TM12-4

SICE02-0613

A Machine embedded in Sensory-Motor Coupling of Human
-Emergence of Subjective Time-

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Abstract: In 'co-emergent' process such as cooperative walk, how the human's subjective domain works? To investigate it, we carried out an experiment on subjective time perception of human. As a result, it was found that the time recognized by human isn't the same as the physical time. This domain still has lots of unclear and interesting phenomenon.
Keywords: Cooperative Walk, Sensory-Motor Coupling, Entrainment, Welfare robot

1. Introduction

When two persons walk together, their paces may coincide with each other naturally. Neither of them tries to adapt its walking rhythm to the others. In the walk assistance for elderly people, the care worker often stabilizes the patient's walk by facing or nestling to the person[1]. We consider such a process named 'co-emergence' in which walking movements of two persons are mutually adapted is ideal for cooperative actions. And the purposes of this study are to introduce a new viewpoint into cooperation in Human-Machine systems by making the process into a model and to search a possibility of applying the process to a mutual adaptation-system. Thus, we carry out an experiment that used a virtual walking robot that realize virtual cooperative walk with human. The experiment is the first one to observe the dynamics of the human being as a part of Human-Machine cooperation system.

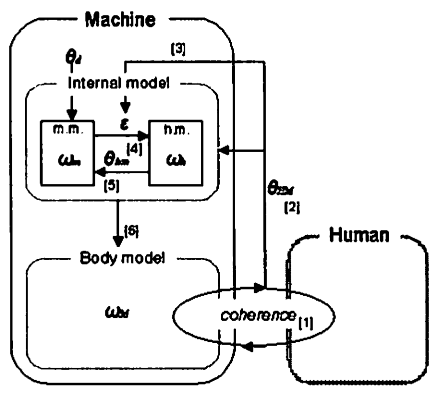
In earlier research, we have already proposed 'Duality model'[2)-6)] to realize co-emerging process. Also, the walking assistance robot that is equipped with this model was developed to realize the process between human and machine. We reported some results from experiments using the robot: Mutual adaptation took place between human and the robot, co-emergent process has been realized partially, and since applying it to elderly person, improvement of stability and symmetric was observed[2)5)7)].

However, the reports dealt with the evaluation of the validity of a model or the performance of the machine, it was hardly observed how a person recognize the co-emerging process during a cooperation walk. In other words, we reported not the function of subjective time perception of human but the bodily motion of human that can be observed from the external viewpoint. Thus, we analyze the temporal development of walking state of the person who is doing the cooperative walk, and clarify the dynamics of human's subjective time perception in the co-emerging process.

In this paper, we firstly explain the background of the study and the reason why we discuss about subjective domain of human beings, in Chapter 2. Secondly, in Chapter 3, we show the architecture of the walking assistance robot. Then, we analyze the subjective domain of human by using the robot. As a result of the experiment, we report an important finding about the time perception mechanism of human being under cooperative walk. Finally, through the consideration to the result, we suggest the existence of two different dynamics in the co-emergent process of subjective time.

2. Background

The basic themes in our research are to analyze the co-emerging process in Human-Human communication and re-



1. Self-organize coherence between human motion and body model
2. Get the organized coherence as phase difference θ_{HM}
3. Modify the internal model parameter ε such as $\min(\theta_{HM}-\theta_d)$
4. Search ω_h such as $\min(\theta_{HM}-\theta_{hm})$ under the fixed ω_m in internal model
5. Search ω_m such as $\min(\theta_d-\theta_{hm})$ under the fixed ω_h in internal model
6. Change ω_M in body model corresponding to searched ω_m
7. Back to 1.

Fig.1: Process of realizing co-emergence

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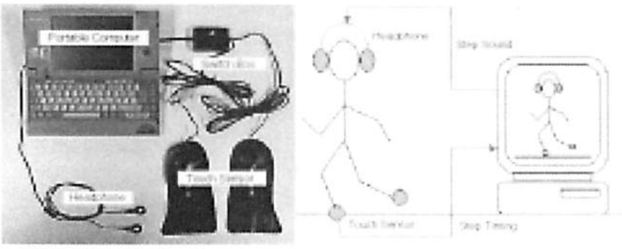

Fig.2 Walking assistance robot

production it in Human-Machine system. By now, we have suggested 'Duality Model' that could approximately express the co-emergent process. The model is a framework dealing with consciousness and unconsciousness behavior in co-emerging process. The operation of the model is shown in Fig.1, and explained in detail in Chapter 3.

