Internal Observation and Mutual Adaptation in Human-Robot Cooperation

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Abstract

"Internal observation" means that an agent observes environment in inseparable mutual interference between the agent and its environment, and similar situations are widely observed in cooperative behavior in multi-agent system, group robots, human interface and so on. However, conventional framework of system theory which is based on separation between controller and controlled object can not be applicable to these mutually interferent situations. Under this kind of dynamical complexity, the agent can't completely identify its environment, and it should generate internal model to solve such ill-posed problem. Thus, to overcome this essential difficulty, we propose "dual-center model" based autonomous agent which is composed of two different dynamics. One is to self-organize coherent relationship in mutual interference, and the other is to separate the coherence into two one-sided interactions by using internal model. Through mutual constraint between these two different dynamics, the agent generates hypothetical constraints as an internal model which represents interaction between the agent and its environment. By using this model, internal observation under mutual interference becomes possible. As an example of it, mutual adaptation in cooperative behavior between human and robotic agent was realized.

* Internal observation originally means ontological generation process of the world, and it is completely different from dynamics under a fixed representation. Therefore, by constructing representations of internal observation in our interface region, we would like to approach to the generation process of representation. Thus, in this study, we propose a human-interface system as a first step of it [1].

1. Introduction

What is the most difficult problem to realize autonomous agent which cooperate with human behavior? Probably, it is the fact that human behavior is not a static environment for the agent. Especially, dynamical and mutual interference between them is the most essential difficulty, and similar situations are widely observed in multi-agent system, group robots, human interface and so on. However, since conventional framework of system theory is based on linear separation between controller and controlled object, it isn't applicable to these mutually interferent situations. Under this kind of dynamical complexity, the agent can't completely identify its environment due to its nonlinear interaction, and the agent should generate hypothetical constraints by itself to transform such ill-posed problem into well-posed problem. We call this kind of observation process as "internal observation."*

However, it has not been clarified how to generate such hypothetical constraints by the agent. Even in the computational theory of brain, the hypothesis are previously assumed and fixed as an internal model [2]. Thus, we have been trying to establish a new framework which enables to overcome these essential difficulties in internal observation [3-6]. In this study, we propose "dual-center model" [7] based autonomous agent which is composed of two different dynamics. One is to self-organize dynamical coherence in mutual interference, and the other is to separate the coherent relationship into two one-sided interactions by using internal model. Complimentarily using these dynamics, hypothetical constraints as an internal model are

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generated and internal observation process is realized. In this report, mutual adaptation in human-robot cooperative walk is studied as an example of it.

2. Internal observation

framework

In conventional framework, such as visual recognition [2], observation for the agent is to identify its environment. In other words, the agent optimize its internal state under fixed constraints corresponding to the environment. This optimization process has been modeled as a minimizing process of potential under fixed potential field. This type of observation is available when time scale of the agent is sufficiently faster than that of environment.

In this study, we extend this framework to the condition in which time scale of the agent is not largely different from that of environment and mutual interference is not negligible. This means that potential field can not be defined within the agent. Under this kind of mutual interference, what the agent can observe is not a static environment but a dynamical relationship between the agent and environment. Therefore, to achieve a purpose of the agent, it should identify the agent and its environment from one dynamical relationship. This is an ill-posed problem, and the internal observation process should be regarded as a generation process of hypothetical internal model to solve such ill-posed problem.

model

Thus, we propose "dual-center model" based autonomous agent which is composed of two different dynamics. This is based on our previous studies in biological pattern formation [8-10]. In the present model, one dynamics is to self-organize dynamical coherence through mutual interference, such as mutual entrainment between nonlinear oscillations. We call this region body model. The other is to separate the coherent relationship into two one-sided interactions, and it is represented by using adiabatic approximation in mutual interference [11]. We call this region internal model. By using these two dynamics, the agent generates hypothetical internal model to be relevant in mutual constraint process between these two dynamics.

Two time axes and one temporal relationship are necessitated to describe the above dynamics. The first axis is continuous time which describes the body model, i.e., physically defined time. The next one is continuous time to simulate the body dynamics by using internal model, and it is independent to the physical time. The last one is discrete time to describe the mutual constraint process. Since a finite time is necessary to self-organize coherency in both regions, the time which represents temporal relationship between these two time axes becomes discrete.

