SICE02-0492

Development of New Ensamble System based on Coupled Phase Oscillator

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Abstract: Mutual interaction of rhythm is widely observed in the music performance between humans. In this study, based on our previous research, we used mutual entrainment model in coupled phase oscillators. And we try to construct an ensemble support system to realize such mutual interaction process. As a result, comparing with direct ensemble between two humans, effectiveness of our new support system was suggested.

Key Words: ensamble support system, mutual entrainment model

1. Introduction

In music performance, mutual interaction of rythm is widely observed. Accordingly how to realize such a dynamical interaction is one of the important problems to establish good ensamble. In recent years, the various kind of automatic performance system, such as CD Player, Synthesizer are constructed. [1] With using such a system, the problem of the above became more conspicuous. Because such a system has no interactivity so that human have to adapt one-sidedly. However, in the performance between humans, performer synchronize their rhythms each other sponteneously.

Thus the difference in interactivity causes the difference of performance quality and mostly the mutual interaction is better than one-sided action.[2] So there are some precedent researches to settle such problems. Horiuchi's research is that the machine plays music in fixed tempo, and they investigated how human adapts to it. In the precedence research of Kobayashi , they built the accompaniment system using the mutual entrainment model.[3]They had succeeded to simulate the interaction between human and machine in this accompaniment system by using coupled phase oscillator.In the research by Horiuchi et al.[4], it is suggested that mutual interaction is important in the human cooperation performance.[5] Kobayashi et al.[6] succeeded building the accompaniment system in which such interaction exists,by using mutual entrainment dynamics.

The purpose of this study is to make a system which supports human's ensemble by using two Kobayashi's models, and making it intervene between humans.In the accompaniment system of Kobayashi et al., coupled phase oscillator simulate the interaction between human and a machine.Here we considered that the system "human-machine-human" is realizable by using two coupled phase oscillators. In this paper, the interaction model is proposed in Section 2, and performance experiment is shown in Section 3.

2. New Ensamble Model

In the research of Kobayashi et al. they realized interactive automatic accompaniment system by using a coupled phase oscillator .We proposes an extention and considere that the system "human-machine-human" can be realized by using two coupled phase oscillators. In other words, we take the model "human-machine", and the model "machine-human" , and connect them ,finally the model "human-machine-machine-human" will be obtained. In this case, the coupled phase oscillator should be modified. The phase oscillator used in Kobayashi model simulates the interaction between "human-machine". So new phase oscillator is needed to simulate also the interaction between "machine-machine".

2.1 Precedent Model

Kobayashi's model is basically constructed by using mutual entrainment phenomenon. The model of human and machine is expressed by following equation.

$$\dot{\theta}_m = \omega_m + K_m \cdot \sin(\theta_h - \theta_m) \qquad (1)$$

$$\dot{\theta}_h = \omega_h + K_h \cdot \sin(\theta_m - \theta_h) \qquad (2)$$

The fundamental tempo of human and machine is respectively expressed with characteristic frequency ω_h and ω_m. The performance position of human and a machine is expressed as θ_h and θ_m, respectively. Mutual interaction between them is specified by the phase difference of each rhythm, so θ_h-θ_m is reinput as a feedback signal. Assuming such structures music performances is controlled by not only basic tempo but also phase relationship. K_h and K_m are the coupling coefficient of human and machine.

2.2 Proposed Model

The purpose of this new model is to realize a "human-machine-human" interactive system with two human performers. Our new model is designed to support the ensamble between two humans. As shown in Fig.1, the machine interposes between humans. In such situation, human performs with the machine and each machine interacts together. To realize such a situation, we extended the model explained in section 2.1. The equations of each machine model is expressed as following.

$$\dot{\theta}_{m1} = \omega_{m1} + K_{m1} \cdot \sin\theta_{h1} - \theta_{m1}) + K_{m1'} \cdot \sin\theta_{m2} - \theta_{m1}) \qquad (3)$$

$$\dot{\theta}_{m2} = \omega_{m2} + K_{m2} \cdot \sin\theta_{h2} - \theta_{m2}) + K_{m2'} \cdot \sin\theta_{m1} - \theta_{m2}) \qquad (4)$$

For example, in eq. (3) machine interacts with human as θ_{h1}-θ_{m1} and with the other machine as θ_{m2}-θ_{m1}. Similarly, Eq. (4) is symmetrical to eq. (3). Each machine's coupling coefficient is expressed as K_{m1}, K_{m2}.

