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Mood-transition-based Emotion Generation Model for the Robot's Personality

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***Abstract*—Recently, as the relationship between robot and human has become closer, humans demand that robots pose familiar human-like characteristics. For a robot to live and communicate with people, it requires its own personality or individuality. Changing the mood transition of robots can change the perceptions people have of their characteristics. We propose an emotion generation model that represents a robot's internal state. This model can assess the robot's individuality through mood transitions. We report experiments of emotional conversation with a robot that had this model installed. The experimental results showed that personality could be effectively expressed by changing robot's mood transitions. We also report significant results of evaluations of psychological impact.**

***Index Terms*—Sensitivity communication robot, Emotion generation model, Personality, Mood**

I. Introduction

Recently, as the relationship between robot and human has become closer [1], humans demand that robots pose familiar human-like characteristics. Now, robots are seen not just as tools, but as partners for humans to communicate with. There are many studies on emotion simulation for robotic agents. Breazeal [2] has introduced Kismet, that is an autonomous robot designed for social interactions with humans. Patrick [3] has introduced ALMA, that integrates three major affective characteristics: emotions, moods and personality. Miwa [4] has proposed the mental model for humanoid robots, WE-4RII. The robot changes its behavior according to its consciousness and learning. We also have proposed a sensitivity communication robot that changes behaviors according to the impression received from a person it is conversing with [5]. It dynamically changes its emotions according to the answer of the dialogist in conversation. The robot can assess the answers and then display "compatible" emotions to the dialogist through conversation.

For a robot to live and communicate with people in a natural way, it requires its own personality or individuality. Otherwise, it would seem awkward and out of place. We present an emotion generation model that represents a robot's psychological state of mind. This model can assess the robot's individuality through mood transitions. Mood is defined as a weak but relatively lasting affective state. It is an allowed or rejected expression of emotions [6], [7]. Human emotion is a comparatively intense, transient affective state, which is produced rapidly and is generally accompanied by clear expressive change [8].

We divide the robot's affective state into mood and emotion. Mood is a long lasting affective state that influences emotion. Emotion is a short lasting affective state that is clear and shown directly through expressions. Emotion is assessed from the amount of pleasure-displeasure of the robot and occurs in response to the influence of mood. Mood dynamically changes with the accumulation of past emotions. Changing the mood transition of robots can produce various characterizations in them as well as individuality that enables the robots to demonstrate a wide range of behaviors.

II. A Sensitivity Communication Robot Ifbot

A novel robot, the Ifbot, can communicate with humans through expressive and engaging conversations and emotional expressions that have been developed by our industry-university joint research project [9], [10]. With two arms, wheels instead of legs and with an astronaut's helmet, the Ifbot is 45 centimeter tall and weighs 7 kilograms. The Ifbot can converse with a person through fundamental voice recognition and voice synthesis engines. It can also communicate with a person, while showing its "emotions" through facial expression mechanisms and gestures. The mechanism for controlling Ifbot's emotional facial expressions has 10 motors and 101 LED lights. The motors manipulate Ifbot's neck (2 DOFs), both eyes and eyelids individually (2 DOFs for each). The Ifbot is also capable of recognizing up to 10 people using CCD cameras and a vision system.

III. Emotion Generatoion Model

Fig. 1 shows the overview of our emotion generation model. This model, in form that a dialogist answers to the question that a robot says, controls robot's emotions based on its mood and what is talked. The interior of the robot consists of three main processes: authentication, emotion, and conversation. In this paper, one set of a question and an answer is called one *QA*. A conversation is represented as a sequence *Conv* of *QA*s completed between the robot and the dialogist.

1) Authentication Process: A robot identifies a dialogist P from his face picture, and refers to the dialogist likability DB for likability L_P to P held in old conversations. When P does not exist in the dialogist likability DB, P is registered into this DB as a first partner who talks. The initial value of L_P is taken as 0.

