Paper:

Psychological Effects of a Synchronously Reliant Agent on Human Beings

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The ability of human symbiosis robots to communicate is indispensable for their coexistence with humans, so studies on the interaction between humans and robots are important. In this paper, we propose a model robot self-sufficiency system that empathizes with human emotions, a model in which we apply the urge system to an autonomous system of emotions. We carry out simulation experiments on this model and verify the psychological interaction between the software robot and its users.

Keywords: urge system, self-sufficiency, Kansei agents, human-agent interaction

1. Introduction

The function of emotion is important in the study of robots with frequent human interactions. In [1, 2], we developed a pet robot with the ability to act as if it had autonomous emotions. When interacting with human beings, this kind of robot has the potential to entertain and relax. In addition, in [3, 4], a robot, Kismet, was developed with coordinated eyebrows, eyes, a mouth, and ears. In this robot, emotion was generated from 3 axes, namely arousal, valence, and stance, and a method for generating corresponding facial expressions was proposed. Furthermore, in [5, 6], it is stated that in order to give machines a warmer feel, there is a need for an Active Human Interface (AHI). The proposed AHI is "an expression selection system. It expresses the robot's state and desires, depending on the external environment."

As in the systems mentioned above, there has recently been the development of emotion as an autonomous function that allows the robot to act emotionally according to the dynamics of the environment. Ando et al. have proposed a self-sufficiency model which uses the urge system [7, 8]. This system uses an emotion theory which has within it an autonomous selection system that adapts to the environment. This model's effects on the psychological state of humans have been verified [9, 10]. As a result, a robot that is able to communicate its psychological and physiological state as well as to meet its needs by depending on others is psychologically relaxing and entertaining for human beings. However, because the emotion expression selection process is fixed and dependent on the agent, the experience for users is unambiguously fixed.

In this paper, we propose a model that actively attunes its expressions of emotion of the agent to the emotions of the user. The model uses Russell's circumplex model of affect [11].

This paper is organized as follows. First, in Sections 2 and 3, self-sufficiency and the urge system are explained. Then, in Section 4, a conventional self-sufficiency model is explained [9, 10]. In Section 5, we propose a model which attunes itself to people, extending the conventional decision making phase. In Section 6, the validity of the proposed model is verified through a simulation experiment. Section 7 presents our conclusions.

2. Self-Sufficiency

Self-sufficiency is the ability of an agent to maintain itself over a long period of time, and it is one of the five characteristics (adaptability, autonomy, self-sufficiency, embodiment, and situatedness) of a completely autonomous agent [12, 13]. For example, a robot may maintain its battery level by supplying itself with fuel. At first, self-sufficiency may seem to imply complete independence, but many real world examples depend on others for maintenance. For example, human babies are dependent on their mothers, and they attain self-sufficiency through their mothers. In other words, babies express their emotional and physiological state through expressions and actions which are detected by the mother, who then satisfies the baby's needs.

3. Urge System

Urge theory is a theory of emotion that extends conventional emotion concepts. In this theory, it is assumed that emotion includes a sophisticated wilderness rationality, which is an environment-adaptive action selection system (mental software). The basic framework of the system is assumed to be passed on genetically. The mental software controls the physical and mental abilities used for physiological activation, such as learning, recognition, memory, awareness, and physical functions. An emotion, which is activated for an objective, is called an "urge," and the mental software is called the "urge system."

3.1. Urge

In the urge system, emotional concepts are divided into urge and mood. For example, the "anger urge" occurs when "someone breaks something that one treasures." On top of conventional emotional concepts, "hunger," a "physiological urge" that is triggered by an inner signal, is also defined as movement of one's emotional state. As one of the defining characteristics of the urge system, physiological functions such as hunger, which conventionally is not seen as an emotional state, is categorized as an emotion.

3.2. Mood

While urge is an emotional state with a unique objective, mood is an emotional state without an objective. For example, emotional states such as "joy" and "sadness" are moods. In the rage urge, an activity plan, such as "revenge against the assailant," is generated. Urges such as the joy urge and sadness urge do not exist; such actions are part of the "demonstration urge." On the other hand, mood controls the ease of urge generation.

3.3. Four Phases of Urge Activities

The urge system separates an urge activity into the following four phases: activation, decision-making, action-control, and post-mortem. The activation phase is the process of assessing the situation, the decision-making phase is the selection of an activity plan generated by the urge, the action-control phase is the execution of the activity plan, and the post-mortem phase is the examination of the activity (a type of recognition urge).

