Developing Sophisticated Robot Reactions by Long-Term Human Interaction

Hiromi Nagano, Miho Harata[1], and Masataka Tokumaru[2]

[1] Graduate School of Kansai University
3-3-35 Yamate-cho, Suita-shi, Osaka 564-8680, Japan
[2] Kansai University, 3-3-35 Yamate-cho, Suita-shi, Osaka 564-8680, Japan
{k757820,k149657,toku}@kansai-u.ac.jp

Abstract. In this study, we proposed an emotion generation model for robots that considers mutual effects of desires and emotions. Many researchers are developing partner robots for communicating with people and entertaining them, rather than for performing practical functions. However, people quickly grow tired of these robots owing to their simplistic emotional responses. To solve this issue, we attempted to implement the mutual effects of desires and emotions using internal-states, such as physiological factors. Herein, the simulation results verified that the proposed model expresses complex emotions similar to humans. The results confirmed that the emotions expressed by the proposed model are more complex and realistic than those expressed by a reference model.

1 Introduction

Many researchers are attempting to develop partner robots. Communication is a quality required for robots to coexist with humans. These partner robots are need the ability to communicate which is essential for the robots to coexist with humans. These robots are problematic in that people quickly grow tired of them because of their simplistic emotion generation algorithms. To solve this issue, many models have attempted to generate more complex expressions of emotion. However, none of these studies have focused on "the growth of the robot." This feature can result in the robot growing in a manner similar to humans. Previously, we proposed a growth model for emotions that involved changing the structure of a self-organizing map (SOM)[2]. Also, the study attempted to make the expression of emotions more sophisticated using growth functions in a multilayer perceptron neural network (NN). Although our earlier model closely simulated the development of emotions in genetic psychology, it is still imperfect, because robots always express the same emotions when they receive the same input from a user, because their output emotions are only influenced by these inputs. A possible solution is to provide robots with some internal factors that are related to the natural and realistic expressions of emotion.

Herein, we applied the mutual effects of desires and emotions to the model. These effects are defined as a "consecutive cycle" in which experiences influence

M. Kurosu (Ed.): Human-Computer Interaction, Part V, HCII 2013, LNCS 8008, pp. 319–328, 2013.

future actions. Also, the proposed model distinguishes emotions from feelings according to their characteristics. We expressed the mutual effects of desires and emotions using the internal-states of the robot. For example, along with saving a hunger state and an exhaustion state, the robot also saves the states of desires and feelings as numerical data. Desires and emotions can be mutually influenced by using the internal-states to generate different desires and emotions. With this model, a partner robot can express different emotions even though it receives the same input from users for solving the predictability problem observed in conventional partner robots. Herein, using numerical simulations, we verified that the model expressed various natural emotions similar to humans. We also used four types of input sets to examine the variations in the emotions expressed by the experimental model.

2 Proposed Model

This study aims to construct a robot that communicates better with humans via the functioning of emotions. We propose an emotion generation model for robots that considers the mutual effects of desires and emotions to create more complex and life-like emotions. Hence, it was important for the simulated emotions and desires that are used in the proposed model to be supported by proper psychological reasoning. Also, we needed to combine a person's desires, which are very closely related to his/her body, with the emotions that express these mutual effects. We distinguish emotions from feelings using a neuroscience perspective and consider the relationship among emotions, feelings, and desires in a human's body.

Moreover, we present the development of emotions and their relationship to robots. To introduce the capability of emotions and desires into robots, we use a self-organizing map (SOM) to represent and generate those emotions and desires. We also construct a function for the development of emotions in the proposed model using examples from our previous study, because our previous study demonstrated the effectiveness of an emotion-growing model. The emotional expression of the proposed model is based on M. Lewis's study on the differentiation and development of emotions as an emotional genetic model in psychology [1]. The generation of desires is based on Maslow's hierarchy of needs and is also represented using SOMs [3]. Also, we provide the robots with internal-states to enable them to have the equivalent of human body functions.

In the next section, we explain in detail the proposed emotion generation model and the methods used in this model.

2.1 Structure of the Proposed Model

Figure 1 shows the structure of the proposed model. It contains an internal-state with a section for emotion generation and a section for desire generation. Also, there is an external environment.