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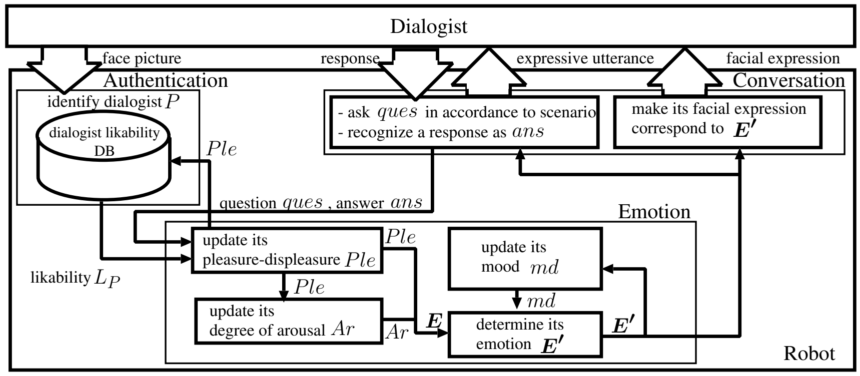


Fig. 1. Emotion generation model.

2) Emotion Process: The robot determines its emotion $\boldsymbol{E}$ from the pleasure-displeasure Ple and the degree of arousal Ar. By adding the influence of the robot's mood md to this, its emotion $\boldsymbol{E'}$ is determined. Ar and md are then updated accordingly. When a conversation is completed, Ple at the time is saved in the dialogist likability DB.

3) Conversation Process: The robot asks a question $ques$ in accordance to a scenario and then recognizes the response of the dialogist P as ans. When the robot's emotion $\boldsymbol{E'}$ is received from the emotion process, expressions corresponding to $\boldsymbol{E'}$ is expressed to P.

IV. Emotional Space

We use 2D emotion space model, Russel's circumplex model of affect [11], to determine emotion for simplicity. In this model, all affects exist on the two dimensional plane of pleasure-displeasure and degree of arousal. The kind and intensity of affects are represented by the direction and magnitude of a polar coordinates vector respectively. On the basis of this model, we built an emotional space of the robot that is defined in terms of two orthogonal dimensions, pleasure-displeasure and degree of arousal. The robot calculates its emotion $\boldsymbol{E}$ as follows in plotting the pleasure-displeasure Ple and the degree of arousal Ar.

$$\theta = \begin{cases} \cos^{-1}\left(\frac{Ple}{\sqrt{Ple^2+Ar^2}}\right) & (Ar \geq 0), \\ 2\pi - \cos^{-1}\left(\frac{Ple}{\sqrt{Ple^2+Ar^2}}\right) & (Ar < 0), \end{cases} \tag{1}$$

$$r = \begin{cases} \sqrt{Ple^2+Ar^2} & (\sqrt{Ple^2+Ar^2} \leq 1), \\ 1 & (\sqrt{Ple^2+Ar^2} > 1), \end{cases} \tag{2}$$

where (r, θ) is the polar coordinate expression of the position vector (Ple, Ar) in the robot's emotional space. The robot calculates its Ple from a word in the conversation and the word's likability rating that the robot has [5]. The robot calculates its Ar from its level of arousal and psychological load (such as fatigue and stress) from the conversation [12].

V. Mood

In this paper, we account for the robot's mood md as a transition model that changes between domains by accumulation of past emotions $\boldsymbol{E'}$. The emotional space is divided into four domains with the axis of pleasure-displeasure and degree of arousal. Each domain is considered as one mood domain and is called M_1, M_2, M_3, M_4, beginning at the first quadrant. The robot's mood md changes between these domains. The initial value of md is chosen one among M_1, M_2, M_3, M_4 randomly.

The robot has stacks for the changes in each mood, and the emotion $\boldsymbol{E'} = (r', \theta')$ calculated in Section VI is accumulated in a corresponding stack. The robot changes its md when the stack is over its threshold. The stacks $\boldsymbol{S}$ is defined as:

$$\boldsymbol{S} = \begin{pmatrix} s_1 & s_2 & s_3 & s_4 \end{pmatrix}^T, \tag{3}$$

where s_1, s_2, s_3, s_4 represent the stacks that control to change md to M_1, M_2, M_3, M_4, respectively. The initial value of $\boldsymbol{S}$ is taken as $\begin{pmatrix} 0 & 0 & 0 & 0 \end{pmatrix}^T$. The threshold $\boldsymbol{Th}$ that $\boldsymbol{S}$ has is expressed as:

$$\boldsymbol{Th} = \begin{pmatrix} Th_{11} & Th_{12} & Th_{13} & Th_{14} \\ Th_{21} & Th_{22} & Th_{23} & Th_{24} \\ Th_{31} & Th_{32} & Th_{33} & Th_{34} \\ Th_{41} & Th_{42} & Th_{43} & Th_{44} \end{pmatrix}, \tag{4}$$

where Th_{ij} $(0 < Th_{ij})$ is the threshold of the stack s_j and expresses the ease of carrying out of the changes to M_j from M_i.