4. Conventional Model

4.1. Overview

Figure 1 presents an overview of the conventional model [9, 10]. In the conventional model, the urge process is based on the four phases, which are processed sequentially. First, in the activation phase, information is recognized from the environment (situation recognition), and a corresponding urge is generated. Then, in the decision-making phase, an activity plan is selected for the performance of specific actions (such as facial expressions) based on the urge that is invoked. The action that is performed in the activation phase allows the user to observe the change in mental state of the agent. Therefore, it is possible for the user to dynamically approach the agent. Furthermore, situation recognition is altered by the approach of the agent, which can be used to model the post-mortem phase. For example, if the user approach is desirable for the agent, the joy mood can be increased. If the user approach is not desirable for the agent, then the sadness mood is increased. Using the above flow, it is possible for the agent to satisfy its self-sufficiency while depending on others (users).

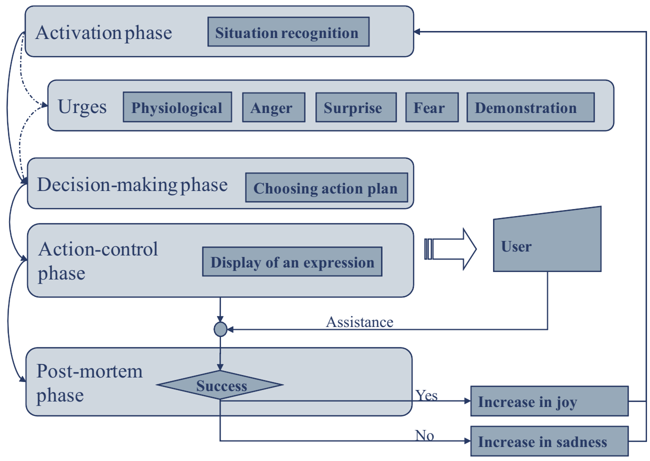

Fig. 1. Overview of the conventional model.

4.2. Execution of the Urge System

Situation recognition, which generates each urge for the agent, will be defined.

4.2.1. Situation Recognition

The input of the agent is divided into inner and outer components. The parameter inputs for the inner component are physical load $p(t)$ at time t, and the favorability ranking for the target of attention[1] $f(t)$. These parameters are calculated in the following equations:

$$\mathscr{P}(t) = \alpha_p \mathscr{P}(t-1) + p(t), \quad \ldots\ldots\ldots (1)$$

$$\mathscr{F}(t) = \alpha_f \mathscr{F}(t-1) + f(t). \quad \ldots\ldots\ldots (2)$$

Here, α_p and α_f are damping constants, where $0 < \alpha_p, \alpha_f < 1$. Take note that the number of physical load types is equal to the number of input signals for the inner component. For example, robot agents have physiological urges, such as the urge that is generated when the battery is low or when the CPU temperature is high. For each physical load, $p(t)$ and $\mathscr{P}(t)$ must be defined. Therefore, physical load can be defined as vectors $\mathbf{p}(t) = (p_1(t), p_2(t), \ldots)$ and $\mathbf{P}(t) = (\mathscr{P}_1(t), \mathscr{P}_2(t), \ldots)$ (subscripts are the physical load identifiers).

Next, the external component of the input determines the existence of the user with variable $o(t)$.

$$o(t) = \begin{cases} 1 & \text{(User exists)} \\ 0 & \text{(User does not exist).} \end{cases} \quad \ldots\ldots (3)$$

1. Target of attention means target for selection. For example, if the agent desires a handy stick, the target of attention includes all possible sticks that meet certain criteria, e.g., the stick cannot be too big.

The abovementioned situation recognition determines the process of the activation phase.

4.2.2. Activation Phase

According to Ekman, there are six basic emotions generated as urges (anger, surprise, fear, disgust, sadness, and joy) [14]. Out of the six urges in the activation phase, the ones that correspond to conventional emotions are the anger, surprise, and fear urges. Joy and sadness are expressed by the demonstration urge. In addition, physiological urges, which include internal factors specific to the agent (physiological and physical state variable), are activated when the physiological state has deteriorated and can be associated with the expression of disgust.

In the activation phase, each urge is activated according to situation recognition. During this phase, the agent takes in input variables so that urge can be generated at any time.

Conditions for the generation of each urge are mentioned below.

(a) Physiological urge:

The physiological urge includes pain, appetite, and sexual desire. It is mostly activated through internal signals. The physiological urge that corresponds to the physical load i is activated by the following equation.

$$\mathscr{P}_i(t) > \theta_{phys}. \qquad (4)$$

Here, θ_{phys} is the criteria for physiological urge activation.

(b) Anger urge:

Characteristics of anger can be seen in the territory defense behavior of animals. In other words, when an infringing entity compromises the authority of a turf, the occupants will feel anger against that entity. In this research, such raw emotional functions observed in wild animals can be used as references. The activation condition for the anger urge is defined as abnormal physiological values caused by an external input (user).

$$o(t) = 1 \text{ and } \exists i(p_i(t) > \theta_{ang}). \qquad (5)$$

Here, θ_{ang} is the criteria which activates the anger urge.

