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Emotion Generation System based on MaC Model with Neural Networks

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***Abstract*—In this paper, we propose an emotion generation system based on MaC model using neural networks. In the proposed system, the chaotic neural network and the Boltzmann machine are used in the Emotion Generator of the MaC model. In the Boltzmann machine, the plural pattern can be recalled stochastically for the same input. The proposed system makes use of this property in order to generate different emotions for same external input. On the other hand, the chaotic neural network can recall the training patterns dynamically based on external input and the history. The proposed system makes use of this property in order to generate emotions based on its history.**

***Index Terms*—Emotion Generation System, MaC (Mind and Consciousness) Model, Boltzmann Machine, Chaotic Neural Network**

I. Introduction

In the field of brain science, cognitive science and psychology, it is clarified that emotions play important role in decision making. The MaC (Mind and Consciousness) model[1] which is the conceptual model of mind and consciousness has been proposed. The MaC model has (1) mind mechanism which uses emotions for value judgment and (2) consciousness mechanism which processes selective attention and reflection.

In various digital mechanical pets and human interfaces, not only autonomous actions but also emotions are introduced based on such conceptual model. In most of emotions systems, emotions are generated based on only external input. However, internal emotions are not considered in these systems. Moreover, these emotion generation systems assume only emotions of animals.

In this paper, we propose the emotion generation system based on MaC model using neural networks. In the proposed system, the chaotic neural network and the Boltzmann machine are used in the Emotion Generator of the MaC model. In the Boltzmann machine, the plural pattern can be recalled stochastically for the same input. The proposed system makes use of this property in order to generate different emotions for same external input. On the other hand, the chaotic neural network can recall the training patterns dynamically based on external input and the history. The proposed system makes use of this property in order to generate emotions based on its history.

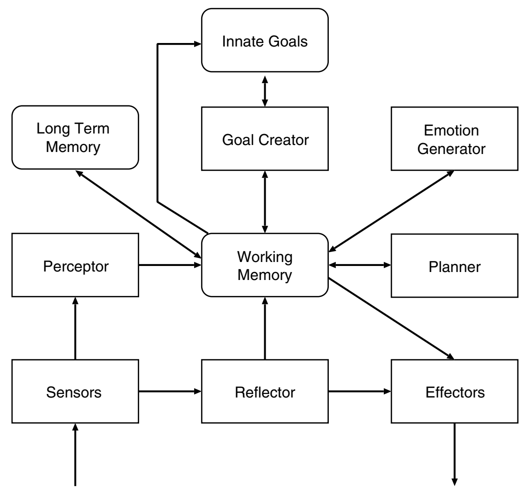

Fig. 1. Architecture of Proposed System.

II. Emotion Generation System based on MaC Model with Neural Networks

A. Outline

In the proposed system, the chaotic neural network[2] and the Boltzmann machine[3] are used in the Emotion Generator of the MaC (Mind and Consciousness) model[1]. In the Boltzmann machine, the plural pattern can be recalled stochastically for the same input. The proposed system makes use of this property in order to generate different emotions for same external input. On the other hand, the chaotic neural network can be recall the training patterns dynamically based on external input and the history. The proposed system makes use of this property in order to generate emotions based on its history.

Figure 1 shows the architecture of the proposed system, and Fig. 2 shows the Emotion Generator in the proposed system.

B. Emotion Model

In the proposed system, the basic emotion model proposed by Plutchik[4] is used as the emotion model. In this model, “anger”, “anticipation”, “joy”, “trust”, “fear”, “surprise”, “sadness” and “disgust” are the basic emotions (See Fig.3).

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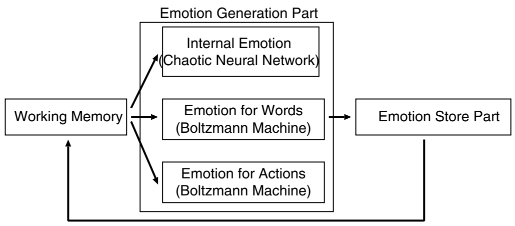


Fig. 2. Emotion Generation Part.

