Why Always Versatile?: Dynamically Customizable Musical Instruments Facilitate Expressive Performances

Kazushi Nishimoto
Japan Advanced Institute of Science and Technology
/ PRESTO, JST
/ ATR Media Information Science Laboratories
1-1, Asahidai, Tatsunokuchi, Nomi,
Ishikawa, 923-1292, Japan
+81 761 51 1812
knishi@jaist.ac.jp

Chika Oshima and Yohei Miyagawa
Japan Advanced Institute of Science and Technology
1-1, Asahidai, Tatsunokuchi, Nomi,
Ishikawa, 923-1292, Japan
+81 761 51 1812
{cooshi, y-miyaga}@jaist.ac.jp

ABSTRACT
In this paper, we discuss a design principle for the musical instruments that are useful for both novices and professional musicians and that facilitate musically rich expression. We believe that the versatility of conventional musical instruments causes difficulty in performance. By dynamically specializing a musical instrument for performing a specific (genre of) piece, the musical instrument could become more useful for performing the piece and facilitates expressive performance. Based on this idea, we developed two new types of musical instruments, i.e., a "given-melody-based musical instrument" and a "harmonic-function-based musical instrument." From the experimental results using two prototypes, we demonstrate the efficiency of the design principle.

Keywords
Musical instruments, expression, design principle, degree of freedom, dynamic specialization

1. INTRODUCTION
Musical instruments are tools for expressing our inner musical emotion. The more easily, directly, freely and perfectly we can express our musical emotion through a musical instrument, the more desirable the musical instrument is, not only for novices who have never or seldom performed any musical instruments but also for professionals. However, it is actually very difficult for us, in particular for novices, to express our musical emotion by using conventional musical instruments. Even after long and hard practice, we often cannot achieve satisfactory performances.

We think that this problem arises from the versatility of the conventional musical instruments. The conventional (acoustic) musical instruments are independent of the musical pieces to be performed while using them. Therefore, people can enjoy performing any musical piece of any genre with the identical musical instrument. Although this feature greatly benefits people, the wide applicability of conventional musical instruments requires a large degree of freedom in operation and generality. The large degree of freedom makes it unnecessarily difficult for the performer to perform a piece of music.

Therefore, it is necessary to reduce or eliminate the excessive degree of freedom in operation and to specialize the musical instruments for performing a specific piece. Now, we have high-quality sound synthesizers and PCs. These allow us to create new electrical musical instruments that we can freely, easily, quickly and dynamically customize as the occasion demands. By appropriately reducing the degree of freedom in operation and by specializing for a certain piece, such new musical instruments facilitate expressive performance not only for novices but also for professionals.

In section 2, we discuss the requirements of a musical instrument that facilitates expressive performances as well as how the excessive degree of freedom in operation should be reduced or eliminated and how the musical instrument should be specialized for a certain piece. Sections 3 and 4 describe two new types of musical instruments, i.e., a "given-melody-based musical instrument" and a "harmonic-function-based musical instrument," and we illustrate two prototype musical instruments, named the "Coloring-in Piano (CiP)" for typical classical music and "RhyMe" for Be-Bop style jazz improvisation. We also show experiments and their results and evaluate the advantages of the proposed new musical instruments in these sections. Section 5 compares our approach with the related works. Section 6 concludes this paper.

2. A DESIGN PRINCIPLE
2.1 Requirements
A musical instrument that facilitates expressive performances for everybody should satisfy the following requirements:

1. the initial barrier is low,
2. there is enough room for improvement by practice and study, and the improvement can be recognized by the player, and
3. the ultimately achievable quality of performance is not inferior to that by conventional musical instruments.

In order for novices to readily enjoy performing music, the initial barrier must be sufficiently low. If it is too high, most of the novices, in particular adult novices, would inevitably give up the idea of enjoying musical performance from the beginning. However, it is not practical to create a musical instrument with which a performer can immediately perform his/her ideal performance without any practice and/or study. This is because direct extraction of the performer's idea from his/her brain is impossible, and an established ideal performance does not initially exist in the performer's mind but is created through practice and/or study[1]. Accordingly, the room for improvement by practice and study is necessary. Additionally, from the novices' viewpoint, they would immediately lose interest in playing it if they cannot improve or cannot feel improvement in performance even after practicing hard. A feeling of steady and recognizable improvement toward ultimate excellent performances motivates players to continue practicing and performing. However, even if a musical instrument satisfies the above two requirements, professional performers would never use it if the ultimately achievable quality of performance were inferior to that by a conventional musical instrument.

