[5] K. Pelechrinis, M. Iliofotou, and S. Krishnamurthy, "Denial of service attacks in wireless networks: The case of jammers," *Communications Surveys Tutorials, IEEE*, vol. 13, no. 2, pp. 245 –257, quarter 2011.

[6] S. Smallwood, D. Trueman, P. R. Cook, and G. Wang, "Composing for laptop orchestra," *Computer Music Journal*, vol. 32, no. 1, pp. 9–25, Mar. 2008.

[7] G. Surges and C. Burns, "Networking infrastructure for collaborative laptop improvisation," 2008.

[8] G. Wang and P. R. Cook, "ChucK: a concurrent, on-the-fly, audio programming language," 2003.

[9] M. Wright, "Open sound control: an enabling technology for musical networking," *Organised Sound*, vol. 10, no. 3, pp. 193–200, 2005.



_ICMC2012 NON-COCHLEAR SOUND
LJUBLJANA _9.–14. SEPTEMBER

# A PIANO LEARNING SUPPORT SYSTEM CONSIDERING RHYTHM

*Yoshinari Takegawa*
Future University Hakodate
Hakodate, Japan

*Tsutomu Terada*
Kobe University / PRESTO, JST
Kobe, Japan

*Masahiko Tsukamoto*
Kobe University
Kobe, Japan

**ABSTRACT**

Playing the piano requires various techniques such as correct keying, fingering and rhythm. Our research group developed a piano learning system to support correct keying and fingering for beginners. However, the system did not support the learning of rhythm. Rhythm consists of various kinds of note and rest, and it is difficult for beginners, who are not used to reading a score, to understand the different duration of each note and rest. Alternatively, there are piano roll scores, which describe timing of keying and releasing clearly, but which do not teach players how to read a musical staff. Therefore, the goal of our study is to construct a piano learning support system that considers rhythm. We discuss methods of effectively indicating information for piano performance, such as rhythm information, while teaching how to read a musical staff. We have developed a prototype system, and evaluated its effectiveness through actual use of the system. We found that it had significant advantages over a piano roll method.

## 1. INTRODUCTION

Piano players need to master various techniques and skills, such as reading a score, correct keying, proper fingering, correct rhythm (the timing of pressing and releasing a key), keeping tempo, and dynamics. Players generally need long-term training. Unfortunately, beginners often give up because of the difficulty of acquiring these techniques.

Our research group developed a piano learning system to support correct keying and fingering for beginners[20]. It uses a projector which is set above the keyboard and can display information along the entire MIDI keyboard. The proposed system has a fingering check function that uses the real-time fingering recognition technique that our research group developed [21]. Additionally, we devised presentation methods to indicate useful information for piano performances effectively. We place emphasis on teaching how to read a musical staff in order to enable learners to be independent from our proposed system after training.

Another important aspect of performance is rhythm because it affects performance quality. When learners play rhythm incorrectly, the performance is awkward even they press the correct keys. There are various kinds of note and rest on a score. It is difficult for beginners, who are not used to reading a score, to understand the different duration of each note and rest, thus they can learn rhythm most effectively by using a mechanism that allows them to intuitively understand the different durations. Additionally, piano performance requires complicated and precise fingering control for each hand in regard to timing. Many beginners give up playing the piano with both hands due to the difficulty of the independent movement of each finger and hand, for example the difference between the timing of releasing a key with a right-hand finger and that of a left-hand finger. It is important to make learners understand their mistakes for example by imposing penalties for errors. The effectiveness of rhythm learning improves through checking mistakes and imposing penalties, such as the system withholding the next piece of learning support information when a learner makes a mistake. Moreover, learners have to acquire proper rhythm as early as possible since it is difficult for them to rectify their mistakes once they are accustomed to playing incorrect rhythm. Furthermore, as the duration of each note and rest depends on tempo, learners have to be conscious of this as well.

Our research group developed a piano learning system to support correct keying and fingering for beginners. However, the system did not support the learning of rhythm. Even if users, who are beginners but practice playing the piano using the proposed system, press the correct keys with proper fingering in slow tempo with both hands and can foresee the next keys which are to be pressed, the performance is awkward because of the incorrect duration of holding keys and inserting incorrect rests. This is due to the difficulty of paying attention to the notes' duration while moving each hand in different timing. There are piano roll scores, which describe timing of keying and releasing clearly, but which do not teach players how to read a musical staff. The musical staff is the general medium used in musical performance. If beginners cannot read music, they cannot play pieces of music which are not stored on the system, without using the system.

