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Autonomous Emotional Expression Generation of a Robotic Face

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***Abstract*—This paper presents a novel design of autonomous robotic facial expression generation using a fuzzy-neuro network. The emotional characteristics of a robot can be specified in this design by assigning weights in the fuzzy-neuro network. The robotic face generates appropriate expressions in responding to the image recognition results of a user's emotional state and the assigned robotic emotional characteristics. In this study, two contrast emotional characteristics, optimistic and pessimistic, have been designed and tested to verify their responses to the recognized user emotional states (neutral, happiness, sadness and anger). Computer simulations of a robotic face show that the proposed facial expression generation system effectively responds to a user's emotional states in a human-like manner by fusing outputs of four facial expressions (boring, happiness, sadness and surprise).**

***Keywords*—emotional characteristics, facial expression generation, fuzzy-neuro network, human-robot interaction.**

I. Introduction

In recent years, a popular research area in robotics is to develop intelligent robots that can interact with people as a companion, rather than as a machine. The study of sociable humanoid robots has become an important part in human-robot interaction [1].There have been many research efforts that focus on sociable humanoid robots. Breazeal *et al.* [2] developed a sociable robot Leonardo, which has an expressive face capable of near human-level expression based on an active binocular vision system to recognize human facial features. MIT Media Lab has demonstrated a humanoid robot Nexi [3]. The robot shows a wide range of facial expressions to communicate with people in human-centric terms. In Japan, Takanishi *et al.* studied the expression of human-like emotion of the robot WE-4RII using facial expressions and gestures [4-5]. They proposed a mental space model to build the robotic emotional state from external sensor inputs. Hanson Robotics developed the robot Jules, which can mimic a real person's expressions by watching their faces [6]. Kobayashi *et al.* [7] developed a reception robot SAYA to realize a realistic speaking as a natural interactive behavior by using fourteen Ekman's action units [8]. The robot can express six typical facial expressions [9]. Korea Institute of Industrial Technology (KITECH) presented a singer robot EveR-2 [10], which can acquire visual and speech information to express facial emotion and synchronize its lips with voice. The above-mentioned robots have successfully demonstrated various types of human-like interaction functions. However, these robots cannot generate a wide range of human-like emotional states in a continuous manner. Furthermore, the creation of humanoid emotional characteristics of robot has not been discussed yet.

In this study, we propose a method for autonomous emotional expression generation in responding to various degrees of the user's emotional state. The robotic emotional nature can be modified by adjusting the prototype patterns of a rule table. The rest of this paper is organized as follows. Section 2 describes the algorithm of an interactive emotional brain. In section 3, the emotional behavior-fusion with two contrast emotional characteristics is presented. Section 4 presents the designed robotic facial expression simulator. Several experimental results under optimistic and pessimistic nature are described in section 5. Section 6 summarizes the contribution of this study and gives directions of future research.

II. Interactive Emotional Brain

It is desirable to development a robot or a robotic face that can respond to a user differently according to its individual emotional characteristics. In order to design autonomous expression generation of a robot, a kind of interactive emotional brain is proposed. Through the function of interactive emotional brain, it is thus possible to let a robot possess certain emotional characteristics in dealing with human-robot interaction.

Figure 1 shows the block diagram of the proposed emotional brain for autonomous emotional expression generation. There are four major blocks in this design, including emotion state recognizer, primitive emotional behaviors, behavior fusion and a robotic facial simulator. In the stage of emotion state recognizing, a camera captures the user's face in front of the robot and passes the detected face to the stage of emotional state recognizer. In this paper, we do not discuss methods for recognizing the emotional states. We assume that the emotional states and their strength of the detected face can be recognized by some software module. The user's emotional state is expressed as a combination of four emotional intensities, including neutral, happiness, anger and sadness intensities (E_i, i=1~4). After image recognition, these intensities are collected and sent to the behavior-fusion stage. A

