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Dynamics of the duality model in two agents system

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Abstract: We have already proposed the duality model before, however, there are still remaining some problems: such as the validity verification of co-emergence process, parameters analysis and so on. We established a two agents system to investigate them. As a result, the co-emergence process was observed. We also showed the limits of some parameters, and gave them effective range.

Keywords: co-emergence system, duality model, multi-agents system.

1. INTRODUCTION

The relationship between human and human through communication can be created in real-time, which can be thought of as co-emergence process in communication. The co-emergence process can be approximately expressed by a duality process(Miyake 1999,2001)[1),2),3)]. The duality process has two parts. One of them is the real-time interaction between itself and others in an open space in which all of us are living. The other is the retrospective processing in a closed space usually in the brain.

If such duality process is equipped in the Machine, We could develop a humanlike communication in man-machine or machine-machine environment. Thus a duality model that can be used in a machine interface was proposed to simulate the duality process in communication. It has been successfully applied in a walk support robot[1),4)]. But it still has to be verified in a way of experiment. And the parameters of the model have to be analyzed.

To overcome these problems, we established a simulation to create a two agents based adaptive system that was used to simulate the human communication. The two duality model agents were made to interact in a closed environment. In this way we can observe the dynamics characteristic to the model, and study the properties of the model's parameters.

2. METHOD

2.1 Duality Model

The duality model is composed of two sub-models, the body model and the internal model. The body model used to realize the real-time interaction in an open space was created by means of mutual entrainment[5)]. That can be observed in human body movement[6),7)]. On the other hand, the internal model used to realize retrospective processing was created by one-side action[8)], such as some searching process. On following statements, we take the Agent1 as an example to express the duality model.

2.2 Algorithm

A coherent phase relationship (which reflects the stable entrainment) can be calculated in body model of the two interacting agents respectively. By using this relationship, internal model predicts its environment (the other agent), and refresh the inherent frequency of its body model to realize its "goal"—reference phase difference on the contrary. But this is a kind of ill-posed problem. Here we give the duality model of Agent1:

1. In body model, coherent phase relationship (θ_{B1}) is self-organized by mutual entrainment between Agent1 and its environment (Agent2).
2. In internal model, error measure is calculated by the difference between predicted relationship θ_{21} and organized relationship θ_{B1} which created by body model in step 1,and parameter of internal model (ε) is modified to decrease the

measure.

3. predicted frequency of environment (ω_2) is searched under fixed predicted frequency of self (ω_1) to satisfy an equality between $\theta_{\square 1}$ and θ_{21}.

4. predicted frequency of self (ω_1) is searched under fixed predicted frequency of environment (ω_2) to satisfy an equality between θ_{21} and θ_d, the later is the reference phase difference.

5. Refresh the inherent frequency (ω_1) by $=\omega_1$.

6. Return to the first step.

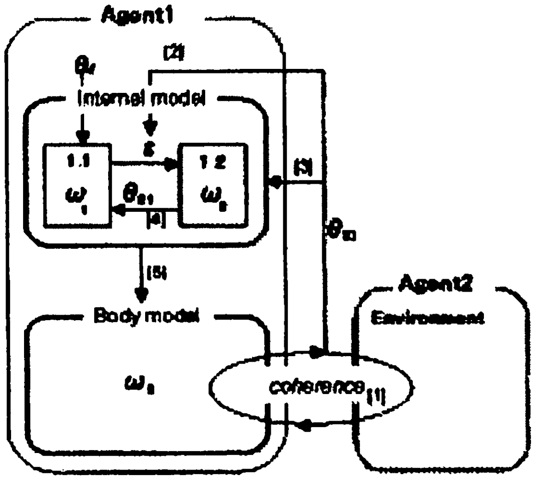

Fig.1 Algorithm of the duality model in Agent1.