In the present problem, the purpose of the robotic agent is to realize cooperative walk between human and robot, and the cooperation was defined as a synchronized walk with desired phase relationship. Thus, body model represents movement of robotic agent which mutually interacts with human walk, and it is constructed by using following nonlinear oscillators which is similar to neural rhythm generator in human walk. Here, χ_R means height of foot. When χ_R is negative it is regarded as a stance phase, and when χ_R is positive it is regarded as a swing phase. ω_R means an original walk frequency, and ξ means nonlinear parameter, and $pulse_H$ corresponds to step timing of human walk. t_{ec} and t_{id} describe the dynamics of body model and mutual constraint, respectively.

$$\ddot{x}_R(t_{ec}) + \omega_R^2(t_{id})x_R(t_{ec}) = f(x_R(t_{ec}), \dot{x}_R(t_{ec}), \xi) + pulse_H(t_{ec}) ,$$
$$where \quad f(x, \dot{x}, \xi) = \xi(1-x^2)\dot{x} . \quad (1)$$

Internal model represents mutual interaction between the body model and human, and it is constructed within the agent by using two nonlinear oscillators. Since this model is a hypothetical model for the robotic agent, ring oscillator was assumed as the most simple one for the body movement. Here, ϕ_r and ϕ_h mean phase of the ring oscillator in robotic agent and human, respectively. ω_r and ω_h show original frequency, and t_{ic} describes dynamics of the internal model. Furthermore, this model is modified by the agent depending on the relevancy between the body model and internal model. This modification is achieved in mutual constraint process between these two models, and this developmental process is represented as the change of ε.

$$\begin{cases} \dot{\phi}_r(t_{ic}) = \omega_r(t_{ic}) + \varepsilon(t_{id})\sin(\phi_h(t_{ic}) - \phi_r(t_{ic})) \;, \\ \dot{\phi}_h(t_{ic}) = \omega_h(t_{ic}) + \varepsilon(t_{id})\sin(\phi_r(t_{ic}) - \phi_h(t_{ic})) \;. \end{cases} \quad (2)$$

In this system, internal observation process is summarized as shown in Fig.1.

i) At first stage, coherent phase relationship ($\Delta\phi_{HR}$) is self-organized by mutual entrainment between human walk rhythm and robot body model. This phase relationship is used as a constraint for the internal model in next step.

ii) Then, at mutually entrained coherent state ($\Delta\phi_{hr}$) in internal model, original frequency of human-side oscillator (ω_h) which satisfies the organized phase relationship in body model ($\Delta\phi_{HR}$) is searched under fixed original frequency of robot-side oscillator (ω_r). By this optimization process, original frequency of human walk is predicted.

iii) After that, at coherent state ($\Delta\phi_{hr}$) in internal model, original frequency of robot-side oscillator (ω_r) which satisfies the desired phase relationship ($\Delta\phi_d$) is searched under the predicted original frequency of human-side oscillator (ω_h) obtained in the above step. By this optimization process, desired original frequency in robot is predicted.

iv) Based on these two one-sided relationships obtained by using adiabatic approximation, original walk frequency (ω_R) to realize desired phase relationship in body model is obtained.

v) Thus, new coherent state ($\Delta\phi_{HR}$) is re-organized between human walk and robot body model.

vi) Then, by using the difference between the predicted phase relationship ($\Delta\phi_{hr}$) in internal model and the obtained phase relationship ($\Delta\phi_{HR}$) in body model, parameter of internal model (ε) is modified to decrease the difference. However, this modification is not an optimization process, because the robotic agent can not have complete information concerning to its environment. Therefore, this internal model is a relevant model which is valid only in its mutual constraint process.

vii) After these processing, return to the first step.