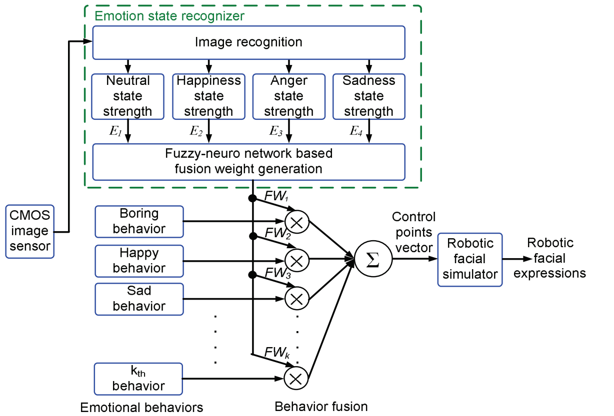


Fig. 1. The block diagram of the autonomous emotional expression generation system.

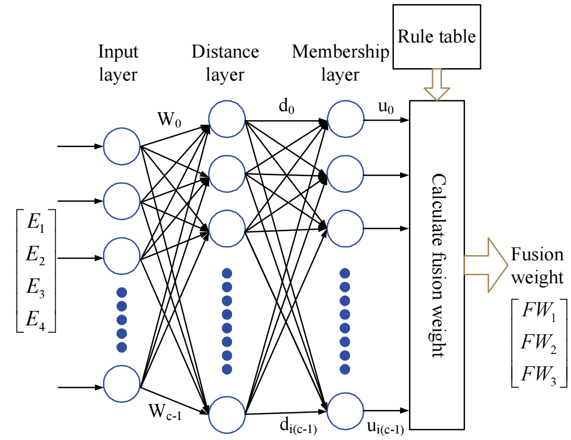


Fig. 2. The FKCN for fusion weights determination.

novel behavior fusion scheme has been designed using Fuzzy Kohonen Clustering Network (FKCN) to autonomously generate the response of the robotic face. Furthermore, the emotional characteristics of the robotic face can be assigned by setting parameters in the FKCN rule table. By setting rule tables, the emotional characteristics of robot can be assigned, for instance, to be an optimistic nature or a pessimistic nature. In this work, we designed three emotional behaviors for robotic face beforehand, including boring, happy, and sad behaviors. However, more subtle emotional behaviors can be added to the structure as desired. In response to the estimated emotional intensity, a set of fusion weights (FW_i, i=1~k) corresponding to emotional behaviors are generated by the FKCN and sent to behavior fusion stage to generate robot's output facial expressions (behavior). The robot's output facial expressions are generated by summation of each output behavior multiplied by its corresponding fusion weight (see Section III). A robotic facial simulator is employed to produce a responsive behavior for the desired human-robot interaction. Detailed design of behavior-fusion neural network and simulation results will be described in the following sections.

III. Emotional Behavior-Fusion

The concept of pattern recognition was adopted for the robotic behavior fusion design. It is utilized to map the user's emotional state, obtained from camera and image recognition module, to the fusion weights of individual facial expression behavior. FKCN was applied to determine the fusion weights of each emotional behavior [11, 12]. Figure 2 illustrates the structure of the FKCN fuzzy-neuro network for behavior fusion. In the first layer of the network, the intensities of user's emotional state (E_i, i=1~4) are regarded as inputs of FKCN. In the second layer, the distance between input pattern and each prototype pattern is calculated as follows:

$$d_{ij} = \left\| X_i - W_j \right\|^2 = \left(X_i - W_j \right)^T \left(X_i - W_j \right) \tag{1}$$

where X_i denotes the input pattern and W_j denotes the j_{th} prototype pattern. In the second layer, we calculate the degree of difference between the current and the prototype pattern. If the input user's emotional state is not similar with the prototype pattern, the degree of difference becomes larger. The third layer calculates the similarity degree between the input pattern and the prototype patterns. The similarity is represented by a membership value. The determination of the membership value is given such that:

$$u_{ij} = \begin{cases} 1 & if \quad d_{ij} = 0 \\ 0 & if \quad d_{jk} = 0, \ \left(k \neq 0, k \geq 0, j \leq c-1\right) \end{cases} \tag{2}$$

otherwise,

$$u_{ij} = \left[\sum_{i=0}^{c-1} \frac{d_{ij}}{d_{il}} \right] \tag{3}$$

Using the rule table and the obtained the membership values, the current fusion weights (FW_i , i =1~3) are determined. The prototype patterns in the rule table define the weights of basic output behaviors corresponding to some primitive emotional states. FKCN has the capacity to generalize these prototype patterns to all situations that may happen to the robot by calculating the proper fusion weights.