2.3 Body Model

Body model has a real-time scale and an open space to the environment. A kind of non-linear oscillator was composed to realize the entrainment. We use the Van der Pol oscillator in our research.

$$\begin{cases} \dot{x}_1 = y_1 \\ \dot{y}_1 = \xi(1-x_1^2)y_1 - \omega_1^2 x_1 + D(x_2 - x_1) \end{cases} \tag{1}$$

When $\xi>0$, it has a steady limit cycle, that is what we wanted. Here, x and y are state variables. The subscript 1 means Agent1, and the subscript 2 means Agent2. D is coupling coefficient of the interaction between Agent1 and Agent2.

Agent1 calculates the apparent phase difference, when its state variable x is becoming minus from plus.

$$\theta_{\square 1} = \frac{2\pi(last_2 - last_1)}{period_1} \tag{2}$$

Here, $last_1$ stands for the last instant before x of Agent1 reach minus, and so for $last_2$ of Agent2. $period_1$ is the time between two moments when x changes from plus to minus. If the change of Agent1 is near zero, in other words, if the relationship of two agents is becoming stable, then the internal model of Agent1 starts to work.

2.4 Internal model

In internal model, the nature of body rhythm model is represented by an abstract form. By using the non- linear phase equation, we show a basic formula of internal mode:

$$\begin{cases} \dot{\phi}_1 = \omega_1 + \varepsilon \ \sin(\phi_2 - \phi_1) \\ \dot{\phi}_2 = \omega_2 + \varepsilon \ \sin(\phi_1 - \phi_2) \\ \theta_{21} = \phi_2 - \phi_1 \end{cases} \tag{3}$$

Here, ω_1 is the predicted frequency of Agent1 in the internal model of Agent1. ω_2 is the predicted frequency of Agent2 in the internal model of Agent1. ε is coupling coefficient. ϕ is phase state variable. θ_{21} is the predicted phase difference compared to $\theta_{\square 1}$.

$$\begin{aligned} \dot{\theta}_{21} &= \dot{\phi}_2 - \dot{\phi}_1 \\ &= \omega_2 - \omega_1 - 2\varepsilon \ \sin(\theta_{21}) \end{aligned} \tag{4}$$

Since $\dot{\theta}_{\square 1} = 0$ is the condition of entrainment in the body model, we use $\dot{\theta}_{21} = 0$ to express the entrainment in the internal model. The answer is:

$$\begin{aligned} &\theta_{21} = \sin^{-1}\frac{\omega_2 - \omega_1}{2\varepsilon} \\ &(-1 \le \frac{\omega_2 - \omega_1}{2\varepsilon} \le 1) \end{aligned} \tag{5}$$

2.5 Mutual Constraint

2.5.1 Constraint from body model to internal model

Fix its condition(ω_1), and predict the condition of environment(searching ω_2) by reducing the difference between $\theta_{\square 1}$ and θ_{21}. The detail is as follows:

We introduce a potential V_1:

$$V_1 = -\alpha\cos(\theta_{21} - \theta_{\square 1}) \tag{6}$$

α stands for the searching speed, $\alpha>0$. And $\theta_{\square 1}$ = Const.

$$\begin{aligned} \dot{\theta}_{21} &= -\frac{\partial V_1}{\partial \theta_{21}} \\ &= -\alpha\sin(\theta_{21} - \theta_{\square 1}) \end{aligned} \tag{7}$$

is introduced as a restriction, substitute (5) for (7), we can get:

$$\dot{\omega}_2 - \dot{\omega}_1 = -\alpha\sqrt{4\varepsilon^2 - (\omega_2 - \omega_1)^2} \times \sin\left(\sin^{-1}\frac{\omega_2 - \omega_1}{2\varepsilon} - \theta_{\text{II}\,1}\right) \tag{8}$$

Since ω_1 is fixed, $\dot{\omega}_1 = 0$.

$$\dot{\omega}_2 = -\alpha\sqrt{4\varepsilon^2 - (\omega_2 - \omega_1)^2} \times \sin\left(\sin^{-1}\frac{\omega_2 - \omega_1}{2\varepsilon} - \theta_{\text{II}\,1}\right) \tag{9}$$

From equation (9), we can get ω_2

2.5.2 Constraint from internal model to body model

When we got ω_2, we fix ω_2 as a constant ,and began to search ω_1 to reduce the difference between $\theta_{\text{II}\,1}$ and θ_d which is the reference phase difference. Then we change ω_1 of body model.