Therefore, the goal of our study is to construct a piano learning support system that considers rhythm.

We discuss methods to effectively indicate information for piano performance, such as rhythm information, while teaching how to read musical staffs. For example, the proposed system shows the musical staff with colored bars layered over the notes and rests to indicate their duration. In this way, learners can understand the duration of each note and rest intuitively even while playing the piano. Moreover, the system has a rhythm check function to allow learners to notice rhythm mistakes and rectify them, using a metronome function. Learners can flexibly and easily control the speed of the metronome with a foot pedal.

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

## 2. RELATED WORK

There are many studies of methods to support piano learners. Piano Tutor[14] is an interactive expert system that uses with multimedia technology, and has functions such as automatic page-turning based on score-following technology, creating performance support information and presenting it with video, music notation, and graphics in response to learners' performance. Piano Tutor does not use a projector to show performance support information, and the presentation method of Piano Tutor is typically difference from that of the proposed system. However, Piano Tutor is a comprehensive learning system, and there is a possibility that we can develop a more effective learning system by utilizing Piano Tutor's knowledge.

There are keyboards and software [1, 3, 5] that display keying position, fingering, and sample videos as support information during performance. However, these have problems, such as the lack of a rhythm check function, as described in Section 1.

PianoTouch[11], ConcertHands[2], and MaGKeyS Trainer Piano[8] are haptic-based instruction systems for piano learners. They give a player performance information through a tactile feedback unit attached to each finger. Learners are able to learn keying and fingering techniques easily but they are forced to wear bulky devices on the fingers.

Additionally, there are systems that automatically detect the weak points of learners including mis-keying and fluctuation of tempo or dynamics on the basis of a conventional practice log [12, 16, 17, 19]. There are also piano lesson support systems [18] that show current articulation, agogik, and dynamics. Although these systems do not have rhythm check functions, we derived useful 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 system [6, 7, 9, 10, 13, 15] have also been proposed. These works attempt to assist a simple movement-based task. However, our system supports the learning of an intricate physical task by tracking the movements associated with the task and augmenting the physical environment with prompts and other information to aid the task.

## 3. SYSTEM DESIGN

As described in Section 1, our research group developed a piano learning system for beginners to teach correct keying and fingering, as well as how to read a musical staff, to enable learners to play music, which is not stored in the system, without the support of the system. However, the system does not support rhythm. Therefore, we constructed a rhythm learning system on the basis of improving upon the previous system. The proposed system has presentation methods that help to effectively convey piano learning, including not only fingering and keying but also rhythm information (described in Section 3.3 (i)). The rhythm check function uses a clear presentation method to allow the learner to recognize and rectify his or her mistakes (described in Section 3.3 (ii)). Moreover, we propose a metronome function (described in Section 3.3 (iii)) as well as a function to enhance the usability of the metronome (described in Section 3.3 (iv) and (v)).

### 3.1. Previous system

In the previous system, the projector is set above the keyboard and is able to show information along the entire MIDI keyboard, as shown in Figure 1. Learners find the piano learning information easy to understand as the previous system present various kinds of content, such as colorful figures and characters in an appropriate position to allow to learners to see the information easily even while playing the piano. Additionally, the previous system has a function that recognizes fingering using a camera[21], and develops methods for presenting learning support information for users to check their keying and fingering.

In the following section, we explain the information presented by the previous system. The letters in Figure 5 correspond to the following list:

**(a)** NextKey refers to the next key that is to be pressed in a piece of music, as shown in Figure 1, and each NextKey is outlined in color to provide keying information. The NextKeys are indicated by the arrows (a) in Figure 1.

**(b)** The colors and numbers of the NextKeys are the fingering information. When the NextKey is pressed using the correct finger, the key is filled in with the corresponding finger color. The left NextKey is yellow colored 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 other keys besides the NextKeys are pressed, these keys are also colored red. In this way, learners can understand the positions of the NextKeys, learn fingering technique intuitively, and rectify their mistakes.

