to perform a touch [4]. A touch can be performed by the isolated movement of a finger while wrist, elbow, shoulder, and the body support the finger without active movement. Alternatively, a pianist can execute a touch using movement in one of the mentioned joints. For example, a pianist can slightly fixate fingers and use the movement of the wrist, while elbow, shoulder, and body do not move. A pianist can also use a combination of activity in the different joints.

It has been argued in the field of piano pedagogy that awareness of the playing movements can be beneficial. S. Bernstein, for example, states that becoming aware of the playing movements is one of the key goals a pianist should pursue [1]. By giving the pianist more consciousness of her playing movements, she can find movements that better fit the musical and technical demands, and gain more confidence to master stress situations, like public performance.

This paper is structured as follows. First, different piano teaching systems related to this work are discussed in Section 2. The architecture, the main features, and the components of the Elbow Piano system are described in Section 3. Next, the results of our evaluation are presented in Section 4 and conclusions in section 5. Finally, we discuss opportunities for future work in Section 6.

2. RELATED WORK
Systems for music practice education that use sensor data to sonify playing movements have been developed for different instruments. The 3D Augmented Mirror [7] is an example of such a system for a bowed string instrument. The 3D Augmented Mirror provides the user with visual and auditive feedback based on the input of a visual tracking system.

Piano teaching systems can be classified by the type of input they receive from the user. Recent piano teaching systems can be classified to pure MIDI systems and systems that receive physiological or physical data.

2.1 Pure MIDI Piano Teaching Systems
The Piano Tutor [3] uses score following to find errors, to provide accompaniments, and to turn pages. The system gives the user feedback using a combination of video, notation, voice, music, and graphics. An expert system module monitors the success of the student and suggests easier tasks if necessary.

The pianoFORTE system [13] visualizes tempo, articulation and dynamics of a performance. Tempo is visualized by a speed-o-meter, dynamics by the color of the notes. To visualize the articulation, the lengths of the played notes are marked in the score. The MIDIATOR [12] compares a student's performance to the score or a previous performance of the piece and visualizes differences of tempo, note volume, note duration, and articulation.

The practice tool for pianists by Goebl and Widmer [6] generates visual feedback from MIDI input in real-time. The practice tool finds reoccurring patterns by autocorrelation. The student can see timing deviations between successive patterns that indicate uneven play. Other visualizations display beats, time deviations between chord notes, and a piano roll overview.

The Intelligent Virtual Piano Tutor [8] is a system that suggests fingerings for received MIDI sequences. The suggested fingering is animated by a 3D virtual pianist.

2.2 Physiological- and Physical-Data Based Piano Teaching Systems
Montes et al. used EMG biofeedback to teach thumb touches [9]. Electrodes were placed on the abductor pollicis brevis

muscle. While a student performs thumb touches, the amount of muscular activity is shown on a screen. In comparison to a control group that received traditional training of the thumb attack, a biofeedback group was able to match the muscle activity pattern of professional pianists better.

A multimodal feedback system is used by Riley to improve piano lessons [11]. The system can record and replay MIDI, EMG, and video. The video and MIDI output is synchronized with a piano roll of the performance.

Mora et al. developed a system that overlays a 3D mesh of a suggested posture over a video of the student's performance [10]. The student can see the differences and adopt the suggested posture. To generate the 3D mesh, the posture of a professional pianist was recorded using motion capturing.

3. ELBOW PIANO

A user who wants to practice with the Elbow Piano sits at the keyboard and attaches the goniometers to her arms. She then plays a *tuning chord*, which is necessary to initialize the visual tracking system. Visual tracking of the hands is used to assign the goniometer measurements to the notes played. In the following, we describe a typical use case of our system.

The user starts playing. Sometimes the user performs elbow-touches, sometimes the user avoids them. Always when the user plays an elbow-touch, the system plays the elbow-touch sound. Now, if the user unintentionally plays an elbow-touch, the system will also produce the elbow-touch sound. The user can stop playing at this point and use a graphical visualization to analyze this condition. After some time, the user continues playing.

3.1 Hardware Setup and Software Architecture Overview

The Elbow Piano consists of sensors, which are connected to a computer, and a software that analyzes the incoming data stream and controls an attached synthesizer. The sensor hardware of the Elbow Piano consists of a MIDI keyboard, a webcam placed above the keyboard, and a pair of self-built goniometers. The webcam is used to visually track the hands. The goniometers provide data about the angles in the elbow joints.

