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New ensemble system based on mutual entrainment

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Abstract: Mutual interaction of rhythm is widely observed in the performance between humans. However, one-sided action is dominant in the interaction between human and musical machine. Thus, in this research, we try to realize human-like accompaniment system by using mutual interaction between rhythms. To design the model of system, we analyzed performance between human and human and constructed the system

Keywords: Music Performance, Interaction, Entrainment

1. Introduction

Ensemble is a kind of cooperative musical performance between humans, and this kind of flexible cooperation can not be observed between human and music machine. For instance, KARAOKE plays its music independently from humanis state [1]. Thus, human should adapt to the fixed music one-sidedly. On the other hand, mutual adaptation is widely observed in the ensemble between humans, and this kind of ensemble is usually much better than the other type.

Comparing these two types of music performance, it is thought that there is a significant difference in the interaction mechanism between players. In the ensemble between humans, mutual interaction of rhythms is widely observed, however, one-sided action is mainly used in man-machine communication. Therefore, to realize human-like ensemble system between human and musical machine, we have to focus our attention on the mechanism of mutual interaction between human and machine.

From these backgrounds, in this research, we try to realize human-like ensemble system by using mutual interaction between rhythms.

Many previous studies for artificial ensemble tried to overcome the problem of such one-sided action, and most of them aimed at the rapid response of machine which precisely follows human performance [2,3]. However, it is thought that the machine of such follow-up control is insufficient to realize ensemble between human and machine. This is because such kind of interaction can be regarded as an opposite one-sided action, i.e., interaction from human to machine. Furthermore, the present approaches in jam- session-system or jazz-session-system are also supposed to be insufficient to make mutual interaction [4-6]. These systems use two one-directional actions, and action from human to machine and from machine to human is realized alternately.

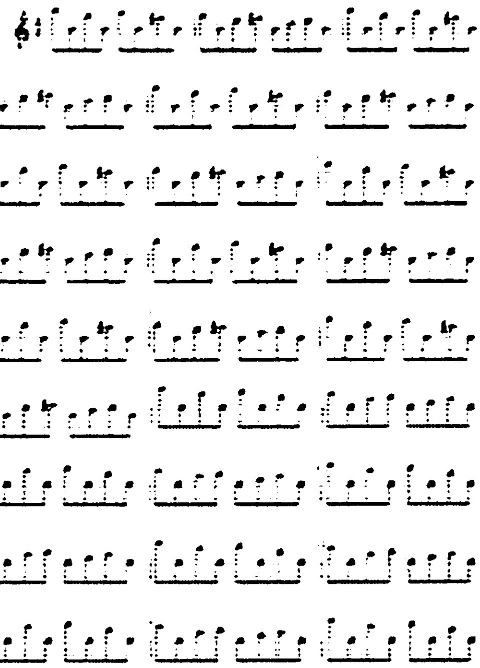


Fig.1 Score for experiment

Table 1 Results of hitting cycle and hitting lag

	1	2	3	4	5	All
Average of hitting cycle (msec)	214	194	191	195	[illegible]	197
Average of hitting lag (msec)	22.1	8.2	1.7	8.2	[illegible]	8.1
Standard Deviation of hitting lag (msec)	20.0	25.3	22.4	25.2	[illegible]	23.2

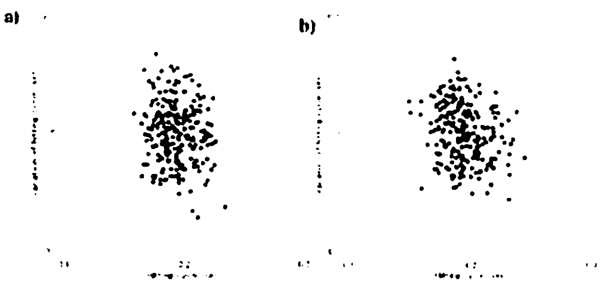


Fig.2 Correlation between hitting cycle and hitting cycle variation

Table 2 Correlation between hitting cycle and variation of hitting cycle

	1	2	3	4	5	All
High → Low	-0.52	-0.11	0.02	-0.11	-0.13	-0.17
Low → High	-0.37	-0.21	-0.11	-0.22	-0.25	-0.13