2.2 How to satisfy the requirements

We think that the key to achieving musical instruments that facilitate expressive performances is dynamic customizability. When a performer performs a Thelonious Monk jazz piece with a musical instrument, the musical instrument should be convenient for performing it but need not be convenient for performing a classical Bach piece, and vice versa. Therefore, the musical instrument must be able to be dynamically, easily and quickly customized depending on what is performed with it. There are two aspects for customizing a musical instrument, i.e., reduction of unnecessary degree of freedom in operation and specialization of an interface depending on the piece to be performed.

2.2.1 Reduction of unnecessary degree of freedom

There are many musical elements, e.g., pitch, timbre, volume and rhythm, that should be controlled in a musical performance. Most of the conventional musical instruments allow the performer to control all of the musical elements. However, such a huge degree of freedom is not always necessary. We can find that some musical elements require no (or less) degree of freedom when performing specific (genre of) pieces. For example, when performing "Fantasie Impromptu Op. 66" by F. Chopin, no degree of freedom in selection of pitch is allowed for the performer. The pitches of all of the notes are *a-priori* decided by Chopin. Therefore, when performing this piece, the degree of freedom in selection of pitch is redundant for the performer. The performer cannot express his/her own musical emotion in reproduction of the sequence of pitches specified in the score. However, the performer cannot skip this task. Furthermore, the task must be accurately executed because even a miss-touch is not allowed. Thus, such a redundant degree of freedom wastes the performer's cognitive and physical abilities.

What the performers of Chopin's piece should essentially do (and should devote themselves to) is expression of their musical emotion that lies beyond the reproduction task. If the performers could skip the reproduction task and directly tackle expression, they could concentrate their cognitive ability on expression. Consequently, if we could eliminate or reduce the unnecessary degree of freedom, the performer would be able to perform more expressively, and hence professionals as well as novices could receive some benefit.

2.2.2 Specializing an interface for pieces

The layout of notes on the interface of a conventional musical instrument is based on the pitch of a note. That is, a certain pitch is always mapped on a certain position of the interface. For example, a C4 note is always mapped on the 24th white key from the leftmost key of a piano. We call this way of layout "pitch-based note mapping," and a musical instrument that employs it a "pitch-based musical instrument." Though this is a simple and intuitive mapping criterion, it is not always the best way of mapping. If the degree of freedom in selection of pitch is reduced when performing a specific (genre of) piece, the pitch-based note mapping actually becomes nonsense. Even if the degree of freedom is not reduced for any musical elements, some different mapping approaches often facilitate performance. In such a case, the layout should be changed based on another mapping criterion. However, it is indispensable to provide a comprehensible, consistent and definite criterion for mapping notes on the interface for the performer to precisely project images in his/her mind to externalized music.

3. GIVEN-MELODY-BASED MUSICAL INSTRUMENT

This section illustrates a "given-melody-based musical instrument" for performing musical pieces that require accurate reproduction of given scores, e.g., typical classical music, as the first example of a musical instrument based on the above design principle.

3.1 Basic Concept

The musical pieces that require accurate reproduction of given scores involve two types of elements from the performer's perspective: non-expressive elements and expressive elements. The pitches, pitch sequence and basic rhythm (that is, the time value of each note) are the "non-expressive elements." The performers must accurately reproduce them as the composer directed and hence they cannot demonstrate their expression. Therefore, control of the non-expressive elements is not an essential task for the performers, although they cannot skip this task when using conventional musical instruments. However, each note has many other attributes, e.g., *Dynamik* (varying and contrasting degrees of intensity or loudness in musical tones) and *Agogik* (a slight deviation from the main rhythm and/or the directed time values for accentuation purposes). We call these attributes "expressive elements." An individual performer's expression is reflected in how these expressive elements are controlled. Therefore, the control of the expressive elements is the essential task for the performers of this type of musical piece.