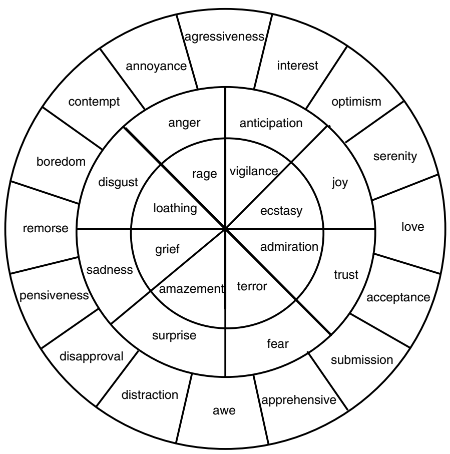


Fig. 3. Plutchik's Basic Emotion Model.

C. Emotion in Proposed System

In the proposed system, the emotion value for eight basic emotions at the time t, $E_e(t)$ $(0 \leq E_e(t))$ is defined. Here, e is given by

$$e = \{joy,\ anticipation,\ trust,\ anger,\ fear,\ sadness,\ disgust,\ surprise\}. \quad (1)$$

In the proposed system, the positive and negative moods $M_p(t)$ and $M_n(t)$ are defended by

$$M_p(t) = (E_{joy}(t-1) + E_{anticipation}(t-1) + E_{trust}(t-1))/3 \quad (2)$$

$$M_n(t) = (E_{anger}(t-1) + E_{fear}(t-1) + E_{sadness}(t-1) + E_{disgust}(t-1))/4. \quad (3)$$

If the positive mood is large, the positive emotions (joy, anticipation, trust) become easy to be generated. In contrast, if the negative mood is large, the negative emotions (anger, fear, sadness, disgust) become easy to be generated.

D. Function of Each Module

(1) Sensors

The Sensors detect stimuli from the environment to extract physical features. In the proposed system, both actions and words are received as stimuli. This module sends the information about the received sensory input to the Reflector and the Receptor. The information which is sent to the Reflector and the Receptor $\boldsymbol{I}(t)$ is described as the $(N_a + N_w + 1)$-dimensional vector. Here, N_a is the number of actions, N_w is the number of words, and $+1$ shows no input is given. $I_{N_a+N_w+1}(t)$ is set to 1 if there is no external input. $I_i(t)$ is set to the strength of the sensory input i at the time t.

(2) Reflector

In the Reflector, whether the input has an urgency is judged. If the input has an urgency, a reflex action (avoidance behavior) is generated.

The urgency level at the time t $D(t)$ is given by

$$D(t) = \sum_{i\ :\ I_i(t)\neq 0} D_i(I_i(t)) \quad (4)$$

where $D_i(I_i(t))$ is the urgency level for the input i whose strength is $I_i(t)$.

If the urgency level $D(t)$ is larger than the threshold θ_D, an avoidance behavior is generated as the reflex action, and the information is sent to the Effectors.

(3) Receptor

In the Receptor, the input stimulus is recognized based on the input information $\boldsymbol{I}(t)$.

In the proposed system, the external input is recognized as pain/pleasantness/like/hate.

At the time t, the strength of the stimulus s $S_s(t)$ is given by

$$S_s(t) = \sum_{i\in C_s} I_i(t) \quad (5)$$

where s is given by

$$s = \{pain,\ pleasantness,\ like,\ hate\} \quad (6)$$

and C_s is the set of the external input for the stimulus s.

The input information $\boldsymbol{I}(t)$ and the recognized strength of the stimulus $S_s(t)$ are sent to the Working Memory.

(4) Innate Goals

In the proposed system, a desire to want to fill hungry stomach/recover from fatigue/avoid from emergency is set as the innate goal.