An input is generated by external stimulations and is received by the robot's internal-state. The desire and emotion generation networks then receive their inputs from the internal-state and generate new desires and emotions. Emotions generated by the emotion generation network are then expressed by the robot. Also, the internal-state is updated by the generated desires and emotions. This means that the internal-state now includes the influence of both the desire generation network and the emotion generation network. The mutual effects of desires and emotions are expressed by connecting the two networks in this way. Thus, the robot can generate emotions that are more similar to those expressed by humans, because the model is influenced by simulated physiological factors and the robot's current state of desire.

2.2 Self-Organizing Map(SOM)

We used SOMs to generate desires and emotions. Figure 2 shows a standard SOM. This type of an NN tends to treat data as vectors that have a characteristic classification of multidimensional data. Learning is unsupervised and uses the commonly used Euclidean distance. The Euclidean distance is the geometric distance between two points in a straight line and is defined by the Pythagorean theorem. An SOM searches for neuron i that assumes a Euclidean distance with x being a minimum when an input vector x is given. We assumed that the neuron had a reference vector (m_c), which assumes a Euclidean distance with x being a minimum toward the winner unit. The winner unit and the units around the outskirts learn the input vector using Eq. (1).

$$m_i(t+1) = m_i(t) + h_{ci}(t)[x(t) - m_i(t)] \quad (1)$$

Here, h represents the neighborhood function, and t is an input step number. The neighborhood function can be expressed using Eq. (2) [4].

$$h_{ci}(t) = a(t) \cdot \exp\left(-\frac{\|r_c - r_i\|^2}{2\sigma^2(t)}\right) \quad (2)$$

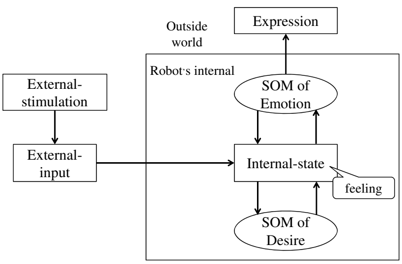


Fig. 1. Structure of the proposed model

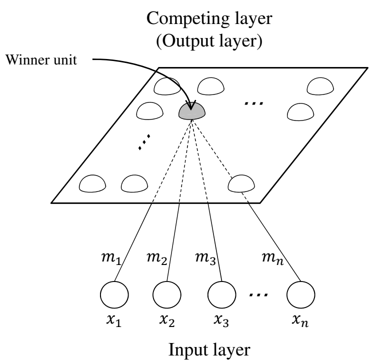


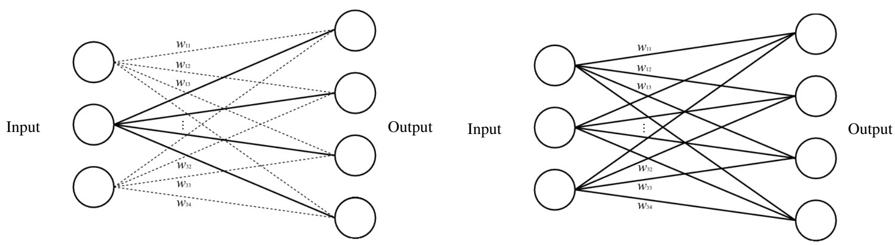
Fig. 2. Self-organizing maps(SOMs)

Here $a(t)$ is the learning rate coefficient and parameter $\sigma(t)$ is the neighborhood radius. The functions $a(t)$ and $\sigma(t)$ are monotone decreasing functions of time. Using this neighborhood function, the neighborhood radius is large for the first learning process, and it gradually reduces as learning converges. By repetitive learning for all vectors, similar units come together for each input vector.

2.3 Network Evolution

From a psychological perspective, it is believed that various human emotions increase with age. Prior research has proposed a method by which the evolution of an NN can replicate this process [2]. Network evolution increases the amount of information that a model can control by increasing the number of combinations of neurons in the NN. In the early stages of evolution, the output layer neurons are not connected with all input layer neurons (shown by dashed lines in Figure 3(a). The output layer neurons only become combined with unconnected input layer neurons during evolution (development). After the evolution of the NN, the output layer neurons are combined with all input layer neurons. Figure 3(b) shows the increase in information at the inputs, and w_{11} - w_{34} represents the combined load between each neuron. Each neuron interval is a non-combination, that is, the combination load between each neuron expresses a 0 state.