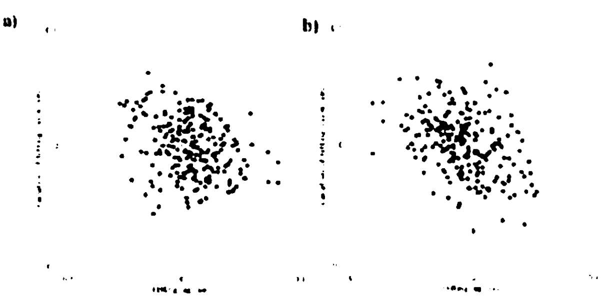


Fig.3 Correlation between hitting lag and variation of hitting cycle

Table 3 Correlation between hitting cycle and variation of hitting cycle

	1	2	3	4	5	All	t-Test
High	-0.29	-0.29	0.30	-0.29	-0.34	-0.30	*
Low	-0.42	-0.38	-0.33	-0.38	-0.39	-0.38	*

We think that simultaneous and mutual interaction between human and machine is important in ensemble and assumed that it is realized by using interaction of rhythms. However, at the present, such kind of artificial ensemble system has not been developed. In this research, to realize human-like ensemble, we learn from ensemble between human and human. In order to achieve such a purpose, in chapter 2, we analyze the interaction in performance between human and human. In chapter 3, such an interaction is modeled and ensemble system is constructed in chapter 4. In chapter 5, 6, experiment is done and system is evaluated.

2. Human performance

To realize human-like ensemble, the analysis of actual performance between human and human is necessery. Then according to the results of analysis, model is made and system is constructed. To analyze such an ensemble, we attach importance to how they interact each other.

An experiment is done by ensemble between two persons. Performers use the same special score as **Fig.1**. The score is constructed only by an eighth note, so the intervals of notes are constant basically. The one performer performs faithfully to the score and the other performer performs 2 octave lower than the score on the same MIDI keyboard. Performers are requested to cooperate each other but basically they are free. Experiment is done 5 times by changing performers, and time of key hitting is measured. Hitting period of one performer and hitting lag between two performers are calculated, and correlation between them are analyzed to clarify interactions between them.

Table 1 shows the average of hitting cycle, average of hitting lag and standard deviation of hitting lag at each trial. It shows the hitting lag is much less than hitting cycle (less than 20% of the hitting cycle) that there is synchronization between performers. To accomplish such synchronization, two kinds of method are expected. The one method is to use the hitting period of partner's performance for index of synchronization, and the other one is to use the hitting lag for its index. To exam which one is the major index, we compare the influence value to the hitting period variation by using correlation between them. The example (the first trial) of relation between hitting cycle of partner and hitting cycle variation of immediate cycle is shown as **Fig.2**. In this graph, **Fig.2a** shows the influence from the higher part to the lower part, and **Fig.2b** shows the the influence from the lower part to the higher part. **Table 2** shows the correlation of them at each trial. In this table, the upper section indicates the influence from the higher part to the lower part, and the lower section indicates the influence from the lower part to the higher part. From this table, the correlation of them are not high and their value is neither not constant. Against this, the example(the first trial) of relation between hitting lag and hitting cycle variation is show in **Fig.3**. In this graph **Fig.3a** shows the influence to the higher part and **Fig.3b** shows the influence to the lower part. **Table 3** shows the correlation of them at

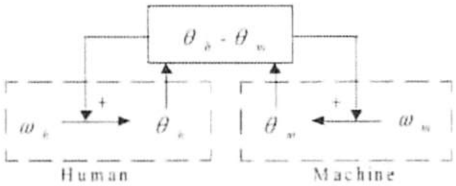


Fig.4 Architecture of interactive performance system

each trial. In this table, the upper section indicates the influence to the higher part, and the a lower section indicates the influence to the lower part. Comparison from **Table 2**, its correlation value is constantly higher and significantly different(* means $P<0.01$ from t-Test) that, the existence of a feedback mechanism from the hitting lag to the hitting cycle variation is observed.

