DESIGN AND IMPLEMENTATION OF A PIANO PRACTICE SUPPORT SYSTEM USING A REAL-TIME FINGERING RECOGNITION TECHNIQUE

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ABSTRACT

Piano players need to learn various techniques such as correct keying and fingering. However, the lighted keyboards, which light up the key and are the most commonly used piano learning supports, have several problems for learners, such as difficulty in understanding the presented fingering information and flow of keying positions, and lack of a fingering check function. To resolve these problems, the goal of our study is to construct a piano practice support system that has a fingering check function using a real-time fingering recognition technique. We discuss the presentation methods that can effectively indicate piano-learning information such as fingering and keying information. We evaluated a prototype system that was actually used by learners, and found that it had significant advantages over lighted keyboards.

1. INTRODUCTION

Piano players need to master various techniques and abilities. They generally need long-term training to be able to read a musical score and correctly perform keying and fingering, and they must develop a good sense of rhythm, dynamics, and tempo. Learning how to read a musical score and perform correct keying and fingering are essential for beginners. Unfortunately, beginners often give up because of difficulty in acquiring these techniques.

There are several commercial products to reduce the learning cost. For example, a lighted keyboard [1] lights up the key that learners are supposed to play. Piano Master [3] additionally presents the keying position, fingering, and sample video. By using such products, learners can easily understand keying even if they are not able to read a musical score, and if they make a mistake in keying, they are able to note its position and rectify it, because the keys after the mistake are not presented. It is an important for learners to be able to note their mistakes.

On the other hand, fingering is important because it affects various performance factors such as execution from one key to the next, tempo, dynamics, and key timing. However, current methods and products present only the correct fingering and do not have functions to indicate fingering mistakes or imposes penalties on learners. This means learners do not receive effective instruction on fingering. Additionally, it is difficult for learners to understand the flow of the keying positions that indicates the keying area to be used hereafter, because lighted keyboards present only the next keying positions. Learners merely pursue lighted keys, and they cannot perform smoothly. The fingering information is presented on a small display embedded in the keyboard. It is difficult to read this information because of the smallness of the display, especially when the learner's hands on the keyboard are far from the display.

To resolve these problems, the goal of our study is to construct a piano practice support system that has a fingering check function using the real-time fingering recognition technique that our research group has developed [18]. Additionally, we devised the presentation methods to indicate useful information for piano performances effectively.

The remainder of this paper is organized as follows. Section 2 describes related work. Section 3 explains fingering recognition technology, and Section 4 describes the design of the learning support system. Section 5 describes its implementation, and Section 6 explains our evaluation and discusses the results. Finally, Section 7 describes our conclusions and future work.

2. RELATED WORK

There are many studies on methods to support piano learners. For example, there are keyboards and software [1, 3, 4] that present the keying position, fingering, and sample video as support information during a performance. These have problems, such as difficulty in understanding the presented fingering information and flow of keying positions, and lack of a fingering check function, described in Section 1.

PianoTouch[10], ConcertHands[2], and MaGKeyS Trainer Piano[7] are a haptic-based instruction system for piano

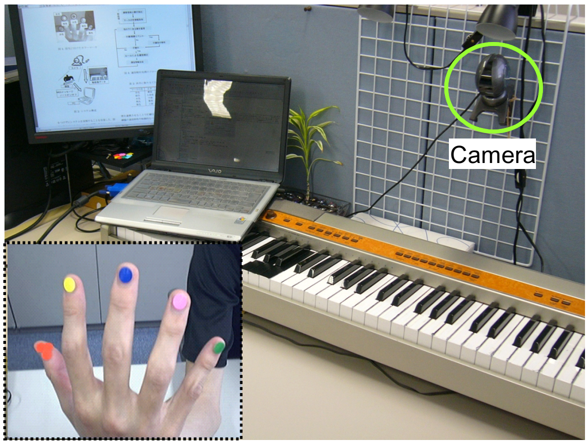

Figure 1. System structure of fingering recognition

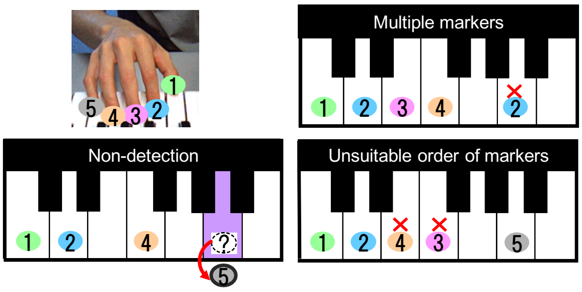

Figure 2. Examples of applying a rule

learners. They tell a player practicing information through attached tactile feedback unit on each finger. Learners are able to learn the keying and fingering techniques easily. However, they force users to wear bulky devices on the fingers.