When the system receives a note-on event from the keyboard, the system assigns the note to the left or right hand. This is done by means of visual tracking (section 4.2). The history of goniometer data of the identified hand is examined to determine if the key was pressed with activity of the elbow joint (section 4.3), or not.

3.2 Visual Tracking

Mapping MIDI data to hands without additional information is only possible to some extent as the mapping is ambiguous. Therefore, visual tracking was used.

A webcam (Genius Slim 1322AF) mounted above the keyboard is monitoring the entire claviature. Before the user can start playing, she has to lock the visual tracking on her hands. This is done by playing a predefined *tuning chord*. To obtain the image coordinates of the hands, the system has to map from keys to horizontal image coordinates. For that reason, it needs to know the horizontal position of the left and right end of the claviature, as well as the vertical coordinate of the front. These positions have to be configured once by the user using a GUI.

The keys are mapped to horizontal positions by linear interpolation. Each key corresponds to an area with the width of 1/88 of the width of the claviature. Although this approximation does not reflect the structure of the claviature, it is sufficiently accurate for the Elbow Piano.

The visual tracking is locked on the hands when the user plays the *tuning chord*. This chord consists of two black keys per hand (each hand plays a f#-c#-chord on different octaves). When the tuning chord is played, the approximate positions of the hands are estimated by the system. Two areas, which are located in front of the claviature at the horizontal positions of the hands, are used to calculate the histograms of the skin colors (for each hand separately) and serve as initial search windows for the tracking algorithm.

The visual tracking of the hands is done with the OpenCV implementation of the CAMSHIFT algorithm. CAMSHIFT [2] climbs the gradient of the probability distribution, which is computed using a histogram, to adjust the position of the search window. CAMSHIFT continuously changes the size of the search window. Therefore, the entire hand of the Elbow Piano user is tracked after some iterations of the algorithm. Because of the operating principle of the CAMSHIFT, the color of the floor and the clothing have to be sufficiently distinct from skin color and it is necessary that the user wears long-sleeved clothing.

The Elbow Piano segments the claviature into a part for the left hand and a part for the right hand. For this purpose, the system examines the rightmost pixel assigned to the left hand and the leftmost pixel assigned to the right and determines the middle. Each note is assigned to the left or right hand by comparing its position to the middle.

The user receives visual feedback about the hand tracking module (Figure 1). The hands are surrounded by a circle in the image from the webcam.

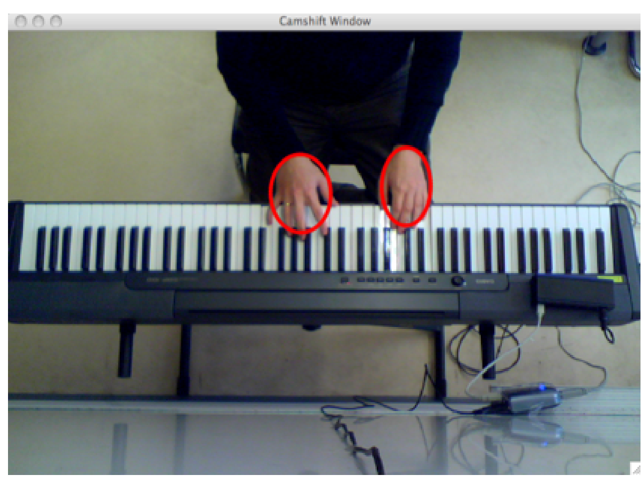

Figure 1. Hands Are Tracked

3.3 Recognition of Elbow Activity

Based on the data from the goniometers, the Elbow Piano decides whether a touch was performed with movement in the elbow joint, or not.

3.3.1 Goniometers

A pair of custom-built goniometers (Figure 3) provide the computer with data about the angles in the elbow joints. Each goniometer consists of a potentiometer and two plastic strips. The plastic strips are connected to the axis of the potentiometer so that the motion of the plastic strips is transferred to the potentiometer. The potentiometer has a aluminum case and can therefore sustain the occurring physical forces. Velcro fasteners are attached to the plastic strips and are used to mount them on a suited pullover. The goniometers are additionally fixated by rubber bands. The potentiometers are wired up as voltage dividers and are connected to A/D converters. The digital signal is transmitted to the computer via USB with a rate of up to 100 Hz (values are transmitted on change only). The A/D converter used is a CreateUSB board.