**(c)** Each musical note is connected to the corresponding key with a line. This visual support enables learners to read a score easily, because they can clearly see the relationship between the musical notes and key positions





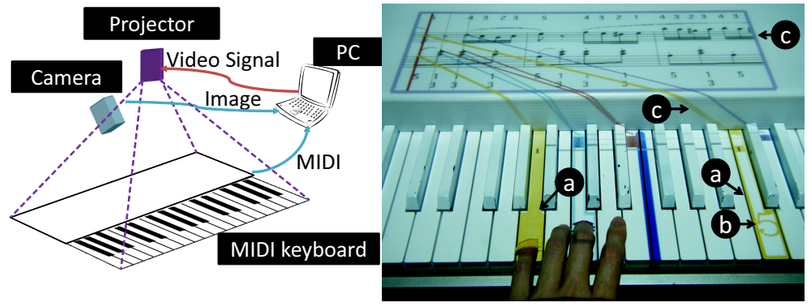


**Figure 1**. System structure and presented contents of the previous system

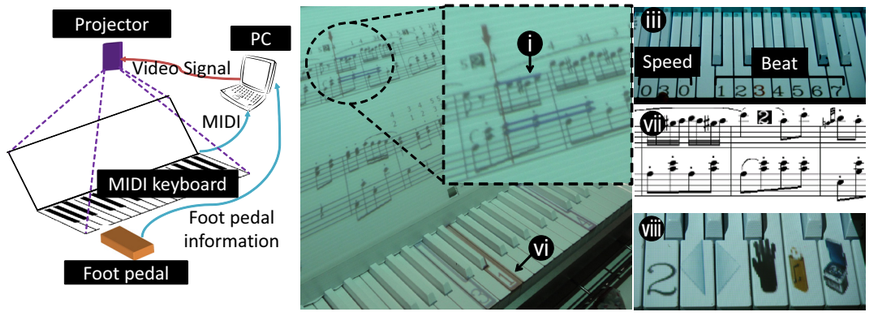


**Figure 2**. System structure and presentation of contents of the proposed system

The results of evaluative experiments confirmed that our system significantly enhanced learning effectiveness in the early stages of practice, when compared with the lighted keyboard method which turns the NextKeys red.

### 3.2. System structure

The structure of the system is shown in Figure 2. The system has a foot pedal to control the tempo of the metronome, and a projector to present learning support information. The projector is set above the keyboard and can display information along the entire MIDI keyboard. The system uses MIDI data including pitch data and intensity data from the MIDI keyboard.

### 3.3. Presented information

We explain the presented information with Figure 2. This information is updated in sync with the performance. The Roman numerals in Figure 2correspond to the following list:

**i) The duration bar** Rhythm consists of various kinds of note and rest, and it is important for beginners to understand the different duration of each one. Therefore, the proposed system enables learners to understand the duration of each note and rest by showing colored bars, the lengths of which correspond to the durations of each note and rest as shown in Figure 3. Additionally, the color of the bar turns from blue to yellow as the learner holds the key. In this way, the learner can intuitively understand the remaining time for which he or she must hold the key. If the learner holds the key too long the color of the bar turns from yellow to red and the length of the bar increases until the learner releases the key.

**ii) Rhythm check function** The system has a function that checks the timing of pressing and releasing a key and whether the key is held for the correct duration. Moreover, the system checks the timing of pressing several keys simultaneously, for example when

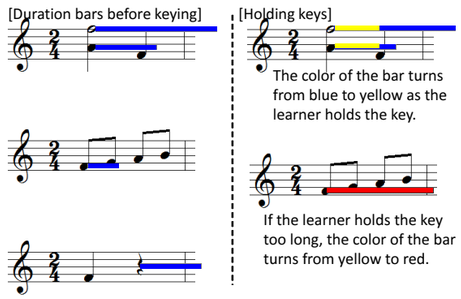


**Figure 3**. Examples of presentation of duration for musical notations

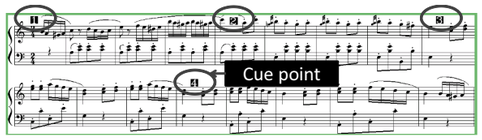


**Figure 4**. Score with cue points

the learner plays a chord, and the unnecessary rests between keys or between rests and notes. The error margin allowed for the timing of actions such as pressing multiple keys is called the allowable time, and depends on tempo, the difficulty of the piece of music and the learning level of the player. The proposed system allows learners to set the allowable time freely.

**iii)The Metronome** Users can turn the metronome on or off. Current tempo and beat are displayed at the distal ends of the keys shown in Figure 2. The tempo and the number of beats of the metronome are controlled by pressing the keys that represent current tempo and beat, respectively.

**iv) Control of the metronome using a foot pedal** Different parts of a piece of music have different degrees of difficulty. When a learner is practicing difficult parts, he or she tends to play in a slow tempo at first and then gradually increase the speed. On the other hand, when the learner practices easy parts, he or she plays in the tempo indicated by the score. Therefore, learners can practice a piece of music more effectively if they have flexible control of the tempo. We adapted a foot pedal to control the tempo of the metronome flexibly, and the tempo gets faster when the learner pedals.