In this design, the emotional characteristics of a robot can be designed into the emotional brain through proper assigning the prototype patterns of FKCN. In order to emphasize that the humanoid emotional characteristics can be designed arbitrarily, two contrary robotic emotional characteristics, namely the optimistic nature and pessimistic nature are presented as an example. Table I shows the assigned behavior fusion weight corresponding to each prototype pattern while the robot's nature is optimistic. In the left part of Table I, we define the observed user's emotional intensity in prototype patterns as a value from 0 to 1 (0 represents no corresponding emotional state; 1 represents that the corresponding emotional intensity is maximum). In the right part of Table I, three fusion weights are designed based on the individual characteristics we want the robot to behave. In the design phase, one needs to assign default fusion weights in the FKCN in order to give desired robotic emotional characteristics. In practical applications, as the robotic face obtains current user's emotional state, the FKCN can generate the fusion weights to respond to the user's immediate emotional inputs.

For example, a weight of boring behavior is assigned as 1 in the third row of Table I, as the intensities of the user's input emotional states are all equal to 0 (no face is detected by the robot). If a user expresses his facial expression as a neutral expression (as shown in the fourth row of Table I), the weights of boring and happy behavior are assigned as 0.7 and 0.3 respectively. Besides, if a user expresses his facial expression as a 50% happy intensity (as shown in the fifth row of Table I), the robot expresses the maximum intensity of happy behavior in responding. Furthermore, if a user expresses his facial expression as an angry emotion (as shown in the sixth row of Table I), the weights of happy and sad behavior are assigned as 0.5 and 0.5 respectively. These settings of prototype patterns and weights show that the robot owns a kind of optimistic nature.

Table II shows the assigned behavior fusion weights for a pessimistic robotic nature. For example, if a user expresses facial expression as a neutral emotion (as shown in the fourth row of Table II), the weights of boring and sad behavior are assigned as 0.5 and 0.5 respectively. If the facial expression of a user is recognized as happy emotion (as shown in the fifth row of Table II), the robot does not express the maximum happy behavior. Furthermore, if a user expresses his facial expression as an angry emotion (as shown in the sixth row of Table II), the robot expresses the maximum sad behavior. These settings of the prototype pattern weights show that the robot is of a pessimistic nature.

As shown in Fig. 1, the user's emotion state recognizer calculates the intensity of emotional state (E_i , i =1~4) from acquired image data. After obtaining the fusion weights from FKCN, the robot's behavior is determined from three behaviors multiply by their corresponding fusion weights (FW_i , i =1~3):

$$\begin{aligned} \textit{Robotic facial expression} = \; & Boring \;\; behavior \; * FW_1 \\ & + \; Happy \;\; behavior \; * FW_2 \\ & + \; Sad \;\; behavior \; * FW_3 \end{aligned} \tag{4}$$

IV. Robotic Facial Simulator

To evaluate the effectiveness of the proposed interactive emotional brain, a robotic facial simulator is designed as shown in Fig. 3. We assume that the user's emotional state can be simulated by adjusting a track bar. Through moving track bars in the upper-right of Fig. 3, the input emotional intensities are inputted to the simulator. The output fusion weights of robotic emotional behaviors will be computed by the proposed emotional brain and shown on the lower right of the figure. As shown in Fig. 3, a robotic face is designed in order to show the variation of output facial expression behavior. The boring behavior is designed as a basic facial expression without any emotional expression. The happy behavior is designed as a variation of facial expression which looks like a smiling face. The control points for generating facial expressions adopted the Ekman action units [8]. Figure 4 shows the robotic face with various emotional behavior weights. While the user expresses facial expression in front of the robot with an emotional state, the proposed emotional expression generation system will present a suitable facial expression behavior immediately to interact with the user.