(c) Surprise urge:

The surprise urge is activated when there is no input, as expected according to the anticipated target system,[2] or when there is input from a target not included in the general targets of attention.[3] For example, the surprise urge is triggered when there is no sound while the agent is expecting one. Therefore, the activation condition for the surprise urge can be defined as "an unexpected input, or no input when one is expected."

$$\exists i\,(p_i(t) - p_i(t-1)) > \theta_{sup} \text{ or } o(t) = 1$$
$$\text{and } \exists j\,(\mathscr{P}_j(t) > \phi_{sup}) \text{ and}$$
$$\exists k\,(p_k(t) > \rho_{sup}),\ (j \neq k). \qquad (6)$$

Here, θ_{sup}, ϕ_{sup} and ρ_{sup} are criteria for activation of the surprise urge.

(d) Fear urge:

The fear urge is activated when the agent feels that "if nothing is done, harm will be done to me" or "I lack the ability to control the dangers of this situation." Therefore, the condition for activation of the fear urge will be defined as a "situation in which an agent cannot rest because of high danger levels." High danger levels can be described using internal input $\mathscr{P}(t)$. The agent cannot go to rest when activation of the physiological urge is constrained by an external input. The activation of the fear urge is defined by the following equation.

$$o(t) = 1 \text{ and } \exists i\left(\mathscr{P}_i(t) > \theta_{fear}\right). \qquad (7)$$

Here, θ_{fear} is criteria for fear urge activation.

(e) Demonstration urge:

The demonstration urge is used to express the agent's change of state to the outside world. The conditions for activation urge are dependent on the increase or decrease in the joy/sadness mood; this increase or decrease is triggered by the approach of the user.

$$\mathscr{F}(t) < \theta_{sad} \text{ or } \theta_{joy} < \mathscr{F}(t). \qquad (8)$$

Here, θ_{sad} and θ_{joy} are criteria for demonstration urge activation, where $\theta_{sad} < \theta_{joy}$. When the criteria are met, the demonstration urge is activated. However, depending on the value of $\mathscr{F}(t)$, the activation plan may change.

4.3. Decision-Making Phase

More than one urge can be activated in the activation phase. In some situations it is possible for multiple urges to be activated, and such situations occur more often than single urge activation does. In addition, even if the same urge is activated, the selected activity plan may not be the same. The implementation of decision making is very difficult because many factors are closely intertwined. Therefore, in the conventional model, urge is prioritized and selected according to this priority list. This list describes the potential strength of each urge and is defined by the following formula:

$$\begin{aligned} &\textit{surprise urge} > \textit{fear urge} > \textit{anger urge} \\ &\quad > \textit{physiological urge} > \textit{demonstration urge}. \end{aligned} \qquad (9)$$

2. The target system is the target system corresponding to an anticipated situation, which includes all targets of attention for a certain period of time.
3. The target of attention is relevant to the survivability of the agent.

4.3.1. Action-Control Phase

In the activity phase, the activity determined in the decision-making phase is executed. In other words, when an activity plan is selected in the decision-making phase, a corresponding activity is generated.

4.3.2. Post-Mortem Phase

In the post-mortem phase, the success or failure of an urge activity is evaluated, and learning is performed to modify future activities. The user's approach is evaluated and feedback is given in the form of joy or sadness moods. In other words, if the user takes the correct actions, the joy mood is increased, while the wrong actions will increase the sadness mood. The favorability rating is described by the following equation:

$$f(t) = \begin{cases} 1 & \text{(Help success)} \\ -1 & \text{(Help failure).} \end{cases} \quad \cdots\cdots \quad (10)$$

5. Self-Sufficiency Model Which Attunes to and is Dependent on Others

A problem with the conventional model [9, 10] is that, because the execution of the decision-making phase uses Eq. (9), the actions of the agent give every user the same impression. Iihoshi et al. [15] proposed a self-sufficiency model that outputs a flexible and appropriate action for each user input. However, this model does not take into account decision making when multiple urges are activated. Furthermore, learning for urges that are rarely activated is difficult because of the lack of data.

In the decision-making ability of a baby, it was observed that the baby attunes its emotional state to that of the mother, with whom the baby is the most familiar. According to the "visual cliff" experiment performed by Gibson and Walk, the baby decides its actions according to the mother's expressions rather than by assessing the situation on his/her own [16]. In the conventional model, the user interacts with the agent by observing the agent's facial expressions, but the agent is not able to understand the user's emotional state. It would take some good effects for the interaction of agents which depend on others for their self-sufficiency that attuning of the other's emotional state like "visual cliff."

Conventional methods use Russell's circumplex model of affect [11] to estimate a user's emotional state and generate emotion for the agent [17, 18]. In this paper, Russell's circumplex model of affect will be included in the decision-making phase for the self-sufficiency model. The circumplex model will be used to capture the user's emotional expressions.