In the Innate Goals, the desire level for the innate goal is calculated. The desire level for the innate goal g_{in} at the time t, $G_{in}(t)$ is calculated by the previous actions $\boldsymbol{O}(t-1)$ and the urgency level $D(t)$. Here, in is the innate goal and is given by

$$in = \{hungry,\ fatigue,\ urgency\}. \quad (7)$$

The desire level for hungry/fatigue is calculated by

$$G_{in}(t) = \begin{cases} 0, & (O_{A_{g_{in}}}(t-1) = 1) \\ G_{in}(t-1) + \sum_{i\ :\ O_i(t-1)=1} \Delta G^i_{in}, & (O_{A_{g_{in}}}(t-1) = 0) \end{cases} \quad (8)$$

where $O_{A_{g_{in}}}(t-1)$ shows whether the action $A_{g_{in}}$ which satisfies the desire g_{in} at the time $t-1$ is taken. ΔG^i_{in} is the increment of the desire level g_{in} for the action i.

The desire level for avoidance is calculated by

$$G_{in}(t) = \begin{cases} D(t), & (D(t) \geq \theta_D) \\ 0, & (D(t) < \theta_D) \end{cases} \tag{9}$$

where $D(t)$ is the urgency level calculated in the Reflector.

(5) Goal Creator

In the Goal Creator, (1)empirical goal for external stimulus, (2)empirical goal for emotion and (3)empirical goal for mood are calculated. From these empirical goal and the desire level for the innate goal, the current goal is set.

(a) Empirical Goal for External Stimulus: As the empirical goal for the external stimulus, a desire to want to avoid pain stimulus/get pleasantness/get favorite things/avoid hate is considered.

The desire level for the empirical goal g_s on the external stimulus s at the time t, $G_s(t)$ is given by

$$G_s(t) = \gamma_s G_s^S(t) + (1-\gamma_s) G_s^{LM}(t) \tag{10}$$

where γ_s is the weighting coefficient for the empirical goal on the external stimulus s. $G_s^S(t)$ is the desire level for the stimulus s based on the stimulus strength at the time t and is given by

$$G_s^S(t) = S_s(t). \tag{11}$$

$G_s^{LM}(t)$ is the desire level for the stimulus s based on the long term memory at the time t, and is given by

$$G_s^{LM}(t) = f_s^{LM}\left(\sum_{\tau=0}^{t-1} C_s(\tau)\right) \tag{12}$$

$$f_s^{LM}(u) = \begin{cases} 1, & (u \geq \theta_s^{LM}) \\ u/\theta_s^{LM}, & (u < \theta_s^{LM}) \end{cases} \tag{13}$$

$$C_s(\tau) = \begin{cases} 1, & (G_s(t-1) > \theta_{G_s} \text{ and } G_s(\tau-1) > \theta_{G_s} \\ & \text{ and } S_s(t-1) > 0 \text{ and } S_s(\tau-1) > 0) \\ 0, & \text{(otherwise)} \end{cases} \tag{14}$$

where θ_s^{LM} is the threshold for the stimulus s, and θ_{G_s} is the threshold for the desire level for the empirical goal g_s, $G_s(t)$.

(b) Empirical Goal for Emotion: As the empirical goal for the emotion, a desire to want to each emotion is considered.

The desire level for the empirical goal g_e on the emotion e at the time t, $G_e(t)$ is given by

$$G_e(t) = \gamma_e G_e^E(t) + (1-\gamma_e) G_e^{LM}(t) \tag{15}$$

where γ_e is the weighting coefficient for the empirical goal on the emotion e. $G_e^E(t)$ is the desire level for the emotion e at the time t and is given by

$$G_e^E(t) = \begin{cases} 1, & (\theta_E^e \leq d_e(t)) \\ d_e(t)/\theta_E^e, & (0 < d_e(t) < \theta_E^e) \\ 0, & (d_e(t) \leq 0) \end{cases} \tag{16}$$