Using the following formulas, $\boldsymbol{S}$ is decreased little by little.

$$\boldsymbol{S} \leftarrow \gamma * \Delta t * \boldsymbol{S}, \tag{5}$$

$$\boldsymbol{\gamma} = \begin{pmatrix} \gamma_1 & \gamma_2 & \gamma_3 & \gamma_4 \end{pmatrix}, \tag{6}$$

where γ_1, γ_2, γ_3, γ_4 $(0 < \gamma_i \leq 1)$ are the damping coefficients per unit time of s_1, s_2, s_3, s_4, respectively, and express a robot's difficulty of forgetting. The time from the last end time of *QA*, is denoted by Δt [1]. Because we consider that the influence on mood weakens like the emotions accumulated in the past, $\boldsymbol{S}$ decrease by Δt.

[1] $\Delta t = 0$ at the beginning of conversation.

TABLE I
THE CONVERSION TABLE OF θ' AND THE STACKS TO ACCUMULATE.

θ' (deg)	stack
$0 \leq \theta' < 90$	s_1
$90 \leq \theta' < 180$	s_2
$180 \leq \theta' < 270$	s_3
$270 \leq \theta' < 360$	s_4

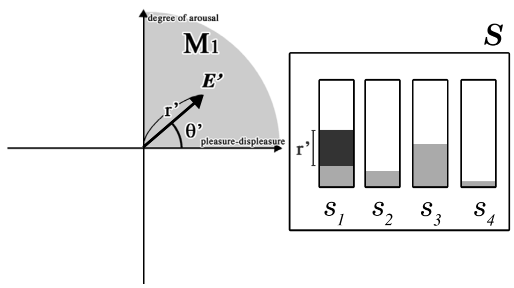


Fig. 2. An accumulation example of $\boldsymbol{E}'$ in $\boldsymbol{S}$.

The robot accumulates $\boldsymbol{E}'$ in a stack that is determined by the direction θ' of $\boldsymbol{E}'$. The conversion table of θ' and the stacks is shown in Table I. Fig. 2 shows accumulation example. The robot updates $\boldsymbol{S}$ by the following formulas for every QA.

$$\boldsymbol{S} \leftarrow \boldsymbol{S} + r' * \boldsymbol{F}, \tag{7}$$

$$\boldsymbol{F} = \begin{pmatrix} f_1 & f_2 & f_3 & f_4 \end{pmatrix}, \tag{8}$$

where f_1, f_2, f_3, f_4 correspond to s_1, s_2, s_3, s_4, respectively. The vector $\boldsymbol{F}$ is set by a four-bit sequence; 1 for those at corresponding to the stack that accumulates the emotions, and 0 for the others. By multiplying the magnitude of $\boldsymbol{E'}$ by $\boldsymbol{F}$, the value according to the intensity of the emotions is accumulated in the stack corresponding to the kind of emotion.

The robot changes md when the stack is over its threshold. Suppose that current md is M_i. For example, if s_j exceeds its threshold Th_{ij} ($s_j < Th_{ij}$), md will change from M_i to M_j. When there is no stack that exceeds its threshold, md remains in the same.

A. Characteristic Parameters

In this research, we consider that the robot's personalities consist of three major components: the vagaries of its mood, the forgetfulness, and the susceptibility to its mood. The parameters corresponding to these components are shown below.

- The vagaries of robot's mood : $\boldsymbol{Th}$
  The ease of carrying out of changes of md is denoted by $\boldsymbol{Th}$ defined by formula (4). It becomes easy to change when $\boldsymbol{Th}$ is small.
- The forgetfulness : $\boldsymbol{\gamma}$
  The coefficient that determines how much the stacks declines around in an unit time is denoted by $\boldsymbol{\gamma}$ defined by formula (6). It represents the difficulty of forgetfulness.
- The susceptibility to its mood : α
  The allowance of the intensity of the robot's emotion not matching its mood md is denoted by α described in Section VI. When α is small, the influence of the mood on the emotions becomes strong.