In the current design, we assigned the prototype patterns and rule table as shown in Table I and Table II to demonstrate the robot's optimistic and pessimistic nature respectively. Even though we do not emphasize what kind of interaction model is the best, the proposed autonomous emotional expression

TABLE I
Rule Table for an Optimistic Robotic Face

If – part prototype patterns				Then – part weighting		
Neutral	Happiness	Anger	Sadness	Boring	Happiness	Sadness
0	0	0	0	1	0	0
1	0	0	0	0.7	0.3	0
0	0.5	0	0	0	1	0
0	0	1	0	0	0.5	0.5
0	0	0	1	0.3	0	0.7

TABLE II
Rule Table for a Pessimistic Robotic Face

If – part prototype patterns				Then – part weighting		
Neutral	Happiness	Anger	Sadness	Boring	Happiness	Sadness
0	0	0	0	1	0	0
1	0	0	0	0.5	0	0.5
0	1	0	0	0	0.2	0.8
0	0	0.5	0	0	0	1
0	0	0	1	0	0	1

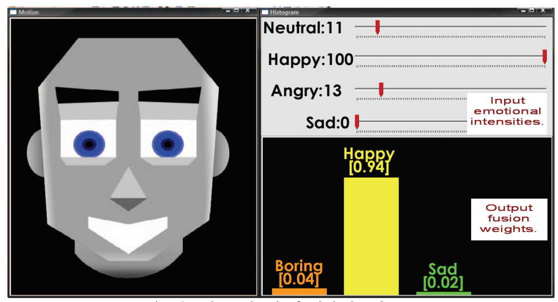


Fig. 3. The robotic facial simulator.

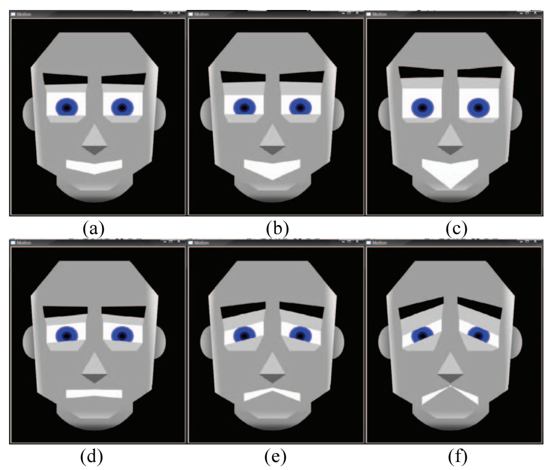


Fig. 4. Facial expressions generated by the simulator with various emotional behavior weights. (a) With 20% happy weight. (b) With 60% happy weight. (c) With 100% happy weight. (d) With 20% sad weight. (e) With 60% sad weight. (f) With 100% sad weight.

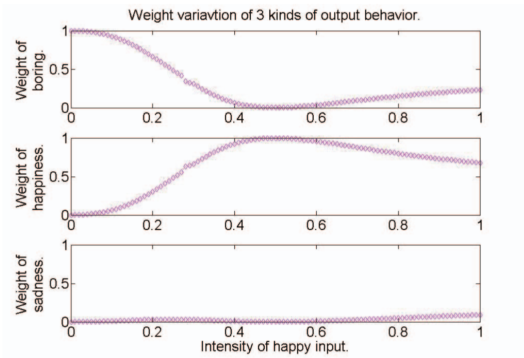


Fig. 5. Variations of three fusion weights under optimistic nature while vary only the happy intensity.

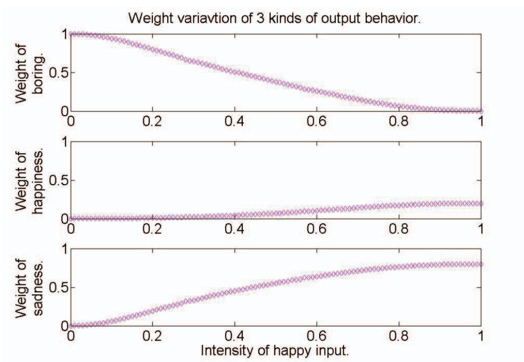


Fig. 6. Variations of three fusion weights under pessimistic nature while vary only the happy intensity.

