Analysis of the Co-emergence Process on the Human-Human Cooperation

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Abstract -- **In this study, it was done the analysis of the Co-emergence process on the human-human cooperation. Especially, we focused on the cooperative walk realized by the synchronization of the two persons' footsteps, and did the analysis of the dynamics. As the results, it was clarified that there was the relation of the mutual constraint between the step motion of the leg and the swing motion of the arm, and that the cycles which the mutual constraint between the arm and the leg synchronized each other through the entrainment of the footstep rhythm. In addition, it became clear that the arm's dynamics was influenced by the attention and the leg's dynamics was not done. Thus, on the cooperative walk, it was suggested that the arm has the different dynamics from the leg's dynamics, and the mutual constraint process between these dynamics realized the Co-emergence process on the Cooperative walk.**

Keywords -- **Man-machin system, Cooperative walk, Co-creation, Entrainment**

I. Introduction

Human is able to create various kind of cooperative behavior simultaneously with adapting the motion mutually. The purpose of this study is to propose the concept of new design theory of the man-machine cooperative system by regarding the "Co-emergence " process[1] observed in the human-human cooperation characteristically as ideal. In this paper, we report the results of the analysis of the Co-emergence process on human-human cooperation on which the concept is based.

Our group have proposed the "Co-emergence model" by considering the "Duality"[1]~[5] of self at human as the model of the Co-emergence process, and proceeded to apply it to the walk-support on welfare. Because the function such as walk-support are able to be regarded as an example of the Co-emergence phenomenon realized by the mutual adaptation of the walking motion between the helper and the handicapper. Concretely we made the walk-support robot "Walk-Mate"[6], and clarified that the cooperative walk between the robot and human realize the stable walking motion and the development of the walking pattern through the mutual entrainment of walking rhythm[1][6]. In addition, it was revealed that the existence of the Co-emergence process which realize the symmetrical temporal development between them[7]~[9].

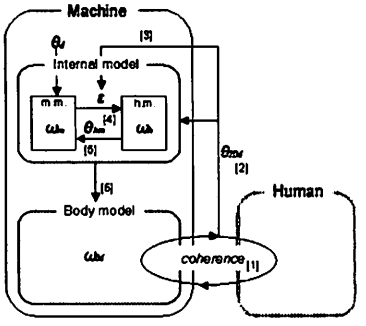
However it have never been analyzed how the cooperative walk between humans, on which the model base, is realized, and never been done the process as the Co-emergence process. Therefore in this study, we made the system that realize the cooperative walk between two people through only their footstep sound, and the system to measure their body motions during cooperative walk. From the results of measurements, it was done the analysis of the Co-emergence process on human-human cooperation.

II. Former Study

A. Co-emergence model

We have proposed the model, which realize the Co-emergence process on the man-machine system by the observation of the Co-emergence process on human-human communication[1][4]. This is the framework focused on the explicit self and the implicit self on the human's mechanism of perception, and relates the mutual constraint relation between the emergence of consciousness of self and the embodied interaction. Here explain just the points on the cooperative walk between human and the walk support robot. (Refer to [1],[4] in detail.)

This model consists of two the sub models that are "Body model" and "Internal model", and the mutual con-



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 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. Co-emergence model[1][4].

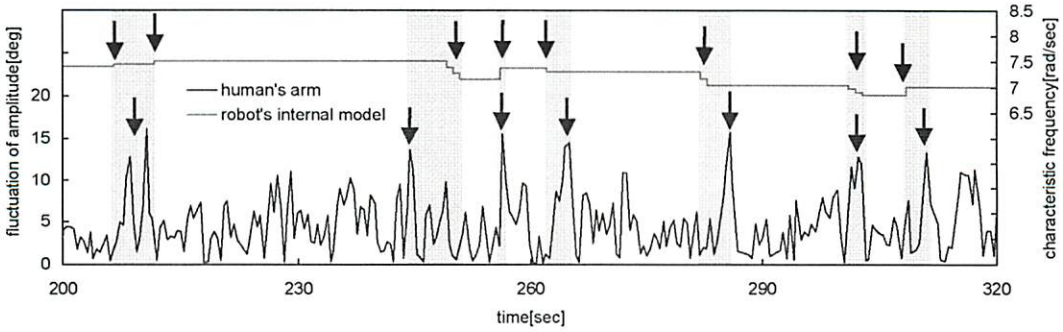


Fig.2. Co-emergence process between human and robot[7]~[9].