Herein, we applied SOMs to control the evolution of the model, and we used an SOM as a desire and emotion generation network to represent the change associated with the development in humans. Hence, we developed an emotion model based on the evolution of the network as follows. First, the cosine degree of resemblance of the input data x_n and data inputs(x_{n-1}, x_{n-2}, ..., x_0) are found. Next, the network is evolved when data is judged to resemble the input data based on the cosine degree of resemblance, with x_n being greater than a predetermined number of times. Here we express the cosine degree of resemblance as two vectors in terms of the numerical values from Eq. (3).



(a) Neural Network before network evolution

(b) Neural Network after network evolution

Fig. 3. Network evolution

$$sim = \frac{x_0 \cdot y_0 + x_1 \cdot y_1 + \cdots + x_n \cdot y_n}{\sqrt{(x_0^2 + x_1^2 + \cdots + x_n^2)(y_0^2 + y_1^2 + \cdots + y_n^2)}} = \frac{x \cdot y}{|x| * |y|} \quad (3)$$

2.4 Emotion Development Model

The proposed model is required to consider the connections between the body and the emotions to adopt a desire. Here the body means a function that causes desires such as physiological needs. Thus, we distinguish feelings from emotions as two states of mind, each having strictly different properties. For example, A. E. Damasio, a brain scientist and philosopher, defines emotions as being external and public and feelings as being internal and private [5]. Based on these definitions, emotions are generated in the NN, while feelings are controlled by the internal-state of the robot. Also, Lewis's study of the differentiation and development of emotions has attracted attention in recent years [1]. Figure 4 shows results from Lewis's study. Lewis explains that infants experience contentment, interest, and distress by nature. Furthermore, he explained that from eight months of age, infants can express joy, surprise, sadness, disgust, anger, and fear, which eventually leads to nine basic emotions. To differentiate between emotions and developmental functions, we use Lewis's emotional development model (Figure 5).

2.5 Desire Model

In this study, we model the concept of desire using NNs. A. H. Maslow's hierarchy of needs, commonly known as the Maslow hierarchy of needs, is famous as the theory of hierarchical human desire [3]. Maslow's hierarchy of needs is shown in Figure 6.

We propose a model for desire to realize an increasing hierarchy of needs (Figure 7). This model includes seven desires from the first to the fourth stage;

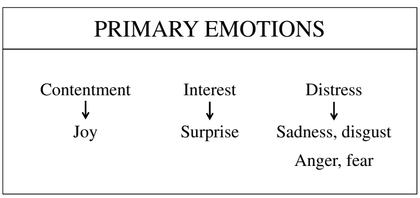


Fig. 4. Lewis's study

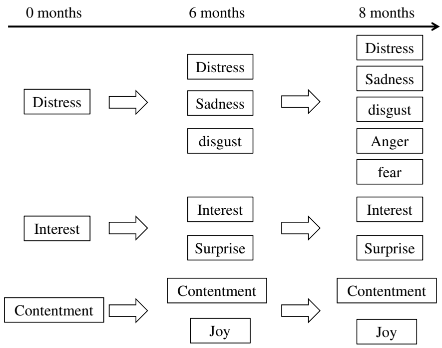


Fig. 5. Emotion development model

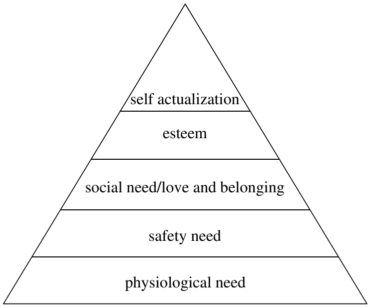


Fig. 6. Maslow's hierarchy of needs

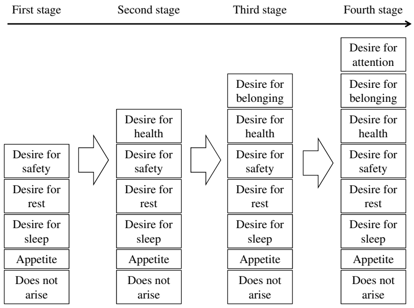


Fig. 7. Desire model

namely, appetite and desires for sleep, rest, safety, health, belonging, and attention.