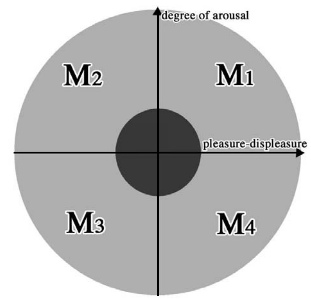


Fig. 3. Allowed domains of emotions affected by mood.

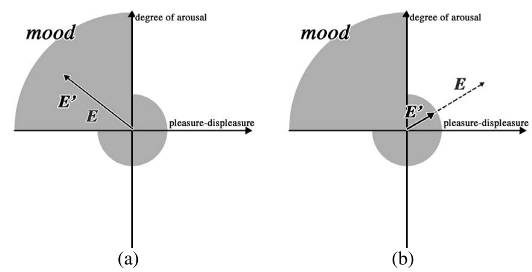


Fig. 4. Calculation examples of $\boldsymbol{E}'$.

We call these parameters characteristic parameters. We give various expressions of personality to the robot by changing these characteristic parameters.

VI. EMOTION

The intensity of the robot's emotion is affected by its mood. We set up an allowed domain of the emotion corresponding to each mood. The robot changes the intensity of its emotion according to this allowed domain.

The allowed domain of the emotions affected by the robot's mood md is shown in Fig. 3. The logical sum of the domain that is composed of one quadrant and the internal domain of the inner circle of radius α is one mood domain. The coefficient α ($0 < \alpha \leq 1$) shows the strength of the emotions affected by md.

Fig. 4 shows calculation examples of the emotion $\boldsymbol{E}' = (r', \theta')$. $\boldsymbol{E}'$ is calculated from the emotion $\boldsymbol{E} = (r, \theta)$ and the allowed domain (Fig. 3) of the emotions affected by md. The intensity of emotion is influenced by mood, but the kind of emotion is not influenced. If $\boldsymbol{E}$ is in the domain corresponding to md [2],

$$\boldsymbol{E}' = (r, \theta). \tag{9}$$

The intensity of $\boldsymbol{E}$ is kept stable by maintaining the magnitude r constant as shown in Fig. 4(a). On the other hand, if $\boldsymbol{E}$ is

[2]"The domain corresponding to md" represents the mood domain that described in Table I.

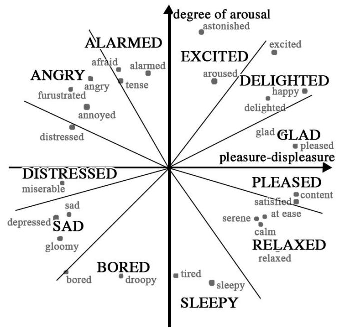


Fig. 5. Classification of emotional space of robot's expressions : eleven domains with typical eleven emotions.

not in the domain corresponding to md,

$$\boldsymbol{E}' = (\alpha * r, \theta). \tag{10}$$

The intensity of $\boldsymbol{E}'$ is reduced by multiplying r and α as shown in Fig. 4(b).

VII. Experiment

Conversation experiments were conducted after our emotion generation model was installed in an Ifbot.

A. Correspondence of the Emotion and Expression in Ifbot

The kinds of expressions that the robot was capable of are shown in Fig. 5. We classified the robot's emotional space in this figure into eleven domains according to the kind θ' of the robot's emotion $\boldsymbol{E}'$. We matched the typical emotions in each domain with the Ifbot's built in expressions. We divided the intensity of the robot's emotion into three steps and matched the different expressions with the corresponding in each step. We express the strong emotions as boldface, and the weak emotions as lower-case. We used the facial expressions that were input into the Ifbot beforehand. Examples of the facial expressions corresponding to each emotion expressed in the experiments are shown in Fig. 6.