**v) Adjustment of the start point of the metronome** There may sometimes be a lot of unexpected pauses because of the difficulty of playing certain parts of a piece of music. Additionally, beginners, who are not used to using one, find it difficult to adjust their own performance to the sound of a metronome. Therefore, we propose a function that automatically adjusts the start point of the metronome to the performance. In this way, beginners do not have to consider the timing of the metronome, and can start playing whenever they like.

**vi) Presentation of keying position and fingering** This function was also included in the previous system. When a key is outlined in color this indicates that it is the next key that should be pressed. A number on the key denotes fingering. This function is useful for beginners, who cannot read out keying and fingering information from a piece of music

**vii) Selection of cue points** Users can select cue points which are indicated on the score by numbers in black squares as shown in Figure 4. The cue points enable learners to change the point from which they want to start practicing. This function is useful when learners want to practice part of the score again and again without having to start from the very beginning each time.

**viii) Switching of each function** These functions are controlled using the keyboard. Keys can be assigned to commands for operating the system, and an icon which represents the command assigned to a key is displayed on the key.

## 4. IMPLEMENTATION

We implemented a prototype of the piano practice support system, as described in Section 3.3. We used a SONY VGNS94PS (Intel Core2 Duo 2.60GHz), running Windows 7, a CASIO PriviA PX-110 equipped with 88 full-sized keys. We used a BenQ MP776 ST as the projector. The projected area was 6 octaves (72 keys) and we painted all the black keys of the MIDI keyboard white. We implemented the system using Microsoft Visual C++.NET 2010 and Intel OpenCV Library. The prototype is shown in Figure 5.

## 5. EVALUATION

We conducted an evaluative experiment to investigate the effectiveness of the proposed system in the beginning stage of piano performance, when a piano beginner is practicing the keying, fingering, and rhythm of a new score.

### 5.1. Experimental Procedure

The evaluation procedure was as follows:

**Comparative method** In this evaluation, we compared the proposed method to a piano roll method, and a method without rhythm support, based on the number of keying and rhythm errors. Piano roll scores describe timing of keying and releasing clearly, and are used in KEYBOARD MANIA[4], which enables players who have no formal musical instrument training to enjoy piano performance easily. In the piano roll method, each key has a corresponding vertical bar on the screen as shown in Figure 6. Rectangular icons scroll down the bars to indicate which keys the learner should press. Users can understand the duration of each note and rest because the size of the rectangular icons is based on the duration of the corresponding notes. Timing is also easy to understand as the user simply presses the matching keys when the rectangle icons descend to the bottom of the screen.

Table 1 shows the application of functions for each method.

In the piano roll method, the system displays not only a piano roll score but also a musical staff on the piano roll score. Users are able to see both scores.

The proposed method presented the next learning information when subjects had pressed a correct key with correct rhythm, whereas the piano roll method and the method without rhythm support presented the next information when subjects had pressed only a correct key. The default speed of a metronome is that the duration between clicks is 0.6sec. One sixteenth note is equal to two clicks. The Sixteenth note was the smallest note in the trial score.

**Subject** Nine subjects took part in this experiment, and there were three subjects for each method. All subjects belonged to a graduate school of Engineering, had no formal piano training, and were not able to read a score. We explained how to read pitch and duration from notes and rests on the musical staff, and how to use the proposed functions. Moreover, the subjects using the piano roll method were taught how to read the piano roll as well.