Additionally, there are the systems that automatically detect weak points of learners including including mis-keying and fluctuation of tempo or dynamics on the basis of a conventional practice log [11, 14, 15, 17]. There are also piano lesson support system [16] that show current articulation, agogik, and dynamics. Although these systems do not have fingering check functions, we will derive knowledge from their development and have put it to use in our learning support system.

Our research also relates to augmented reality research. Many new types of projector-based augmented reality[5, 6, 8, 9, 12, 13] have also been proposed. These works attempt to assist a movement-based simple task. However, our system supports learning of an intricate physical task by tracking the movements associated with the task and augmenting the physical environment with prompting and other information supporting the task.

3. FINGERING RECOGNITION TECHNOLOGY

We have developed a real-time fingering detection system for piano performance.

The fingering recognition system tracks fingering by means of simple image processing of color markers at-

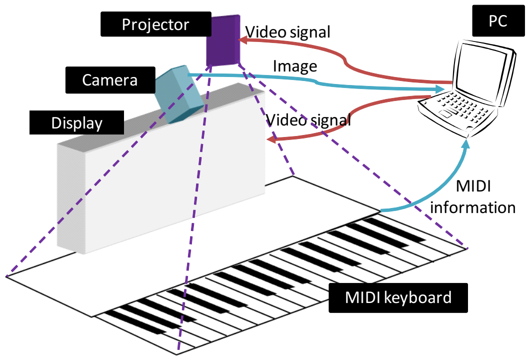

Figure 3. System structure

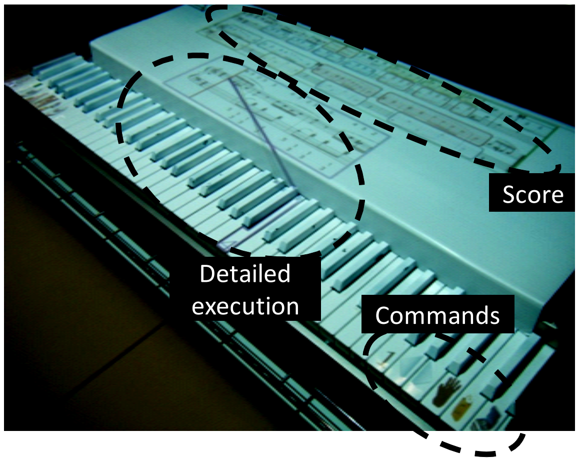

Figure 4. Information presented by projecting it on keyboard surface

tached to the finger nails which does not interfere with performance (as shown in Figure 1). Furthermore it is able to conduct the fingering recognition in real-time. Our system corrects fingering inefficiencies detected by the image processing by applying four rules based on a natural manner when playing music. These rules are defined by the features of piano performance, the physical characteristics of a keyboard, and common fingering functions. High-accuracy fingering detection is difficult not only in the image processing, but due to the fact that fingers frequently overlap each other; for example, the thumb is easily hidden by the other fingers in piano performance.

We have defined the four rules. As an example of these rules, "The horizontal order of fingers 2 to 5 does not change." This rule notes the non-detection of a marker and correct recognition errors of markers. We demonstrate how to apply this rule with Figure 2. When the system was not able to detect the marker on the purple colored key, and then a user pressed the key, this marker number was determined to be number 5. Additionally, the system is able to correct for erroneous color detection such as multiple markers and unsuitable marker order.