straint process realized by them make the Co-emergence of the cooperative process between human and the robot possible, as shown in Fig.1. The Body model is described as the non-linear oscillators, and realizes the mutual interaction, which based on the unconscious process of human through the mutual entrainment [10][11] of the embodied rhythm with human's walking motion and do the self-organization of the coherent phase relationships θ_{HM}. The Internal model is also described as the coupled phase oscillators[12], and has the function to reconstruct the relation, which was constructed on the Body model, on inside of itself, basing on the process of consciousness. It is able to predict the internal status of human and itself by dividing it to the one-sided effects relation.

Concretely when the coherent phase relation θ_{HM} between the Body model and the human's walking motion is realized, the Internal model starts to work by regarding the relation as the constraint condition. In the Internal model, the characteristic frequency of human's walking period ω_h is estimated, and the characteristic frequency of the model's walking period ω_m is fixed by ω_h. Then the characteristic frequency in the Body model ω_M is constrained by ω_m, the Body model will construct the new coherent status. The mutual constraint is such process that constrained mutually between these sub models, predicts the relation between self and the other by continuing to take turns at the reconstruction and the division, and realize the Co-emergence of the function at the cooperative behavior.

B. Co-emergence process on man-machine system

From the analysis of the cooperative walk process between human and the walk support robot "Walk-Mate" on which mount the Co-emergence model, it was already shown that the similar temporal development between them was realized[7]~[9].

Concretely, at the robot side, it was observed the emergence process as the mutual constraint process between the Body model and the Internal model in the Co-emergence model, and it was shown that there is the process, which corresponds to the emergence process, between the step motion of leg and the swing motion of arm at human side. It was clarified that the both these processes were the cyclic process and that their temporal development almost synchronized each other[7]~[9].

Here shows an example of the analysis of the process in Fig.2. This shows the comparison of the temporal development between the characteristic frequency at the Internal model of the robot ω_m and the fluctuation of the amplitude of the arm's angular oscillation when the Walk-Mate realize the cooperative walk with human. From the figure, it was observed that the timing of changing the Internal model synchronized with the timing when the fluctuations of arm become large remarkably. It was shown the area where they seemed to relate by the halftone. From this result, it was suggested that the emergence process was developing as the Co-emergence with putting the timings together between them.

In this paper, we regarded such process as the characteristics of the Co-emergence process, and analyzed the temporal development of the arm's motion and the leg's motion, which correspond to it on human-human cooperation.

III. Experiment system

A. cooperative walk system

The purpose of the system is to realize cooperative walk through the two subjects' footstep sounds, as shown Fig. 3. Both subjects' footsteps were sensed by the touch sensor (OJIDEN, OT-NO-1) set on their foots. The informa-

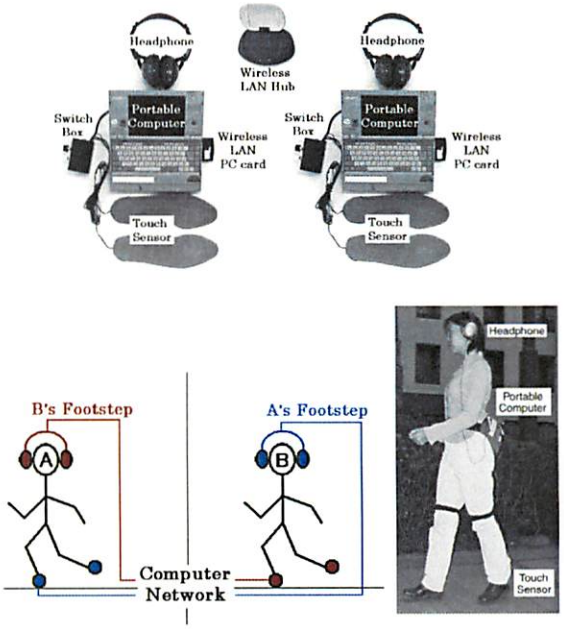


Fig.3. Cooerative Walk System.

