Keyboard Interface with Shape-Distortion Expression for Interactive Performance

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ABSTRACT

This paper presents a design of a shape-distortion keyboard as a kind of visual feedback of finger input on a piano interface for interactive performance. By tracking the movements of a finger and by controlling MIDI output, the keyboard interface of the proposed design provides expressive control in accordance with the finger movements during playing. Unlike an ordinary piano interface with a static keyboard, the shape-distortion design transforms the positions and shapes of keys, allowing swiping and shaking the finger to tune expressive control. To test the designs of the shape distortion, we implemented three variations of shape distortion and three types of expressive control such as volume change, pitch bend, and timbre-mixing balance, thereby enabling us to find the effective combinations between them. In a user study, three participants tried these variations of shape-distortion design and provided comments for feedback, improvement, and the future design of the interactive keyboard's interface and performance.

1. INTRODUCTION

People use musical instruments as an interface to express their musical imagination, and the resulting sounds can delight and inspire people. Conventional musical instruments are physical objects, so the function on each interface is physically limited. They cannot proactively change their shape in accordance with user behavior. In comparison with the conventional keyboard interface, a visual keyboard interface drawn on a display by software has an advantage in designing multi-functional input and in giving interactive visual feedback in accordance with the user's input. Some research has focused on an assist method and visual feedback of piano playing but not on playing style and function. In addition, several interactive systems have been proposed that augment the piano and provide visual or haptic feedback to enhance the user experience, but they leave the keyboard shape as is.

Our research question is on designing an interactive piano interface for playing style and performance with sound effects. An instrument whose shape could adapt to the user in some way could open new possibilities for music instruction or music expression. We aim to design an interactive instrument that can change its shape. We are particularly interested in designing a musical instrument that bends the visual feedback in accordance with the user's movements.

In this study, we set it as our goal to design an interactive keyboard that changes its shape in response to the user's finger movements. The keyboard provides visual feedback in real time to make the user aware of the sound they are producing, allowing the user to handle expressive control by swiping the finger after touching the keyboard. We implemented three variations of the shape-distortion design and its animation. We also implemented three types of expressive control (volume change, pitch bend, and timbre-mixing balance) for testing each shape-distortion design and for finding the best combinations between shape distortion and expressive control.

We created the visual expression of a piano interface on a two-dimensional planar surface (a touch display) and expressive control with MIDI control. Unlike an ordinary touch display that can only provide touch events, the system also detects finger hovering by tracking the three-dimensional position of the finger with 0.1-mm accuracy and at up to 100 Hz. With this accurate and frequent position, the keyboard changes its shape at up to 20 frames per second in accordance with the proposed shape-distortion design. The number of fingers tracked is currently limited to one to prevent recognition error when touching the keyboard. Thus, we have designed the current exploratory system for one-finger piano playing.

To test the concept of shape-distortion design, three keyboardists were asked to play music using the variations of shape distortion with expressive control, and they discussed their preferred combination. On the basis of this feedback, we determined an efficient and preferred com-

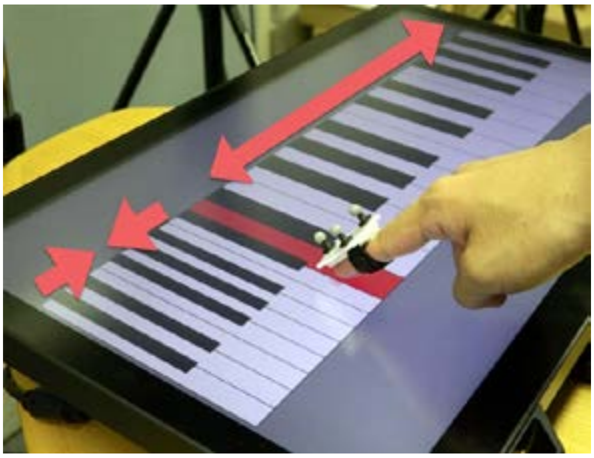

Figure 1. Responding to finger movements by distorting shape and changing color in accordance with finger position. The marker of motion tracking was worn on one finger.