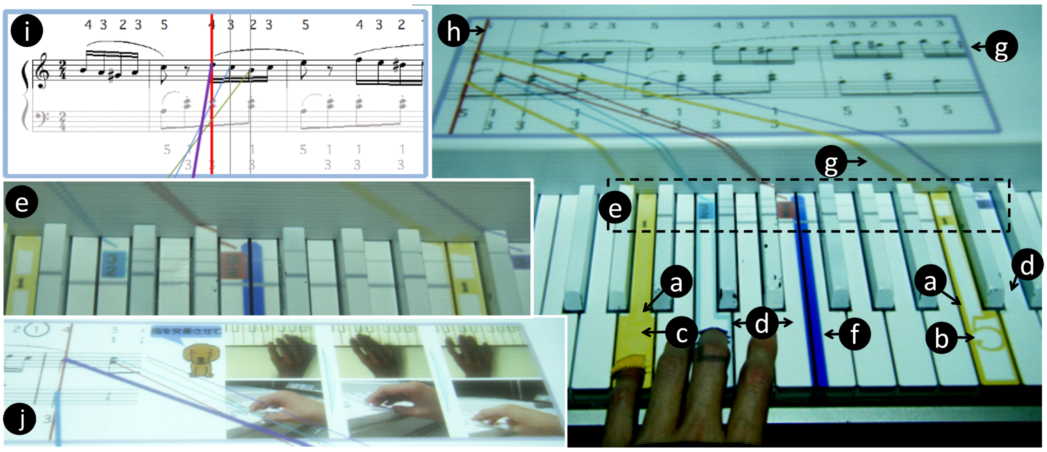

Figure 5. Detailed execution information

We conducted an evaluative experiment using three trial pieces to look into the effectiveness of the our fingering detection system rate. We compared the recognition rates while applying the rules verses not applying the rules. The average rate in the case of the rules is 95%, however the average rate in the case of not applying the rules is only 74%. Using musical rules, the system can recognize the fingering during the crossing of fingers, the simultaneous detection of two or more fingerings, fast tempo, and complex execution. Our system uses the simple image-processing method and corrects fingering with the above rules. Therefore, the proposed system can recognize the fingering in real time. The average processing time per frame is 20 msec, and the average frame rate of the camera that the prototype uses is 30 frames per second. The prototype system can complete the image processing within this frame rate.

4. SYSTEM DESIGN

As described in Section 1, conventional learning applications and keyboards do not have a fingering check function and do not enable users to learn fingering effectively. We created a fingering check function and developed methods to present learning support information for users to check their keying and fingering.

4.1. System structure

Our system uses a fingering recognition technique as described in Section 2. The technique requires a camera, colored markers attached to the finger-nails, and a MIDI musical keyboard.

There are various presentation devices such as audio, vibration, display, and projector to inform users of piano performance information. We employed a display and a projector, because it does not interfere with the performance, and it can express various information simultaneously. Additionally, we present learning information in front of users and along the entire keyboard, because players generally perform while looking at a keyboard and musical score in front of them.

The structure of the system is shown in Figure 3. The system has a camera to detect fingering and a display or a projector to present learning support information. The display is put in front of a user. The projector is set above the keyboard and can show information along the entire MIDI keyboard.

The system detects the fingering technique in the captured images of markers, and MIDI data including pitch data and intensity data from the MIDI keyboard. The system analyzes this input and presents the results on the display or projector. The system has two modes: FrontMode and DirectMode. FrontMode shows information on the display, and DirectMode shows information on the MIDI keyboard with the projector. The system also has a function that users select two modes.

4.2. Presented Information

The system presents three types of content: detailed execution information, score information, and command information. These are presented on a display, or projected on the keyboard as shown in Figure 4. In the following, we explain the roles of this information.

4.2.1. Detailed execution

The detailed execution information includes the current execution position, as shown in Figure 5. This information is updated in sync with the performance. The numerical values in Figure 5 correspond to the following list number and the parenthetical numbers in the following list.

(a) NextKey refers to the next key that is to be pressed in a piece of music as shown in Figure 6, and each presented NextKey outline provides keying information. The NextKeys are indicated by arrows (a) in Figure 5.