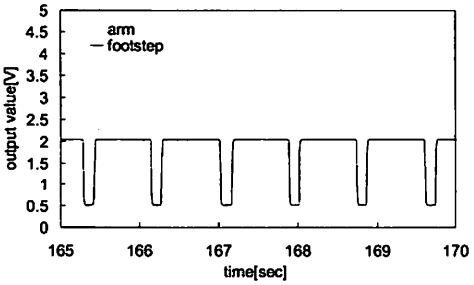


Fig.4. An example of measured data.

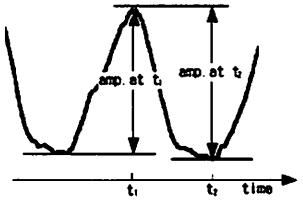


Fig.5. Definition of amplitude.

tion was measured by the portable computer (Toshiba, Libretto 60), and it transfers to the other subject's portable computer by using TCP protocol on Local Area Network. When the information arrived to the other subject's portable computer, he hears the rhythm sound which correspond to the other subject's footstep. The accuracy of time constant is less than 0.01sec.

B. Measuring system of body motion

The purpose of this system is to measure the dynamics of arm and leg simultaneously.

The motion of leg is measured as the data of step timing of foot by the touch sensor mentioned on the last section, and the motion of arm is measured as the data of angular oscillation of elbow, which is measured by angular sensor (NIHON KOHDEN, EG 511H). These data are sent to telemeter (NIHON KODEN, WEB-5000) by its transmitter (NIHON KODEN, ZB-5812) and converted with 128Hz into discrete voltage data, which can be recorded by the PC (IBM, ThinkPad 570) through the A/D converter (ADTEK, AXP-AD02). Here shows an example of the measured data. The foot's data was recorded as the time when the measured voltage drop down. The voltage value of arm's data is proportional to the angular value. The value 0V correspond to the status that the elbow is straight, and the more the value increase, the bent the angle of elbow become. The amplitude of arm's angular oscillation is defined as Fig.5.

C. Experimental condition

We take 4 subjects (native Japanese, twenties, male, students). They formed groups of two (divided into other room), and walked along the circular tracks in the very quiet rooms in 600sec with measuring the grounding timing of foot and the angular oscillation of arm.

This condition was measure all patterns of groups, which is 6 patterns. We had already confirmed that all subjects were able to percept the rhythm sound, and required to concentrate only to hear it during cooperative walk.

IV. Results

In this chapter, it is done the analysis of the emergence process on human-human cooperative walk system. Already mentioned, the emergence process on cooperative walk is characterized by the phase difference of the walking rhythm and the fluctuation of the arm's swing motion. Accordingly we analyze the temporal development of both subjects' their motions, and their quantitative evaluation is done. Then it is clarified the roles of their dynamics by the relation to the process of consciousness.

A. Temporal development of the dynamics

The relation of the leg's dynamics on cooperative walk was analyzed by the fluctuation of the phase difference of the walking rhythm as the phase relation between their leg's dynamics. The fluctuation of phase difference was defined as the sum total of the continuous 3 times absolute value of the difference value between the continuous two phase differences.

On the other hand, the dynamics of arm was analyzed by the data of the amplitude of elbow's angular oscillation. However, in the data, there were the differences between individuals, which could not be ignored. Accordingly the analysis of the arm's motions was done by the fluctuation of the amplitude rate, which was defined as the ratio of the arm's every data on cooperative walk to the average value of the arm's data on the alone walk. Concretely the average value was defined from the preparatory experiment that the subjects walk alone 600sec. The fluctuation of arm was defined the absolute value of the difference between each amplitude rate and the 10 cycle's running average of the data. The object for analysis was the area of 120sec where the mutual interaction between human and the robot was realized enough by applying the motion of leg to doing that.

As an example of the results, it was shown in Fig.6 the temporal development of the subjects' fluctuation of arm's amplitude rate and of phase difference when subject A walk with subject B. it was observed the tendency that there was some points which the arm's fluctuation increased and the points was occurred cyclically with almost 10~30sec period. In addition, such points ware observed in both subjects with almost 5sec fluctuation. To clarify the tendency, the points where they relate were put the halftone in the figure.