As the same as (6), potential V_2 is introduced:

$$V_2 = -\beta\cos(\theta_{21} - \theta_d) \tag{10}$$

Here $\beta > 0$.

As the same method which has been showed in environment recognition as above,

$$\dot{\theta}_{21} = -\frac{\partial V_2}{\partial \theta_{21}} = -\beta\sin(\theta_{21} - \theta_d) \tag{11}$$

Substitute (5) for (11):

$$\dot{\omega}_2 - \dot{\omega}_1 = -\beta\sqrt{4\varepsilon^2 - (\omega_2 - \omega_1)^2} \times \sin\left(\sin^{-1}\frac{\omega_2 - \omega_1}{2\varepsilon} - \theta_d\right) \tag{12}$$

Since ω_2 is fixed, $\dot{\omega}_2 = 0$.

$$\dot{\omega}_1 = \beta\sqrt{4\varepsilon^2 - (\omega_2 - \omega_1)^2} \times \sin\left(\sin^{-1}\frac{\omega_2 - \omega_1}{2\varepsilon} - \theta_d\right) \tag{13}$$

We get ω_1 from equation (13)

Then ω_1 of body model is refreshed by

$\omega_1 = \omega_1$

2.5.3 Self refresh of internal model

Error measure is defined as:

$E = 1/2\,(\theta_{\text{II}\,1} - \theta_{21})^2$.

ε is modified to decrease the measure:

$$\varepsilon - \varepsilon_{old} = -\eta(\Delta E / \Delta \varepsilon) \tag{14}$$

$\varepsilon_{old} = \varepsilon$

ε_{old} is ε before refresh. η is a parameter stands for the speed of refresh process.

2.6 Two agents system

In a human communication at least 2 people are needed. Therefore, we took the simplest way (using two agents) simulating the human communication. Each agent had the duality model. We made them interact through their body models in the same time schedule. The system was closed. For one agent, it could only know the phase difference between each other, and used this incomplete information to realize its goal. The process that two agents got their goal through the interference between each other can be thought of as the co-emergence.

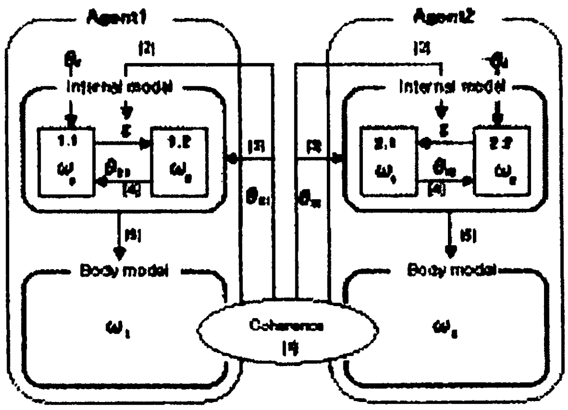

Fig.2 Construction of two agents system.

3. RESULTS

3.1 Typical example

The whole simulation time is 100 seconds. Interaction starts at 30 seconds from the beginning. Fig.3-a shows the apparent period in the body model. Fig.3-b shows the apparent phase difference in the body model. Fig.3-c shows inherent frequency of the body model, Fig.3-d shows predicted frequency from internal model, here we only show the partner's frequency, for example Data Agent_1 in Fig3-d is the predicted frequency of Agent1 in internal model of

Agent2, and it is different from the data Agent_1 in Fig.3-c which is the inherent frequency of Agent1 in body model of Agent1.Fig.3-e shows the coupling parameter ε of internal model.We can discuss it from three steps:

1 The workings of body model

As soon as the interaction starts, for work of body model, as shown in Fig.3-a, the two apparent periods are coming nearer and nearer. At time "A", two period lines overlapped. Two apparent phase differences in Fig.3-b were also becoming stable. This phenomenon was referred to as entrainment or coherent. The two inherent frequencies were not changed yet shown in Fig.3-c.

