Concept and Realization of Interactive Adaptation Interface Using Recursive Fuzzy Reasoning*

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We design a machine that adapts to the user considering his/her personal differences. This paper deals with the interactive relationship between both user and machine as they try to adapt to each other. We call this relationship interactive adaptation. The interactive adaptation interface (IAI/F) is an intelligent interface that is designed based on interactive adaptation. This interface changes the characteristics of the system according to the given task, considering the state of the user, such as skill level, technique, characteristics, and physical conditions. We propose a design and a method for realization of IAI/F, based on recursive fuzzy reasoning. As an application example, we present a virtual-reality simulation game and apply the proposed IAI/F based on the user's performance and the galvanic skin reflex (G.S.R.). We present the system considering interactive adaptation, and show some experimental results and statistical evaluation results to discuss its effectiveness.

Key Words: Human Engineering, Human Interface, Adaptive Interface, Interactive Adaptation, Recursive Fuzzy Reasoning, Galvanic Skin Reflex, Virtual Environment

1. Introduction

In recent years, difficult tasks have become possible with the highly efficient changes of a machine for task execution. However, special skill and knowledge are required for such machine operation. Thus the interface that connects human and machine is important. For the case when communication of knowledge or information between human and machine is insufficient, an intelligent interface that can present appropriate knowledge and information or can supplement insufficiency has been studied⁽¹⁾⁻⁽³⁾.

The manner of assistance of this intelligent interface can be divided into (1) the knowledge level and (2) the motion level. As an example of the knowledge

level assistance, CAI (computer aided instruction)⁽³⁾ that can provide messages based on the skill level of the operator has been studied for complicated systems. As an example of a telerobot system, MEISTER (model enhanced intelligent and skillful teleoperational robot)⁽⁴⁾ has an assistance system on both the knowledge and motion levels, and is designed so that the operator and robot can perform the task cooperatively. In particular, the assistance system on the motion level is designed well so that the operator can easily cooperate with the robot which is superior at precise and repetitive control.

In designing an intelligent interface, it is important for us to consider if the assistance system plays an important role. Then, personal differences among users become a problem. For this problem, an adaptive interface that adapts to the user, rather than the user adapting to the system, was studied⁽⁵⁾⁻⁽⁸⁾. The adaptive interface has an adaptation mechanism so that the system supports the user. CAI has an adaptive assistance capability on the knowledge level. However, on the motion level, the adaptive assistance system is hardly reported considering personal differences. In particular, most conventional interfaces

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on the motion level, such as semi-automatic operation systems, consider only the efficiency for working aim, and discomfort of a user is neglected. Thus we have studied an interface that is comfortable and efficient for use by the user during his/her cooperative work with machine. That is, we have considered the inclusion of an adaptive mechanism based on the G.S.R. (galvanic skin reflex)⁽⁹⁾ that is considered to have a relationship with the discomfort of humans, and we have shown the effectiveness of this system⁽⁸⁾.

In our previous works, we have considered the system's way of adapting to humans. However, in reality, human and machine both try to adapt to each other. Therefore, in this paper, we consider the importance of interaction between human and machine, and we propose a design and method for realization of the interactive adaptation interface based on recursive fuzzy reasoning⁽¹⁰⁾. We present the system considering the interactive adaptation and show some experimental results and their statistical evaluation results to discuss its effectiveness.

2. Interactive Adaptation Interface

In the process that a machine adapts to a user considering the interaction between them, we cannot neglect the relationship that both user and machine try to adapt to each other. We call this relationship interactive adaptation. The interactive adaptation interface (IAI/F) is an intelligent interface that is designed based on interactive adaptation. The interactive adaptation interface changes the characteristics of the system according to the given task by considering the state of the user such as skill level, technique, characteristics, and physical condition. This idea is shown in Fig. 1.

This kind of intelligent interface is supposed to be applicable in the future for the following example cases.

(1) Adaptive Operational Assistance Interface

Basically, the role of human is to execute a task

Fig. 1 Interactive adaptation interface

that is easy to deal with, and a task that is hard to deal with is executed by machine. Both of them cooperate with each other and perform their respective tasks safely and smoothly.

(2) Adaptive Information Assistance Interface

Human and machine understand each other, and maintain good communication efficiency with little redundancy. This is a kind of intelligent communication.

Figure 2 shows the application examples of the interactive adaptation system.

In this paper, we consider case (1) and aim at realization of the adaptive assistance on the motion level, and then propose a design method of an intelligent interface. As a concrete example of the cooperatively operating system, we applied this system to a virtual-reality simulation game (air hockey game). Using various subjects, we conducted a number of experiments and statistical evaluations.