In Fig.1, 'Human' is simplified, but from human's position, cooperative walk is interpreted as follows: one's walking rhythm is observed by the other, the other's walking period is changed, and the one observes the other's renewed rhythm. So it can be said that the movement of self can create feedback process through the movement of others, which is called Sensory-Motor Coupling, from bodily motion to sensory input. Since some communication exists while doing some cooperative work, so it is insufficient to analyze only physical synchronization when we deal with cooperation. Therefore, we start to investigate the subjective factor. We think it is necessary to consider subjective domain for improved human interface.

3. Method

3.1 Architecture of the Machine

The walking assistance robot[2)5)7)] is a virtual robot in a small personal computer (TOSHIBA, Libretto 60) as shown in Fig.2. When the user's feet reach the ground, touch sensors (OJIDEN, OT-NO-1) send signals to the robot. The robot produces sounds as footsteps of robot by calculating the timing using the observed periods of human steps and the target value. Then, the user listens the sound through a headphone. By exchanging the information of footsteps, the robot interacts with human. Thus a cooperative walking is realized.

3.2 Duality model

This model mounted in the walking assistance robot is composed of two sub models, which are 'body model' and 'internal model'. It realize flexible cooperative behavior with human through the process called 'mutual constraint'[8)9)10)], which is realized by the process that one sub model constrain another. The body model, which is constructed as a kind of nonlinear oscillator, has a possibility to self-organize coherent relationship with human bodily rhythm through mutual entrainment[11)]. On the other hand, the internal model is described by the couple of phase equation as the reduced form of the body model. And its function is to interpret the above coherent relationship by separating the coherence into one-sided[12)] actions. The process of summarized as follows:

1. Coherent relationship between the agent and its environment(human) is self-organized in body model, and it starts the following procedure to interpret the coherence.
2. The space for internal model is generated to decrease the difference between coherent relationship predicted by the internal model and that organized by the body model.
3. In the internal model, internal state of environment-side model which satisfies the organized coherent relationship is searched under fixed internal state of agent-side model.
4. In the internal model, internal state of agent-side model which satisfies the desired relationship is searched under fixed internal state of environment-side model.
5. Based on these two one-sided relationships obtained in the internal model, internal state of the agent and its environment are predicted and body model is modified to realize desired relationship.
6. Return to the first step.

So, the feature of Duality model is to co-emerge cooperative process by estimating the relationship between the robot and the user, through repeating the composition and decomposition of relationship in turn.

And, two Duality models are prepared for each foot.

3.3 Purpose

Through using a walking assistance robot on which 'Duality model' is mounted, we're investigating these two topics: to realize co-emerging process between human and machine, and to intervene in human walking by intentional operation on machine. The achievement of the first aim was already reported in another papers.

For the second purpose, the fact has been reported that the bodily rhythm of human is affected by the difference of machine's target value. The phase difference between human and machine is set to the target value, and the value corresponds to the difference of their natural frequency. By setting the target value bigger, the frequency of human bodily rhythm becomes higher than that of machine relatively. Then, since the human modifies the frequency, it becomes lower (the walking period becomes longer) and vice versa. There is an example utilizing this property that setting the desired value separately to each foot eases the asymmetry of elder's walking.

However, we don't know what relation exists between subjective time perception and bodily motion when these changes of bodily motion are observed. Thus, we investigate the correlation between the phase difference between bodily level and cognitive level by analyze the variation of walking period.

4. Experiment

4.1 Outline

Subjects (twenties, male student) are instructed to walk in 180 seconds with walking assistance robot, according to the