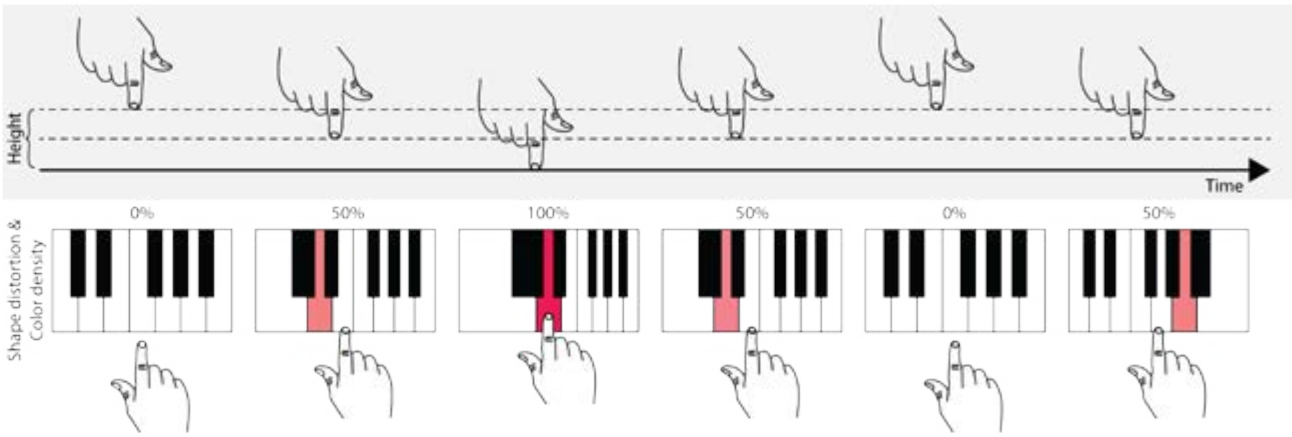

Figure 2. Timing and animation sequence of shape-distortion design. This is a "wide distortion" pattern. The shape distortion and density of color are applied in accordance with the distance from the display. The target key to be touched next is in red. The first target key is the second one from the left, and the second target key is the second one from the right.

bination between the shape distortion and expressive control. The responses also helped with other improvements, and the future design of the interactive keyboard to enhance performance.

2. RELATED WORK

On the subject of novel piano playing systems, we can classify previous approaches as novel interfaces or novel visualizations. Novel interfaces are piano augmentations that enable new gestures in performance, whereas novel visualizations are piano augmentations that visually convey extra information to the player. Systems that are targeted at users of a certain skill level may be of either type.

2.1 Interface Approach

This section presents previous research related to the interface approach. The magnetic resonator piano [14] is a mechanically modified piano keyboard that uses electromagnetic actuation to induce vibration, allowing novel gestures like vibrato and after-touch volume control. With the Kinect, PiaF [12] investigated the relationship between pianist's body movements and acoustic parameters while performing to find the way to augment performance. AirPiano [11] uses the finger tracker LeapMotion to build a different musical touch interface for exploring gesture motions and musical interactions. Several types of sensors were combined to create a new hardware keyboard for musical applications [13]. It captures five separate dimensions of motion and key movements for rich gesture input. The portable scanner hardware [15] attached on the piano keyboard turns the conventional piano into MIDI or Open Sound Control instruments. The gesturally extended piano [17] is an augmented instrument controller to handle real-time audiovisual processing using a motion tracker. Real-time emotion detection [16] is done by motion tracking using a wireless sensor and an algorithm to classify the motions for mapping.
Virtual reality systems have also been developed to help people play the piano. PianoTouch [1] and Mobile Music Touch [2] are both wearable systems for piano instruction that generate vibrations on the user's fingers using vibrators attached to a glove. The glove instructs the user on where to move his/her fingers while the user listens to the music. Seaboard [3] is based on a different idea. The keyboard changes from hard to soft material to let the user play a continuous melody with one finger.
Unlike related projects, proposed system does not change the user's movements or augment the user's body. We selected the motion tracker to capture the player's finger motion correctly. Instead, this paper contributes novel designs of shape-distortion keyboards that adapt to the user.