At the time when such phenomenon occurred, it was observed the tendency that the fluctuations of the phase difference of walking period change the little value to the large value. To clarify the tendency, about the arm's data, the points that correspond the threshold value0.5 ware shown by the dotted line, and the points were regarded as significant if it took more than the value. The dotted circle marked the data of phase differences where the significant fluctuations were observed.

B. Statistics analysis of the dynamics

To evaluate the relation statistically, about the fluctuation of phase difference at the time observed the arm's fluctuations just before 5sec and just after 5sec, the average value and the standard deviation value of them were calculated, as shown in Fig.7. From the results, it was significantly observed at all 4 subjects the tendency that the fluctuation of phase difference took larger value just after

the arm's large fluctuation than just before.

In addition, it was clarified that the time when the subject's fluctuation of arm was large was close to the time when the other subject's was large on cooperative walk, as shown Fig.8. This figure shows the subject's motion of arm expressed by the upper black cells and the lower gray cells, which were plotted the temporal development of them with the units of 5sec about all groups of the subjects.

To estimate such tendency quantitatively, the auto-correlation functions of these time series data about all groups of the subjects were calculated. In details, the areas for the analysis were divided with the unit of 5sec, and the bit array that took 1 if the arm's fluctuation was large or that took 0 in other case were made for the calculations of auto-correlation function for all groups. The average of the functions and its standard error was shown in Fig.9. The peak points of the function was observed on 0sec. Accordingly it became clear that both time series almost synchronized each other with the fluctuations about 5sec.

Thus, at just before and just after the time when the fluctuation of arm become large, it was clarified that the fluctuation of the phase difference on the leg's walking motion change remarkably and that the cycles of the arm's fluctuations synchronize each other with the phase fluctuations of walking period.

From the results, the temporal development of the fluctuation of the phase difference was similar to the temporal development of the fluctuations of the swing motion of the arm. Therefore it was suggested that there was the mutual constraint relation between the arm's motion and the leg's motion.

It became clear that the process that both subjects' fluctuations of the arm's swing motion occurred synchronized each other with the fluctuation of 5 sec through the foot's phase fluctuations. Thus, same as the Co-emergence process observed at the man-machine cooperation, it is suggested that the cycle of the mutual constraint process between the arm and the leg synchronized each other though the phase fluctuations.

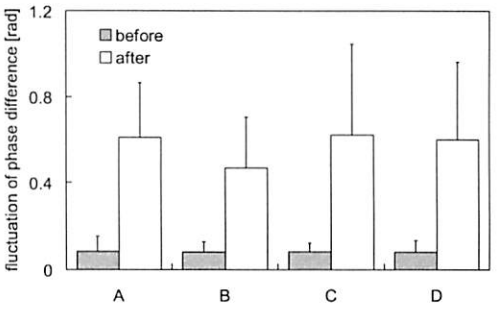


Fig.7. Change of fluctuation of phase difference.

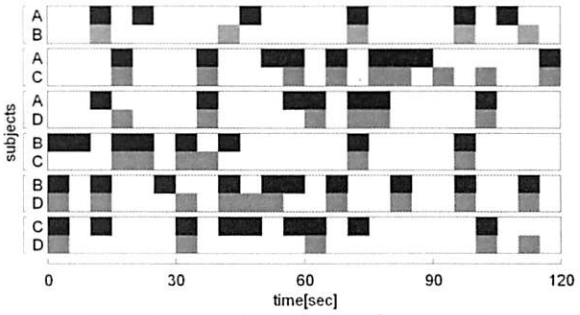


Fig.8. Correlation of arm's fluctuation.

C. Estimation of the role of the dynamics

From the symmetry of the temporal development of the walking dynamics, it have been already suggested that the motion of leg is based on the process of the unconsciousness and that the motion of arm is based on the process of the consciousness on the cooperative walk between human and the walk support robot[7]~[9]. In addition, from the results of section IV-B., it was suggested that the process, which is similar to the process on the cooperative walk with the robot, was observed on the human-human cooperative walk. However in this case, it has not clarified that the motion of the arm and the leg were based on the process of the consciousness and the unconsciousness, which ware modeled by the Internal mode and the Body model on the Co-emergence model, respectively. There-