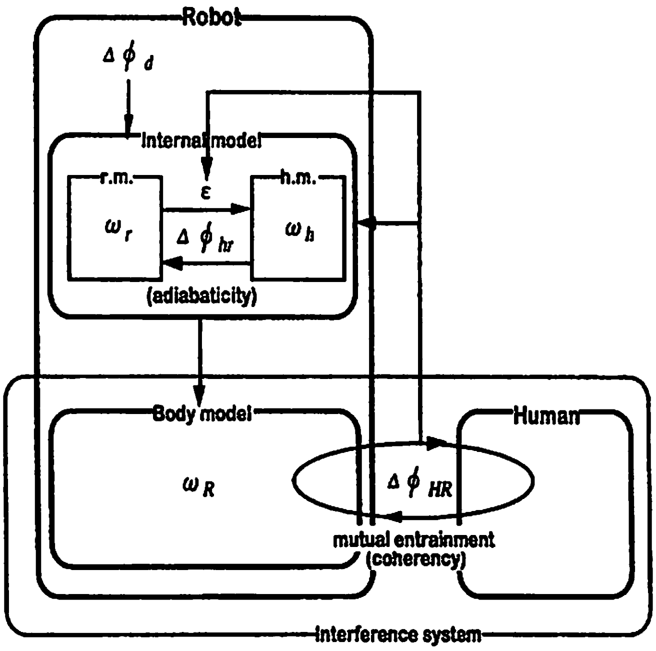

Fig.1 Internal observation process

3. Mutual adaptation in human-robot cooperative walk

Simulations

At first, internal observation process between two robotic agents was investigated by using computer simulations. An example of obtained results is shown as follows. Figs.2a-c indicate walk period, organized phase difference, and original walk period in body model. Figs.2d-f indicate predicted original frequency, error measure, and parameter in internal model, respectively.

Before interaction, robot-1 and robot-2 walked at their original walk periods. After the start of interaction indicated by left arrow, both walk periods gradually coincided and phase difference became stable by mutual entrainment. Then, internal model in both robots predicted their original periods which realize desired phase difference, and they changed their original walk period in body model. This prediction perturbed