Consequently, in order to facilitate the performance of this type of music, we should reduce the degree of freedom in the non-expressive elements as much as possible. In this type of music, which notes must be performed at every point in a piece are definitely decided. Therefore, only the necessary pitches should always be mapped on the interface, and the mapped notes should dynamically change as the performance of the piece progresses. As a result, the performer can output the necessary notes without looking for them on the interface.

Owing to this way of mapping notes, the performer is freed from most of the nonessential tasks, and his/her cognitive and physical loads are alleviated. Accordingly, the initial barrier becomes low. On the other hand, the performer is still in charge of controlling all of the expressive elements for adding his/her original expression. Namely, the degree of freedom for expression is not reduced at all. Therefore, the given-melody-based musical instrument is as expressive as conventional musical instruments and provides much room for improvement of musical expression.

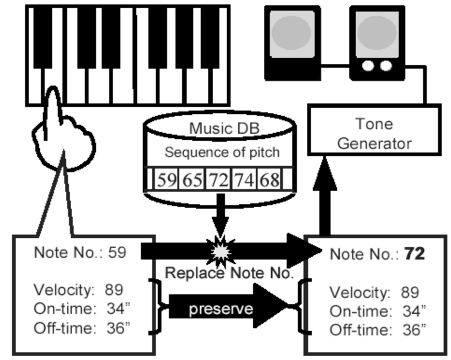

Figure 1: Setup of CiP

3.2 Coloring-in Piano

Here, we describe a prototype given-melody-based musical instrument named "Coloring-in Piano (CiP)."

3.2.1 Setup of CiP

Figure 1 shows the setup of CiP. CiP consists of a MIDI (Musical Instrument Digital Interface) keyboard, a music-database, a function for replacing note numbers, and a tone-generator. Before performing, it is necessary to prepare a sequence of MIDI note-numbers (corresponding to pitches) of the piece to be performed in the music-database. While performing, the replacing function replaces the played note-numbers with the note-numbers registered in the music-database, based on the order in which they were input. Accordingly, the correct note number is always output by touching any key. On the other hand, the expressive elements, i.e., note-on (key down) velocity, note-off (key up) velocity, onset/offset timing, and pedal messages, are output as the performer plays. Finally, the replaced pitch numbers are input into the sound generator with the expressive elements preserved as they were performed. We implemented the above system on a laptop PC (OS: Windows 2000) using Delphi 6. We used a YAMAHA silent grand piano C5 professional model that outputs MIDI note-on/off, and pedal control messages. The piano was connected to the laptop PC.

3.2.2 Experiment to Evaluate CiP's Expressiveness

This section describes experiments conducted to evaluate the potential expressiveness of CiP. In addition, we discuss how the interface of CiP should be designed.

3.2.2.1 Method of evaluations

The second author of this paper, who is a professional piano teacher, performed parts of two pieces on the conventional piano and on CiP. One of the pieces was "Tendre Fleur," which is one of the 25 Leichte etuden Op. 100 by F. Burgmuller. We called it "Piece-A." The other piece was "Grande Polonaise Brillante Op. 22" by F. Chopin, which was called "Piece-B." Both are examples of the style known as romanticism and include various articulations. Figures 2 and 3 show eight bars selected from each piece. She played only the melody without accompaniment. In the CiP case, the pieces were performed three ways, e.g., using only one finger for one key performance (CiP-1), using only two fingers for two-key performance (CiP-2), and using five fingers for all-key performance (CiP-5). All performances were recorded.

We asked twenty subjects who are experienced in piano playing, e.g., those who had finished the Bayer Manual, to evaluate the recorded performances. We let the subjects listen to four pairs of performances, i.e., pairs of a performance on a conventional piano and CiP-1, CiP-2, CiP-5 or the performance on the conventional piano. All of the evaluations were conducted under blind conditions. Therefore, the subjects did not know how a performance was recorded or which performances they were comparing even when they listened to the pair of the same performances on the conventional piano. We asked them to evaluate each performance from the perspective of whether it is musical (1: not musical to 5: very musical), where we explained that "musical" means "interesting" or/and "comfortable."