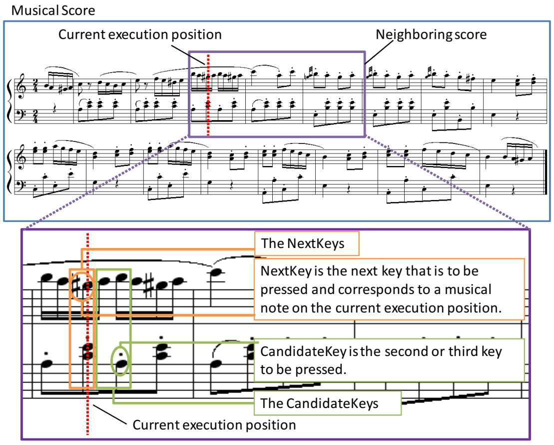

Figure 6. Definition of terms

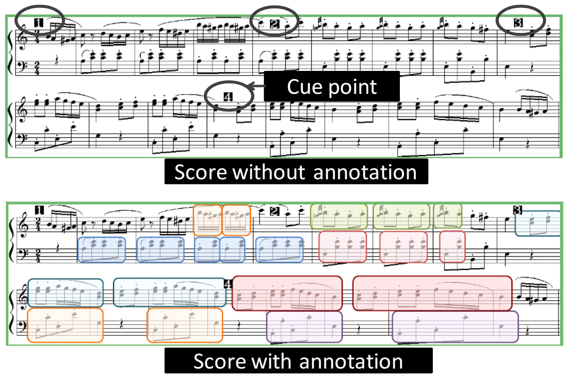

Figure 7. Score information

(b) The color of the NextKeys and the numbers (b) presented on the NextKeys are the fingering information. The colors are the same as those of the markers attached to the learner's finger-nails.

(c) When the correct finger is set on the NextKey, the whole area of the NextKey is filled in with the corresponding finger color. The left NextKey is colored (c) because the correct finger has been placed on it. On the other hand, when the NextKey is pressed with the incorrect finger, the key is colored red. When the keys except the NextKeys are pressed, these keys are also colored red. In this way, learners can understand the positions of NextKeys, learn fingering technique intuitively, and rectify their mistakes.

(d) The outline of the CandidateKey, which is the second or third key to be pressed as shown in Figure 6, shows up on the key, when the correct fingering has been placed on it. The colors of the outlines are the same as those of the markers attached to the learner's finger-nails. The CandidateKeys are indicated by arrows (d). The outline of the left CandidateKey is presented, because the correct fingering has been placed on it. Learners have noted that when the outline shows up on a key, they do not have worry about moving their fingers because the outline means it is already in the proper position.

(e) The keying sequence numbers are shown on the distal ends of the NextKeys and the CandidateKeys. Additionally, the background color of the keying sequence number corresponds to the fingering color. Keys to be pressed simultaneously are connected with a horizontal line. In this way, learners can easily understand the keying sequence, and some have noted that they are able to simultaneously key widespread diapasons with this support.

(f) The system presents a base-line between the execution area of the right hand and that of the left hand.

(g) The neighboring score (Figure 6) based on the current execution position is shown above the keyboard. Each musical note is connected to the corresponding key with a line. This support enables learners to read a score easily, because he or she can see the relationship between the musical notes and key positions intuitively.

(h) The bar indicating the current execution position in the neighboring score is shown. This support helps learners read the keying timing of both hands easily from the score.

(i) It is important for beginners, who are trying to learn a new musical score, to practice with one hand. The system can deliver the scores for both hands or one hand, and the learner can use them selectively. Additionally, since it is important for the learner to be conscious of the relationship between the executions of each hand (even if the learner practices in one-handed mode), the musical notes for the other hand are also shown in a lighter shade. The right-handed score is shown in (i).

(j) Pianists frequently cross the thumb and other fingers to achieve smooth execution. Since beginners do not fully understand either the timing or the method, the system shows the timing, and then shows the proper method.

Users who are novice in piano look at the information to check the key positions and their fingering on the keyboard at first. When they get used to playing the music and they have musical notes where they are able to play the correct key and fingering in touch typing, they see the neighboring score inch by inch. They confirm the relationship between musical notes and key positions, and at the same time, they can read the musical score. Finally, they can play the music while seeing the score smoothly.

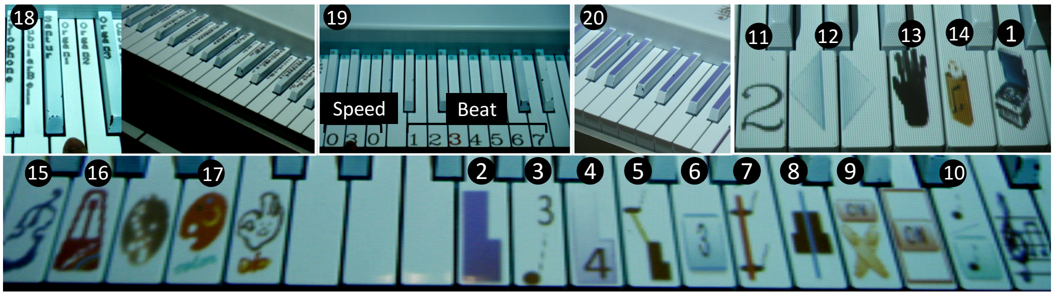

Figure 8. Command information

4.2.2. Score

Figure 7 shows a snapshot of the score information. The roles of the score information are the same as those of the conventional score. A black box with a number in the score is a cue point which indicates the start point of the neighboring score of the detailed execution. This function is useful when learners want to practice the same phrase over and over.