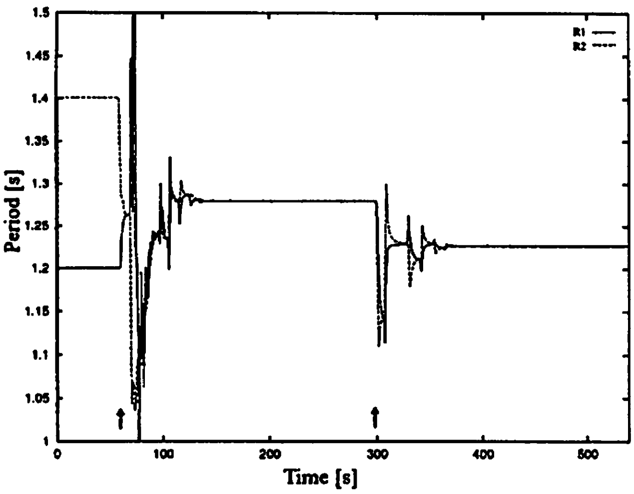

Fig.2a

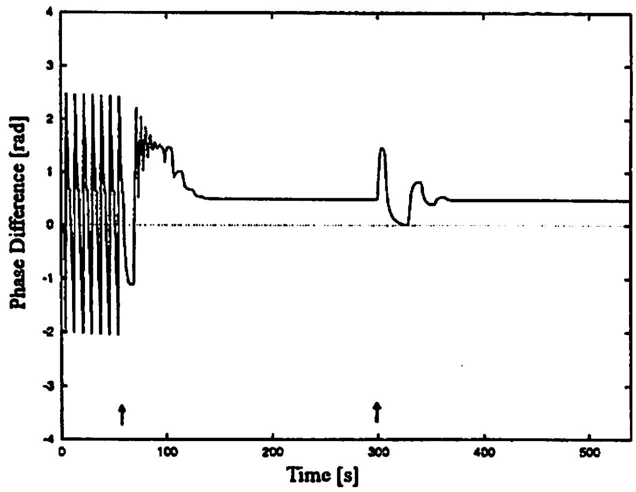

Fig.2b

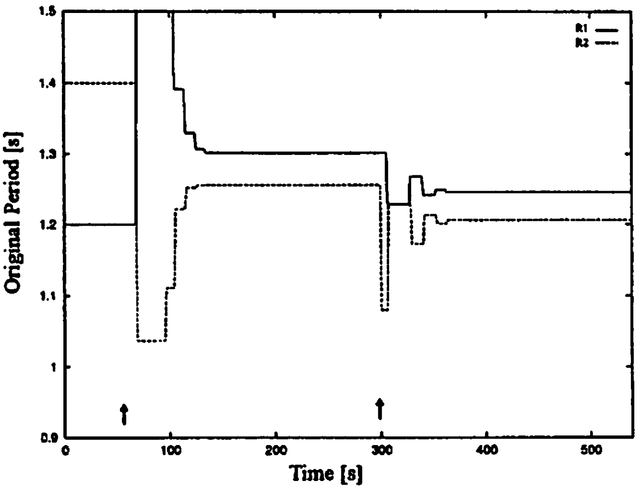

Fig.2c

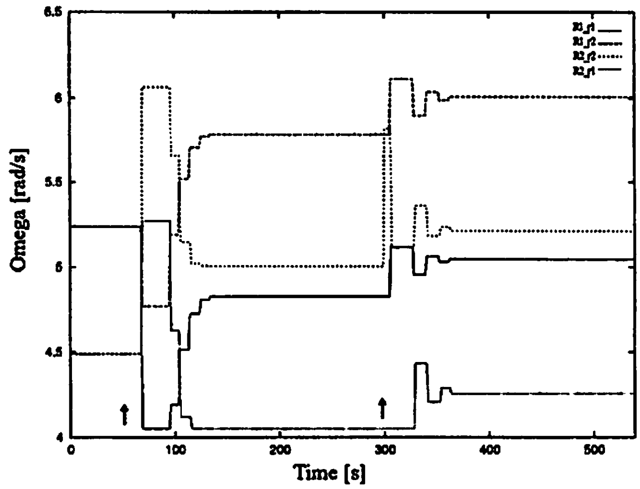

Fig.2d

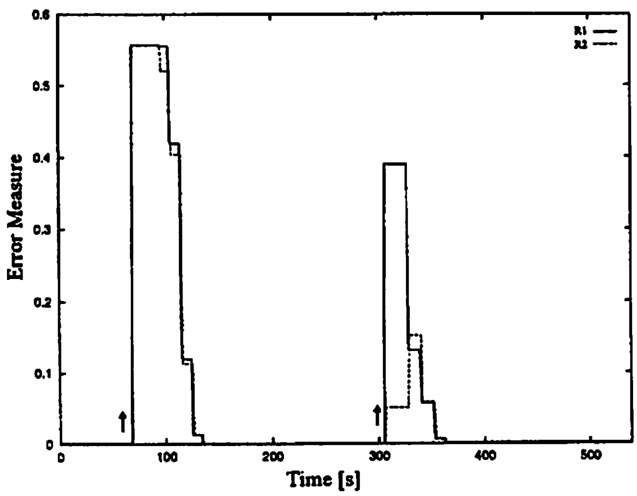

Fig.2e

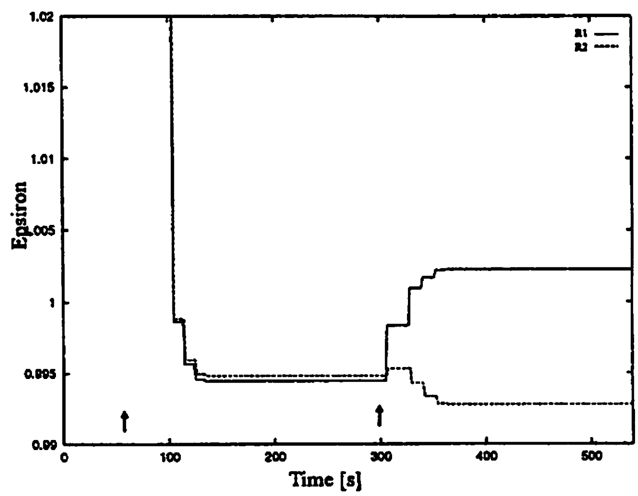

Fig.2f

Fig.2 Cooperativewalk between two robotic agents the coherent entrained state in body model, and it was gradually re-organized. Then, by using the error measure between predicted phase relationship in internal model and obtained relationship in body model, parameter of internal model is modified to decrease the difference. Through this mutual constraint process between body model and internal model, the phase difference in body model converged to the desired value. In this simulation, the desired phase difference was fixed to 0.5 rad, and both robots mutually adapted to realize the phase relationship. This kind of stability seemed to depend on relevancy of the internal model which is generated in mutual constraint process.