3.2.2.2 Analysis of performance data

Based on the performance data in the MIDI format, we calculated inter-onset interval (IOI) and gap time. The IOI is obtained as

$$IOI_i = t_{Non(i+1)} - t_{Non(i)}\,, \qquad (1)$$

where IOI_i is the i-th IOI, and $t_{Non(i)}$ is emitted time of the i-th note-on message $N_{on(i)}$. The gap time is obtained as

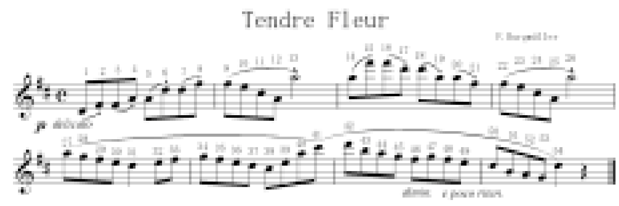

Figure 2: Bars 1-8 of "Tendre Fleur," which is one of the 25 Leichte Etuden Op. 100 by A. Burgmuller

Figure 3: Bars 220-227 of "Grande Polonaise Brillante Op. 22" by F. Chopin

$$gap_i = t_{Non(i+1)} - t_{Noff(i)}\,, \qquad (2)$$

where gap_i is the i-th gap time, and $t_{Noff(i)}$ is the emitted time of the i-th note-off message $N_{off(i)}$. Hence, if gap_i is positive, the performer shortened the i-th note. Additionally, we extracted the velocity values included in the MIDI note-on message. The velocity of a note-on message shows the velocity of stepping down a key and nearly corresponds to the sound level of the note.

Table 1: Average values of evaluations of musicality. An asterisk (*) indicates a significant difference of 1%.

	Piece A				Piece B		
	conventional	CiP-1	t-value		conventional	CiP-1	t-value
1	3.17	2.00	5.63*	1	2.92	1.92	3.63*
	conventional	CiP-2	t-value		conventional	CiP-2	t-value
2	3.50	3.67	0.46	2	2.67	3.00	0.84
	conventional	CiP-5	t-value		conventional	CiP-5	t-value
3	3.58	3.41	0.62	3	3.25	3.50	1.00
	conventional	conventional	t-value		conventional	conventional	t-value
4	3.50	3.33	1.00	4	3.58	3.58	0.00

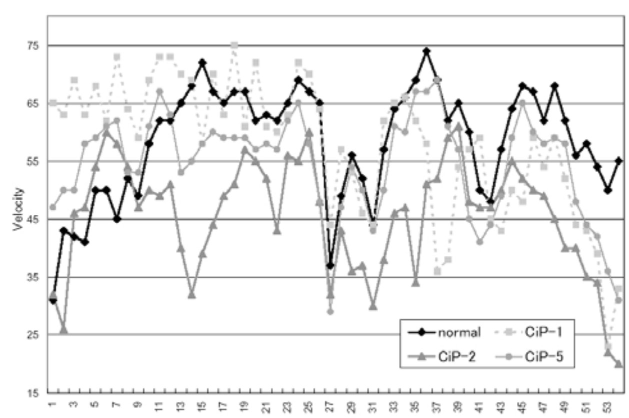

Figure 4: Transition of average note-on velocity values of the four ways of performance of Piece-A.

3.2.3 Results

3.2.3.1 Evaluation by the subjects

Table 1 shows the average evaluation values of musicality by the twenty subjects. The reason why the values of "conventional" for each piece are different is that all of the evaluations were conducted under blind conditions. The results of a t-test indicate that CiP-2 and 5 performances are as musical as that of the conventional piano performance, though the musicality of the CiP-1 performance is significantly worse than that of the conventional piano performance.

3.2.3.2 Performance data

The *IOI*s of the four performance methods (CiP-1, CiP-2, CiP-5 and a conventional piano) are very similar for both pieces. Therefore, the performer could reproduce the basic structures of the pieces by any of the musical instruments. However, we found evident differences in gap time and velocity data. The gap time of CiP-1 was always positive. When performing CiP-1, the performer must always release the key. This means that the performer cannot perform a *legato* expression with CiP-1. Figure 4 shows the transition of the average note-on velocity values of the four performance methods for Piece-A. It is clear that the velocity of the CiP-2 performance decreases remarkably around the 14th note comparing to the other performances.