3.3.2 Decision

The goniometer data is continuously stored with the corresponding timestamps. When the keyboard sends a note-on message, the sensor data log of the arm that produced the tone is examined. The latest 0.2 seconds of the sensor data is analyzed. Considering the rapid sequences of movements that can occur in piano playing, the choice of this rather large time interval is reasonable, because elbow-touches cannot be done (much) more rapidly. The lowest angle in the elbow during that time interval and the last measured angle are compared. If the difference of these angles exceeds a predefined threshold, the touch is classified as a touch with elbow activity.

3.3.3 Decision Visualization

To provide feedback to the user, a visualization of the decision process was developed. The Elbow View (Figure 4) shows the goniometer data that was used to decide whether the touch was executed with activity in the elbow joint, or not. The graph is inverted along the y-axis to provide a more intuitive visualization. The graph of an elbow touch begins with high values and slopes to the right; this corresponds to the movement of the forearm performing an elbow-touch, which starts at a high position and then moves downwards. Relevant information about the graph and the decision is provided to the user: the lowest angle, the last angle, the difference between the two and the result of the decision. The user can access past visualizations. To assist the user to navigate, a separate view is provided for each hand. Furthermore, the graphs are stacked when a hand plays a chord, i.e., if two notes are received within 0.1 seconds.

Figure 2. Goniometer

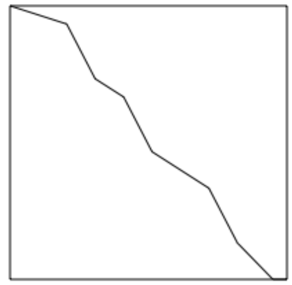

Figure 3. Visualization of an elbow touch

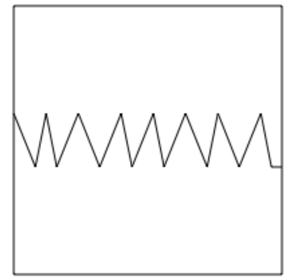

Figure 4. Visualization of a non-elbow touch

3.4 Sound Generation

When an elbow-touch is recognized, the system passes the note-on MIDI message that was received from the keyboard to the connected (software or hardware) synthesizer. The system changes the channel of the MIDI message to reflect which arm executed the elbow-touch. By configuring the synthesizer to play different instruments on these channels, the Elbow Piano can play different sounds for the left and right arm. The generated sound effects can be prolonged by using the sustain pedal of the MIDI keyboard.

4. EVALUATION

The Elbow Piano was evaluated with students of the HfMDK Frankfurt (University of Music and Performing Arts Frankfurt). Four pianists (professional level), one composer (advanced level), and one singer (intermediate level) participated in the user study. The system was briefly explained to each participant. Each participant then played pieces of her/his own choice with the Elbow Piano. Afterwards, the participant filled out a questionnaire and was interviewed. The questionnaire contained different statements, which were rated by the participants on a scale from 1 (disagree) to 5 (agree) (Table 1).

It was evident that the participants improved their ability to control the system during the sessions. At the beginning, the participants tended to imitate the mere appearance of the motion, which had been shown to them. The participants often did not consistently use the elbow joint to move the fingers but used the wrist, the shoulder and (in one occasion) the back instead. During the session, the participants moved more consistently and could therefore control the system better. The participants expected that they could learn to control the system better if they have had more time to practice with it and they stated that the system increased their awareness of arm movements. Despite all that, all but one participants did rather not want to use the system for practice or teaching because the system focuses only on one specific aspect of piano technique and can therefore not (yet) be integrated into a piano syllabus.

Overall, we received very positive feedback and were encouraged to continue with our approach.

Table 1. Questionnaire

Statement	Score (Avg.)
I have good control of the sound.	3.5 of 5
I would learn to control the system better if I had more time to practice with it.	4.8 of 5
I am more aware of the movement of my arm when using the system.	4.5 of 5
Using the system is fun.	4.2 of 5
I would use the system to practice or teach the piano.	2.5 of 5

5. CONCLUSIONS

Awareness of playing movements can be beneficial for instrumental performance. The Elbow Piano distinguishes two types of touch: a touch with movement in the elbow joint and a touch without. Therefore, the Elbow Piano can increase awareness of these movements with possible beneficial effects on normal piano performance.