Additionally, there are identical phrases, similar phrases, difficult phrases, and unfamiliar musical symbols in a score. Therefore, we propose to use not only a general score but also a score added with annotations such as similar phrases enclosed with the same color. Learners use them selectively.

4.2.3. Commands

A musical keyboard is useful as not only a musical instrument but also an input interface. Its keys can be assigned to commands for operating the system, and we present an icon, which expresses the meaning assigned to the key, on the key. The commands are executed by keying. Additionally, the command operation and the performance are selected with a foot pedal and the unused keys in a score.

The commands indicated by the numerical values in Figure 8 are described as follows.

- The system presents various learning support information. The necessity of such information depends on the learners' skills, and our goal is that learners eventually learn to perform without a support system. Therefore, we enable learners to turn on or off each part of the learning support information. When a user presses the key under icon (1), icons (2)–(10) show up, and their corresponding keys can be pressed to select the desired information to support the presentation.
- Users can operate cue points in the score by pressing the key under icon (11).
- Users can turn the page of a score by pressing the key under icon (12).
- By pressing the key under icon (13), users can select the training hand(s): right hand, left hand, or both hands.
- Users control the play of a sample song by pressing the key under icon (14).
- When users press the key under icon (15), the list of tones is presented on the keyboard (18), and then users set the tone by pressing the key corresponding desired tone.
- Users can turn on or off the metronome by pressing the key under icon (16). Current speed and beat are displayed at the distal ends of the keys (19). The speed and number of beats of the metronome are controlled by pressing the keys presenting current speed and beat, respectively.
- The black keys in DirectMode are painted white, because the images from the projector are clearly presented in this way. Users press the key under icon (17) to control the color of the black keys (20).

5. IMPLEMENTATION

We implemented a prototype of the piano practice support system, as described in Section 4[1]. The DirectMode prototype is shown in Figure 9. We used a SONY VGN-S94PS (Intel Core2 Duo 2.60GHz), whose platform was Windows, a CASIO PriviA PX-110 equipped with 88 full-sized keys, and a Basler scA640-70fc (Resolution 640 x 480 pixels, 30 fps) camera, and we placed the camera in a position that afforded a good view of the color markers attached to the fingernails. The fingering recognition area of this prototype is limited to 3 octaves 5 degrees (45 keys), and this prototype recognizes the fingerings of both hands. We used a Samsung SyncMaster 275T as the display in FontMode and a BenQ MP522 as the projector in DirectMode. The projected area was 6 octaves (72 keys), and we painted all black keys of the MIDI keyboard white. We implemented the system using Microsoft Visual C++ .NET 2005 and Intel OpenCV Library.

[1]You can watch a demonstration video at http://cse.eedept.kobe-u.ac.jp/˜takegawa/movie.html