From above results, it is considered that human performers use hitting lag rather than hitting cycle for the indicator of synchronization.

3. Model for Ensemble

We modeled the mechanism of above-mentioned by using mutual entrainment respect from forced entrainment. The mutual entrainment is the phenomenon that two oscillators interact each other and their rhythms became the same [9]. Their rhythm is regulated by natural frequency and phase. The mechanism of preceding chapter is able to substitute for the entrainment. The hitting cycle is able to substitute for a reciprocal of natural frequency and hitting lag is also able to substitute for phase difference.

As shown in **Fig.4**, human performs at the left side and machine performs at the right side. The tempo (BPM) of music performance in each player is defined based on the frequency ω, and ω usually affect to the performance directly. Then, the temporal development of music performance is described by using the phase θ. In ensemble process, the phase relationship (θ_h-θ_m) is feed backed to each player. Thus θ changes not only by frequency ω but also by their phase relationship of performance (θ_h-θ_m). In this condition, the harmonics between them can be defined by the temporal development of the relationship (θ_h-θ_m).

As a detailed mechanism of entrainment between human and the machine, a coupled nonlinear oscillators model was used. The tempo of the machineis performance is controlled based on the frequency of the model oscillator. And they are expressed as follows,

$$\dot{\theta}_m = \omega_m + K_m \cdot \sin(\theta_h - \theta_m) \text{ ....(Machine)}$$
$$\dot{\theta}_h = \omega_h + K_h \cdot \sin(\theta_m - \theta_h) \text{ ....(Human)} \quad (1)$$

where θ is the phase of each oscillator, ω is the intrinsic frequency, and K is the coupling constant. In this equation, the tempo of performance corresponds to ω. The temporal development of music performance corresponds to θ. The phase difference indicates the relationship between these two players. Coupling constant K indicates the influence from the feedback. Forced entrainment is realized when K=0, and mutual entrainment is realized when K>0, respectively.