$$d_e(t) = E_e(t-1) - E_e(t-2) \tag{17}$$

where θ_E^e is the threshold for the difference between the emotion value at the time $t-1$ and the emotion value at the time $t-2$. $G_e^{LM}(t)$ is the desire level based on the long term memory at the time t for the emotion e, and is given by

$$G_e^{LM}(t) = f_e^{LM}\left(\sum_{\tau=0}^{t-1} C_e(\tau)\right) \tag{18}$$

$$f_e^{LM}(u) = \begin{cases} 1, & (u \geq \theta_e^{LM}) \\ u/\theta_e^{LM}, & (u < \theta_e^{LM}) \end{cases} \tag{19}$$

$$C_e(\tau) = \begin{cases} 1, & (G_e(t-1) > \theta_{G_e} \text{ and } G_e(\tau-1) > \theta_{G_e} \\ & \text{ and } E_e(t-1) > 0 \text{ and } E_e(\tau-1) > 0) \\ 0, & \text{(otherwise)} \end{cases} \tag{20}$$

where θ_e^{LM} is the threshold for the long term memory of the emotion e, and θ_{G_e} is the threshold of the desire level $G_e(t)$ for the empirical goal g_e.

(c) Empirical Goal for Mood: As the empirical goal for the mood, a desire to want to positive or negative emotion is considered.

The desire level for the empirical goal g_M on the mood at the time t, $G_M(t)$ is given by

$$G_M(t) = \gamma_M G_M^M(t) + (1-\gamma_M) G_M^{LM}(t) \tag{21}$$

where γ_M is the weighting coefficient for the empirical goal on the mood. $G_M^M(t)$ is the desire level for the mood at the time t, and is given by

$$G_M^M(t) = f_M^M\left(M(t-1),\ M(t-2)\right) \tag{22}$$

$$f_M^M(u_1,\ u_2) = \begin{cases} 1, & (u_1 \cdot u_2 > 0 \text{ and } \theta_M^M < (|u_1| - |u_2|)) \\ 2(|u_1| - |u_2|), & \\ & (u_1 \cdot u_2 > 0 \text{ and } 0 < (|u_1| - |u_2|) \leq \theta_M^M) \\ 0, & \text{(otherwise)} \end{cases} \tag{23}$$

where θ_E^M is the threshold for the difference between the emotion value at the time $t-1$ and the mood at the time $t-2$. $G_M^{LM}(t)$ is the desire level based on the long term memory at the time t for the mood, and is given by

$$G_M^{LM}(t) = f_M^{LM}\left(\sum_{\tau=0}^{t-2} C_M(\tau)\right) \tag{24}$$

$$f_M^{LM}(u) = \begin{cases} 1, & (u \geq \theta_M^{LM}) \\ u/\theta_M^{LM}, & (u < \theta_M^{LM}) \end{cases} \tag{25}$$

$$C_M(\tau) = \begin{cases} 1, & (G_M(t-1) > \theta_{G_M} \text{ and } G_M(\tau-1) > \theta_{G_M} \\ & \text{ and } M(t-1) > 0 \text{ and } M(\tau) > 0) \\ 0, & \text{(otherwise)} \end{cases} \tag{26}$$

where θ_M^{LM} is the threshold for the long term memory of the mood, and θ_{G_M} is the threshold of the desire level $G_M(t)$ for the empirical goal g_M.

(d) Goal Setting: The goal at the time t $g(t)$ is set based on the desire level for innate goals and the empirical goals.

Step 1 : Whether there is desire for avoidance is judged. If the desire level for urgency is positive ($G_{urgency} > 0$), the goal is set to the avoidance. If $G_{urgency} = 0$, go to **Step 2**.

Step 2 : Whether there is desire for hungry/fatigue is judged. If

$$\max(G_{hungry}(t), G_{fatigue}(t)) > \theta_{In} \qquad (27)$$

is satisfied, the goal whose desire level is high is set as the goal.

$$g(t) = \text{argmax}(G_{hungry}(t), G_{fatigue}(t)) \qquad (28)$$

θ_{In} is the threshold for the innate goals. If both desire levels are smaller than the threshold, go to **Step 3**.