5.1. Russell's Circumplex Model of Affect

In this paper, in order for the agent to understand the user's emotional state, Russell's circumplex model of affect [11] is used. In the circumplex model, the emotional state is described in a 2-dimensional space, with axes alertness-sleepiness and pleasure-displeasure. Therefore, each emotion is expressed as points designated by two-dimensional coordinates, and the distance between points can be used as a quantitative measure of emotions. Mapping user emotions onto this 2-dimensional space clarifies the user's emotions.

5.2. Decision-Making Phase for a Self-Sufficiency Model Which Understands the User's Emotional State

In the polar coordinate system of Russell's circumplex model of affect, joy and sadness are described by the amplitudes ϕ_{joy} and ϕ_{sad}. The integral of the favorability rating $\mathscr{F}(t)$ is the integral of $f(t)$. The function $f(t)$ is given a -1 when assistance of the user fails, and it is given a $+1$ when the assistance of the user succeeds. Therefore, when $\mathscr{F}(t)$ is positive, joy is expressed, and when $\mathscr{F}(t)$ is negative, sadness is expressed. The absolute value of $\mathscr{F}(t)$ describes the strength of the mood. The coordinates of the agent's mood $(r_x(t), r_y(t))^T$ (rectangular coordinates) can be described using $\mathscr{F}(t)$ in the following equations:

$$\begin{pmatrix} r_x(t) \\ r_y(t) \end{pmatrix} = \begin{cases} \begin{pmatrix} \mathscr{F}(t)\cos\phi_{joy} \\ \mathscr{F}(t)\sin\phi_{joy} \end{pmatrix} & (\mathscr{F}(t) \geq 0) \\ \begin{pmatrix} \mathscr{F}(t)\cos\phi_{sad} \\ \mathscr{F}(t)\sin\phi_{sad} \end{pmatrix} & (\mathscr{F}(t) < 0) \end{cases}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots \quad (11)$$

Here, if the user's emotional state is given as coordinates $(u_x(t), u_y(t))^T$, then the mixed mood of the user and the agent $\mathbf{F}^*(t) = (r_x^*(t), r_y^*(t))^T$ can be defined by the following equation:

$$\begin{pmatrix} r_x^*(t) \\ r_y^*(t) \end{pmatrix} = \begin{pmatrix} r_x(t) + u_x(t) \\ r_y(t) + u_y(t) \end{pmatrix} \quad \cdots\cdots \quad (12)$$

In urge theory, mood affects the activation of an urge. In this paper, the agent's mood is calculated as the sum of the user's emotional state and the agent's mood. For example, if the user is expressing sadness and the agent is expressing joy, then the agent's mood will be affected by the user's, and the agent will become calm. This kind of change in mood activates different urges.

In Russell's circumplex model of affect, the similarity between emotions is described by the distance on the 2-dimensional plane. In urge theory, mood affects the activation of urges. Therefore, in this paper, during the decision-making phase, urge $\mathscr{D}(t)$ closest to mixed mood $\mathbf{F}^*(t)$ is activated.

$$\mathscr{D}(t) = \arg\min_{d \in D} |\mathbf{F}^*(t)\mathbf{E}(d)| \quad \cdots\cdots\cdots \quad (13)$$

Here, D is the set of possible urges, where $D = \{distressed, angry, surprise, fearfull, sad, joy\}$, and each element corresponds to physiological, anger, surprise, fear, and expression (expression of sadness/joy) urges. $\mathbf{E}(d)$ describes the coordinates in Russell's circumplex model of affect (**Fig. 2**). For example, if the user and agent's mixed mood is SAD and the possible urges are surprise and fear, the conventional method will prioritize surprise, but the proposed method will prioritize fear.

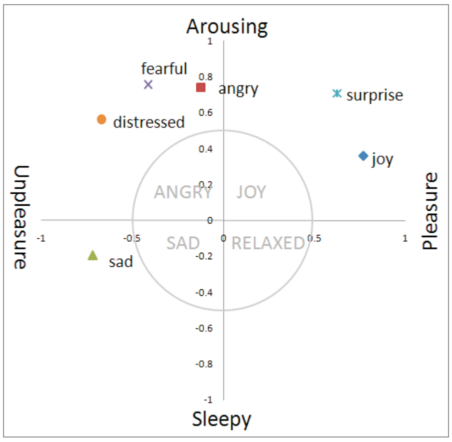

Fig. 2. Coordinates for each emotion on Russell's circumplex model of affect.

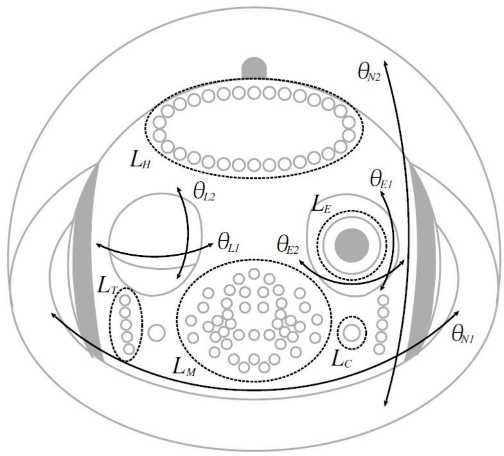

Fig. 4. Expression display mechanism of ifbot.