3. System Configuration

3.1 Basic system structure

In realizing an adaptive interface, it is considered

(a) Adaptive operational assistance interface

(b) Adaptive information assistance interface

Fig. 2 Application examples of interactive adaptation system

that the following knowledge is needed⁽⁵⁾:

- 1) knowledge of the system;
- 2) knowledge of the user;
- 3) knowledge of the application;
- 4) knowledge of the interaction (the system and the user).

Based on the knowledge, the system needs to decide on an assistance method or level in an adaptive manner based on the user and his/her condition. The minimum necessary composition elements are (1) user observation system, (2) knowledge database, and (3) adaptive assistance system.

In order to change the interface characteristics based on the user's attribute and his condition, a system that observes the user, and estimates his/her skill level, emotion, and physical conditions is required. Then the interface refers to the knowledge database to check if it is necessary to change its characteristics. This step must be performed so as it reduces discomfort of the user and task is performed smoothly. We call the part that changes the interface characteristics in order to adapt to user's condition the adaptive assistance system.

Figure 3 shows the system configuration. The observation system evaluates the task performance of the user and measures the mental stress. If the mental stress is high, the interface works to reduce the mental stress and to improve the performance. Psychological evaluation is hardly performed before as we did in this paper to design the assistance system.

3.2 Evaluation method of operational state

The skill level of the user can be judged by evaluating the task performance. On the other hand, psychological evaluation of the user has been researched actively in the experimental field of psychology. Recently it has become easier possible to obtain an electroencephalogram, an electrocardiogram, a heart-beat, respiration, galvanic skin reflex, and measurement of eye movements. Moreover, much research work concerning human recognition processing that is based on analyses of these data has been performed already. However, it is difficult to understand the condition of the user completely, because the amount

of data is too much due to individual differences and the data are complicated. Therefore, in this paper, in order to simplify a problem as much as possible, we pay attention to the evaluation result of the task performance and mental stress of the user, and propose a way of improving the adaptability of the assistance system. Here, we use the galvanic skin reflex to evaluate the psychological state of the user. A G.S.R. measuring apparatus is used in several psychological experiments.

3.3 Assistance method

The assistance method at the adaptive assistance part is divided into knowledge level and motion level. In this paper, we consider the interactive adaptation on the motion level. The system changes the automation level according to the user's performance and mental state.

In designing an intelligent interface, it is important to develop a useful assistance system. In general, if the skill level of the user is low, it is preferable to prepare a strong assistance system. On the other hand, for the user whose skill level is high, the strong assistance system may make the task boring, and the opportunity to get higher skill will decrease. Thus, in this work, the system is designed to reduce its automation level as the skill level of the user becomes high. On the other hand, when the mental stress is increased, we increase the assistance level to improve the user's performance. If the performance is improved, the mental stress will be decreased and the working condition will be improved. This will have a good effect on the user performing the task. This is a kind of interactive effect caused by increasing the assistance level.

3.4 Interactive adaptive assistance using recursive fuzzy reasoning

If the user's skill is evaluated only by an indirect parameter such as score, a sudden change of the assistance system may occur depending on the sampling period. In such cases, assistance level changes suddenly in the previous system⁽⁶⁾. Generally speaking, few users can adapt to such a sudden change and it is not preferable for the users. This will cause maladjustment of the user to the operation system and problems on the part of the users. This situation is shown in Fig. 4(a). In the process of the user adapting to the system, the following are the problems that must be solved in order to realize interactive adaptation.

- (1) Difficulty in obtaining the characteristics of the user continuously.
- (2) Difficulty in adjusting from a single observation.
- (3) Inability of the user to cope with the sudden

Fig. 3 System configuration

Fig. 4 Transition in adaptation process

change of the system.

In order to prevent sudden change and to consider the interaction between human and machine in their attempt to adapt to each other, we propose that the assistance level be determined under transition of the measurement data. Moreover, since the state of a human is obvious in general, we apply fuzzy reasoning to determine the assistance level. We propose the use of recursive fuzzy reasoning⁽¹⁰⁾ in calculating the assistance level. Equations (1) and (2) are used for recursive fuzzy reasoning based on the simplified fuzzy reasoning.

$$f^{(1)} = \frac{\sum_{i,j} (\mu_a^{(1)} \times \mu_b^{(1)}) K(a_i^{(1)}, \beta_j^{(1)})}{\sum_{i,j} (\mu_a^{(1)} \times \mu_b^{(1)})} \quad (n=1) \quad (1)$$

$$f^{(n)} = \frac{\sum_{k=0}^n \sum_{i,j} \rho^k (\mu_a^{(n-k)} \times \mu_b^{(n-k)}) K(a_i^{(n-k)}, \beta_j^{(n-k)})}{\sum_{k=0}^n \sum_{i,j} (\mu_a^{(n-k)} \times \mu_b^{(n-k)})} \quad (n \geq 2) \quad (2)$$

where ρ : Fading factor

We can estimate the change of user's skill level by evaluating transition of the measurement data. Based on the assistance system, we can expect a gradual improvement of the user's skill level as shown in Fig. 4(b). This kind of system can keep pace with the user, and we call it the "pacing system." The pacing system changes the assistance level in accordance with the performance and mental state of the user, leading to a gradual improvement of the user's skill. It can be applied to an educational system.