Step 3 : The goal whose desire level calculated in (a)∼(c) is maximum is set as the goal.

$$g(t) = \underset{s,e,M}{\text{argmax}}\, G_{\{s,e,M\}}(t) \qquad (29)$$

(6) Emotion Generator

In the Emotion Generator, the emotion is generated by the chaotic neural network and the Boltzmann machine, and the emotion value and the mood are calculated.

(a) Emotion Generation by Neural Networks: In the proposed system, the chaotic neural network and the Boltzmann machine are used in the Emotion Generation. In the Boltzmann machine, the plural pattern can be recalled stochastically for the same input. The proposed system makes use of this property in order to generate different emotions for same external input. On the other hand, the chaotic neural network can recall the training patterns dynamically based on external input and the history. The proposed system makes use of this property in order to generate emotions based on its history.

(b) Calculation of Mood: Here, the mood is calculated based on the emotion value at the previous time. The positive mood at the time t ($M_p(t)$) and the negative mood at the time t ($M_n(t)$) are calculated by Eqs.(2) and (3). The mood at the time t ($M(t)$) is given by

$$M(t) = \begin{cases} M_p(t), & |M_p(t) - M_n(t)| > \theta_M \\ & \text{and } M_p(t) > M_n(t) \\ 0, & |M_p(t) - M_n(t)| \leq \theta_M \\ -M_n(t), & |M_p(t) - M_n(t)| > \theta_M \\ & \text{and } M_p(t) < M_n(t) \end{cases} \qquad (30)$$

where θ_M is the threshold for the mood.

(c) Calculation of Emotion Value: The emotion value for the emotion e at the time t $E_e(t)$ is given by

$$E_e(t) = f^E\Bigg(E_e(t-1) + M_E(t) + T_e(t) + C_e \qquad (31)$$
$$+ \sum_{c=1}^{3} E_e^c(t)\Big(1 + \sum_{in \in N} f_G^{In}(G_{in}(t)) + \sum_{\{s,e,M\} \in N} f_G^{Ex}(G_{\{s,e,M\}}(t))\Big)\Bigg)$$

where $M_E(t)$ is the effect parameter of the mood at the time t to the emotion value and is given by

$$M_E(t) = \begin{cases} M(t)/T_{M_E}, & (M(t) \neq 0) \\ 0.0, & (M(t) = 0) \end{cases} \qquad (32)$$

where T_{M_E} ($0.0 < T_{M_E} < 0.5$) is the constant.

$T_e(t)$ is the coefficient for the emotion e at the time t and is given by

$$T_e(t) = f_e^{E_T}\left(\sum_{n \in N} G_n(t) - G_n(t-1), E_e(t-1)\right) \qquad (33)$$

$$f_e^{E_T}(u_1, u_2) = \begin{cases} \text{sgn}(u_1)T_e^4, & (\theta_e^3 \leq u_2) \\ \text{sgn}(u_1)T_e^3, & (\theta_e^2 \leq u_2 < \theta_e^3) \\ \text{sgn}(u_1)T_e^2, & (\theta_e^1 \leq u_2 < \theta_e^2) \\ \text{sgn}(u_1)T_e^1, & (u_2 < \theta_e^1) \end{cases} \qquad (34)$$

where $\theta_e^1 \sim \theta_e^3$ are the thresholds for the emotion e, and $T_e^1 \sim T_e^4$ are the constant for the emotion e.

C_e is the inhibitory value for the emotion e and is given by

$$C_e = f_e^{E_c}(E_e(t-1)) \qquad (35)$$

$$f_e^{E_c}(u) = \begin{cases} C_e^4, & (\theta_e^3 \leq u) \\ C_e^3, & (\theta_e^2 \leq u < \theta_e^3) \\ C_e^2, & (\theta_e^1 \leq u < \theta_e^2) \\ C_e^1, & (u < \theta_e^1) \end{cases} \qquad (36)$$

where $C_e^1 \sim C_e^4$ are the constants for the emotion e ($C_e^4 > C_e^3 > C_e^2 > C_e^1$).