2.6 Internal-States and External-Stimulation

In the proposed model, robots have internal-states, which is similar to a memory holder in which the robot saves its current state. This internal-state is similar to the main states of being for a human. For example, the robot saves hunger and exhaustion, which are physiological factors, as numerical values in its internal-state. The factors of internal-states are shown in Table 1.

Also, we consider external-stimulations. An external-stimulation is defined as one from a robot's environment that influences it. Because there are many such causes of external-stimulation in the real world, we cannot consider all possible causes. Therefore, in this study, we consider only common external-stimulations. An example of the type of external stimulation that is used for this study is shown in Table 2.

3 Simulation

3.1 Simulation of Emotion Generation

In this simulation, we compared the emotional expression of the proposed model to that of a reference model to determine the usefulness of the proposed model. Although the reference model does not have the characteristics of the proposed model, such as the mutual effects of desires and emotions, its emotion generation network is identical to that of the proposed model. Each parameter for the two SOMs used for the simulation is shown in Table 3. Also, we used four types of input sets to examine variations in the expressed emotions for our proposed model. These sets were created with the assumption that the robot and human would have a long-term interaction. Of the four types, express positive (Table 4) and negative (Table 5) images in each other. The other two are a mix of positive and negative image inputs (Tables 6 and 7). These four types of input

Table 1. Factors of internal-states

Factor of internal-states	Category	
Hunger	States influenced by desires	
Sleep		
Exhaustion		
Safety		
Growth		
Comfort		
Love		
Injury		
Distress	Feelings	
Interest		
Contentment		
Sadness		
Disgust		
Surprise		
Joy		
Anger		
Fear		
Euphoria	States changed by feelings	
Enjoyment		
Contempt		
Curiosity	Feelings of will generated by desires	
Expectation		
Volition		
Appetite	Physiological need	Container for desires
Desire for sleep		
Desire for rest		
Desire for safety	Safety need	
Desire for health		
Desire for belonging	Love and belonging	
Desire for attention	Esteem	

Table 2. Types of external-stimulation

Type of external-stimulation	Category
Praise	Stimulation by users
Slap	
Scold	
Call	
Show	
Prepare a meal	
Play	
Amuse	
Heal	
Cry	Stimulation by action
Move	
Sleep	
Motion with emotions (ME)	
Brightness	Stimulation by environment
Sound	
Temperature	

Table 3. SOM parameters

Common parameter	
Number of times of learning	2,000
Number of times of external-input	-1.0 - 1.0
Parameter of emotion generation SOM	
Combination load	-1.0 - 1.0
Inputlayer neuron	30
Output layer neuron	Initial value 1, maximum 9
Parameter of desire generation SOM	
Inputlayer neuron	30
Output layer neuron	Initial value 4, maximum 8

sets consist of stimulations of 20 steps. Each step consists of an interference stimulation, parent's emotion, action stimulation, and environment stimulation. Here a "step" is the time taken by a robot to recognize an important input from a number of real-world inputs. Therefore, the time between steps is not uniform.

3.2 Simulation Results and Discussion

Only some of the results of the emotion generation simulation can be discussed here owing to space limitations.

Figure 8 shows the differentiation state of this simulation data, from which we confirm that each emotion is differentiated into one or more sub-emotions. That is, each of these emotions belongs to a system of emotions. In this figure, we assign colors to units in each system so as to distinguish between systems. Tables 8 and 9 and Figure 9 show the results of the emotion generation simulation.