B. The Experiment about Character Expression

We created three Ifbots (IfbotA, IfbotB and IfbotC), each of which had a corresponding character image, and an adjustment in three characteristic parameters $\boldsymbol{Th}$, $\boldsymbol{\gamma}$, and α. The dialogist G had a conversation with each Ifbot. In this experiments, G gave the same response under the same scenario to all the Ifbots. We consider the differences of the robot's mood transition and expression changes by having conversations with three Ifbots that have different characteristics. The parameters of IfbotA, IfbotB and IfbotC are shown below.

- IfbotA

$$\boldsymbol{Th} = \begin{pmatrix} - & 0.25 & 0.5 & 0.5 \\ 0.5 & - & 0.5 & 0.5 \\ 0.5 & 0.25 & - & 0.5 \\ 0.5 & 0.25 & 0.5 & - \end{pmatrix}. \quad \boldsymbol{\gamma} = \begin{pmatrix} 0.8 & 0.9 & 0.87 & 0.79 \end{pmatrix}. \quad \alpha = 0.3. \tag{11}$$

We gave IfbotA a "short tempered" characteristic by setting; the threshold of the stack s_2 (i.e., Th_{j2} $j = 1, \cdots, 4$) : low, γ_2: comparatively large, and α: comparatively small. Because of this, its mood easily changes to M_2, its emotions of the past corresponding to M_2 are difficult to forget, and its emotions are easily influenced by its mood.

- IfbotB

$$\alpha = 0.3. \quad \boldsymbol{Th} = \begin{pmatrix} - & 0.2 & 0.2 & 0.2 \\ 0.2 & - & 0.2 & 0.2 \\ 0.2 & 0.2 & - & 0.2 \\ 0.2 & 0.2 & 0.2 & - \end{pmatrix}. \quad \boldsymbol{\gamma} = \begin{pmatrix} 0.75 & 0.75 & 0.75 & 0.75 \end{pmatrix}. \tag{12}$$

We give IfbotB an "arbitrary" characteristic by setting; all values in $\boldsymbol{Th}$: low, α: comparatively small, and all values in $\boldsymbol{\gamma}$: small. Because of this, its mood easily changes, its emotions are easily influenced by its mood, and all emotions experienced in the past are easily forgotten.

- IfbotC

$$\boldsymbol{Th} = \begin{pmatrix} - & 0.6 & 0.6 & 0.25 \\ 0.3 & - & 0.6 & 0.25 \\ 0.3 & 0.6 & - & 0.25 \\ 0.3 & 0.6 & 0.6 & - \end{pmatrix}. \quad \boldsymbol{\gamma} = \begin{pmatrix} 0.85 & 0.7 & 0.8 & 0.9 \end{pmatrix}. \quad \alpha = 0.5. \tag{13}$$

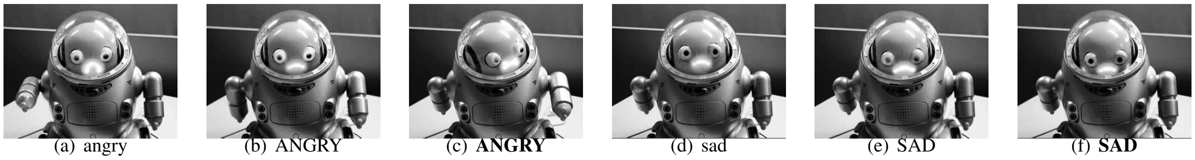
We give IfbotC a "cheerful and peaceful" characteristic by setting; the threshold of the stacks s_1 and s_4 (i.e., Th_{j1} and Th_{j4} $j = 1, \cdots, 4$) : low, γ_2: comparatively small, α: comparatively large. Because of this, its mood easily changes to M_1 and M_4, its emotions of the past corresponding to M_2 are easily forgotten, and its emotions are difficult to be influenced by its mood.

The conversation example between each of Ifbot and G is shown in Table II. The table gives the conversation history, the accumulated emotion stacks with each *QA*, and the robot's mood md and the expression of each Ifbot has. The initial domain of md is set as M_4.

The transition of md and expression suggest that there are differences despite the same conversation taking place. The expression is differ due to the various mood transitions caused by the characterization of each Ifbot.

On IfbotA, its md leans towards M_2. After md changes to M_4 at the 7th *QA*, it changes to M_2 at the 8th *QA* although s_2 has not been stacked with emotions. This suggests that the emotions experienced in the past corresponding to M_2 is difficult to forget. On the expressions, the strong emotions that are not corresponding to md is not held.