$E_e^c(t)$ is the emotion value which is generated by the neural networks at the time t. c means the neural network ID (1: chaotic neural network, 2: Boltzmann machine for actions 3: Boltzmann machine for words). $E_e^c(t)$ takes 0 (when the emotion e is not generated at the time t) or z_c (($0 < z_c < 1$) when the emotion e is generated at the time t).

In Eq.(31), $G_{in}(t)$ is the desire level for the innate goal at the time t, and $G_{\{s,e,M\}}(t)$ is the desire level for the empirical goal at the time t. $f_G^{In}(\cdot)$ and $f_G^{Ex}(\cdot)$ are given by

$$f_G^{In}(u) = \begin{cases} u, & (u \geq \theta^{In}) \\ 0, & (u < \theta^{In}) \end{cases} \qquad (37)$$

$$f_G^{Ex}(u) = \begin{cases} u, & (u \geq \theta^{Ex}) \\ 0, & (u < \theta^{Ex}) \end{cases} \qquad (38)$$

where θ^{In} and θ^{Ex} are the thresholds for the desire level of the innate and empirical goals.

In Eq.(31), f^E is given by

$$f^E(u) = \begin{cases} u, & (u > 0) \\ 0, & (u \leq 0). \end{cases} \qquad (39)$$

(7) Planner

In the Planner, the action is selected as follows:

Step 1 : If the goal is set to the avoidance ($g(t)$=*urgency*), the avoidance behavior is selected. Otherwise, go to **Step 2**.

Step 2 : If the innate goal is set to the goal and its desire level is larger than 1.0, the action to satisfy the innate goal is selected. Otherwise, go to **Step 3**.

Step 3 : If the empirical goal is set to the goal, the action to satisfy the empirical goal is selected. Otherwise, go to **Step 4**.

Step 4 : If any actions are not selected until **Step 3**, the action is selected based on the emotion value. Based on the emotion value at the time t, two emotions whose emotion value is large $E_f(t)$ and $E_s(t)$ are determined.

$$E_f(t) = \underset{e}{\text{argmax}}\, E_e(t) \tag{40}$$

$$E_s(t) = \underset{e:e \neq E_f(t)}{\text{argmax}}\, E_e(t) \tag{41}$$

If the emotion value for $E_f(t)$ and $E_s(t)$, $E_{E_f}(t)$ and $E_{E_s}(t)$ are larger than the thresholds ($\theta^2_{E_f}$ and $\theta^2_{E_s}$), the emotion is output. If the emotion value is larger than the threshold $\theta^3_{E_f}$ or $\theta^3_{E_s}$, the emotion is output strongly.

Step 5 : If any actions are not selected until **Step 4**, if the innate goal is set to the goal, the action which satisfy the innate goal is selected. Otherwise go to **Step 6**.

Step 6 : If any actions are not selected until **Step 5**, the action is selected based on the emotion value again. If the emotion value of $E_f(t)$ and $E_s(t)$ ($E_{E_f}(t)$, $E_{E_s}(t)$) are larger than the thresholds ($\theta^1_{E_f}$ and $\theta^1_{E_s}$), the emotion is output weakly.

Step 7 : If any actions are not selected until **Step 6**, the agent does nothing.

(8) Effector

In the Effector, the action which is selected in the Reflector or the Planner is carried out.

(9) Long Term Memory Part

In the Long Term Memory, the information from the other modules are memorized. Here,

- the input information at the time t $\boldsymbol{I}(t)$
- the emotions at the time t ($E_f(t)$, $E_s(t)$) and their emotion values ($E_{E_f}(t)$, $E_{E_s}(t)$)
- the mood at the time t $M(t)$
- the goal at the time t $g(t)$
- the desire level at the time t $G_{in}(t)$, $G_s(t)$, $G_e(t)$, $G_M(t)$
- the action at the time t $\boldsymbol{O}(t)$

are memorized.