After applying a disturbance to the robot-1 indicated by right arrow, original walk periods not only in robot-1but also in robot-2 changed and their phase relationship was re-organized toward the desired value. In this process, parameters of internal model became different in each robot, even though they are in the same situation. This clearly shows that internal model is a hypothetical model which is generated based on a relevance for each robot.

Experiments

We tested the above system for the interaction between robot and human, by constructing the following experimental device. When human foot attaches to ground, it is sensed by touch sensor equipped with shoe and its signal is transmitted to robot simulator. On the other hand, step timing of simulated robot is modified into step sound and transmitted to human by using headphone. Under this experimental condition, following results were obtained.

Figs.3a and 3b show walk period and organized phase difference, respectively. Before interaction, human and robot walked at their original walk periods. After the start of interaction indicated by left arrow, walk periods in human and robot gradually coincided and phase difference converged to the desired value. In this case, the desired phase difference was fixed to 0 rad.

After stopping interaction indicated by right arrow, both walk periods show difference from those of before interaction. This means that original walk periods of human and robot

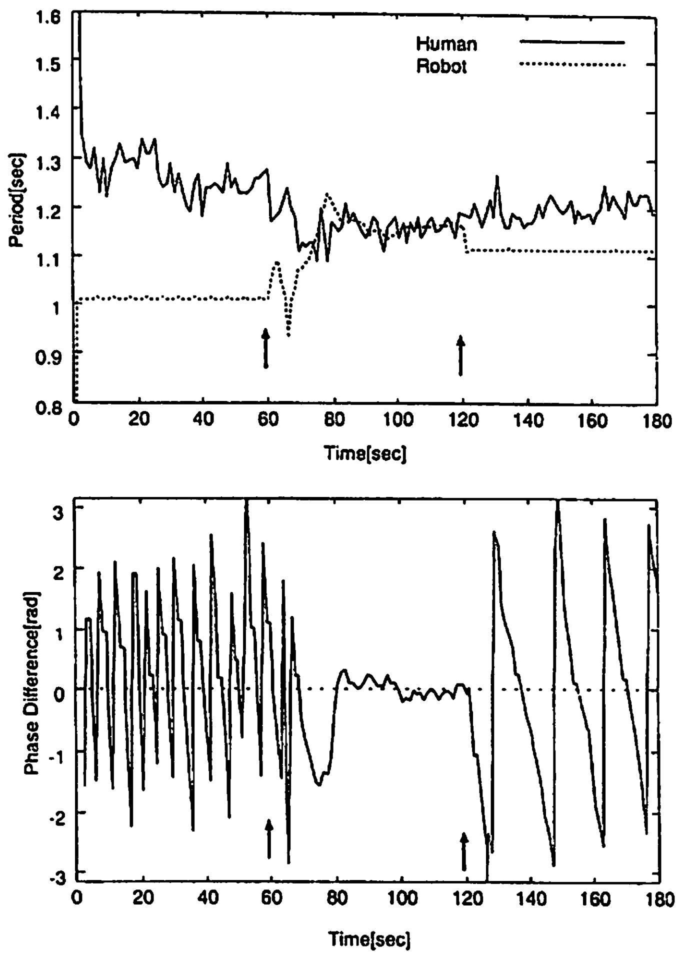

Fig.3 Cooperative walk between human and robotic agent

adapted mutually in this interaction process. Thus, it is suggested that the dual centers model based cooperative dynamics is realized not only in robot but also in human.

4. Conclusion

In this report, we proposed dual-center model based internal observation agent, which is composed of dynamical coherent relationship and one-sided relationships between the agent and its environment. As an example of it, mutual adaptation in human-robot cooperative walk was realized.

5. References

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