Fig. 3. External view of ifbot.

6. Simulation Experiment

To verify the validity of the proposed model, three agents were created. An application was created that interacts with each agent, and a comparison experiment was performed. As the agent, ifbot was used.

6.1. ifbot

Figure 3 is an overview of ifbot. ifbot is 45 cm tall and weighs 9.5 kg. It has two arms and moves on its attached wheels. **Fig. 4** gives an overview of the expression display components of ifbot. ifbot has 10 motors and 101 LEDs for expression display. The motors are placed as follows: 2-axis in the neck (θ_{N1}, θ_{N2}), 2-axis for both eyes ($\theta^{(L)}_{E1}$, $\theta^{(L)}_{E2}$; $\theta^{(R)}_{E1}$, $\theta^{(R)}_{E2}$), and 2-axis for both eyelids ($\theta^{(L)}_{L1}$, $\theta^{(L)}_{L2}$; $\theta^{(R)}_{L1}$, $\theta^{(R)}_{L2}$). LEDs are placed as follows: head (L_H, orange, green, red), mouth (L_M, orange), eyes (L_E, green, red, blue), cheeks (L_C, red), tears (L_T, blue), and ears (orange). ifbot uses these components to interact with the user [19–21].

In this paper, the parameters ($\theta^{(L)}_{E1}$, $\theta^{(L)}_{E2}$, $\theta^{(R)}_{E1}$, $\theta^{(R)}_{E2}$, $\theta^{(L)}_{L1}$, $\theta^{(L)}_{L2}$, $\theta^{(R)}_{L1}$, $\theta^{(R)}_{L2}$, L_M, L_T) were used for expression display. The expressions displayed are shown in **Fig. 5**. The expression activated by the physiological urge de-

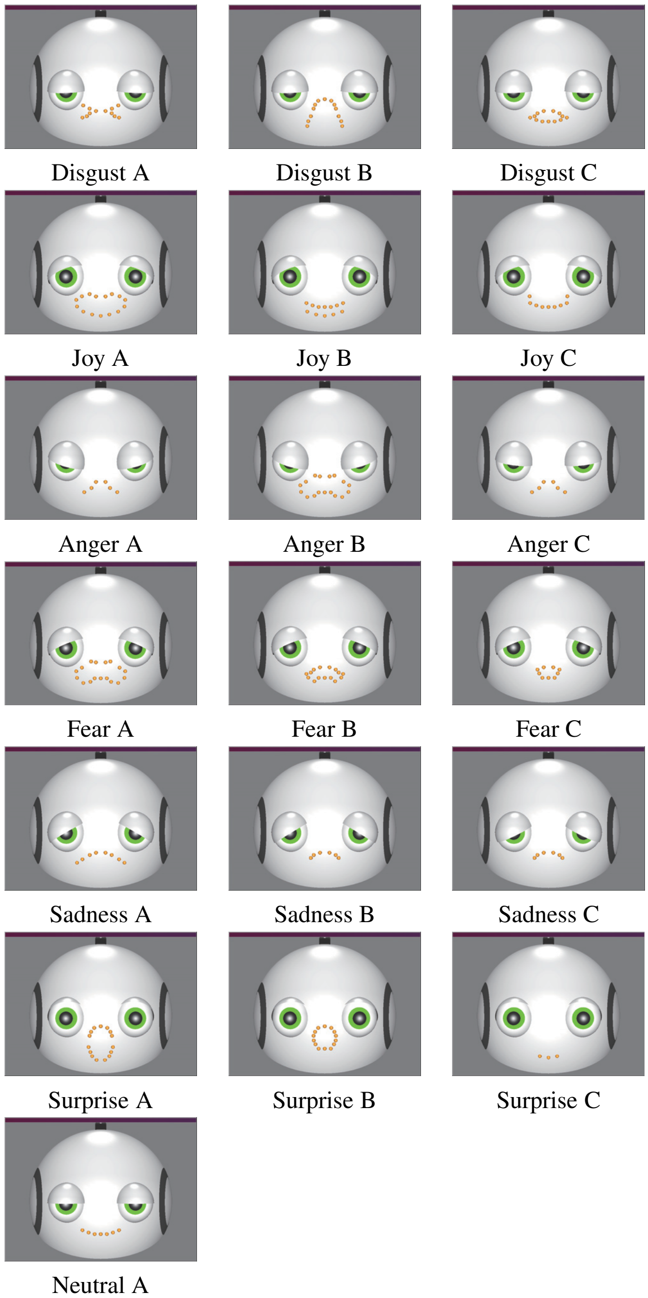

Fig. 5. Displayed expressions.