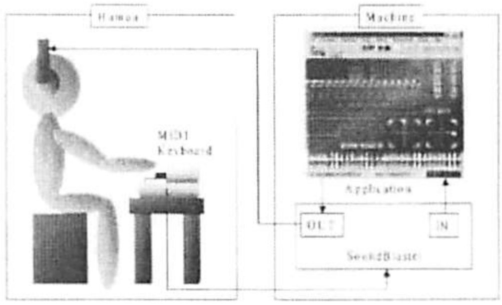


Fig.5 MIDIdata flow

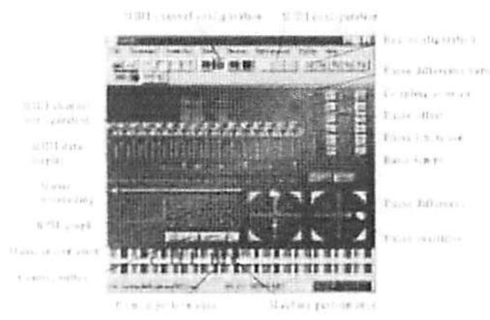


Fig.6 Application

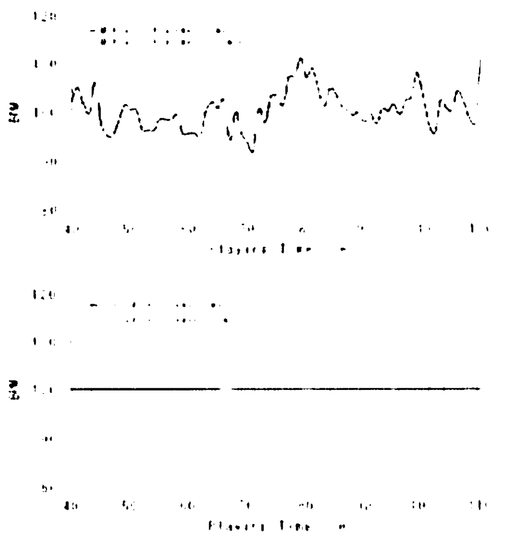
4. Experimental system

Our system is constructed as cooperation between human player and MIDI (Musical Instruments Digital Interface) application designed on Windows as shown in **Fig.5** [10]. In this experimental system, human plays MIDI keyboard and its signal is transmitted to MIDI application. On the other hand, the sound signal from MIDI application is transmitted to human by using speaker.

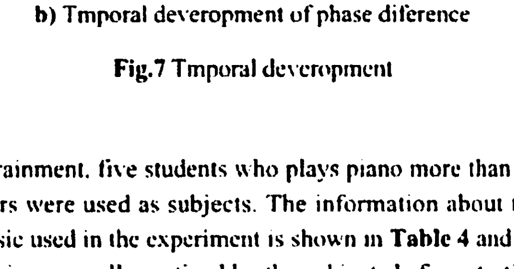
Application software to operate the above experimental system is shown in **Fig.6**. This application performs the SMF format MIDI file designed on the Windows [11,12]. The event timing of the machine performance is determined by the phase defined in the coupled oscillator model. This application also measures the timing of human performance in the MIDI data in real time. To compare the system based on forced entrainment and mutual

Table 4 Information of music

	Music A	Music B	Music C
Basic tempo (BPM)	[illegible]	[illegible]	147
Meter	4/4	[illegible]	[illegible]
Basic music length (sec)	[illegible]	[illegible]	[illegible]
Number of events	168	[illegible]	[illegible]
Average of event interval (sec)	[illegible]	[illegible]	[illegible]



a) Tmporal deveropment of BPM



b) Tmporal deveropment of phase diference

Fig.7 Tmporal deveropment

entrainment. five students who plays piano more than 10 years were used as subjects. The information about the music used in the experiment is shown in **Table 4** and all music was well practiced by the subjects before starting the experiment. The experiment was done in a silent room by using a PC (Pentium2 450MHz) and electric piano (Roland RD-600). Human performs by watching music score and PC was located to the hide space.

In experiments, K value is settled to 20% of ω and 0% to

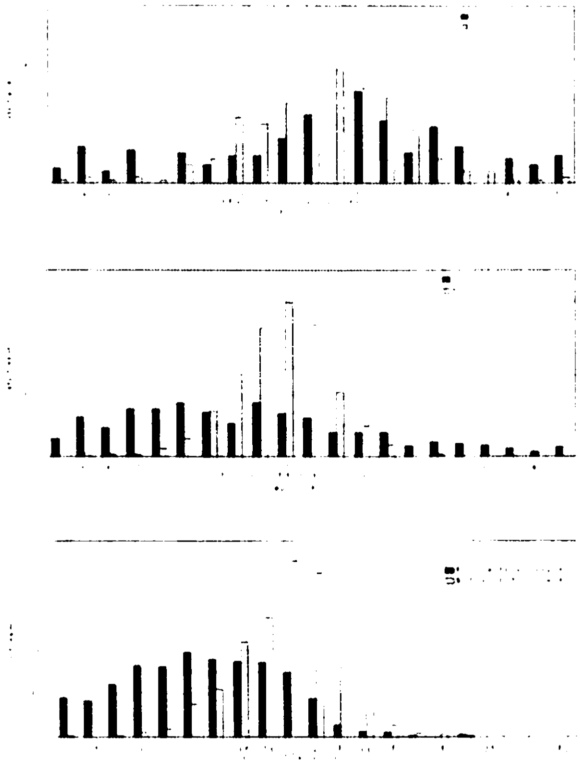
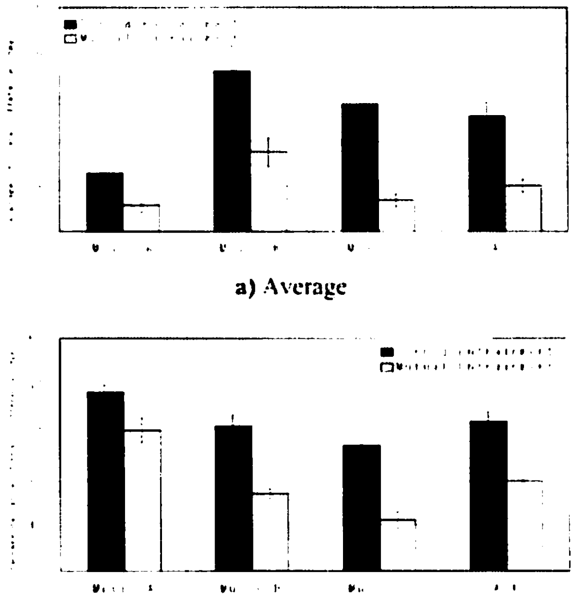