4. Experimental System

Next we present an application example of the proposed system. We use a virtual-reality simulation game (air hockey game⁽⁸⁾) as the model, because it is relatively easy for realization and for implementation

Fig. 5 Experiment system

Fig. 6 Photograph of experiment

of the assistance system.

In the air hockey game, a ball bounces on a court, and the user strikes the ball with a racket. Direction and speed of the ball change depending on its point of contact on the racket. If the user fails to hit the ball, the ball disappears, and if the user strikes, a score of 1 point is obtained.

The user is fit with a H.M.D. (head mount display), and while viewing through the H.M.D., the user plays the game. The inclined angle of the user's head is detected by angle speed sensors in the yaw, roll, and pitch angle directions, and those data are utilized for coordinate transformation of 3D graphics on the display of the H.M.D. In this way, the user can experience a virtual-reality world through the H.M.D.

As an input device for locating the racket on the display, a one degree of freedom manipulator is used as a joystick. An encoder and a DC motor have been equipped in the manipulator, and position control is possible. An experimental system is shown in Fig. 5, and a photograph is shown in Fig. 6.

5. Observation of Psychological State

5.1 Galvanic skin reflex (G.S.R.)⁽⁹⁾

It is widely known in the psychological field that the mental stress is reflected as a change of G.S.R. The G.S.R. measuring apparatus shown in Fig. 7 can

measure the skin potential reflex that is related to emotional changes of a user, and is used frequently in psychological experiments. The skin potential reflex of the user is influenced by emotion, especially tension. This apparatus is also known as a lie detector.

With the G.S.R. measuring apparatus, skin potential reflex is detected from the resistance values of the middle finger and the third finger of the hand that does not hold the joystick. Generally, the resistance values are constant when the user is calm. On the other hand, when the user suffers from discomfort, the resistance values increase. The resistance change reflects the mental state of the user.

5.2 Measurement condition

The G.S.R. measuring apparatus detects a slight change of skin resistance; thus, various factors can affect measurement data. For example, if the user talks, sways his/her body, or coughs, a change in the output appears. In the experiments, users are prohibited to talk and make unnecessary movements, and the experiments are conducted under the condition that the user is alone. Every user washes his/her hands with soap prior to the experiments

5.3 Definition of mental stress

Here we define the mental stress in an operational way. Definition of a concept based on objective operation and actual measurement is called "operational definition." Here, based on the operational definition, we define the maximum value of the mental stress using the G.S.R.

In order to include maximum mental stress in users, we let them start the game without any assistance or preparation. We define the maximum value of the G.S.R. as the state of the user suffering from the maximum mental stress. In the experiments, the maximum value of the G.S.R. is used to normalize the G.S.R. measurement data collected from each user.

Fig. 7 G.S.R. measuring apparatus

6. Assistance System

One set of the game consists of a total of 10 sessions. In each session, the total number of balls is 4 and perfect score is 15 points. In the first 5 sessions, the joystick's input moving direction and racket's output moving direction are the same. However, in the last 5 sessions, they are reversed. The users are informed of this just before the direction is changed. In the first 5 sessions, the user gets accustomed to the system to some extent. By introducing this change, we can easily observe how the subject gets accustomed to the task in the next 5 sessions. In the first and the 6th session, the assistance system is turned off. In the other sessions, the assistance system is turned on and the automation level is calculated by recursive fuzzy reasoning. To calculate the automation level of the joystick, we define the score rate as follows.

$$\text{Score Rate} : P = (\text{Point}/15) / (\text{Number of Balls Used}) \times 100 [\%] \quad (3)$$

As an assistance method, we use the compliance control system based on the deviation between the estimated ball position x_d and the present racket position x . Figure 8 shows deviation of the compliance control system. The equation of the racket's motion is as follows.

$$m\ddot{x} = F \quad (4)$$

$$F = k(x_d - x) - c\dot{x} \quad (5)$$

$$k = f^{(n)} \cdot k_0 \quad (6)$$

where F : Assistance force

k : Assistance force gain,

c : Damping coefficient

Assistance force is changed by the assistance force gain. k is calculated from the score rate and the G.S.R. ratio using recursive fuzzy reasoning. Table 1 shows the assistance rules for calculating k . Figure 9 shows the membership functions. Here, the interactive adaptation system aims at improvement of the skill level and reduction of the mental stress. As stated in section 3, we aim at the skill level improvement and not at merely increasing the score rate. Thus, the assistance force is decreased as the score rate increases. This is because we want to prevent the

Fig. 8 Deviation of the compliance control system

Table 1 Assistance rules

		(a)		(b)	
		G.S.R. (Mental)	Relax $\beta 1$	Impatience/ Excitement $\beta 2$	Assit Strength
Expert	$\alpha 1$	A1	A2	No	A1 0.00
Intermediate	$\alpha 2$	A2	A3	Weak	A2 0.33
Beginner	$\alpha 3$	A3	A4	Intermediate	A3 0.67
				Strong	A4 1.00

(a) Score rate

(b) G.S.R. ratio

Fig. 9 Membership functions

system from becoming boring and to give the user an opportunity to exercise. On the other hand, if the mental stress is high, we increase the assistance level so that the score rate increases.