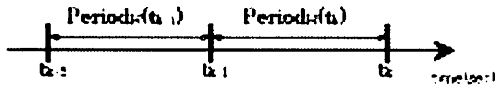

Fig.3: Definition of walking period

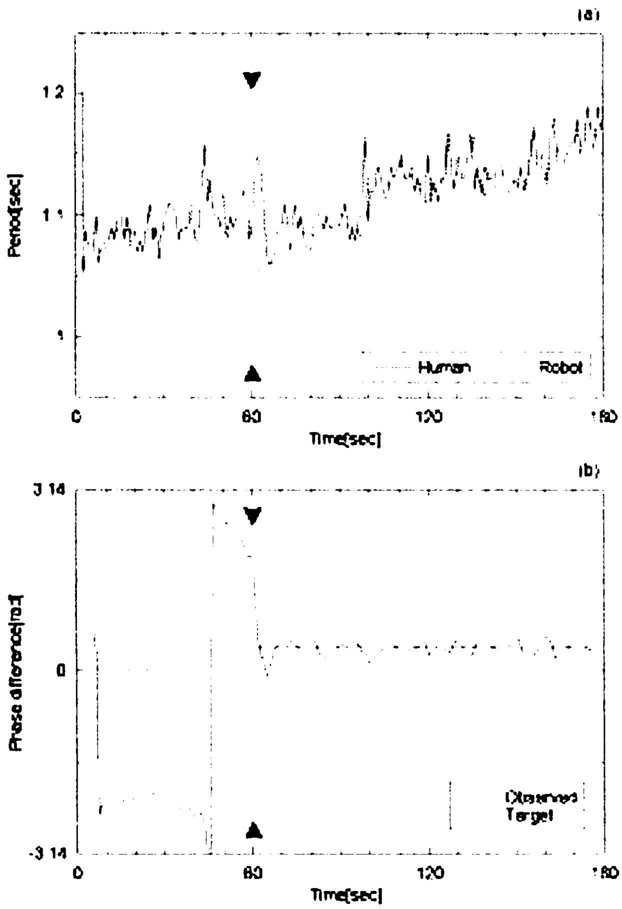

Fig.4: Temporal development of walking periods(a) or phase difference(b) (Subject A, Target = 0.4[rad])

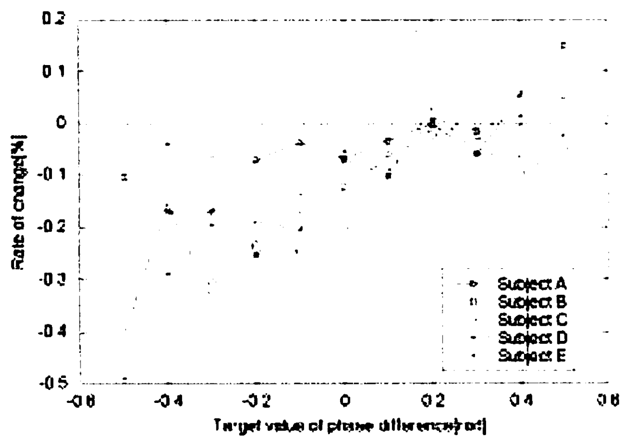

Fig.5: Changing rate of walking period

Time[sec]	mode
0 - 60	mode 1
60 - 120	mode 2

Table1: Timetable of experiment

timetable shown in Table1.

mode1: walking freely with no sounds from the robot.

mode2: walking with sounds from the robot, under one target of phase difference.

Eleven targets of phase difference for mode 2 are prepared at intervals of 0.1[rad] from -0.5[rad] to 0.5[rad]. The subjects are directed to walk along the sound.

Examples of measured data is shown in Fig.3a, 3b. Arrows are showing the timing that interaction starts. In this experiment, rate of change of walking period is set that corresponds to target phase difference. The rate is defined as follows, and

$$\frac{Period_H(t_i) - Period_H(t_{i-1})}{Period_H(t_i)} \times 100[\%] \qquad \textbf{(Eqn.1)}$$

'PeriodH' in this equation is defined as shown in Fig.4.

And, the averages of the rate are calculated for the periods during interaction, 60[sec]-180[sec].