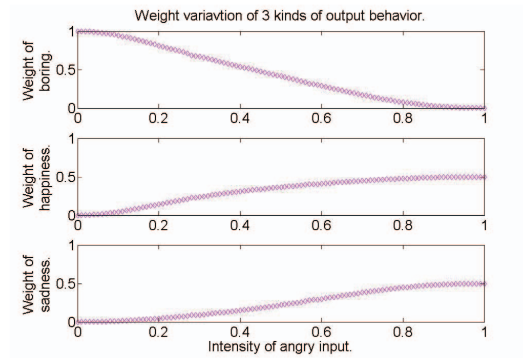


Fig. 7. Variations of three fusion weights under optimistic nature while vary only the angry intensity.

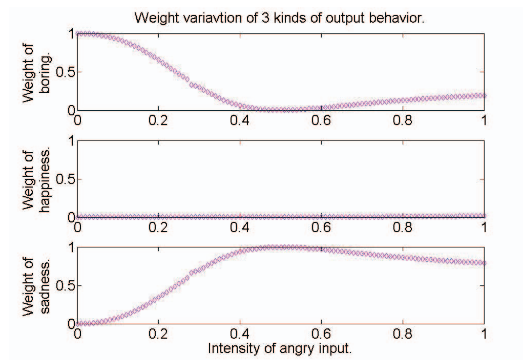


Fig. 8. Variations of three fusion weights under pessimistic nature while vary only the angry intensity.

generation system can be verified by observing three fusion weights of output behaviors. Figures 5-6 show the variation of three fusion weights under optimistic and pessimistic nature respectively as we only vary the happy intensity. In the current designed prototype patterns, the fusion weight of boring and happy behavior should decrease and increase respectively while happy intensity increases. It can be seen that the simulation results in Figs. 5 and 6 match this tendency. Comparing Fig. 5 with Fig. 6, the weight variation of happy behavior in optimistic nature is higher than that of pessimistic nature. Besides, the weight variation of sad behavior in optimistic nature is lower than that in the pessimistic nature.

Figures 7-8 show the variation of three fusion weights under optimistic and pessimistic nature respectively as we vary only the angry intensity. Comparing Fig. 7 with Fig. 8, the weight variation of happy behavior in optimistic nature is higher than that of pessimistic nature. Besides, the weight variation of sad behavior in optimistic nature is lower than that of pessimistic nature. It can be seen that the simulation results of Figs. 7 and 8 matches the expected response.

V. SIMULATION RESULTS

In this section, we will observe the output emotional behavior as various intensities of happy and angry emotional states are mixed. The variations of robot output behavior occur mainly on happiness and sadness as input emotion intensities belonging to happy and angry states. The purpose of this simulation is to investigate to what extent that the proposed emotional behavior control system can achieve. Furthermore, a surprise behavior is added to increase the vivid expression of the robotic face. From the simulation results, we can analyze the emotional characteristics of the designed robot. It also means that we could build a robotic emotional nature arbitrarily.

A. Mixing of Happy and Angry Emotional States

Figures 9-10 show that the variation of the weight of happiness under optimistic and pessimistic nature respectively as the happy and angry intensities are adjusted. In the current prototype patterns, the fusion weight of happy behavior should increase while the detected happy intensity of the user increases. The fusion weight of happy behavior should decrease as the detected angry intensity increases. Comparing Fig. 9 with Fig. 10, all the weight variation of happy behavior in Fig. 9 is higher than the corresponding ones in Fig. 10. It is clear that the robot nature in Fig. 9 is happier than that in Fig. 10.