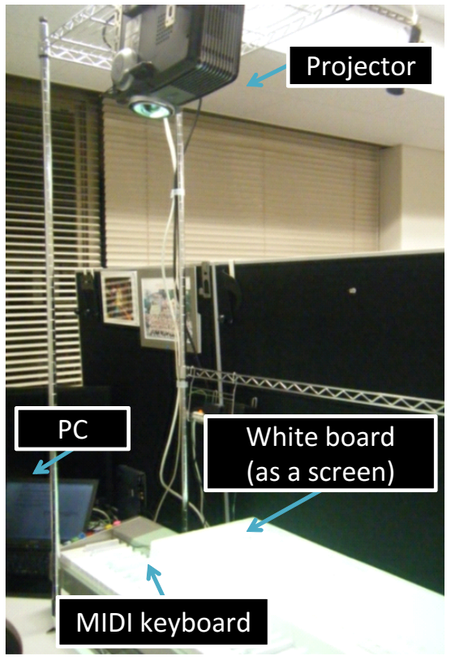


**Figure 5**. Prototype system

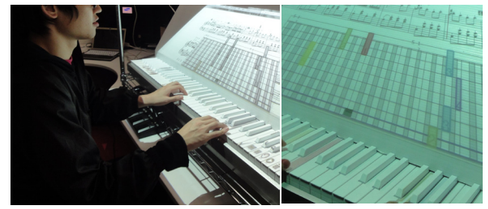

**Figure 6**. An example of a piano roll

**Trial piece** The subjects practiced "Piano Sonata No. 11 in A major, K. 331: III (W. A. Mozart)" ,from the beginning to bar 18, as the trial piece for two-handed playing. The total number of musical notes on the trial piece is 99.

**Flow of the evaluation** This examination consisted of two phases: practice and testing. The subjects practiced the trial piece for 30 minutes during the practice phase. We instructed them to practice freely. They basically learned the trial piece by practicing over and over and using the functions assigned to each method. Then they played the trial piece from beginning to end in the test phase, during which the system logged the press and release timing of the keys. In the test phase, we presented a score that was the same as the score used in the practice phase, and this was accompanied by the sound of the metronome. The speed of the metronome was the same as the default speed in the practice phase. Finally, we interviewed the subjects after the examination.

There are three types of keying error: incorrect keying, when the subject presses an incorrect key, as shown in Figure 7-(a), non-keying, when the subject does not press a key that the musical staff indicates should be pressed, as shown in Figure 7-(b), and extra keying, when the subject presses not only correct keys but also other keys, as shown in Figure 7-(c).

There are two types of rhythm error: extra rest and incorrect holding time. Incorrect holding time is when the subject holds a key over or under the indicated time, taking into account the time allowed for error. In this evaluation, we define the error margin as plus or minus 0.3sec. For example, the duration of the sixteenth note is 1.2sec in the tempo used in the test phase, and the rhythm is deemed correct if the subject holds the sixteenth note from 0.9sec to 1.5sec. Moreover, extra rest is when the time from releasing the current key to pressing the next key exceeds 0.6sec.

Some subjects sometimes held keys while searching for the next keys to be pressed, and released keys ahead of

**Table 1**. The applicable functions

| | Proposed method | Piano roll method | Method without rhythm support |
|---|---|---|---|
| The duration bar | Applicable | NA | NA |
| Rhythm check function | Applicable | NA | NA |
| The metronome | Applicable | Applicable | Applicable |
| Control of the metronome using a foot pedal | Applicable | Applicable | NA |
| Adjustment of the start point of the metronome | Applicable | Applicable | NA |
| Presentation of keying position and fingering | Applicable | Applicable | Applicable |
| Selection of cue points | Applicable | Applicable | Applicable |
| Displaying a piano roll | NA | Applicable | NA |

‘ NA’ stands for not applicable.

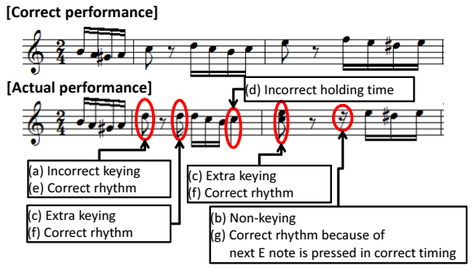


**Figure 7**. The measurement of rhythm errors and keying errors

**Table 2**. The average number of keying and rhythm errors

| | Keying error | | Rhythm error | |
|---|---|---|---|---|
| | Average | SD | Average | SD |
| Proposed method | 6.0 | 2.6 | 10.7 | 3.8 |
| Piano roll method | 31.0 | 1.4 | 27.5 | 3.5 |
| Method without rhythm support | 34.5 | 0.7 | 46.0 | 11.3 |

* Standard Deviation

the indicated release timing in order to search for the next keys. We consider this to be not only incorrect pressing but also extra rest. We judge the rhythm error based on the duration of an incorrect keying error when the subject presses an incorrect key as shown in Figure.7-(e). The case where the subject noticed the keying error and rectified it by pressing the correct key counts as a keying error but not a rhythm error as shown in Figure 7-(f). Non-keying is not a rhythm error, as shown in Figure 7-(g).

### 5.2. Results and Consideration

Table 2 shows the average number of keying and rhythm errors.