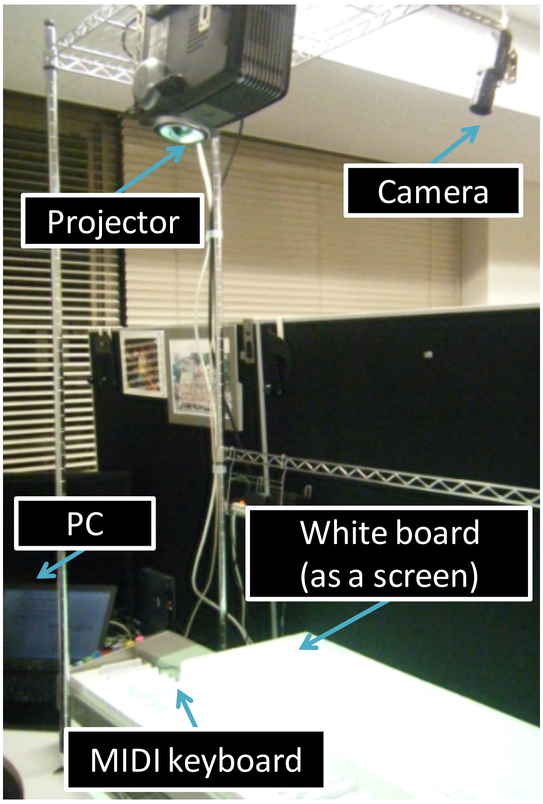

Figure 9. Prototype system

6. EVALUATION

We conducted two evaluative experiments to investigate the effectiveness of the method. One evaluation was for one-handed playing, the other was for both-handed playing.

6.1. Evaluation of one-handed playing

6.1.1. Experimental Procedure

In this evaluation, we compared FrontMode that shows information on the display, DirectMode that shows information on the MIDI keyboard using the projector, and a lighted keyboard method on the basis of the number of keying errors and fingering errors. In the lighted keyboard method, the whole area of the NextKeys was filled in red, we call this LightedKeyboardMode. Lighted keyboard method is the most commonly used interactive learning method for piano beginner. We presented the next NextKey information when subjects had pressed a correct key with correct fingering in FrontMode and Direct Mode, whereas we presented the next NextKey information when subjects had pressed only a correct key in LightedKeyboardMethod. We also presented a score with fingering information added to all of its musical notes in all methods.

Eighteen subjects took part in this experiment, and there were six subjects for each mode. All subjects belonged to a graduate school of Engineering, had no formal piano training, and were not able to read a score. They practiced "Piano Sonata No. 11 in A major, K. 331: III (W. A. Mozart)" whose range was from the beginning to bar 18 as the trial piece for one-handed playing. The total number of musical notes on the trial piece is 99.

This examination consisted of two phases: practice and testing. The subjects practiced the trial piece for 15 minutes during the practice phase. We instructed them to practice freely. Basically, they learned the trial piece by practicing over and over and using the function assigned to each mode.

Then they played the trial piece from beginning to end in the test phase after the practice phase. The system logged the number of keying errors and fingering errors during the test phase. In the test phase, we presented a score that had fingering information added to its musical notes. We also instructed the subjects to pay attention to correct keying with the proper fingers indicated in the score, but not to pay attention to the tempo. Additionally, we interviewed them after the examination.

Table 1. Average number of keying errors and fingering errors

	Keying error		Fingering error	
	Average	SD*	Average	SD
FrontMode	19.8	8.8	3.8	4.2
DirectMode	2.5	1.8	0.5	0.8
LightedKeyboardMode	31.5	4.2	35.3	8.2

* Standard Deviation

6.1.2. Results and Considerations

Table 1 shows the average number of errors for each mode.

The results show that both FrontMode and DirectMode significantly enhanced learning effectiveness, as compared with LightedKeyboardMode. The average number of keying errors and fingering errors of DirectMode was small. The average number of keying errors and average number of fingering errors of FrontMode was somewhat higher than those of DirectMode. On the other hand, the average number of keying errors and fingering errors of LightedKeyboardMode was much higher. The significance of the average number of errors was at a level of 5% calculated from Steel-Dwass' multiple comparison test. The reason that the standard deviations corresponding to the number of keying/fingering errors of FrontMode/LightedKeyboard Mode are high is that the number of errors of FrontMode/ LightedKeyboardMode for one subject was small/large.

The subjects who used LightedKeyboardMode did not memorize the key positions; they merely pursued keys in red because of their inability to read the musical score. As a result, they made a lot of keying mistakes during the test phase. Moreover, they made many fingering errors because they had to concentrate on correct keying and could not pay enough attention to fingering. Moreover, they were not able to read score or read out the fingering information, and hence, they did not notice their fingering mistakes.

On the other hand, the subjects who used DirectMode and FrontMode were for the large part able to understand the relationship between the musical note on the score and the keying position. However, they still made some keying and fingering mistakes, because part of their lack of understanding.

Almost all of the subjects who used DirectMode and FrontMode paid attention to the outline images displaying the NextKeys in the early stage of the evaluation, and they studied the score by using the lines connecting the musical notes and the NextKeys. They eventually learned to read the score, and consequently, we believe that is why they had fewer keying and fingering errors.