7. Experimental Results

7.1 Evaluation method

First, the experiments were conducted for a total number of 29 persons who were instructed to play one set (10 sessions) without assistance. Next, a total number of 14 persons were selected randomly out of the 29, and the experiments were conducted to see the effectiveness of using recursive fuzzy reasoning. That is, 7 persons selected randomly out of the 14 played one set with the assistance based on ordinary fuzzy reasoning first, then they played another set with the assistance based on recursive fuzzy reasoning. The other 7 persons out of the 14 played one set with the assistance of recursive fuzzy reasoning first, then they played another set with the assistance of ordinary fuzzy reasoning. To exclude the effect of the subjects being accustomed to the game, the order of the experiments is reversed like this.

For the evaluation of the experimental results, we used the following criterion function.

$$J = c_1 P + c_2 (1 - G) - c_3 A \quad (7)$$

where

$$G = (\text{G.S.R.}) / (\text{G.S.R.}_{\max}) \quad (8)$$

$$A = k / k_{\max} \quad (9)$$

Fig. 10 Comparison between assistance types (Transition of criterion function)

c_1, c_2, c_3 : weight functions

We evaluate the experimental results by setting $c_1 = 1$, $c_2 = 0.5$, $c_3 = 0.3$.

7.2 Experimental data

Figure 10 shows the results obtained with and without using the recursive method. In the experiments, the fading factor ρ is 0.5, which was determined based on experience. The mean values of the criterion functions for each session are depicted here. Figure 10 also shows the mean values of the criterion functions for the case without assistance. With assistance, we can clearly see that the criterion function increases. In fact, the users became accustomed to the task to some extent in the first set. However, we can say that the assistance is useful in their performance of the task. This is also clear from the introspective report from the subjects after the experiments. All subjects felt that the assistance system was useful.

Figures 11 and 12 show the standard deviation of the experimental data obtained with and without the recursive method. From these results, we can see that the criterion function increases with the use of the recursive method. In the case of using the recursive method, the mean value change of the criterion function is smooth compared with the case without the recursive method. Therefore, the concept of the preferable change in the adaptation process in Fig. 4(b) is attained.

7.3 Analysis of variance

We conducted the statistical analysis (analysis of variance), and the results are shown in Table 2. Table 2 is the results comparing the case of using recursive fuzzy reasoning with the case of using ordinary fuzzy reasoning. Variance ratio is 3.671, and is larger than significant F calculated from the F -distribution table (2.909). Thus the hypothesis "There is a difference between the case using recursive fuzzy reasoning and that using ordinary fuzzy reasoning" is significant at 10% level of significance.

From these results, we can say that the performance is improved and G.S.R. is kept at a low value

Table 2 Statistical analysis
(Effectiveness of Recursive Method)

Total number of subjects: 14

(a) Mean of criterion function

F.R. (Fuzzy Reasoning)	2.56
R.F.R. (Recursive Fuzzy Reasoning)	4.50
Total variables	3.53

(b) Analysis of variance

	Sum of squares	Degree of freedom	Unbiased variance	Variance ratio
Total variation	50.913	27		
Between class variation	6.2985	1	6.299	3.671
Within class variation	44.614	26	1.716	

(c) *F*-distribution

Degree of freedom 1	Degree of freedom 2	Level of significance	F
1	26	0.050	4.225
1	26	0.100	2.909

Fig. 11 Experimental results (Ordinary Fuzzy Reasoning)

Fig. 12 Experimental results (Recursive Fuzzy Reasoning)

by using the proposed assistance system. Realization of interactive adaptation is attained by evaluating G.S.R. and using recursive fuzzy reasoning in the

system.

8. Conclusions

The proposed interactive adaptation interface is found to be effective from the statistical analysis of results from various experiments. The previous problem of sudden change in the assistance level is improved by recursive fuzzy reasoning. In this paper, the assistance rules are fixed for every subject and we can get fairly good results. However, for the realization of a much more adaptable interface for personal use, we hope that the assistance rules can be tuned automatically depending on the user in the future. The proposed system can be used in the educational system, and we hope that the system is useful for designing CAI on the motion level.

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