Figures 11-12 show the sadness weight variation under optimistic and pessimistic nature respectively, as the happy and angry intensities are adjusted. In the current prototype patterns, the fusion weight of sad behavior should increase as the intensity of angry emotional state increases. The fusion weight of sad behavior should decrease as the intensity of happy emotional state increases. Comparing Fig. 11 with Fig. 12, all the weight variation of sad behavior in Fig. 12 is higher than

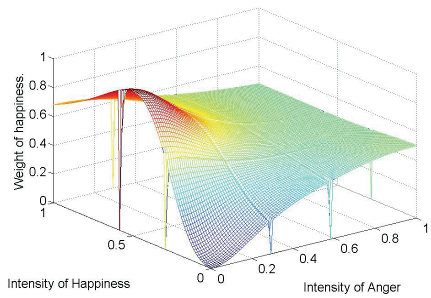


Fig. 9. Variations of happy weights under optimistic nature while vary the happy and angry intensities

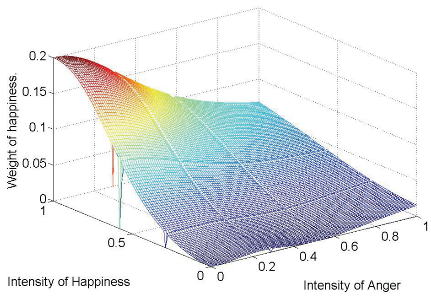


Fig. 10. Variations of happy weights under pessimistic nature while vary the happy and angry intensities.

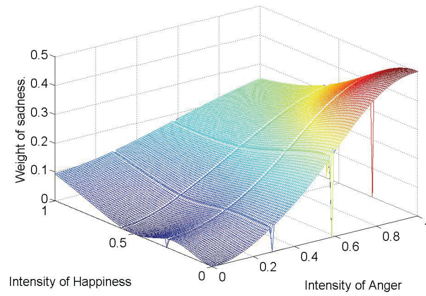


Fig. 11. Variations of sad weights under optimistic nature while vary the happy and angry intensities.

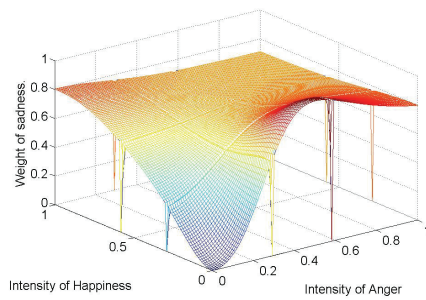


Fig. 12. Variations of sad weights under pessimistic nature while vary the happy and angry intensities.

the corresponding ones in Fig. 11. It is clear that the robot nature in Fig. 12 is sadder than the one in Fig. 11 and the robot character in Fig. 12 belongs to pessimistic nature.

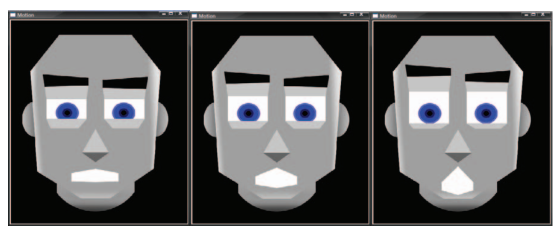
B. Add a Surprise Behavior

The surprise behavior is designed as a variation of facial expression, with which the robot looks amazed. Figure 13 shows the designed surprise behavior of robotic face with various intensities. Table III shows the behavior fusion weights corresponding to each prototype pattern where the surprise behavior is added. In the current design, we assume that the surprise behavior manifesting strongly while the angry and sad expressions appear on a user's face at the same time.

Figure 14 shows that the output emotional behavior changes as input happy, angry and sad intensities are varying. In Fig. 14(a), the robotic face expresses as a result of the input intensities of happy and angry intensities are 10% and 80% respectively. Here a slightly sad face appears on the robotic face. Figure 14(b) shows output robotic facial expressions as a result of the input happy and sad intensities are 10% and 80% respectively. It is clear that In Fig.14 (b) the robotic face shows a very sad expression as expected. Figure 14(c) shows the robotic facial expressions as a result of the input happy, angry and sad intensities are 10%, 50% and 50% respectively. A little surprise facial expression occurs in this situation. Fig 14(d) shows the robotic facial expressions as a result of the input happy, angry and sad intensities are 10%, 80% and 80% respectively. Here, a more surprise expression appears on the robotic face. As shown in Fig. 14, the proposed interactive emotional brain express the mixture emotional states and allow the robotic face behave in a human-like manner. A video clip of experimental results can be found in [13].