2 The workings of internal model

Just after time "A", because of the entrainment created by body model of two agents, internal model is now beginning to work. For each model has its own judgment of entrainment, the two agents may not let their internal model start at the same time. In this example, model Agent2 started first. That would be proved by these two facts: First, as Fig.3-d shows, data Agent_1 changed just after "A". That means Agent2 predicted the frequency of Agent1 by its internal model for recognize its environment (Agent1). Secondly, From Fig.3-c, we can also see the change of data Agent_2. That means Agent2 refreshed its body model in order to try to realize its "goal"(reference phase difference) after recognizing the environment. Furthermore, the two facts above also show us the dynamics of internal model.

3 Conversion in two sub models

After the changing inherent frequency in body model, the entrainment of two agents was broken. Look at Time "C" in Fig.3-a. But this would be recovered by interaction of two agents in body model. And at time "B", entrainment came back again.

Repeating the same process (1-3), at about 62 second, the whole system became stable. Both agents attained their goals (apparent phase differences) were equal to their reference phase difference. Agent1 was +0.4 radian and Agent2 was –0.4 radian shown as Fig.3-b. The dynamics process itself was just the co-emergence process. For the whole system, the relationship (phase difference) was co-created by the interference between the two agents. Each agent state (represented by inherent frequency and ε) changed with the other one's shown in Fig.3-c and Fig.3-e. In other words, each agent was created by this whole dynamics. The inseparability between the whole system and its part (each agent) represents the co-emergence.

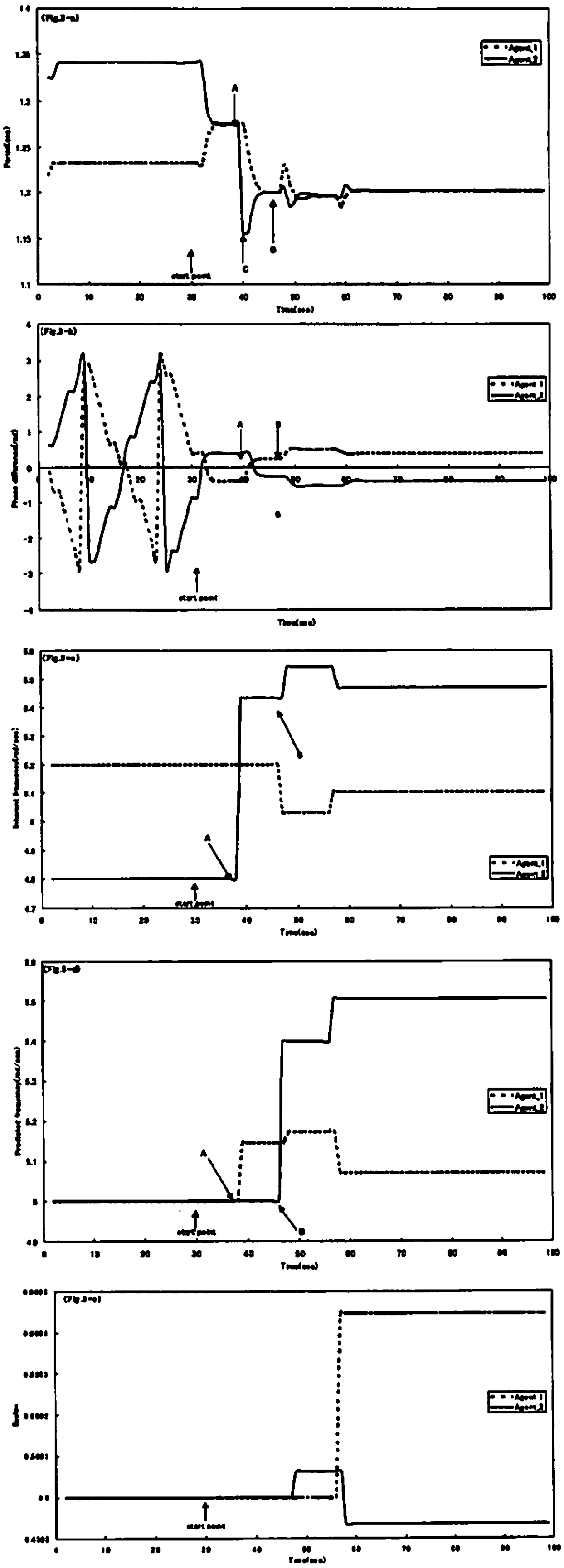

Fig.3 Temporal development in two-agents simulation.