2.2 Visualization Approach

Andantino [10] and Andate [9] are piano playing systems that project animations and characters on top of the keyboard. They aim at pedagogical music visualization to keep the user motivated. P.I.A.N.O. [5] provides a simple music score visualization to let the users quickly understand where their fingers should move and to address the steep learning curve of the piano. Musical notes in the score are represented as blocks flowing down to the keyboard. These approaches augment the ordinary piano and leave the keyboard as is. In contrast, our approach changes the shape of the keyboard flexibly to enhance the style of the user's playing proactively.
Takegawa et al. [8, 6, 7] developed and evaluated a camera-based finger tracking system on a piano keyboard, which captures five color markers put on different fingernails to understand the user's finger motions in real-time.
The metamorphosis hand [4] shows virtually extended fingers that reach the target keys to make users feel like they are playing the piano correctly regardless of the real positions of their fingers. While our aim is closely related to theirs, we chose to distort the keyboard shape rather than the user's body image.

3. CONCEPT

Shape-distortion design achieves the aim of this study: enhancing the style and performance of piano playing by providing visual feedback as the shape distortion of a piano interface that changes its shape. Unlike a conventional piano, the shape-distortion design makes the keyboard interactive and flexible in accordance with the movements and touches of a user's finger. We created new designs of interactive piano interfaces powered by sensing techniques and the interactive design of visual feedback. In shape-distortion design, the goal was for the shape to change interactively to generate visual feedback that enhances the user's ability to play the piano.

We simplified the design of shape distortion and implemented visual feedback written in software, and we conducted a test of the design concept with keyboardists. The playing method was limited to assisted playing, wherein users touched the next key to play along with a music score. The music score was set in advance and played on the software when the users' finger touched the keyboard. Our goals for the shape-distortion design for an interactive piano interface on a touch display were as follows: (1) to create a design of a keyboard interface using shape distortion as visual feedback of control for intuitive and interactive playing, (2) to connect expressive control to types of shape distortion to find effective and preferred combinations through the user study, and (3) to utilize the keyboard interface design of interactive playing, allowing users degrees of freedom in their hand and body.

3.1 Types of Shape-Distortion

We prepared three types of shape distortion by imaging animation as visual feedback to express the results of tuning expressive control. The frame rate of graphic images is about 15–20 Hz. The animation and transition styles of each variation are shown in Figure 4 with the time sequence going left to right. The key where the next note should be played on the touch screen is called the "target key" in the following paragraphs.

Figure 3. Setup of motion tracking camera and display arrangement. It was also used for the actual user study.

3.1.1 Wide Distortion

The target key moves under the finger when touched and while keeping its width the same. Other keys to the right and left of the correct key are widened or narrowed by the distortion. Each white and black key is drawn with equal intervals. Thus, both the right and left parts of the keyboard shrink in accordance with the finger position.

3.1.2 Curve Distortion

Only the target key is distorted and moved over the keyboard. The target key overlays other keys and moves in accordance with the finger position. Therefore, just one key is moved under the finger, while the others are fixed.