VI. Conclusion

This paper presents a design of interactive robotic emotional brain for autonomous emotional expression generation of a robotic face. The desired emotional characteristics of a robot can be established using the proposed method. Simulation results reveal that the autonomous

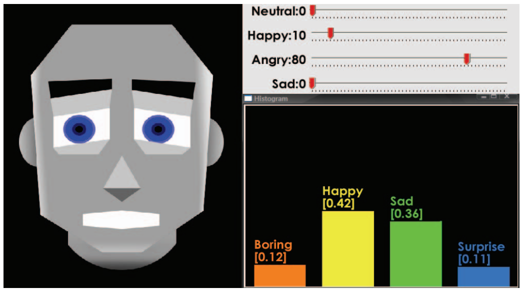


(a) (b) (c)

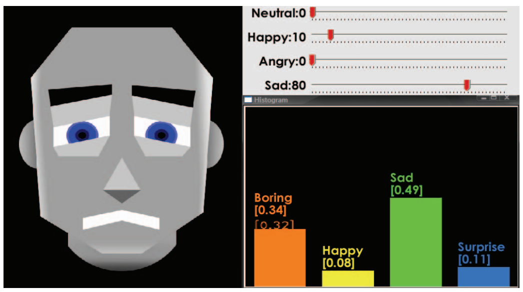
Fig. 13. The surprise behavior of the robotic face with different weights. (a) With 20% surprise weight. (b) With 60% surprise weight. (c) With 100% surprise weight.

TABLE III
Rule Table with Added Surprise Behavior

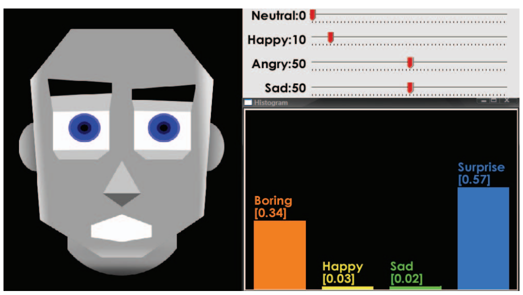
If – part Patterns of emotional intensities				Then – part Behavior weights			
Neutral	Happiness	Anger	Sadness	Boring	Happiness	Sadness	Surprise
0	0	0	0	1	0	0	0
1	0	0	0	0.7	0.3	0	0
0	0.5	0	0	0	1	0	0
0	0	1	0	0	0.5	0.5	0
0	0	0	1	0.3	0	0.7	0
0	0	0.5	0.5	0.4	0	0	0.6
0	0	0.8	0.8	0.1	0	0	0.9



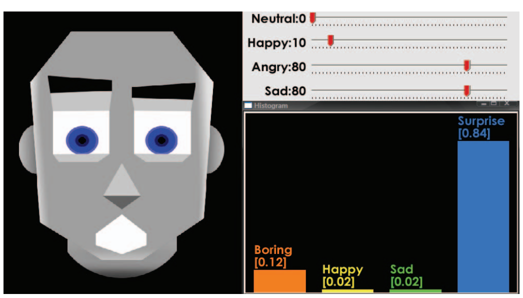
(a)



(b)



(c)



(d)

Fig. 14. The generated facial expressions in responding to varying input intensities of happy, angry and sad emotional states. (a) Input of 10% happy and 80% angry emotional intensities. (b) Input of 10% happy and 80% sad emotional intensities. (c) Input of 10% happy, 50% angry and 50% sad emotional intensities. (d) Input of 10% happy, 80% angry and 80% sad emotional states.

emotional expression generation algorithm determines the proper facial behaviors and responses to various facial expression intensities. In the future, we will focus on the estimation of the strength of emotional states. The proposed method will be implemented on a practical robotic face, which is equipped with a 16 degree of freedom robot head and an embedded facial expression recognition system.

ACKNOWLEDGMENT

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