The human model are expressed by following equations.

$$\dot{\theta}_{h1} = \omega_{h1} + K_{h1} \cdot \sin(\theta_{m1} - \theta_{h1}) \qquad (5)$$

$$\dot{\theta}_{h2} = \omega_{h2} + K_{h2} \cdot \sin(\theta_{m2} - \theta_{h2}) \qquad (6)$$

Human only interacts with his machine. For example, in Eq.(5) human interacts with machine as θ_{m1}-θ_{h1} and does not interacts with the other. Similarly, Eq. (6) is symmetrical to eq. (5). And each human's coupling coefficient is expressed as K_{h1}, K_{h2}.

By using these methods, Kobayashi's model was extended and "human-machine-machine-human" interactive system was constructed as a consequance.

2.3 Relation between Oscillator Model and Score Information

Matching between score information and phase oscillator model was defined as follows. The tempo (Beat Per Minute) corresponding to characteristic frequency ω is an oscillator pitch. The quarter note which is equivalent to one beat by usual performance is corresponded to an oscillator's one cycle. If it is quadruple time rythm, an oscillator will take 4 round by one measure. The relation between phase θ and score is defined as shown in Fig.2. We made the position where oscillator's phase is 0 correspond with the beginning of a beat and the beginning of a measure in this system. For example, when performing the score like Fig.2, D of the 1st beat is performed in the position of a phase 0 degree of the 1st round. The following A is performed in the position of 180 degree of the 1st round. If it passes over the 4th beat, it will go into the next measure. By defining the above relations, it is enabled to synchronize the time development of the phase in a phase oscillator and the advance of the score.

About matching between phase oscillator model from score information, we defined as follows. In a phase oscillator model, a required mutual interaction is only phase difference θ_h-θ_m. So we made phase difference $\Delta\ \theta_{hm}=\theta_h$-$\theta_m$ substitute θ_h-θ_m. difference $\Delta\ \theta_{hm}=\theta_h$-$\theta_m$ is the phase difference at the moment when the musical event of both human and machine existed.

The architecture of our system was shown in Fig.1. Two human performers are separated to distant place and also each machine is placed at each human-side by using two PC. Each human performs only with their machine, and their two machines interact together through LAN. To operate these systems on application working on Windows was constructed by using MIDI (Music Instruments Digital Interface). The application is able to play the SMF (Standard MIDI File) format MIDI data, and also able to measure human performance in real time.