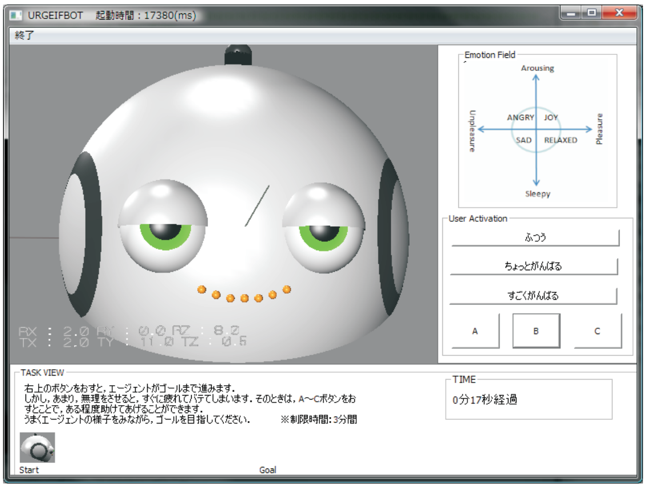

Fig. 6. Simulation experiment environment.

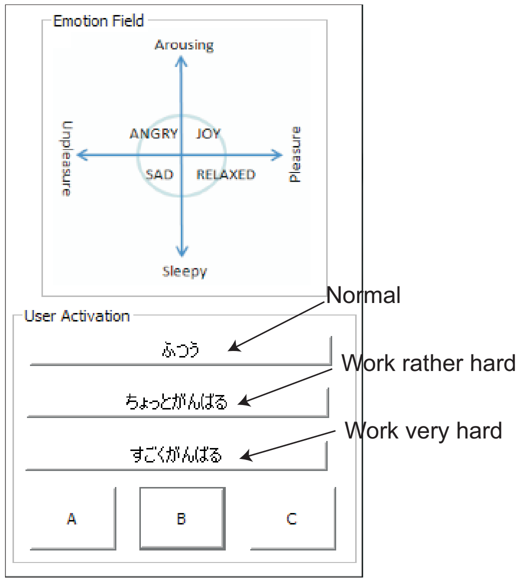

Fig. 7. Emotion Field window and User Activation window.

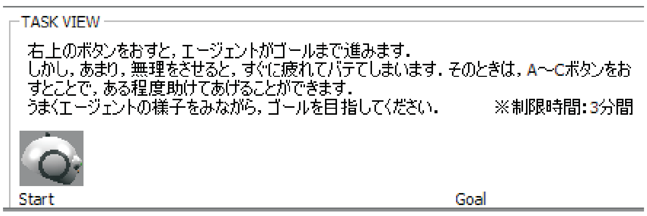

Fig. 8. TASK VIEW window.

scribes hatred. Expressions for anger, surprise, fear, sadness, and joy were also created according to each urge's characteristics. For example, for anger, the corners of the eyes point upwards and the corners of the mouth point downwards. These expression patterns were created from the characteristics of emotions, which were introduced in [14].

6.2. Experiment Application

An application was created (**Fig. 6**) for the interaction experiment. The application is a type of game in which the user assists the agents in reaching the goal within the time limit. The user and robot must work together to complete the tasks. In **Fig. 6**, the agent's expression is shown in the main window. The right hand side of the main window is the User Activation window and Emotion Field window (**Fig. 7**); the bottom portion is the TASK VIEW window (**Fig. 8**).

First, the user sets the amount of work of the agent by selecting either "normal," "work rather hard," or "work very hard." The amount of work is ordered as "normal" < "work rather hard" < "work very hard," and the greater work load increases the agent's movement and physical load. The amount of movement is displayed in the TASK VIEW window. In this experiment, there are three types of physical load, one of which is assigned randomly at the time of selecting the amount of work. Therefore, the user must determine the type of physical load from the expression of the agent shown in the main window.

Next, the user observes the agent's expression and assists the agent by pressing the A, B, or C button in the User Activation window. The assistance changes the situation recognition of the agent and activates a new physiological, anger, fear, surprise, or expression urge. The user observes the changes in the agent and decides the amount of work and type of assistance.

In the Emotion Field window, the user inputs his emotions. ifbot uses the input for its activity decision-making. In an optimal situation, the user's expression should be recognized through an emotion estimation system via a camera. However, emotion recognition is extremely difficult, so it was cut out from this experiment. The user inputs his emotion on an Emotion Field coordinate ($-1 < x < 1$, $-1 < y < 1$).

Russell's circumplex model of affect in [22] is used to categorize anger, joy, sadness, and calmness. In other words, the emotional state of the user is specified using the two axes of Russell's circumplex model of affect (alertness-sleepiness and pleasure-displeasure) and basic emotion labels corresponding to each quadrant.

Through the process mentioned above, the user assists the agent in reaching the goal. The agent is required to keep the physical load low and satisfy its self-sufficiency while reaching the goal as quickly as possible. However, the user cannot directly see the amount of internal physical load. The proposed method is verified by posing a trade-off problem between satisfying self-sufficiency and reaching the goal as quickly as possible.