3.2.4 Discussion

The results shown in Table 1 indicate that CiP, except for CiP-1, have enough potential for rich musical expression and are not inferior to the conventional piano. The reason why CiP-1 is inferior to the others is that CiP-1 reduced the degree of freedom in a necessary element, i.e., the overlap time between two consecutive notes, which is preserved in CiP-2 and 5. However, from the result shown in Figs. 4, we found that the pieces were expressed differently between, in particular, CiP-2 performances and the conventional piano performances. This might derive from the differences in fingering between two-finger use and five-finger use. For example, there is quite a large pitch gap between notes No. 12 and No. 13 in Piece-A (see Fig. 3). While the performer's hand had to move a long way to the right when performing the part on the conventional piano, her hand did not need to move so far when performing the part on CiP-2 (only one-key distance). This motion difference should have affected the difference between the expressions (velocity, in particular).

We cannot easily conclude which expression is better. Please note that CiP is not a subspecies of the conventional piano but a new musical instrument. Therefore, CiP does not need to have the same expressiveness as that of the conventional piano. In fact, CiP-2 may permit novel expression that cannot be achieved by the conventional piano: CiP-2 always allows *legato* expression, however large the difference in pitch between consecutive notes is.

4. HARMONIC-FUNCTION-BASED MUSICAL INSTRUMENT

This section describes a "harmonic-function-based musical instrument" for performing musical pieces that require harmonic analysis of chord progression while performing a given piece, e.g., improvisational performance in the Be-Bop style of jazz music.

4.1 Basic Concept

In this section, we describe the basic concept of the harmonic-function-based musical instrument by using as an example the improvisational performance in Be-Bop style jazz (hereafter, simply called "jazz improvisation"). In contrast with the performance of classical music, the performer is required to concurrently execute two different tasks in jazz improvisation: composing melodies based on a given chord progression and externalizing the composed melodies while adding expression with a musical instrument.

Although it seems that the entire former task, i.e., composing melodies, is expressive, we think that there are still non-expressive sub-tasks involved. When composing melodies in jazz improvisation, a performer 1) reads the chord progression from a score, 2) analyzes it based on a harmonic theory, 3) obtains a function of each note, 4) chooses notes having functions that are suitable for the performer's desired expressions, and 5) finally composes melodies by concatenating the chosen notes with suitable rhythm. In other words, the performer translates the attribute of each note from "pitch" to "harmonic function" through theoretical analysis (steps 1 to 3) and then composes melodies based on the functions of the notes, not on the pitches of the notes (steps 4 and 5). In these five steps, we can say that the performer's expressiveness is reflected only in steps 4 and 5. Though steps 1 to 3 can be executed mechanically based on established theory, these steps place a very high cognitive load on the performer. As a result, novices, in particular, cannot have the extra cognitive ability to compose good melodies.

In the externalization of composed melodies, the performer must look for notes based on their harmonic functions, not their pitch, on a musical instrument interface. Therefore, the notes should be mapped on the interface based on their harmonic functions. Each of the twelve notes in an octave has a different function in a certain harmony. By providing the twelve positions in an octave on the interface of a musical instrument, by assigning a specific function to a specific position, and by constantly mapping a note with a specific function to the corresponding position, we can construct a new musical instrument specialized for jazz improvisation. By operating a certain position, the performer can always immediately obtain a note with the required function, though the pitch of the obtained note changes along with the chord progression. Thus, even a novice can directly tackle the expressive tasks by skipping these non-expressive tasks, and a professional can concentrate more of his/her ability on expressive tasks.

4.2 RhyMe

Here, we describe a prototype harmonic-function-based musical instrument named "RhyMe."