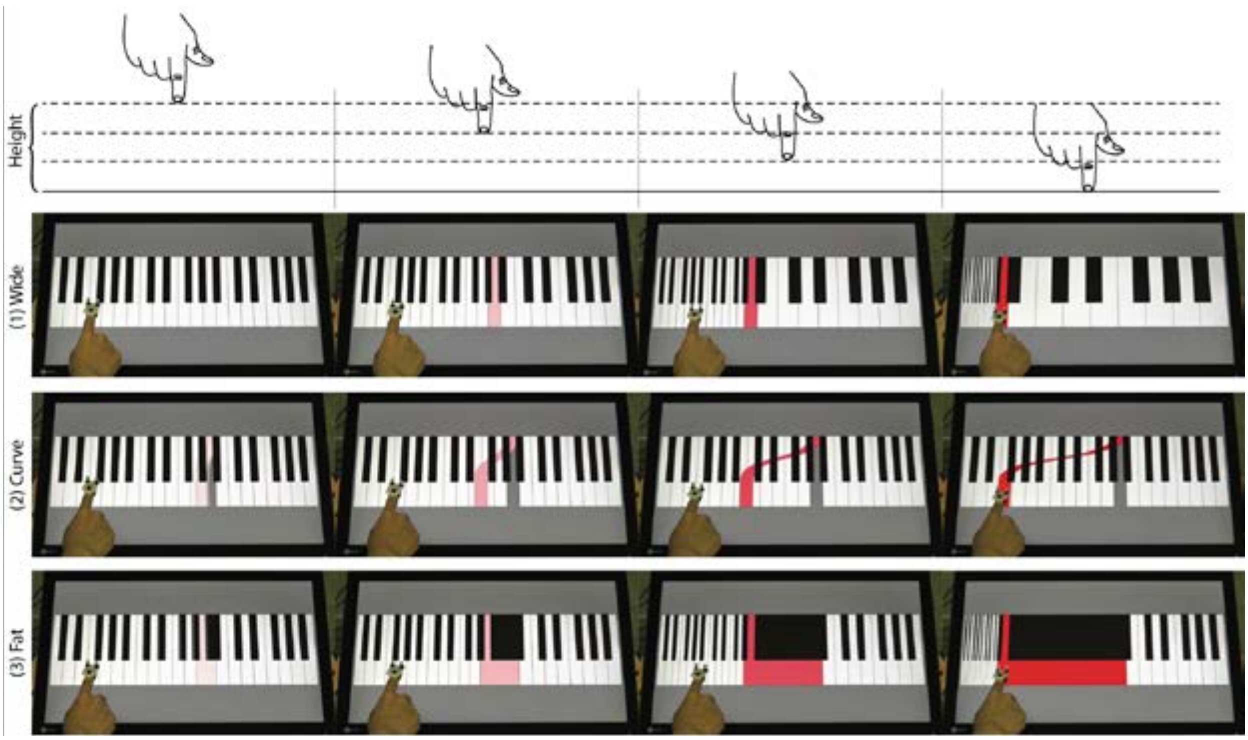

Figure 4. Three types of effect (Wide, Curve, and Fat) are shown with four levels of distortion ratio. Each effect and finger position is captured by a camera above the display. The distortion ratio is estimated, and the finger height is roughly indicated for each situation.

3.1.3 Fat Distortion

The target key is widened to cover the position of the finger while keeping the target key in its original position in the key order. Half of part of the keyboard shrinks in accordance with the finger position. Thus, this is the same as a wide distortion for half the area of the keyboard.

3.2 Timing and Animation

Matching the timing and animation generation are required to achieve an interactive keyboard interface on a touch display. We designed a shape- and color-changing sequence in accordance with the ratio of the depth position of the finger (Figure 2). All visual feedback and shape distortions are drawn as animations to present the visual feedback and reaction in response to the user behavior. We designed three types of shape distortion to fit the "target" key—the key that is highlighted in anticipation of the user's next press—for the user's finger position. Our implementation of the shape-distortion algorithm makes it important that the vertical finger position from the display (height from the display surface) generate visual feedback with animation.

3.3 Finger, Sound, and Score

The shape-distortion design presents an interface that changes its shape in accordance with the finger position in three dimensions. Parallel axes of the display (x and y axes) make points on the keyboard for the finger to touch. From the threshold of height (z axis) to zero distance, the keyboard shape distorts in various ways when the finger comes close to the keyboard. A sound is made when the finger touches a key on the keyboard.

The system has a piano score prepared in advance. The system presents the recorded score on the keyboard and moves the next key to be touched under the user's finger when he/she is about to touch the keyboard. Like an electric lighted keyboard (which turns the light on the key to touch), an indication is shown on the keyboard to direct the player to touch the correct key to continue playing the score. The indication turns both white and black keys into red.

3.4 Limitation

First, we tested the proposed design by implementing a system that can let a player use one finger to interact with the piano interface. We set the limitation as one finger input to test the interactive system and the distortion design. This limitation of one finger input is natural and does not cause any problem when performing a monophonic solo instrument on a synthesizer. This also enables avoiding sensing errors by the finger tracker when too many fingers are on the marker(s). In this system, a touched state is recognized as a touch sound on the display, but an untouched state is recognized as the distance from the display. Thus, the user has to raise the finger over the threshold to make sure that the system detects the finger has left the key.

4. IMPLEMENTATION

The system consists of a touch display, finger tracker, and software interface. Figure 3 shows the setup of the environment for this system.