Each test is concluded when the agent reaches the goal or the time reaches the limit. The conditions for the goal are when the label on the side of the agent's face changes from Start to Goal (shown in the TASK VIEW window). The agent aims for the goal while performing the amount of work chosen by the user (e.g., "normal" means to take one step and "work rather hard" means to take two steps) and at each timestep changes its facial expression in the main window according to environmental inputs. The as-

Table 1. Questionnaire items.

feels good – feels bad	kind – unkind
warm – cold	cheerful – gloomy
tender – tough	humorous – serious
rational – emotional	complicated – simple
square – round	shiftless – responsible
entertaining – boring	

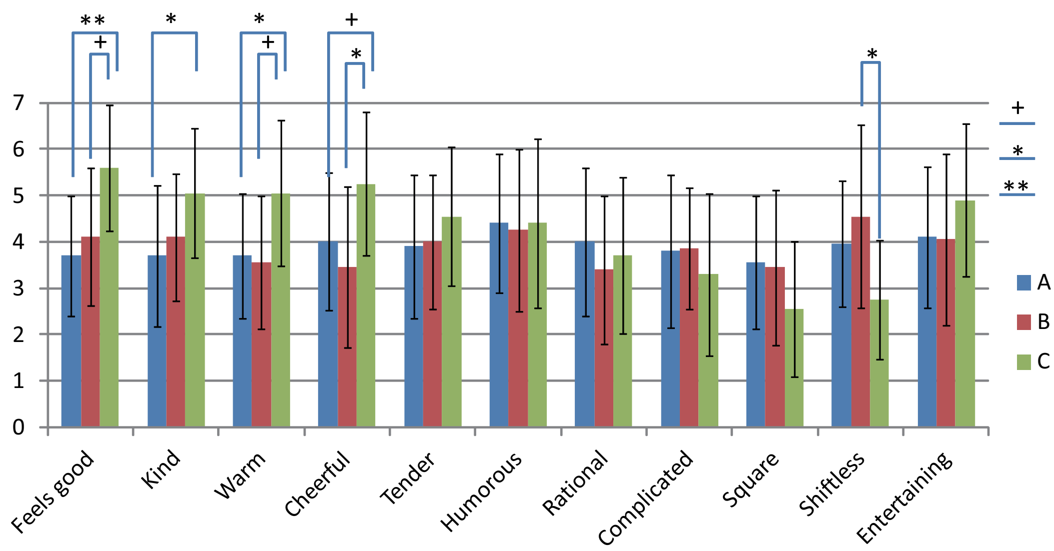

Fig. 9. Questionnaire answers.

sistance buttons A, B, and C in the User Activation window can only be pressed once during a specified time period. This is to account for the agent's response time.

6.3. Evaluation Method

A comparison experiment was performed using the application introduced in Section 6.2. Three applications were compared in the experiment.

- **Application (A)**

  In this application, the agent is not affected by the user's emotion input from the Emotion Field (**Fig. 6**). Therefore, the decision making for the expression display is random.

- **Application (B)**

  In this application, the decision-making process is performed by using the conventional model (priority ranking of urges) [9, 10]. The agent uses Eq. (9) for the decision making process and does not consider the user's emotion input from the Emotion Field.

- **Application (C)**

  In this application, the agent attunes to the user by using Russell's circumplex model of affect (proposed method). The agent recognizes the user's emotion through the user's input and changes its own emotional state accordingly. In this method, Eq. (13) is used for the decision-making process, as opposed to the conventional method, which uses Eq. (9).

In this paper, the agent is not trained to attune to the agent but instead observes the favorability of the user without training. Therefore, comparison with a method which uses training [15] was not included in the experiment.

The experiment was performed with 20 college students, and a questionnaire was administered by the SD method (**Table 1**) and free form.

6.4. Experimental Results

The Friedman test was used on the responses to the questionnaire, and Scheffe's multiple comparison was used to look for significant differences. **Fig. 9** shows the responses to the questionnaire, **Fig. 10** shows the goal timings, and **Fig. 11** shows the total physical load. The "$**$" and "$*$" in the figure indicate combinations with significance levels of 1% and 5%. The "+" indicates marginal significance ($p < .1$).

6.5. Discussion

First, when comparing application (A) (random) and application (C) (the proposed method), there was a 1%

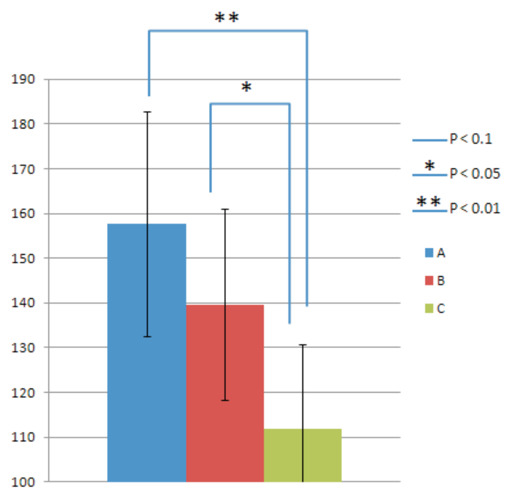

Fig. 10. Goal timings.