4.2.1 Setup of RhyMe

Figure 5 shows the setup of RhyMe. The system consists of two modules: a chord-progression analysis module and a dynamic mapping module. The chord-progression analysis module analyzes the chord progression of a musical piece based on the Berklee theory, which was developed at the Berklee College of Music and is the most well known harmonic theory in Be-Bop style jazz improvisation, and then obtains available note scales for each chord. Using the obtained available note scale data, the dynamic mapping module dynamically maps the notes to an interface in the following manner. Usually, a scale consists of seven notes. Each note is named by a number relative to the position from the root note, i.e., I, II, III, IV, V, VI and VII, where I is the root note. These positions correspond to the functions of the notes. For example, the III note has the function of expressing tonality: minor or major of the chord/scale. Accordingly, we name the function of each note by the number of the note's position, e.g., the function of the III note is named "function-III." For example, the F-mixolydian scale consists of F, G, A, B-flat, C, D, and E-flat notes. Therefore, the function-III note of this scale is A. The functions of the notes not included in the currently available note scale are also named based on the number of scale-notes, e.g., function-flat-II and function-sharp-IV. Finally, a note of a certain function is constantly mapped to a corresponding position on the interface. For instance, the note of function-III is always mapped to the position of function-III. As a result, all of the notes are mapped on the interface based on their harmonic functions. The mapping dynamically changes as the chord progresses (i.e., the available note scale changes). Moreover, we can choice notes based on their intervals by this way of mapping. For instance, if we want a note that is two degree higher than the function-II note, we can get it by the position of function-IV. Thus, the mapping of notes is specialized for Be-bop improvisation, while RhyMe does not reduce the degree of freedom of any musical element.

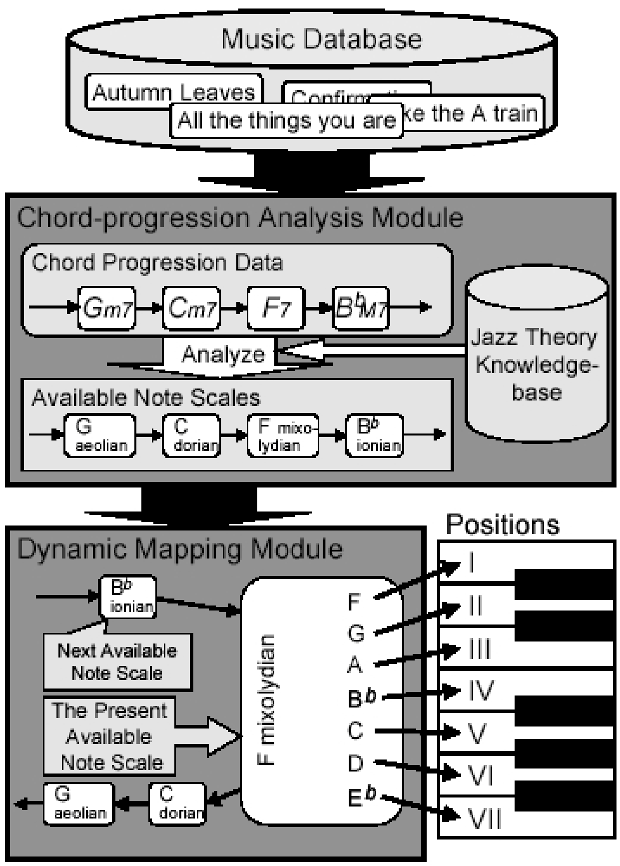

Figure 5: Setup of RhyMe

In the current implementation, we applied a MIDI keyboard (KORG M1) as the interface. Functions I to VII were assigned to the C to B keys, respectively. The out-of-scale functions were mapped on the black keys. In this prototype, a note that is a semi-tone lower than the white key to the right of the black key is mapped as an expedient. Because of this mapping method for the black keys, an in-scale note is assigned to a black key in some cases.