On IfbotB, its md frequently changes through *Conv*. It changes to M_1 at the 1st *QA*, and to M_4 at the 2nd *QA*. The relationship of the accumulating stacks and mood transitions show that mood transitions due to the stacked experienced emotions are comparatively low. This suggests that experienced emotions are easily forgotten. The expression changes drastically, including after IfbotB expressed a strong SAD at the



(a) angry (b) ANGRY (c) **ANGRY** (d) sad (e) SAD (f) **SAD**

Fig. 6. Examples of facial expressions of Ifbot.

TABLE II
MOOD TRANSITIONS AND EXPRESSIONS OF THREE CHARACTERIZED IFBOTS

Conv				-	IfbotA		IfbotB		IfbotC	
QA#	Question	Answer	Response	stack	md	Expression	md	Expression	md	Expression
1	Have you ever made a snowman?	Yes.	You must have rolled so many times.	s_1	M_4	glad	M_4	glad	M_4	glad
2	Did you make a big one?	Yes.	Wow, that's great!	s_4	M_4	**PLEASED**	M_1	pleased	M_4	**PLEASED**
3	Was it cold?	It was cold.	Really? But I want to make it like you.	s_2	M_4	distressed	M_4	distressed	M_4	distressed
4	Can you make it with me?	No	Oh, no.	s_3	M_2	distressed	M_2	distressed	M_4	distressed
5	Then, play with me instead of that!	Sure.	Yes!! Its promise, ok?	s_4	M_2	relaxed	M_4	**RELAXED**	M_4	**RELAXED**
6	Is there something else you like to do in winter?	I watch the stars.	Stars. It's must be so beautiful during winter!	s_4	M_2	RELAXED	M_2	RELAXED	M_4	**RELAXED**
7	Can you find constellations well?	No.	I can't either.	s_3	M_4	sad	M_3	**SAD**	M_4	sad
8	Well, have you ever seen shooting stars?	Yes.	Oh that's so cool.	s_4	M_2	pleased	M_4	**PLEASED**	M_4	**PLEASED**
9	Did you wish something?	No.	When you pray your wish 3 times while a star is falling, it will be true!	s_2	M_4	**DISTRESSED**	M_3	DISTRESSED	M_4	DISTRESSED
10	Do you have any wish?	No.	I have a lot!	s_2	M_2	**DISTRESSED**	M_2	**DISTRESSED**	M_4	DISTRESSED
11	If I can say well, do you think my wishes can be true?	Yes, I think so.	Really? Do you think so?	s_1	M_2	delighted	M_4	delighted	M_2	**DELIGHTED**
12	Do you want to hear what's my wishes?	Yes.	Fine, whatever. Have a nice day!	s_2	M_2	**ANGRY**	M_2	**ANGRY**	M_4	angry

7th *QA*, it expressed a strong PLEASED at the 8th *QA*. These show that IfbotB has a large mood transition.

On IfbotC, its md leans towards M_1 and M_4. Although the emotions are accumulated to s_2 several times, md does not move to M_2. This shows that the experienced emotions corresponding to M_2 is easily forgotten and md does not easily change to M_2. Because md changes gently, the expressions do not change drastically, but change gently.

C. An Evaluation of Psychological Impact

We evaluated the psychological impact that the robots made on the dialogist. A subjective evaluation on the emotional changes was conducted after the dialogist had conversations with IfbotA, IfbotB and IfbotC, which were used in the foregoing experiments, and IfbotN, in the original system.

In these experiments, we used the semantic differential [14] for evaluating sensitivity. The pairs of adjective that used for SD, are shown below.