4.1 Setup

For sensing the user's finger, we placed five OptiTrack FLEX 13 cameras (an IR camera tracking system) above the touchscreen to measure finger gestures and height from the screen. Each camera is placed so as not to interfere with the other cameras because reflection on the touch display may generate noise and lead to misrecognition of the finger position. We designed an IR marker to be worn on the finger for finger tracking. The touch screen display (EIZO T2381W) is used for both displaying the keyboard and measuring the timing of each touch. To increase robustness, we also used acoustic sensing with a contact microphone installed in the back of the display to sense touch sound on the display, thereby ensuring every touch is captured.

For output, the piano interface is projected on a display placed on a table. We selected the MIDI interface to generate sound in accordance with keyboard touches. Because the MIDI interface implemented in Windows suffers from noticeable delays, we used a MIDI interface (Roland Edirol SD-90 Studio Canvas) that outputs sound within a time short enough for humans to not notice any delay.

4.2 Tracking

The tracking system should be fast and reactive to the user's finger motion because playing piano requires active and fast movements. Measuring the finger position and touch is one of the requirements of this system. Our first prototype used a Microsoft Kinect version 2 device to capture depth images and to extract the finger position, but it did not work due to the slow response time and low-resolution image. The OptiTrack cameras and accompanying software provide the exact position (up to 0.1 mm) and a high frame rate (over 100 Hz). The software gives the position of the IR marker worn on the finger.

The finger position is used to determine the finger height from the screen. To avoid an error where multiple keypresses are detected during a single keypress event, the finger must be moved above the threshold (about 5 cm from the screen surface) before going to the next touch position. Without doing this, the keyboard is locked, and it sustains the current note.

Only during timbre-mixing balance, we selected the sound as "StringEnsemble1" (Left side) and "Piano" (Right side) for mixing. Other types of expressive control used "Lead2Sawtooth" for the sound.

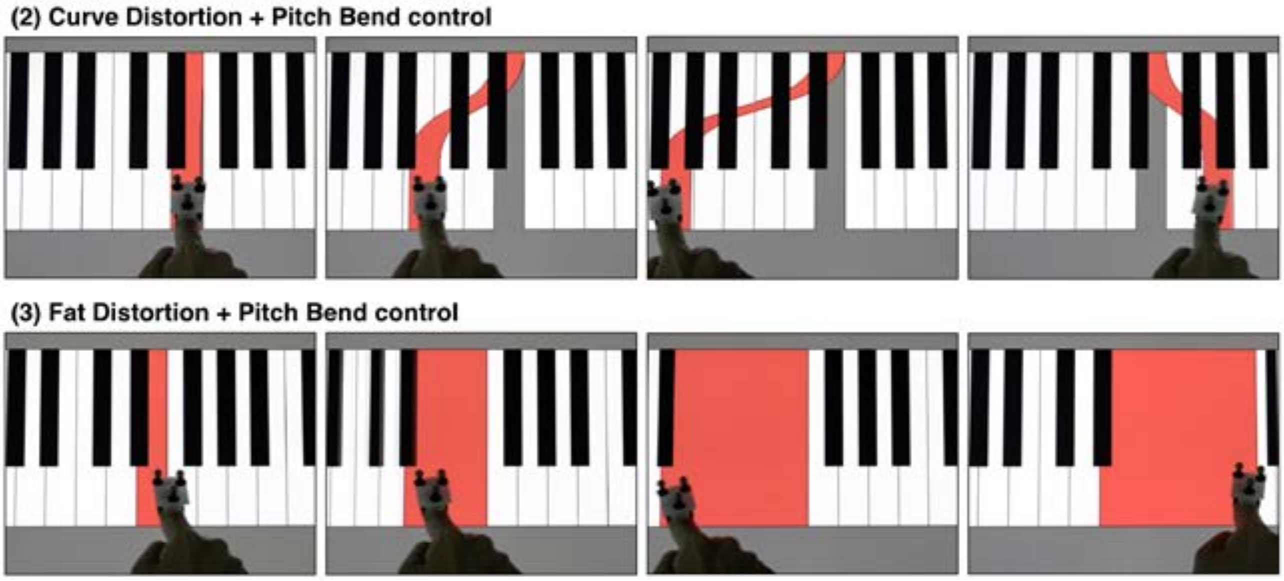

Figure 5. Implementation and use of pitch bend. The time goes from left to right while the finger moves around the correct key position. The sound from MIDI varies from four semitones below to four semitones above. When too sensitive, users can change the rate of magnification. The pitch changes in accordance with the vertical position of the finger and reflects the distance from the indication key.