(10) Working Memory

In the Working Memory, the information from the other modules are memorized temporarily.

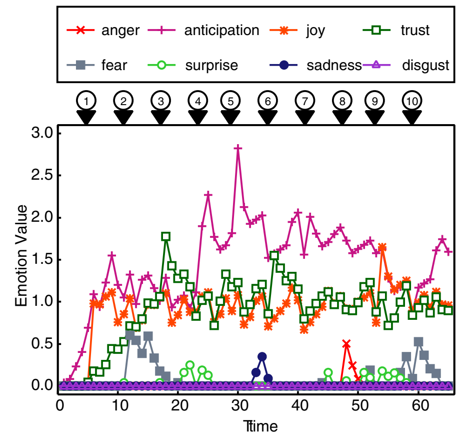
III. Experiment Results

A. Emotion Generation

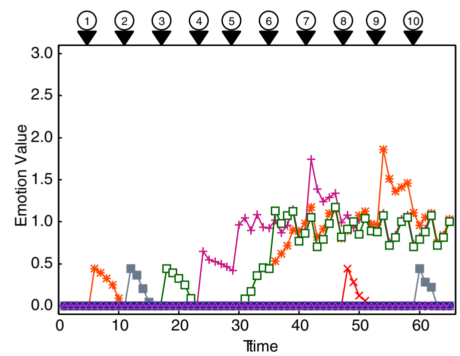
Here, the emotions were generated by the proposed system and the method without internal emotions.

As the stimuli which makes to generate the positive emotions,

1. "Hello." ⇒ 2. approach ⇒ 3. "Let's play together." ⇒ 4. "You are happy, aren't you?" ⇒ 5. "Do you want candies?" ⇒ 6. show favorite thing ⇒ 7. "Eat it well." ⇒ 8. "Is it nice?" ⇒ 9. "Good." ⇒ 10. pat



(a) Proposed System.



(b) Method without Internal Emotions

Fig. 4. Variation of Emotion Values.

were given. Figure 4(a) shows the variation of emotion values in the proposed system and Figure 4(b) shows the variation of emotion values in the method without internal emotions. In these figures, the numbers at the top show the action and words.

As shown in Fig.4, emotions of joy, trust and anticipation are generated from the beginning of the simulation in the proposed system. In contrast, emotions of joy, trust and anticipation not are generated from the beginning of the simulation, and they are generated after $t = 30$ in the system without internal emotions.

From these results, we can see that the proposed system can generate emotions naturally independent only external input.

B. Experiment using Robot

Here, we examined using the robot based on the proposed system (Robot A), the robot based on the system without internal emotions (Robot B) and the robot operated manually (Robot C). We used the robot build of the LEGO mindstorms NXT.

We used the SD (semantic differential) method and the subjects evaluated the behavior of the robot in 7 levels ($-3 \sim 3$).

TABLE I
EXPERIMENTAL CONDITIONS.

degree of freedom (the number of subjects)	N	4 (5)
significance level	α	0.05
t statistic($N-1=4$, $\alpha=0.05$)	t_α	2.776

TABLE II
t STATISTIC.

	Question 1	Question 2	Question 3
Robot A and Robot B	1.371	1.509	0.589
Robot A and Robot C	0.000	2.449	4.810
Robot B and Robot C	2.138	4.333	4.490
	Question 4	Question 5	Question 6
Robot A and Robot B	1.118	0.250	1.088
Robot A and Robot C	2.064	2.057	0.492
Robot B and Robot C	6.000	2.745	2.449

[Q1] hostile ↔ friendly
[Q2] action looks to have no aim ↔ action looks to have aim
[Q3] unnatural ↔ natural
[Q4] hard to communicate ↔ easy to communicate
[Q5] looks like machine ↔ looks like creature
[Q6] looks like non-human ↔ looks like human

Here, we used the t-test. The t statistic is given by

$$t = \frac{\bar{d}\sqrt{N}}{s_d} \tag{42}$$

where $\bar{d}$ is the average of the difference between two data, N is the number of data ($N-1$ is the degree of freedom), and s_d is the standard deviation.