3.2 Effect of parameters

3.2.1 Body model

The difference between inherent frequencies of two agents has a limitation. If the limitation was exceeded, entrainment cannot be established (Fig4). We fixed ω_{II} at 5.0 radians/sec, and searched the range ofin which entrainment can be established. As a result the range was [4.1—5.7] radians/sec.

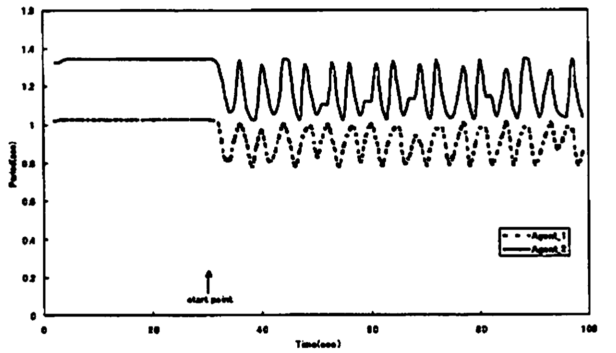

Fig.4 Temporal development of apparent period in the body model. (ω_I =5.0 radians/sec, ω_{II} =6.2 radians/sec)

ξ and D shows the strength of interaction in body model. The limitation of inherent frequency difference changes with ξ or D. According to our research, the limitation would decrease with the increase of ξ. On the contrary, the limitation would increase with the increase of D.

3.2.2 Internal model

α stands for the search speed in predicting partner's frequency. The speed could increase with the increase of α. β stands for the search speed in predicting self's frequency. The speed could increase with the increase of β. Here we discuss about four conditions:

1. α is large and β is small.

The time before convergence was relatively long as shown in Fig.5. But each time the overlapped two periods were closing to the convergence period step by step. In other words, system converges stably.

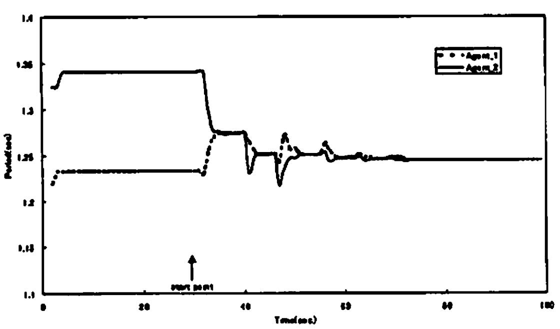

Fig.5 Temporal development of apparent period in the body model. (α=1, β=0.1)

2. α is large and β is large.

It converged quickly and stably, as shown in Fig.6.

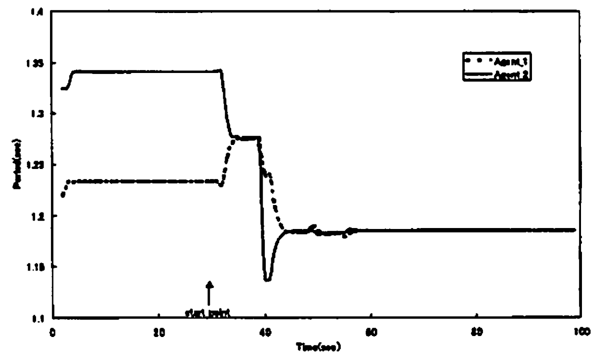

Fig.6 Temporal development of apparent period in the body model. (α=1, β=1)

3. α is small and β is large.

Fig.7 shows, Convergent time is the longest. And it was unstable, almost divergent.