Table 8 shows the changes in the emotional expressions in the proposed model with respect to the positive and negative image inputs. The results show that the proposed model expresses biased emotions when given biased inputs. Also, we confirmed that emotional expression and all the input sets in the reference model have a one-to-one relation between this figure and Table 4. Table 9 shows the changes in the emotional expression in the proposed model for mixed inputs and demonstrates the variation in the expressed emotions when mixed inputs are received from both the positive and negative input sets. Figure 9 shows the changes in the internal-state when the proposed model received positive image inputs. This confirms that the robot's emotions are influenced by previously expressed emotions, the present state, and the present desires of the robot. Clearly,

Table 4. Positive image inputs

	Interference stimulation	Parent's emotion	Action stimulation	Environment stimulation
$t = 1$	None	None	Cry	Temperature
$t = 2$	Amuse	Contentment	Cry	Brightness
$t = 3$	Prepare a meal	Contentment	ME	Brightness
$t = 4$	None	None	Sleep	Temperature
$t = 5$	Amuse	Interest	ME	Sound
$t = 6$	Praise	Joy	ME	Temperature
$t = 7$	None	None	Cry	Sound
$t = 8$	Play	Joy	Move	Sound
$t = 9$	Heal	Interest	Move	Sound
$t = 10$	None	None	Sleep	Brightness
$t = 11$	None	None	Cry	Temperature
$t = 12$	Amuse	Contentment	Cry	Brightness
$t = 13$	Prepare a meal	Contentment	ME	Brightness
$t = 14$	None	None	Sleep	Temperature
$t = 15$	Amuse	Interest	ME	Sound
$t = 16$	Praise	Joy	ME	Temperature
$t = 17$	None	None	Cry	Sound
$t = 18$	Play	Joy	Move	Sound
$t = 19$	Heal	interest	Move	Sound
$t = 20$	None	None	Sleep	Brightness

Table 5. Negative image inputs

	Interference stimulation	Parent's emotion	Action stimulation	Environment stimulation
$t = 1$	None	None	Cry	Temperature
$t = 2$	None	None	Cry	Brightness
$t = 3$	Prepare a meal	Interest	ME	Brightness
$t = 4$	None	None	Cry	Temperature
$t = 5$	None	None	ME	Brightness
$t = 6$	None	None	ME	Brightness
$t = 7$	None	None	Cry	Sound
$t = 8$	Amuse	Contentment	Cry	Brightness
$t = 9$	None	None	Cry	Sound
$t = 10$	None	None	ME	Brightness
$t = 11$	None	None	Cry	Sound
$t = 12$	None	None	Cry	Temperature
$t = 13$	Prepare a meal	Joy	ME	Sound
$t = 14$	None	None	ME	Sound
$t = 15$	None	None	ME	Sound
$t = 16$	None	None	ME	Sound
$t = 17$	None	None	Cry	Sound
$t = 18$	Play	Joy	Cry	Sound
$t = 19$	None	Joy	Sleep	Sound
$t = 20$	None	Joy	ME	Sound

Table 6. Positive and Negative image inputs

	Interference stimulation	Parent's emotion	Action stimulation	Environment stimulation
$t = 1$	None	None	Cry	Temperature
$t = 2$	Amuse	Contentment	Cry	Brightness
$t = 3$	Prepare a meal	Contentment	ME	Brightness
$t = 4$	None	None	Sleep	Temperature
$t = 5$	Amuse	Interest	ME	Sound
$t = 6$	Praise	Joy	ME	Temperature
$t = 7$	None	None	Cry	Sound
$t = 8$	Play	Joy	Move	Sound
$t = 9$	Heal	Interest	Move	Sound
$t = 10$	None	None	Sleep	Brightness
$t = 11$	None	None	Cry	Sound
$t = 12$	None	None	Cry	Temperature
$t = 13$	Prepare a meal	Joy	ME	Sound
$t = 14$	None	None	ME	Sound
$t = 15$	None	None	ME	Sound
$t = 16$	None	None	ME	Sound
$t = 17$	None	None	Cry	Sound
$t = 18$	Play	Joy	Cry	Sound
$t = 19$	None	Joy	Sleep	Sound
$t = 20$	None	Joy	ME	Sound