4.3 Expressive Controls

We also implemented three types of expressive control using MIDI control. Thus, the keyboard interface works like the MIDI synthesizer, but the control method differs from the ordinary MIDI synthesizer because of the shape distortion using an integrated control method with the finger movements. Users can select the reference point of expressive control as the center of the keyboard screen or the position of the target key. If users select the center of the keyboard as the reference point, the minimum and maximum of the control level is set to the left and right edge of the keyboard screen.

5. USER STUDY

We asked three participants to play with our keyboard interface to evaluate the playing style using shape distortion with expressive control. As described in the Concept chapter, the music score (Edward Elgar's Pomp and Circumstance, Op.39) was already set in advance, so the participants played the music by tracing in accordance with the music score. We also prepared the printed score for reference, but they did not need to see it because the required keys were highlighted on the screen as aforementioned.

5.1 Results of User Study

In figure 6, we show the result of an evaluation for each combination of shape distortion and expressive control. We used a symbol to express the result rather than a numerical value (such as a Likert scale) to describe the efficacy and intuitiveness of playing style with them. The best match was "◎," which indicates satisfaction, and the lowest was "×," which indicates dissatisfaction. In the following, we summarize the comments from all participants for each distortion method:

5.1.1 Wide Distortion

Because the side distortion changes the shape of the whole keyboard, it was useful for expressive control that uses absolute values such as volume control. Timbre-mixing balance was also evaluated when used with the reference point on the keyboard. The participants were not satisfied with the pitch bend because the sense of shape distortion does not match the expressive control.

5.1.2 Curve Distortion

The curve distortion is only the shape-distortion design which matches the expressive control of the pitch bend with the reference point of the target key. Because of the type of shape distortion, the curve changes only the shape of the target key, and the other keys are fixed. Thus, the participants preferred using curve distortion with the ref-

	Volume change	Pitch bend	Timbre-mixing balance
(1) Wide	◎ (Screen Center)	×	○ (Screen Center)
(2) Curve	×	◎ (Target Key)	×
(3) Fat	△ (Target Key)	×	×

Figure 6. Result of user study with evaluations for each combination of shape distortion and expressive control. The symbols mean the level of efficacy and intuitiveness of the combination. The screen center or target key under the symbol means the effective selection of the reference point of expressive control.

erence point of the target key and pitch bend, which controls the relative pitch from the pitch of each touched key.

5.1.3 Fat Distortion

The participants reported that fat distortion is similar to wide distortion because half of the keyboard shrinks. Because of dynamic change in the keyboard design, it does not match the pitch bend. Furthermore, expressive control of volume change and timbre-mixing balance were not evaluated to compare with wide distortion.

5.2 Discussion

We found that the efficient and preferred combination depended on the reference point and the type of expressive control. Because of its unusual shape, Curve distortion was expected to be the worst candidate for the shape-distortion design before the user study, but it was actually evaluated as being the best for combinations with pitch bend control because of the ease of playing and because of the sense of playing style in using the finger position for the control function. Keyboardists usually use the right hand for such a monophonic performance and the left hand to move the pitch bend wheel/lever, but in our design, they can take the advantage of just using one finger to control both the keyboard and the pitch bend.

6. CONCLUSION

We designed and implemented a conceptual piano interface that uses shape distortion. With accurate finger tracking and an interactive interface design, the positions and shapes of keys flexibly change in response to finger movements. We tested three types of shape-distortion design with three types of expressive control to find an efficient and preferred combination of two of them for playing style. We found that the planar keyboard interface with graphical feedback of distortion design had an advantage in intuitively performing expressive control such as pitch bend just by using one finger. Typical expressive synthesizer performances with pitch bend usually require both hands, one for pressing a key and the other for controlling the pitch bend wheel. Participants in a user study classified and evaluated their preferred combination, and our future design of the keyboard interface will be changed on the basis of their comments.

Acknowledgments

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