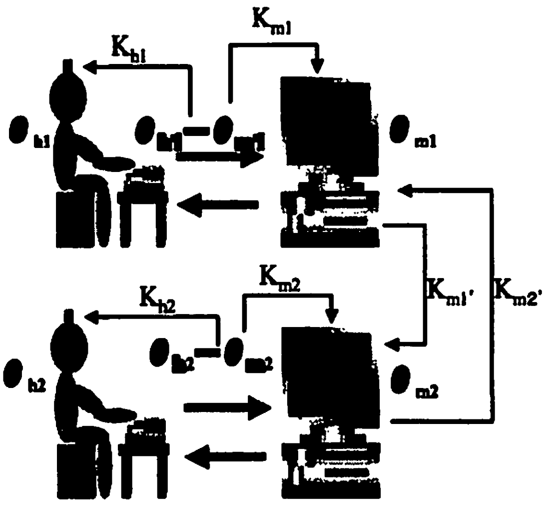

Fig.1 System Diagrams

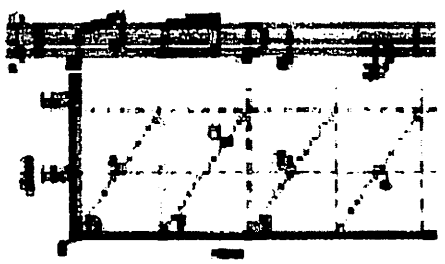

Fig.2 Relation between phase and notes

3. Performance Experiment

3.1 Methods

Experiment is done between two human performers. Each subject performs with his machine and is required to synchronize to the machine's music. The Beethoven piano sonata No.2 is used as an experimental music. The subjects had musical education and were well trained to perform the experimental music.One trial is done for about one and half minute and the number of touches required to subject is about 360.The characteristic frequency of each machine is settled to be BPM 150 at first. The human performs the part of right hand in the music by using MIDI keyboard and its performance is send to machine as MIDI note message. Machine perform the part of left hand in the music and its performance is presented to human by using headphone.

The measurement parameter is as follows. Phase different between human and machine, phase different between machines and BPM of each machine were measured and their temporal development were recorded. Each trial is done for 5 times by changing parameter of coupling coefficient in the proposed model. Then the average and standard deviation of phase difference is calculated through each trial.

3.2 Results and Discussion

Temporal development of phase difference between two human is shown in Fig.3. In the figure,small fluctuation of phase difference around 0ms was observed, suggesting that tempo is synchronized together between two humans.

In Table 1, average and standard deviation of the phase difference were calculated.Each Table corresponds to different parameter set. From these data, it is suggested that averaged value of phase difference depends on the coupling coefficient. When coupling coefficient is large, averaged value becomes small. Similar averaged values were obtained in the direct ensemble between two humans as shown in Table 2. These results suggest that our new system could partially support the ensemble process. However, standard deviation in Table 1 and Table2 are largely different. This means that dynamical analysis is required to clarify the mechanism of this ensemble process. We are going to do such further analysis.

4. Conclusion

In this research,we constructed an ensamble support system by extending coupled phase oscillator model proposed by Kobayashi et al.We are going to verify the validity of this system and its effectiveness.

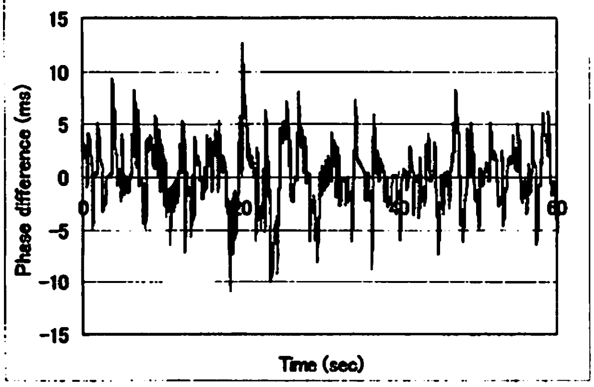

Fig. 3 Time development of phase difference of human

Table 1 Average and standard deviation of phase difference of human

	Human-Machine	Machine - Machine	Subject	Average (msec)	Standard Deviation (msec)
a	20	20	A	12.7	9.2
			B	10.2	12.3
			ALL	11.5	10.8
b	20	40	A	5.7	9.2
			B	7.7	12.3
			ALL	6.7	10.8
c	20	20	A	6.6	12.8
			B	7.6	11.2
			ALL	7.1	12.0
d	20	40	A	2.3	12.1
			B	5.5	13.0
			ALL	3.9	12.6

Table 2 Average and standard deviation of phase difference of human (Direct ensamble)

	Average (msec)	Standard Deviation (msec)
1	22.1	20.0
2	8.2	25.3
3	1.7	22.4
4	8.2	25.2
5	0.0	22.9
ALL	8.1	23.2

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