The results show that the proposed method significantly enhanced learning effectiveness, when compared with the piano roll method and the method without rhythm support. The average number of keying errors and rhythm errors of the proposed method is small. The difference between the average number of each error, when comparing the proposed method to the piano roll method and the method without rhythm support, was at a level of 5%, calculated from Steel-Dwass' multiple comparison test. We discuss the results relating to the proposed functions as follows. The behavior of the subjects was observed by the person overseeing the experiment, who consulted with the subjects directly after the evaluation.

**The duration bar** The reason that the subjects who used the proposed method were able to learn piano performance effectively is that the comprehension of rhythm and the reading of a musical staff were improved. The subjects who used the proposed method or the piano roll method passed on comments such as that the explicit presentation of the rhythm helped them to enhance their comprehension of it.

The subjects using the proposed method were able to acquire not only the rhythm information but also pitch information at the same time, as the duration bar is was layered over the notes of the trial piece. In the beginning stage of the evaluation, the subjects concentrated on acquiring the keying information presented on the musical keyboard and rhythm information from the duration bars, and playing with the correct keying and rhythm based on the acquired information. Once they were used to playing the trial piece, they began to understand the connection between the keying and rhythm information and the notations on the musical staff, and they became able to read out the pitch and rhythm information from the musical notes directly. The subjects using the piano roll method, in the beginning stage of the evaluation, did not look at the musical notations on the trial piece, as they practiced the keying and fingering while looking at the information presented on the keyboard. Next, they used the piano roll score to learn the rhythm once they had almost mastered the keying position and fingering. They could not afford to look up at the musical staff above the piano roll score. Finally, they hardly spent any time practicing with only the musical staff score. As a result, when they performed the trial piece in the test phase and unknown or difficult notations appeared, they made a lot of mistakes because they weren ’ t able to read out information from the musical staff.

The subjects using the method without rhythm support hardly looked at the musical staff in the beginning stage of the evaluation. They practiced rhythm with the musical notation after they had acquired the keying position and fingering, but they did not have much time to practice them. As a result, they made many mistakes.

**Rhythm check function** The rhythm check function contributes to improving the ability to read the musical staff. The subjects who used the proposed method had to be conscious of the keying timing and the release timing from the beginning stage of this evaluation, because if they made rhythm errors the system did not show the next keys information. As a result, they paid more attention to the musical staff.

Regarding the number of rhythm errors, the subjects rectified incorrect rhythm as they went along, by using the rhythm check function. Generally, it is difficult for beginners to time the pressing and releasing of keys for each hand and to be conscious of their own mistakes. The subjects made a lot of rhythm mistakes relating to this timing. The rhythm check function enabled the subjects who used the proposed method to improve their playing because they noticed their mistakes and they could practice the difficult parts again and again.

**Control of the metronome using a foot pedal** The control of the speed of the metronome using a foot pedal was applied to the subjects who used the proposed method and the piano roll method. However, only two subjects playing with the proposed method used the foot pedal function because the other subjects focused entirely on the other functions. The two subjects who used the pedal practiced the parts which they found easy or difficult in faster or slower tempo by using this function.

**Adjustment of the start point of the metronome** In regard to the adjustment function for the start point of the metronome, the subjects passed on comments such as that the function was convenient because they did not have to consider the timing of the metronome before starting to play. We particularly noticed that the subjects needed a lot of rests to check keying position and fingering in the beginning stage of this evaluation. Therefore, subjects using the method without rhythm support sometimes ignored the click of the metronome because of the added difficulty of keeping time with it.

**Presentation of keying position and fingering on the keyboard, and selection of cue points** All the subjects used the function that presents keying position and fingering from the beginning stage of this evaluation. Furthermore, the cue point function was also used frequently to practice difficult areas again and again. We confirmed the effectiveness of these two functions from the comments of all the subjects as well.

## 6. CONCLUSIONS

We constructed a musical staff-based piano learning support system considering rhythm learning. The learner understands the duration of notes and rests intuitively by using the duration bars layered over the notes and rests on a score. The learner can also understand the remaining time for which they should hold each key by observing the changing color of the bars. The Rhythm check function helps users notice their own mistakes and rectify them. The results of evaluative experiments confirmed that the subjects using our proposed system played the trial piece using correct keying and rhythm during the 30 minute training period, and the system significantly enhanced learning effectiveness in the early stage, when compared with the piano roll method.