- mechanical - human
- insignificant - significant
- simple - complicated
- introversive - extroversive
- disagreeable - agreeable
- emotionally unstable - emotionally stable
- unconscientious - conscientious
- unintelligent - intelligent

Thirty subjects observed conversations with the four Ifbots and answered questionnaires. We determined the effect of our model by graphing out the average and standard deviation of the evaluations (1-7) for the four Ifbots, item by item. We used the Friedman test [13] as an inferential test of the four Ifbots. The significance level of the test was set to 0.05. The results are shown in Fig. 7 and Table III. IfbotN was not evaluated on the big five [15] (Fig. 7(d) - Fig. 7(h)), which is widely accepted in personality theory, because these items were evaluated only in the Ifbots with special characteristics. In Table III, for example, A $>$ B means that we found a statistically significant difference between IfbotA and IfbotB. On "mechanical - human", shown in Fig. 7(a), IfbotN was rated as "mechanical", but each of experimental Ifbots was rated as "human". On "insignificant - significant", shown in Fig. 7(b), although IfbotA was slightly low, IfbotB and IfbotC were rated as more "significant" compared with IfbotN. On "simple - complicated", shown in Fig. 7(c), compared with IfbotN, each of experimental Ifbots was rated as more "complicated". These three items suggest that giving moods to Ifbot can make its facial expressions more meaningful and complex, and can

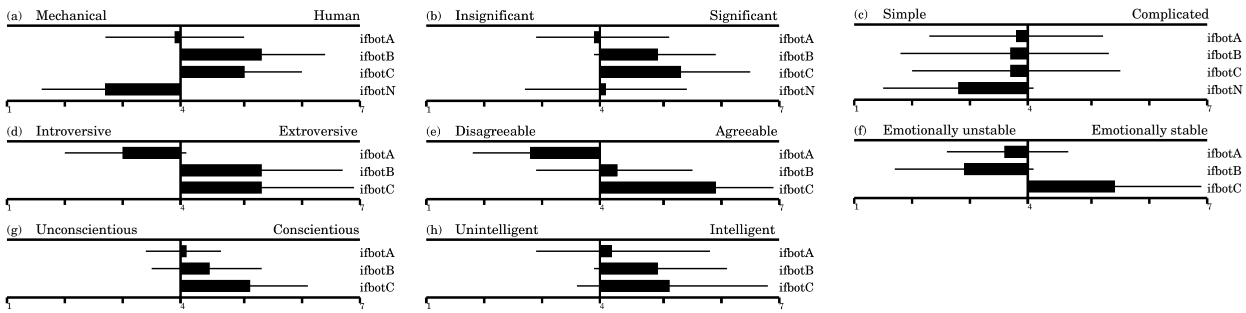


Fig. 7. Results of sensitivity evaluation.

TABLE III
SIGNIFICANT DIFFERENCES.

(a) mechanical - human	B > N, C > N
(b) insignificant - significant	C > A
(c) simple - complicated	
(d) introversive - extroversive	C > A, B > A
(e) disagreeable - agreeable	C > A, C > B
(f) emotionally unstable - emotionally stable	C > A, C > B
(g) unconscientious - conscientious	
(h) unintelligent - intelligent	

facilitate a partner perceiving it to be more human.

On "emotionally unstable - emotionally stable", shown in Fig. 7(f), IfbotC was rated as "emotionally stable", and IfbotB was rated as "emotionally unstable". This is because since in IfbotB, the thresholds for mood translation Th were set low, IfbotB changes its mood more easily than IfbotA and IfbotC. This shows that the personality of our robots can be expressed, whether it is emotionally stable or not.

On "introversive - extroversive" shown in Fig. 7(d), IfbotA was rated as "extroversive", but IfbotB and IfbotC were rated as "introversive". On "disagreeable - agreeable" shown in Fig. 7(e), IfbotA was rated as "disagreeable", and IfbotC was rated as "agreeable". On "unconscientious - conscientious", shown in Fig. 7(g), and "unintelligent - intelligent", shown in Fig. 7(h), the perceived differences were not significant. Except "unconscientious - conscientious" and "unintelligent - intelligent", the perceptions subjects have of these three robots were different, although there is no parameter that correspond directly to these three items in our model.

VIII. CONCLUSION

We proposed an emotion generation model for robots so that they could provide more human-like communications. This model can give the robot personality through mood transitions that change with the accumulation of past emotions. Conversation experiments were conducted after this model was installed in an Ifbot. Our experimental results showed that personality could be effectively expressed by changing the characteristic parameters on mood transitions. However, the relationship between the characteristic parameters and evaluation results of robot's personalities is unclear. In future work, to clear up this relationship, we are going to put robots that have more personality variations through further tests of this model.

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