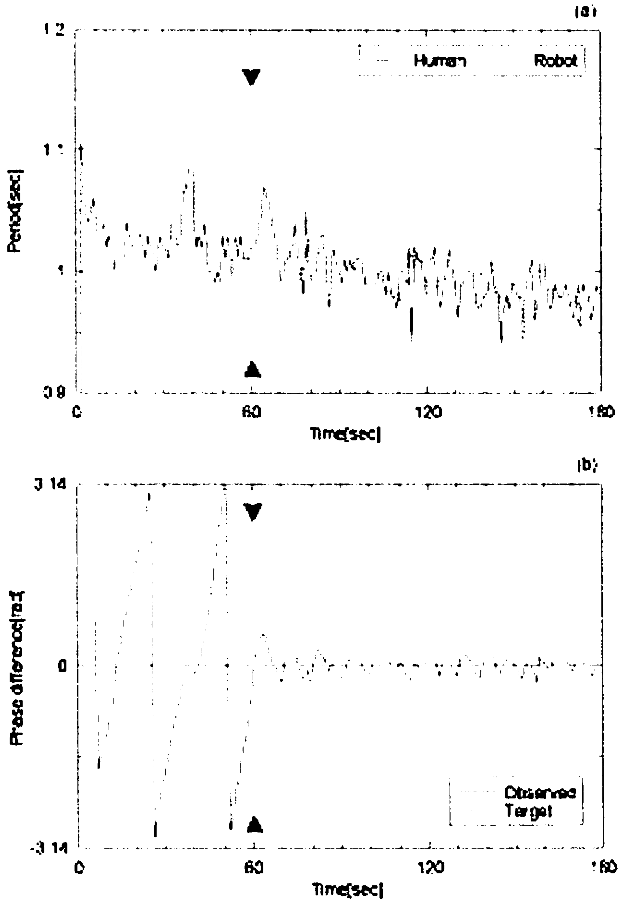

Fig.6: Temporal development of walking periods(a) or phase difference(b) (Subject C, Target = 0.0[rad])

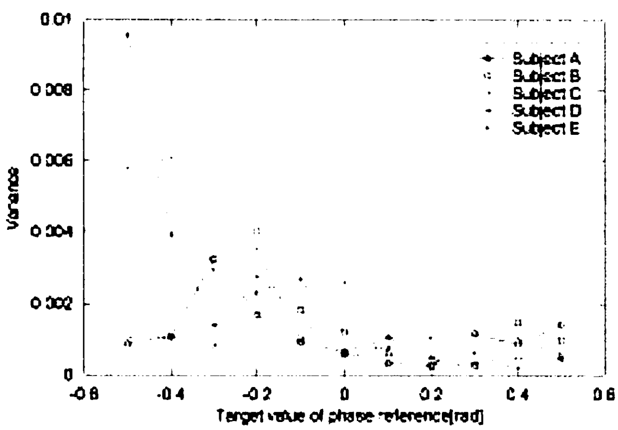

Fig.7: Variance of phase difference

4.2 Results and Discussion

The averages of the rate of change are shown in Table.1 and Fig.5. The facts are observed from the graph that positive correlation between the rate of change and target phase difference exists, and the rates almost reach to zero near the point where the setting value is 0.2[rad].

It is important that the changes were not observed not near 0[rad] but 0.2[rad] in target. Fig.6a and 6b are the charts of temporal developments of walking period and phase difference, when the target value is 0[rad]. From Fig.6b, phase difference remains near 0[rad], so that human steps and sound productions are observed at the same time. However, the walking periods become shorter. It means that human recognize the timing of the sound reaching is earlier than the step. So, the fact is clarified from the result above: The 'subjective coincidence' is different from the 'objective coincidence' from external viewpoint. In other words, the recognized time in human and the physical time are not the same.

Here is a data that can prove the fact: Fig.7 is a graph of variances of gaps between the target and observed phase differences. In the chart, such tendency can be seen: the variances are minimum at the point where the target is set at 0.2[rad], the same point is described in previous paragraph, it reinforces the fact that subjective time and objective time are different.

Furthermore, the values are asymmetry with respect to the point of 0.2[rad]. The phenomenon cannot occur in simulation that is using two models connecting each other or in mere constraint between two physical nonlinear oscillators. That is to say, it is peculiar to cognitive mechanism of human. So, we can say not only the existence of gap between subjective time and objective time but also the possibility the dynamics dealing with events occurring different timing whether before or after the timing of 'subjective coincidence' may be different.

5. Conclusion

In this paper, we analyzed the dynamics of time perception of human as a direction to investigate co-emerged process from human side.

In summary, we demonstrated that the recognized time in human mind is not the same as the physical time. In addition to, the possibility is suggested that the different ways of time processing might exist in human subjective domain.

However, some unclear points are still remained: the difference of processes around 'subjective synchronization' should be verified. Moreover, it is also important theme to analyze the influence of subjective time perception on the co-emerged process by using dual-task methodology.

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