The Elbow Piano consists of a MIDI keyboard, a webcam, a pair of custom-built goniometers, a computer to which these sensors are connected to and a software that analyzes the incoming data stream and controls an attached synthesizer. The system uses visual tracking to find the positions of the hands on the keyboard. On each keypress, the goniometer data of the matched arm is evaluated and the system decides what type of touch the user executed. The user gets visual feedback about the decision process and can evaluate the decision of the system.

A user study with music students of the HfMDK Frankfurt was conducted. The participants learned to better control their arm movements during the sessions. Despite that, most participants did not want to use the system to practice or teach the piano. Although a conservative attitude might be a minor factor for this result, we think that the our approach needs to be integrated into a systematic piano syllabus to make it more convincing. To this end, we are currently applying the presented approach to other playing movements.

6. FUTURE WORK

Gorodnichy and Yogeswaran developed a system that allows to track hands, fingers and the position of the keyboard in the images of a camera placed above the keyboard [5]. The visual tracking of the Elbow Piano could be improved using this approach and the user would not need to configure the position of the keyboard.

Movements in the elbow joints are not only performed to press a key downwards. They also occur when the player moves the hand forwards, backwards or sideways. These changes of elbow angles could be estimated using information gained by visual tracking of the hands. The goniometer data input could be cleaned from this effect before the recognition method is applied. The posture of the player has also an effect on the angles in the elbows. Measured change of posture could be used to clean the goniometer before the recognition method is applied.

We are currently exploring the use of different sensors to generalize the presented approach to other playing movements.

7. REFERENCES

[1] Bernstein, S. Twenty Lessons In Keyboard Choreography. Seymour Bernstein Music, 1991

[2] Bradski, G. R. Real Time Face and Object Tracking as a Component of a Perceptual User Interface. In Fourth IEEE Workshop on Applications of Computer Vision (WACV '98), 1998

[3] Dannenberg, R. B., Sanchez, M., Joseph, A., Joseph, R., Saul, R., and Capell, P. Results from the Piano Tutor Project. In Proceedings of the Fourth Biennial Arts and Technology Symposium, 1993

[4] Gat, J. The Technique of Piano Playing, Collet‘s Holding, London, 1965

[5] Gorodnichy, D. O. , and Yogeswaran, A. Detection and tracking of pianist hands and fingers. In Proceedings of the The 3rd Canadian Conference on Computer and Robot Vision (CRV'06), 2006

[6] Goebl, W., and Widmer, G. Unobstrusive Practice Tools for Pianists. In Proceedings of the 9th International Conference on Music Perception and Cognition (ICMPC9), 2006

[7] Ng, K., Weyde, T., Larkin, O., Neubarth, K., Koerselman, T., and B. Ong. 3D Augmented Mirror: A Multimodal Interface for String Instrument Learning and Teaching with Gesture Support. In ICMI '07: Proceedings of the 9th international conference on Multimodal interfaces, 2007

[8] Lin, C., and Liu, D. S. An Intelligent Virtual Piano Tutor. In Proceedings of the 2006 ACM international conference on Virtual reality continuum and its applications, 2006

[9] Montes, R., Bedmar, M., and Martin, M. S. EMG Biofeedback of the Abductor Pollicis in Piano Performance Brevis. In Biofeedback and Self-Regulation, 2, 18, 1993

[10] Mora, J., Lee, W., Comeau, G., Shirmohammadi, S., and Saddik, A. E. Assisted Piano Pedagogy through 3D Visualization of Piano Playing. In HAVE 2006 - IEEE International Workshop on Haptic Audio Visual Environments and their Application, 2006

[11] Riley, K., Coons, E. E., and Marcarian, D. The Use of Multimodal Feedback in Retraining Complex Technical Skills of Piano Performance. Medical Problems of Performing Artists, 20, 2, 2005

[12] Shirmohammadi, S., Khanafar, A., and Comeau, G. MIDIATOR: A Tool for Analyzing Students' Piano Performance. In Revue de recherche en éducation musicale, 2, 2006

[13] Smoliar, S. W., Waterworth, J. A., and Kellock, P. R. pianoFORTE: A System for Piano Education Beyond Notation Literacy. In MULTIMEDIA '95: Proceedings of the third ACM International Conference on Multimedia, 1995