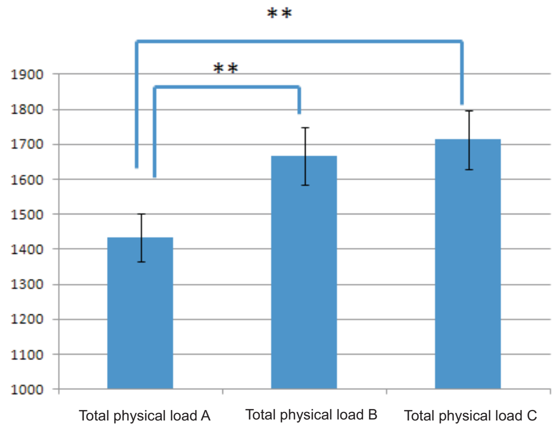

Fig. 11. Total physical load.

significance difference for "feels good," 5% significance difference for "kind" and "warm," and marginal significance for "cheerful." This may be because, in application (C), the user's feelings affect the agent's activities. For example, if the user is in a joyful mood, the agent will express joy as well, therefore giving the user a positive psychological effect. In reality, the test subject commented on application (A) that it was "difficult" and "did not move forward as intended." This is because the expressions of the agent were displayed at random. On the other hand, application (C) received comments such as "variety of expressions" and "moved forward as intended." Furthermore, if the user was not having fun, the agent tuned into the method; as a result, the user felt "good."

Next, application (B) (the conventional method) compared with application (C) had significant differences in "spiritless" and "cheerful" and marginal differences in "feels good" and "warm." Application (B) received comments such as "the tired expression was easy to understand" and "moved forward even though it was tired." This is because the conventional model's priority ranking of urges was able to satisfy the agent's self-sufficiency. However, because of this decision-making process, each time the agent became tired, the physiological and fear urges were activated. This resulted in comments such as "did not smile that much." Therefore, the agent gave off a "spiritless impression." On the other hand, application (C) gave a "cheerful" impression. Furthermore, because marginal differences were seen in "feels good" and "warm" in the comparison with application (C) (the proposed method), application (C) was effective.

Next, when comparing the goal timings, application (C) was significantly faster than the other applications. This may be because, when the user was feeling good, the agent's mood became attuned to the user's, and it retrained fear from activating, which allowed the agent to move forward more. Here, comparing the total physical load (**Fig. 11**) of the agent, there was no significant difference between applications (B) and (C). Therefore, even if the agent's mood became attuned to the user's, self-sufficiency was still satisfied.

Considering the abovementioned discussion, it can be said that the proposed method is able to become attuned to the user's emotional state, giving off an warm and kind impression while satisfying its own self-sufficiency at the same time.

7. Conclusion

In this paper, a decision-making method which includes an emotional state attuning system was introduced into the conventional self-sufficiency model. Specifically, the user's emotional state, which was mapped onto Russell's circumplex model of affect, was mixed with the agent's emotional state. The mixed emotional state was used in the decision making process. In the simulation experiment, the following three applications were compared: (1) random decision making (2) decision making using priority ranking of urges, and (3) decision making by becoming attuned to the user's emotional state (the proposed method). Interaction with the agent which attuned its emotional state to that of the user had a pleasurable effect on the users while satisfying its own self-sufficiency. However, in the proposed method, the agent may continue its movement even when the physical load is high. Therefore, this method is not appropriate for satisfying self-sufficiency in an effective manner. In other words, attuning the emotional state to that of the user gave users a positive impression, but the continuous positive expression of the agent resulted in a decrease in self-sufficiency. In the future, the relation between meeting the agent's self sufficiency, or decreasing the work load, and the user's mental state needs to be evaluated. Specifically, there needs to be compared with an agent that displays a positive expression at all times.

Finally, we will discuss the validity of the proposed agent, which attunes its emotional state to the user's. The method proposed in this paper gives users a "good feeling," a "warm" and "cheerful" impression. This kind of impression creates a feeling of "familiarity" and "commonality" in the users, and it may be possible for the user to use the agent for a long period of time. We feel that "taking care of a robot" gives the elderly a purpose in life, and we are developing a robot called Babyloid [23] for that purpose. Using the proposed method as the emotional state model will create a raison d'être for the robots.

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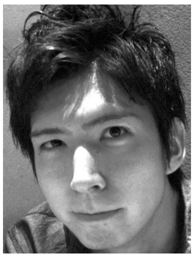

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