Fig.8 Histgram of phase diference

realize mutual entrainment and forced entrainment respectively. Under this condition, temporal development process of phase difference (θ_m-θ_h) and the BPM of machine and human were measured. The experiment was done for three times in each condition.

6. Result

The example (Music A Subject A) of temporal development of BPM and the phase difference are shown in **Fig.6**. Histogram of phase difference in mutual entrainment and forced entrainment are shown in **Fig.7**. In these graphs positive phase difference means precede of human performance and negative phase difference means precede of machine performance. So phase difference indicates the difference between timing of human rhythm and timing of machine rhythm. From this graph. it is suspected that synchronization is defined by standard deviation and average of phase difference. **Fig.9** and **Table 5** shows the value of standard deviation and average of phase diference in each music by comparison between mutual entrainment and forced entrainment. From these graphs of **Fig.9**, it is shown that the value of mutual entrainment is less than that of forced entrainment in both of average and standard



a) Average

b) Standard deviation

Fig.9 Comparison between forced entrainment and mutual entrainment of each music

Table 5 Comparison between forced entrainment and mutual entrainment of each music

	[illegible]	[illegible]		[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]

deviation. From **Table 5**. it is shown that there is a significant difference between value of mutual entrainment and forced entrainment by using t-Test (In the table, *means 1% level of significance **means 5% level of significance).

5. Discussions

It is thought that ensemble quality can be measured by its harmonics. The harmonics are achieved by the flexible coordination between music players. From **Table 5**, it was clarified that average and deviation of the phase difference obtained in mutual entrainment are much smaller than that of forced entrainment. This means that stable dynamics of coordinated performance between human and machine is realized in our ensemble system. Therefore, it is suggested that the better harmonics is obtained in the ensemble system based on mutual entrainment in comparison with that of forced entrainment.

Further more the quality of performance should be evaluated not only by rhythm harmonics but also by its dynamics. However it is difficult to evaluating such a dynamics, because such dynamics cannot appropriate to the analysis using statistic process. So in this stage, we cannot reach to analyze and evaluate such dynamics. But we discovered there are some dynamics differences between forced entrainment and mutual entrainment. If it is able to confirm that the dynamics pattern of mutual entrainment is sweeter able, we can verify the dynamics pattern contained in mutual entrainment is better than that of forced entrainment. But more analysis is necessary for them.

From these considerations, it is concluded that mutual and simultaneous interaction in music performance is essential to realize human-like ensemble.

6. Conclusion

We developed a new ensemble system based on mutual entrainment by using coupled non-linear oscillators. From the comparison between forced entrainment and mutual entrainment, effectiveness of mutual entrainment based system was shown and the importance of mutual interaction was clarified.

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