As described in Section 1, playing the piano requires various techniques, such as correct keying, fingering and rhythm, which generally need long-term practice. Therefore, conventional piano learning methods make learners practice each technique individually, thus beginners often give up as it takes tremendous time and effort to acquire the skills needed to play a song adequately. We propose a comprehensive learning style, which allows learners to acquire several skills at the same time, by enhancing human processing ability using multimedia technology and information design technology. Future work will involve constructing a more comprehensive piano learning system that includes not only keying and rhythm information but also fingering, dynamics, and articulation, and will include evaluative experiments conducted on beginners of various generations, as well experiments carried out over a longer period of time.

## 7. 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.

## 8. REFERENCES

[1] CASIO: Lighted Keys Keyboards: http://www.casio.com/products/Musical_Instruments/Lighted_Keys/.

[2] Concert Hands System: http://www.concerthands.com/.

[3] KAWAI: PianoMaster: http://www.kawai.co.jp/cmusic/products/pm/index.htm. (in Japanese)

[4] Keyboardmania http://en.wikipedia.org/wiki/Keyboardmania.

[5] Roland: http://www.roland.com/piano/DigiScore.html.

[6] A. Butz, M. Schneider, and M. Spassova: SearchLight A Lightweight Search Function for Pervasive

Environments, *Proc. of IEEE International Conference on Pervasive Computing*, pp. 351–356 (2004).

[7] A. Suganuma, Y. Ogata, A. Shimada, D. Arita, and R. Taniguchi: Billiard Instruction System for Beginners with a Projector-Camera System, *Proc. of International Conference on Advances in Computer Entertainment Technology*, pp. 3–8 (2008).

[8] C. Lewiston: MaGKeyS: A Haptic Guidance Keyboard System for Facilitating Sensorimotor Training and Rehabilitation, *PhD Thesis. MIT Media Laboratory* (2008).

[9] C. Pinhanez: The Everywhere Displays Projector: A Device to Create Ubiquitous Graphical Interfaces, *Proc. of ACM International Conference on Ubiquitous Computing* (2001).

[10] H. Ishii, C. Wisneski, J. Orbanes, B. Chun, and J. Paradiso: PingPongPlus: Design of an Athletic-Tangible Interface for Computer-Supported Cooperative Play, *Proc.s of ACM conference on Human factors in computing systems*, pp. 394–401 (1999).

[11] K. Huang, E. Y. Do, and T. Starner: PianoTouch: A wearable Haptic Piano Instruction System for Passive Learning of Piano Skills, *Proc. of IEEE International Symposium on Wearable Computers*, pp. 41–44, (2008).

[12] M. Mukai, N. Emura, M. MIURA, and M. Yanagida: Generation of Suitable Phrases for Basic Training to Overcome Weak Points in Playing the Piano, *Proc. of International Congress on Acoustics*, MUS-07-018 (2007).

[13] P. Misty, P. Maes, and L. Chang: WUW - wear Ur world: a Wearable Gestural Interface, *Proc. of ACM conference on Human factors in computing systems*, pp. 4114–4116 (2009).

[14] R. B. Dannenberg, M. Sanchez, A. Joseph, P. Capell, R. Joseph, and R. Saul: A Computer-Based Multi-Media Tutor for Beginning Piano Students, *Journal of New Music Research*, 19 (2-3), pp. 155–173, 1990.

[15] R. Raskar, J. V. Baar, P. Beardsley, T. Willwacher, W. Rao, and C. Forlines: iLamps: Geometrically Aware and Self-Configuring Projectors, *Proc. of International Conference and Exhibition on Computer Graphics and Interactive Techniques* (2003).

[16] S. Akinaga, M. MIURA, N. Emura, and Masuzo Yanagida: An Algorithm to Evaluate the Appropriateness for Playing Scales on the Piano, *Proc. of International Congress on Acoustics*, MUS-07-005 (2007).

[17] S. Akinaga, M. MIURA, N. Emura, and Masuzo Yanagida: Toward Realizing Automatic Evaluation of Playing Scales on the Piano, *Proc. of International Conference on Music Perception and Cognition*, pp. 1843–1847 (2006).

[18] S. Smoliar, J. Waterworth, and P. Kellock: pianoFORTE: A System for Piano Education Beyond Notation Literacy, *Proc. of the Third ACM International Conference on Multimedia*, pp. 457–465 (1995).

[19] T. Kitamura and M. Miura: Constructing a Support System for Self-learning Playing the Piano at the Beginning Stage, *Proc. of International Conference on Music Perception and Cognition*, pp. 258–262 (2006).

[20] Y. Takegawa, T. Terada, and T. Tsukamoto: Design and Implementation of a Piano Practice Support System using a Real-Time Fingering Recognition Technique, *Proc. of International Computer Music Conference* (2011).