4.2.2 Experiments

We conducted an experiment using RhyMe for jazz improvisation to evaluate whether novice users could easily perform jazz improvisation. We employed nine subjects and let them play improvisations of "Autumn Leaves" using RhyMe as well as using the same keyboard in normal pitch-based note mapping mode, i.e., a conventional keyboard as it is. Before beginning the experiments, we briefly explained how RhyMe works to the subjects. After the experimental performances, we posed the following questions to the subjects:

Table 2: Results of eight-question inquiry for improvisational performances using RhyMe and a normal keyboard

No.	RhyMe	Normal	t	No.	RhyMe	Normal	t
1	2.94	2.56		5	2.50	1.94	
2	2.50	1.75	*	6	3.81	2.50	*
3	3.06	1.94	*	7	4.25	3.19	*
4	3.81	2.50	*	8	3.75	2.25	*

1. Was it easy to operate this instrument? (1: Very difficult, 5: Very easy)
2. Was your performance good? (1: Very bad, 5: Very good)
3. Was your performance jazzy? (1: Not jazzy, 5: Very jazzy)
4. Did you enjoy performing this instrument? (1: No, 5: Yes)
5. Do you think you could perform as you wanted to perform? (1: No, 5: Yes)
6. Do you think you could improve your performance with practice? (1: No, 5: Yes)
7. Do you want to continue to perform on this instrument? (1: No, 5: Yes)
8. Do you think you can play a session performance with other performers using this instrument? (1: No, 5: Yes)

Table 2 shows the average values of each inquiry for RhyMe and for the normal keyboard. The asterisks in the "t" column show the results of t-tests comparing the average values in each inquiry: an asterisk indicates a significant difference of 2%. From these results, we confirmed that RhyMe was evaluated more highly than the normal keyboard for all of the questions. Furthermore, RhyMe scored significantly better than the normal keyboard for all of the questions except Nos. 1 and 5.

4.2.3 Discussion

The harmonic function of notes is not such a common concept, particularly the novices. However, though the subjects did not understand the harmonic function well, they could satisfactorily perform on RhyMe. This fact proves that RhyMe does not initially require a deep understanding of the harmonic-function. Therefore, this novel way of mapping does not have a bad influence on the alleviation of the initial barrier. On the contrary, it makes it easy for the subjects to perform jazz improvisation, as the results in Table 3 show. We could not find any significant difference between RhyMe and the normal keyboard in question No. 1. We think this result relates to the fact that both musical instruments had the same interface device. Namely, it is assumed that the instrument's ease of operation is strongly dominated by its interface device. However, despite the interface problem, RhyMe was evaluated as being much better than the normal keyboard in all other questions. In particular, the high scores of RhyMe in questions 6, 7 and 8 suggest that the subjects had great expectations of their future ability to enjoy performing music with the harmonic-function-based musical instrument, though they did not expect such enjoyment with the conventional instrument.

5. DISCUSSION AND RELATED WORKS

Recently, various instruments for novices' entertainment have been developed. The "Two Finger Piano"[2] is a system that allows the user to coarsely handle tempo and *Dynamik* for each "beat" or for each half-beat (but not for each note) by using two fingers. Therefore, it is impossible to control *Agogik,* which requires note-level control. The CASIO LK-40 Lighted Keyboard [3] is equipped with a similar function to CiP that always only outputs available pitches of a piece by hitting any key. However, this system outputs constant velocity values. Therefore, *Dynamik* cannot be expressed by this system. "MusPlay"[4] and the "any key play" mode of the

Yamaha EZ-20 and 30 keyboards[5] are very similar to CiP. In addition, MusPlay allows us to play a two-handed polyphony performance. As for the mechanism, CiP is not so advanced from these systems. However, it is not assumed that professional musicians use these musical instruments. Therefore, no experiments have been conducted to evaluate their potential for expression. On the contrary, we focused on a mechanism that could benefit professionals as well as novices, and we proved that CiP is as expressive as conventional musical instruments in classical music performances.

The "adlib-musician" function of CASIO CT-647 keyboard is similar to RhyMe. However, in the CT-647, only notes included in the presently available note scale are mapped on the keys. In addition, the way of mapping notes is different from RhyMe: a note whose pitch is the same or the nearest neighbor of the original pitch of a key on the normal keyboard is mapped to the key. "INSPIRATION"[6] also changes input notes to theoretically correct notes automatically. Therefore, in these systems, neither pitch nor the harmonic-function of a note mapped to a certain key is always stable. Consequently, though the performer can perform improvisation as if he/she had become an experienced musician, the performer cannot intentionally compose melodies by using these systems: there always remain unexpected factors. On the other hand, RhyMe always provides an evident and stable criterion of mapping of notes: the harmonic-function-based note mapping. Therefore, the performer can intentionally compose melodies by considering the harmonic functions of notes. In addition, all twelve notes are (basically) always available on RhyMe for allowing a fully expressive and profound improvisation by using even incorrect notes (i.e., dissonant notes).