The reason that there are fewer mistakes in DirectMode than in FrontMode is that watching a physical keyboard is more intuitive than watching a display as visual and haptic feedback are in the same place in DirectMode. The key size presented on the display is half of the key size of the actual physical keyboard, and the subjects who used FrontMode had to adjust to this difference in the early stage of the evaluation.

However, DirectMode has a lot of trouble with installation, while FrontMode can be installed simply by putting a display in front of the user. DirectMode needs a special rack or a ceiling to hang the projector from, the black keys have to be painted white, and the presentation area has to be wide enough. We should thus select between FrontMode and DirectMode according to the user's situation and environment, because both modes have advantages and disadvantages.

CandidateKey: Regarding this function, in which an outline of a CandidateKey shows up when the correct finger has been placed on it, the subjects commented after the test that it helped them to press the correct key with the proper fingering because of the keying preparation beforehand. However, one of the subjects said the projected outline of the NextKey was like that of the CandidateKey, and that was confusing. This means we should redesign them so that they can be more easily distinguished.

Fingering check function: Regarding the fingering check function, the subjects generally found it difficult to play a chord with fingering using the annular or pinky finger. The subjects who used LightedKeyboardMode often played the chord with their own (i.e., wrong) fingering. On the other hand, the subjects who used DirectMode and FrontMode could rectify their mistakes with the fingering check function. Additionally, subjects said it was difficult for them to do the fingering at first, but they adjusted to it. Eventually they realized that keeping the correct fingering would make the score smoothly playable. Comments like these confirmed to us that the fingering check function was effective.

Detailed execution information: The modes contained various information, but the necessity of each piece of information varied between subjects. For example, some subjects used the physical score shown in front of them, but not the neighboring score with the detailed execution information. Others did the opposite. Additionally, all of the subjects except one used the lines connecting the musical notes and the NextKeys/CandidateKeys. The presented information should be selectable, because the need for it varies depending on the characteristics and learning level of the subjects.

6.2. Evaluation of two-handed playing

6.2.1. Experimental Procedure

The procedure of this experiment was almost the same as that of the one for one-handed playing. The six subjects used only DirectMode because it had gotten the best results for one-handed playing.

The subjects practiced "Menuet (BWV Anh.114) (J. S. Bach)", whose range was from the beginning to bar 8. The total number of notes on the trial piece is 42. They practiced this trial piece for 15 minutes and then played it from beginning to end as the test. The system logged the number of keying and fingering errors during the test. The trial piece had fingering added to all of its musical notes, and the instructions we gave the subjects were the same as those for one-handed playing.

6.2.2. Results and Considerations

The average number of keying/fingering errors was 2.1/0.6, and the standard deviation of keying/fingering was 1.4/0.8. The subjects were frequently able to play without the system support.

The subjects selected to practice only with their right hand by using the training hand function, then they selected their left hand . Additionally, when they practiced with their left hand, they also considered the melody and rhythm played with the right hand by looking at the musical note shown in a light shade. Some subjects intensively practiced difficult phrases by using the function to select the cue point. When there were simultaneous keyings with widespread diapasons, they used the horizontal line shown on the distal ends of the NextKey and CandidateKey. They said the keying sequence numbers, which were shown on the distal ends of the NextKey and the CandidateKey, helped them to understand not only the flow of the keying positions but also the meaning of fingering. The comments of the subjects confirmed to us that these functions worked as intended.

Some subjects practiced the trial music with only minimal support by turning off the learning support information at easier parts and selecting information to be displayed at difficult parts. Excessive dependence on the system reduces the learning effect. We intend to develop a function that will automatically detect the learner's weak points and display the necessary information when needed.

Moreover, the executions in the test phase usually had improper rhythm; some subjects read out the rhythm information and requested an effective presentation of rhythm information. We also intend to consider a support for rhythm information in the future.

7. CONCLUSIONS

We constructed a piano learning support system that has a real-time fingering check function, and we analyzed a variety of presentation methods to indicate information for piano performances. The results of evaluative experiments confirmed that the system provided a significant enhancement in learning effectiveness on the early stage, as compared with the lighted keyboard method.

Future work will include evaluative experiments conducted on beginners of various generations and more longitudinal experiments.

8. ACKNOWLEDGMENTS

This research was supported in part by a Grant-in-Aid for Scientific Research for Young Scientists(B) (21700198) from the Japanese Ministry of Education, Culture, Sports, Science and Technology.

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