Table 7. Negative and Positive image inputs

	Interference stimulation	Parent's emotion	Action stimulation	Environment stimulation
$t = 1$	None	None	Cry	Temperature
$t = 2$	None	None	Cry	Brightness
$t = 3$	Prepare a meal	Interest	ME	Brightness
$t = 4$	None	None	Cry	Temperature
$t = 5$	None	None	ME	Brightness
$t = 6$	None	None	ME	Brightness
$t = 7$	None	None	Cry	Sound
$t = 8$	Amuse	Contentment	Cry	Brightness
$t = 9$	None	None	Cry	Sound
$t = 10$	None	None	ME	Brightness
$t = 11$	None	None	Cry	Temperature
$t = 12$	Amuse	Contentment	Cry	Brightness
$t = 13$	Prepare a meal	Contentment	ME	Brightness
$t = 14$	None	None	Sleep	Temperature
$t = 15$	Amuse	Interest	ME	Sound
$t = 16$	Praise	Joy	ME	Temperature
$t = 17$	None	None	Cry	Sound
$t = 18$	Play	Joy	Move	Sound
$t = 19$	Heal	interest	Move	Sound
$t = 20$	None	None	Sleep	Brightness

our simulation results show that the emotions expressed by the proposed model are more complex and realistic than those expressed by the reference model. Also, the results show that the proposed model can generate appropriate and a range of various emotions when it receives biased image inputs.

4 Conclusion

Herein, we discussed the use of an emotion model to systematize a robot's emotions. We noted that human desires and emotions affect each other, and we proposed an emotional development model. Also, we observed that desire and emotion should develop in the same way as experienced in humans. Thus, we constructed an emotion generation model for robots that depended on physiological factors. Furthermore, by evolving its SOM network, the proposed model mimicked emotional development in humans and could generate more complex emotions, which further developed with growth. Finally, we confirmed that emotions expressed by the proposed model were more complex and realistic than those expressed by the reference model.

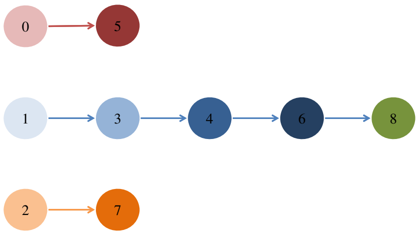


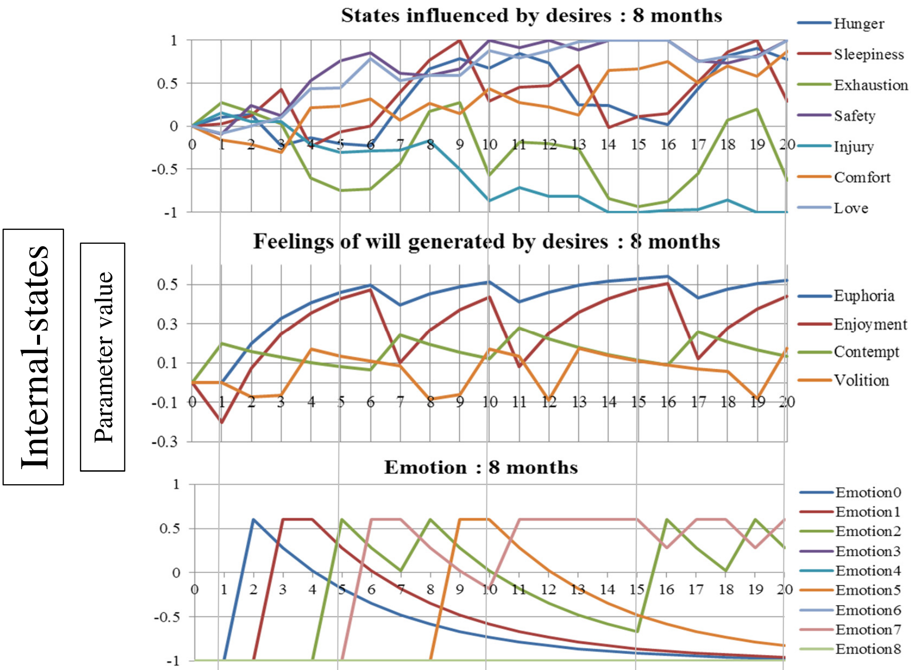
Fig. 8. Differentiation state of the simulation data