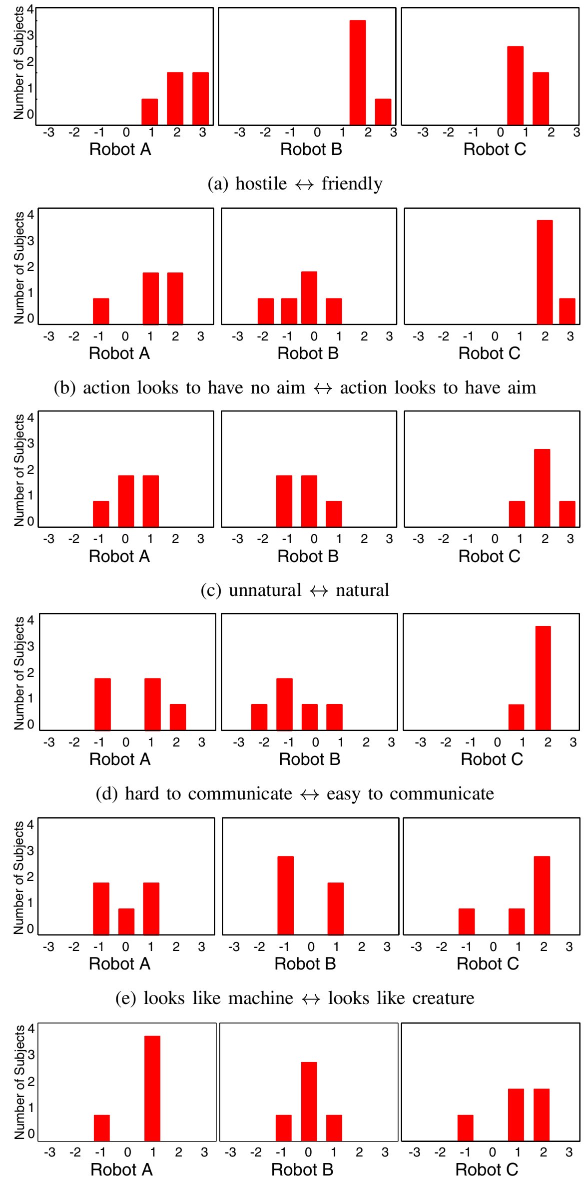
As shown in Table II, there is no question which has significant difference between the Robot A and the Robot B. There is a few questions which have significant difference between the Robot A and the Robot C. In contrast, there is many questions which have significant difference between the Robot B and the Robot C.

From these results, we confirmed that the robot based on the proposed system can decide actions as similar as in the robot operated manually.

Figure 5 shows the questionnaire results.

IV. CONCLUSIONS

In this paper, we have proposed the emotion generation system based on MaC model using neural networks. In the proposed system, the chaotic neural network and the Boltzmann machine are used in the Emotion Generator of the MaC model. In the Boltzmann machine, the plural pattern can be recalled stochastically for the same input. The proposed system makes use of this property in order to generate different emotions for same external input. On the other hand, the chaotic neural network can recall the training patterns dynamically based on external input and the history. The proposed system makes use of this property in order to generate emotions based on its history. We carried out computer experiments, and confirmed that the proposed system can realize autonomous and human-like emotion generation. Moreover, we confirmed that the robot based on the proposed system can decide actions as similar as in the robot operated manually.



(a) hostile ↔ friendly

(b) action looks to have no aim ↔ action looks to have aim

(c) unnatural ↔ natural

(d) hard to communicate ↔ easy to communicate

(e) looks like machine ↔ looks like creature

(f) looks like non-human ↔ looks like human

Fig. 5. Questionnaire Results.

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