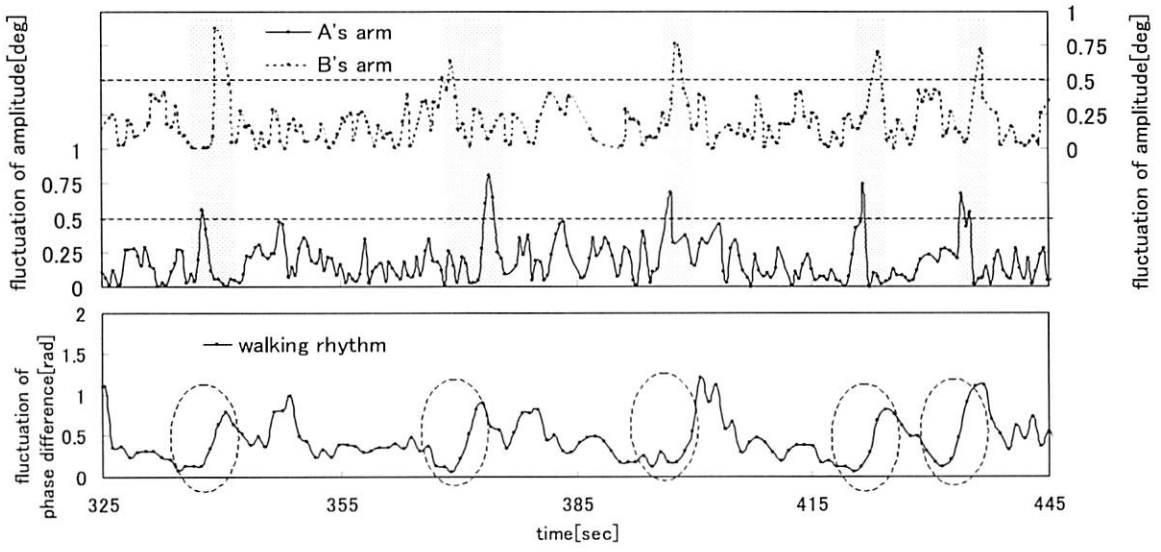


Fig. 6. Compare the dynamics of the arm and the leg.

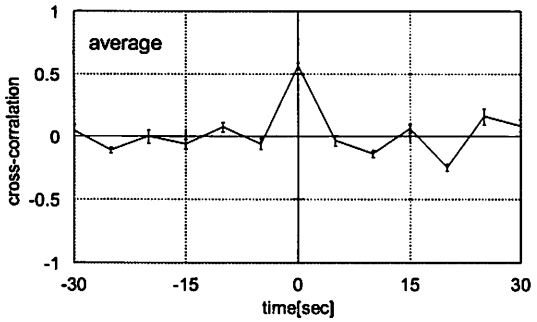


Fig.9. Cross-correlation function of arm's fluctuation.

fore the relation of the process of consciousness to the dynamics of the leg and the arm was estimated from the time series data of the same subjects' results as on section4.2.

Concretely the further experiments, which was applied to the dual task method by setting the 5-words -memorization task based on the short-term memory to the secondary task, were done, and were compared with the data on the normal conditions. Because it has been clarified that the short-term memory relate with the high level brain functions, such as the attention or the working memory, which are based on the consciousness, and it is expected that the differences between these dynamics were observed if they relate with the process of consciousness[13][14].

The memory condition with 5-words -memorization task was realized followings: The subjects were showed 5words which were composed 3~5 Mola *Hiragana* or *Katakana* (Japanese letter) 3sec by the computer display just before they start to cooperative walk. Just after that, they do cooperative walk in 60sec with keeping the memory of these words. Just finish walking, the subjects was required to answer back those with the oral expression. The average percentage of the correct answer was 90.83%.

To analyze the dynamics of leg, it was calculated the auto-correlation coefficient of the all subjects' period of footstep from the lag0 to the lag10. The average and the standard error were shown in Fig.10. The time scale of the 1lag was almost 1sec because the average of walking period in cooperative walk is 1.07sec(Normal condition: Ave.= 1.06sec S.D.=0.03sec, Memory condition: Ave.=1.08sec S.D.=0.03sec). The object area to analyze was the starting time of the cooperative walk after 10sec to 60sec, which duration was 50sec. Then there are no significant differences between the normal condition and the memory condition.