[21] Y. Takegawa, T. Terada, and S. Nishio: Design and Implementation of a Real-Time Fingering Detection System for Piano Performances, *Proc. of International Computer Music Conference, pp. 67–74 (2006).*





# *MAESTRO:* USING TECHNOLOGY TO IMPROVE KINESTHETIC SKILL LEARNING OF MUSIC CONDUCTORS

*Andrea E. Brown* *Yonatan Sasson*

School of Music
Georgia Institute of Technology

**ABSTRACT**

The use of technology in music conductor training is a growing area of interest. The expressive, subtle, and meaning-rich gestures that are used in conducting, serve as fruitful ground for innovative research in areas such as artificial vision, gesture following, and musical mapping. While it is known that the kinesthetic skills of conducting are acquired through hours of intensive training, practice with real time audio and visual feedback is severely limited by availability, focus, and good will of live musicians. The current project, titled *Maestro,* builds upon previous work and provides a new approach for training beginning conductors: a system allowing the conductor to practice basic to advanced baton skills accompanied by a virtual orchestra that responds to the conductor's baton gestures affecting tempo, duration, articulation, and dynamics. By incorporating gesture anticipation and tracking, machine learning for gesture analysis, utilization of physical modeling for high-quality audio, *Maestro* provides immediate feedback that is directly related to subtle variations of performed conducting gestures.

## 1. INTRODUCTION

Performing music, whether playing an instrument, singing, or conducting, requires a combination of aural, cognitive, and kinesthetic skills that require specific practice to improve [1], [2]. Such skills could include learning the fingering patterns of major and minor scales on a particular instrument or the weight on the bow of a stringed instrument. Kinesthetic skills are also the foundation of beginning music conducting skills [3]. Beginning conducting students must learn a plethora of movements that include instruction on torso, head, and arm positions and a variety of expressive movements intended to bring about a response from performers.

The acquisition of such skills is a challenging task, which is historically achieved with individual or group instruction, followed by individual practice. Indeed, several technological innovations address this effort by putting an emphasis on the development of kinesthetic skills related to performing music or providing sophisticated feedback (either in real-time or non real-time) to act as a virtual music teacher.

Such tools present different solutions for the practical issues as well as the psychological aspects of acquiring musical skills. Practicing in front of a teacher, peers, and eventually an audience may cause different responses ranging from indifference to anxiety [4], [5]. Creating individualized instructional tools and allowing more comfortable practicing environments can be invaluable to many populations that are affected by such difficulties. We contend that use of the *Maestro* system in such traditional learning environments would enhance the learning experience and encourage kinesthetic awareness and overall musical skill development.

The project seeks to advance previous conducting technology and pedagogy through two core advances: a) the delivery of rich real-time audio and visual feedback through the *Maestro* system to enable the refinement of kinesthetic skills of conducting gestures affecting variations of speed, articulation, dynamic, and speed, and b) the ability to practice conducting gestures without the need for live musicians or peers. The *Maestro* system introduces technical innovation-based research in three main areas: a) gesture anticipation and tracking; b) machine learning for gesture detection and classification; c) utilization of physical modeling for high quality, subtle musical feedback. This work is designed to foster more opportunities for meaningful learning experiences through the beginning conductor's discovery of subtleties of gestures and their effect on musical performance.

## 2. RELATED WOKS

In recent years, there have been several attempts to simulate the conductor's baton. Developments in mobile technology and the wide availability of sensors and accelerometers encouraged researchers to explore the hitherto relatively uncharted realm of conducting. The Radio Baton [6] was one of the first systems developed in this field. It offered an interactive conducting experience by controlling the tempo of a MIDI sequence as a feedback to the gesture. Other systems in later years incorporated sensors for more precise input analysis, such as measuring the pressure on the baton [7], tracking the conductor's muscle tension [8], and using a built-in camera on the baton [9]. Improvement over the years included transition from MIDI to audio-based musical feedback [10] to more sophisticated and realistic forms of sound generations [11].

Similar projects targeted simulation of the conducting experience as a way to experience controlling an orchestra, rather than for researching the subtleties of conducting gestures and their musical effect. In 2004, Borchers offered children the opportunity to conduct the Vienna Philharmonic Orchestra. The 'conductor' would stand in front of a video screen and control the tempo of an actual performance [12]. Two other systems with similar focus are iSymphony [13] and Pinocchio [14], developed a few years later.

Along with programs designed to familiarize and introduce the conducting experience to non-musicians,