Table 8. Result of emotional expression: biased inputs (positive or negative)

	Positive image inputs : Proposed model			Negative image inputs : Proposed model			Positive image inputs : Reference model		
	3 months	6 months	8 months	3 months	6 months	8 months	3 months	6 months	8 months
Step1	0	0	0	0	0	0	0	4	4
Step2	1	1	1	0	5	5	1	1	1
Step3	1	1	1	1	5	5	2	6	6
Step4	2	2	2	1	5	5	2	3	7
Step5	2	2	7	0	5	5	2	6	6
Step6	2	2	7	0	5	5	2	2	2
Step7	2	2	7	0	5	5	0	4	8
Step8	0	5	5	0	5	5	0	4	4
Step9	0	5	5	0	5	5	0	0	0
Step10	2	2	7	0	5	5	2	3	7
Step11	1	2	2	0	5	5	0	4	4
Step12	2	3	7	0	5	5	1	1	1
Step13	2	4	7	0	5	5	2	6	6
Step14	2	6	7	0	5	5	2	3	7
Step15	2	6	7	0	5	5	2	6	6
Step16	2	6	2	0	5	5	2	2	2
Step17	2	6	7	0	5	5	0	4	8
Step18	2	6	7	0	5	5	0	4	4
Step19	2	6	7	0	5	5	0	0	0
Step20	2	6	7	0	5	5	2	3	7

Table 9. Result of emotional expression: mixed inputs (positive and negative)

	Positive image inputs : Proposed model			Positive and negative image inputs : Proposed model			Negative and positive image inputs : Proposed model		
	3 months	6 months	8 months	3 months	6 months	8 months	3 months	6 months	8 months
Step1	0	0	0	0	0	0	2	2	2
Step2	1	1	1	1	1	1	1	5	5
Step3	1	1	1	1	1	1	1	5	5
Step4	2	2	2	2	2	2	1	5	5
Step5	2	2	7	2	2	7	2	5	5
Step6	2	2	7	2	2	7	2	5	5
Step7	2	2	7	2	2	2	2	5	5
Step8	0	5	5	0	5	5	0	5	5
Step9	0	5	5	0	5	5	0	5	5
Step10	2	2	7	2	2	7	2	2	2
Step11	1	2	2	1	2	7	2	5	5
Step12	2	3	7	1	3	3	2	5	5
Step13	2	4	7	1	4	4	2	5	5
Step14	2	6	7	1	6	6	2	2	2
Step15	2	6	7	2	6	8	2	2	2
Step16	2	6	2	2	6	8	2	2	7
Step17	2	6	7	1	6	8	2	5	5
Step18	2	6	7	1	6	8	0	5	5
Step19	2	6	7	2	6	8	0	5	5
Step20	2	6	7	2	4	4	2	2	2



Emotion expression																					
	3 months	0	1	1	2	2	2	2	0	0	2	1	2	2	2	2	2	2	2	2	2
	6 months	0	1	1	2	2	2	2	5	5	2	2	3	4	6	6	6	6	6	6	6
	8 months	0	1	1	2	7	7	7	5	5	7	2	7	7	7	7	2	7	7	7	7

Step

Fig. 9. Internal-states' change in the simulation

In future studies, we will apply the proposed method to an actual robot system.

References

1. Lewis, M., Jeannette M., Haviland-Jones: Handbook of Emotions, 2nd edn. Guilford Press (2000)
2. Harata, M., Sumitomo, H., Tokumaru, M.: Emotion generation model for a robot with a growth function. In: 12th International Symposium on Advanced Intelligent Systems, ISIS 2011, Suwon, Korea, pp. 319–322, 2011-10 (2011)
3. Goble, F.: The Third Force. The Psychology of Abraham Maslow, Maurice Bassett (1970)
4. Mera, K., Ichimura, T.: Personal Mental State Transition Network using Self Organizing Map. In: 27th Fuzzy System Symposium, Japan, pp. 1281–1286 (2011)
5. Damasio, A.R.: Looking for Spinoza: Joy, Sorrow, and Feeling Brain, Harcourt (2007)