On the other hand, to analyze the dynamics of arm, the auto-correlation coefficient of the all subjects' angular amplitude of the swing of arm was calculated on these conditions. The amplitude of arm's angular oscillation was defined in almost every half period of walking motion. Therefore the dynamics was defied at almost half timescale of the leg's dynamics. Thus the auto-correlation was calculated from the lag0 to the lag20 with the lag2 interval, as shown in fig.11. From the results, the normal condition took higher value of the auto-correlation coefficient than the memory condition, and that is the differences. In addition, the significant difference was observed the area between the lag2 to the lag6.

From the results, it was clarified that the leg's dynamics on the cooperative walk was not influenced the effect of the memory task more than the dynamics of arm. In addition, it became clear that the arm's dynamics was influenced the effect of the memory task and that such influence were observed within almost 3sec period, which correspond to the lag6. Thus it was suggested that the arm's dynamics relate with the process of the consciousness more than the leg's dynamics.

V. Conclusion

The purpose of this study is to propose the concept of new design theory of man-machine system by regarding the Co-emergence process observed in human-human cooperation characteristically as ideal. Therefore, in this paper, in order to analyze the Co-emergence process on human-human cooperation on which it bases, we analyzed the Co-emergence process by measuring the dynamics of the arm and the leg on the cooperative walking realized by the synchronization of the two people's footstep.

As the result, it became clear the possibility that there was the mutual constraint process between the step motion of the leg and the swing motion of the arm and that the cycles which the mutual constraint between the arm and the leg synchronized each other through the phase fluctuation of walking period. . In addition, compared with the further experiments, which was applied to the dual task method by setting the memorization task, it was suggested that the arm's dynamics relate with the process of the consciousness more than the leg's dynamics.

Especially about the arm's dynamics, the significant auto-correlation was observed within almost 3sec period, compared with the memory condition. Thus it was suggested that the dynamics of the time-scale was almost 3sec. This suggestion agrees to the report that the duration of

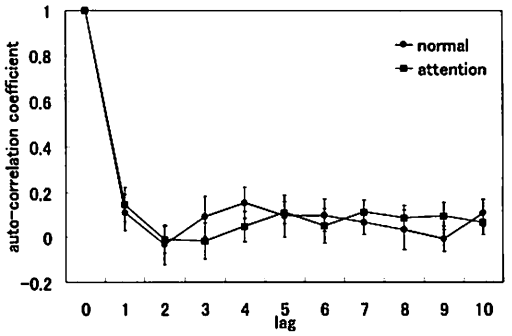


Fig.10. Auto-correlation of the footstep's period.

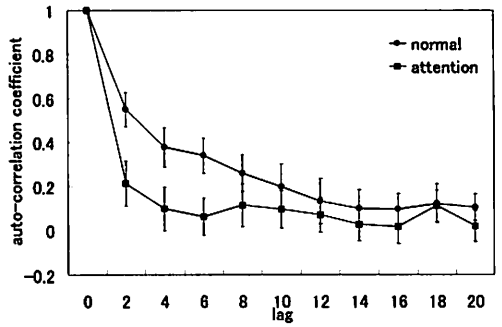


Fig.11. Auto-correlation of arm's amplitude.

the consciousness is almost 3sec[15], and does that the arm's dynamics are based on the process of consciousness.

It was considered that the leg's dynamics is consisted by the rhythm oscillations, which are generated nervous oscillator called Central Pattern Generator (CPG) on the spinal nerves and not relate the higher-level nervous system[16]. That agrees the suggestion that the leg's dynamics are based on the process of the unconsciousness, with the result that the leg's dynamics was influenced by the process of the consciousness.

Hence it became clear the possibility that the process modeled as the mutual constraint between the internal model and the body model on the Co-emergence model we have proposed should be the mutual constraint process between the arm and leg's. Thus it was suggested that the Co-emergence process on the man-machine cooperation in the former study was equate to the Co-emergence process on human-human cooperation in this report, and the suggestion clarified the validity of the Co-emergence model as the human-human cooperation.

In the future works, it becomes important that the measurement and the analysis of the process of walk support in the real welfare situations, concerning the walk support robot. Because it is necessary to clarify the relation the function of the walk support realized at there to the significant points on the dynamics of the human-human cooperative walk that are analyzed in this paper, to construct the robot, which we have proposed.

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