Thus, the three requirements, i.e., low initial barrier, enough room for improvement, and potential for rich expression, have not yet been satisfied in any ordinary (electric) musical instrument. However, we showed that they could be satisfied in one musical instrument by considering the degree of freedom of musical elements and specializing the interface of the musical instrument for a specific (genre of) musical piece.

Hunt et al.[7,8] showed that a multiparametric interface is more useful and expressive than a simple one-to-one mapping between each control input and each musical parameter for most people. We also empirically thought so. Therefore, we employed multi-parametric interfaces for CiP and RhyMe. However, we think that it is not always necessary to integratedly control all the musical parameters and that only "expressive elements" should be integratedly controlled. Our experimental results would support this concept. Hunt et al.[9] discussed the importance of mapping between the way of input and that of output in electric musical instruments. They focused on the importance of a kind of *affordance* of musical instruments, while we focus on the importance of an evident criterion of mapping. Chadabe[10] pointed out that the electric musical instruments have been freed from tight and fixed relationships between controller and sound generator and that the instruments should employ more flexible mapping between them. We strongly agree with this position and believe the two musical instruments described in this paper, i.e., the "given-melody-based musical instrument" and the "harmonic-function-based musical instrument," represent incarnations of this concept.

6. CONCLUSIONS

In this paper, we discussed a design principle of musical instruments that are useful for both novices and professional musicians and that facilitate musically rich expression. We pointed out that versatility causes difficulty in performance. By eliminating the unnecessary degree of freedom in operation and by appropriately specializing a musical instrument for performing a specific (genre of) piece, the musical instrument becomes more useful for performing the piece and facilitates musical expression. Based on the proposed principle, we developed two new types of musical instruments, i.e., a "given-melody-based musical instrument" and a "harmonic-function-based musical instrument." Using two prototypes, we demonstrated the efficiencies of the proposed principle based on the experimental results. By exploiting this principle, we can create new musical instruments that serve as an introduction to musical performance as well as a tool for exploring the entire world of expressive musical performance, without changing the instruments.

This study was supported in part by the Telecommunications Advancement Organization of Japan.

7. REFERENCES

[1] Schon, D. A.: *The Reflective Practitioner: How Professionals Think in Action*, Harpercollins, 1983.

[2] Ueda. K., Hirai. S., Katayose. H. and Inokuchi. S., The improvement of Two Finger Piano, IPSJ Symposium Series Vol.2000, No.4., 2000. (in Japanese)

[3] http://www.casio.com/musicalinstruments/product.cfm?section=35&market=0&product=4057

[4] http://www.cs.utk.edu/~plank/plank/music/musplay/

[5] http://www.yamaha.com/cgi-win/webcgi.exe/DsplyModel/?gPPK00005EZ30

[6] Yatsui, A. and Katayose, H.: An Accommodating Piano which augments intention of inexperienced players, *Proc. Intl. workshop on Entertainment Computing*, 2002.

[7] Hunt, A., Wanderley, M. M., and Kirk, R.: Towards a Model for Instrumental Mapping in Expert Musical Interaction, *Proc. International Computer Music Conference (ICMC2000)*, 2000.

[8] Hunt, A., and Kirk, R.: Mapping Strategies for Musical Performance, *Trends in Gestural Control of Music*, Ircam, 2000.

[9] Hunt, A., Wanderley, M. M., and Paradis, M.: The importance of parameter mapping in electronic instrument design, *Proc. The 2002 Conference on New Instruments for Musical Expression (NIME-2002)*, 2002.

[10] Chadabe, J.: The Limitations of Mapping as a Structural Descriptive in Electric Instruments, *Proc. The 2002 Conference on New Instruments for Musical Expression (NIME-2002)*, 2002.