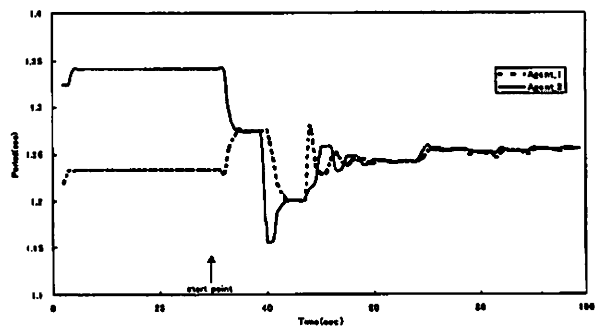

Fig.7 Temporal development of apparent period in the body model. (α=0.1, β=1)

4. α is small and β is small.

In Fig.8, Convergent time was just longer than Condition 2, the stability was worse than Condition 1 but better than Condition3.

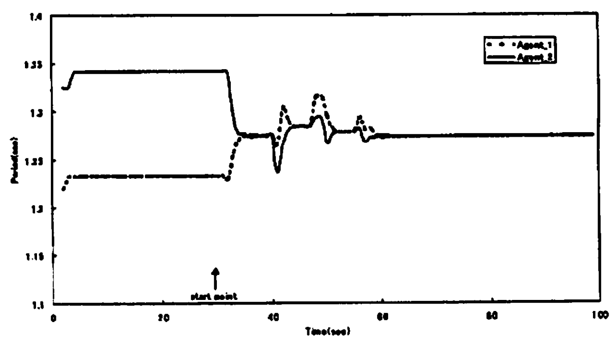

Fig.8 Temporal development of apparent period in the body model. (α=0.1, β=0.1)

Therefore, we conclude, if α is bigger than β or equals to it then the system is stable, and the convergent time becomes shorter while increasing the absolute value of α and β.

2.2.3 Reference phase difference

In the typical example, the reference phase difference θ_d of two agents were (0.4,-0.4)radians. There was a precondition that the double 'θ_d' s had no inconsistency. For example, if one θ_d was value A the other must be minus A (i.e. -A). Otherwise they are inconsistent. Besides, the θ_d has a limitation. We found it was stable in the range of [(0,0)—(0.6, -0.6)] while fixing the other parameters. Exceed this range it would become unstable, such as a pair of (0.7, -0.7) shown in Fig.9.

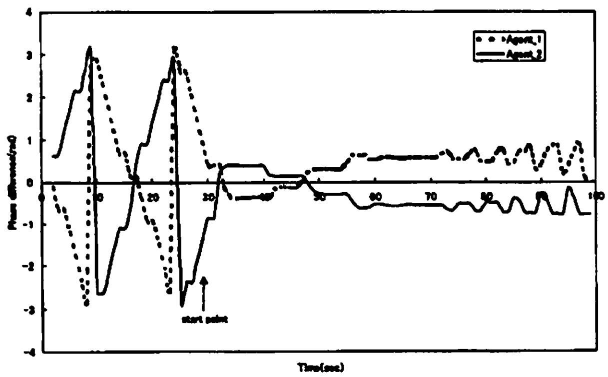

Fig.9 Temporal development of phase difference in the body model. (0.7, -0.7)

4. DISCUSSIONS

We created an adaptive system composed of two agents with duality model. Based on observing the dynamics of this system, the co-emergence process has been found. Thus, the validity of this duality model was verified. The model parameters were studied. The limitations of some parameters were point out. Some new meanings of parameters were found. An optimum set of parameters could be presented.

However, Some parameters were left from being investigated, the others ——qualitative analysis parameters should be quantitatively analyzed. The system's stability under disturbance should be verified. The learning function hadn't been observed.

In future studies, we will go on investigating the parameters such as η, give a quantitative analysis to α and β, observe the stability when a limited disturbance is given, and design a way to discover the learning function hidden in the model. Furthermore, we are going to try to extend our system in two ways, first, one more agents will be added. Use multi-agents to investigate the co-emergence in multi-sides communication. Secondly, the transform time lag will be considered in the interaction between the body models.

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