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Natural Emotion Expression of a Robot Based on Reinforcer Intensity and Contingency

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Abstract— **An emotional robot is regarded as being able to express its diverse emotions in response to internal or external events. This paper presents a robot affective system that is able to express life-like emotions. In order to do that, the overall architecture of our affective system is based on neuroscience from which we obtained the natural emotional processing routines. Based on that architecture, we apply the reinforcer effects expecting that those would lead the affective system to be more similar to real-life's emotion expression. The robot affective system has responsibility for gathering environmental information and evaluating which environmental stimuli are rewarding or punishing. The emotion processing involves with appraisal of the external and internal stimuli, such as homeostasis, and generates the affective states of the robot. Therefore, emotions are associated with the presentation, omission, and termination of the expected rewards or punishers (reinforcers). The experimental results show that our affective system can express several emotions simultaneously as well as the emotions decrease, increase, or changes to another emotion seamlessly as time passes.**

I. INTRODUCTION

An emotion is an essential part of the human-robot interaction (HRI), since emotions influence rational decision-making, perception, learning, and other cognitive functions of a human [1]. According to the somatic marker hypothesis [2], the marker records emotional reaction to a situation. We learn the markers throughout our lives, and use them for our decision-making. Therefore, an emotional robot needs an affective system to synthesize and express emotions. Due to the importance of the emotion in the HRI, there have been several efforts to create robots with emotions to improve the HRI, such as the Sony 'Aibo' [3], and the MIT 'Kismet' [4].

Much of the previous work to build emotional robots is inspired by ethology, and use an affect space to produce an emotion. However, the emotional robot based on the affect space expresses only one emotion at a time, because the affect space has a competitive relationship between emotions. For example, Aibo has six emotions based on Takanishi's model [5], and always expresses only one affective state from among its six emotions. However, contrary to the previous work, humans can have several emotions simultaneously and can express them in various ways. Because of the dynamicity of the human emotional processing, there have been several attempts to understand the human emotion processing in the view of neuroscience and cognitive science.

Cognitive science studies the computational and representational structure of the mind by combining psychology, artificial intelligence, philosophy, and linguistics. In the cognitive science, an emotion involves with external events. For example, the Ortony, Clore, and Collins (OCC) model [6] assumes that emotions arise from valenced reactions to the phenomena perceived in the environment. These reactions to situations consist of a success (or failure) of goals, an attractiveness of objects, and a praiseworthiness (or blameworthiness) of actions. However, because of weak points of cognitive model [7], we suggest a neuroscientific approach to overcome these difficulties.

Contrary to cognitive science, neuroscience is a biological study of the human brain that deals with the structure, function, development, genetics, biochemistry, and pathology of the nervous system. According to neuroscientific researches, human has a complicate and dynamic emotion processing mechanism due to the considerable development in the human brain. Therefore, we can generate and express various affective states simultaneously. Furthermore, because people feel more comfortable with a human-like robot [1], human-oriented robot should have an emotion generation method similar to that of a human. Hence, we propose a robot affective system for intelligence robots inspired from neuroscientific research.

We proposed neuroscientific affective system to overcome disadvantages of previous works such as affective space model and cognitive emotion model. The emotional expression of the affective space model is limited because this model always generates only one emotion at a time. In addition, the cognitive emotion model needs to be extended with a history function and a personality [7] because it overlooks internal stimuli such as homeostasis. However, contrary to the affective space model, the proposed system generates various emotional expressions and implements internal stimuli such as homeostasis.

This paper is organized as follows. Section II presents the human emotion processing in the aspect of both neuroscience

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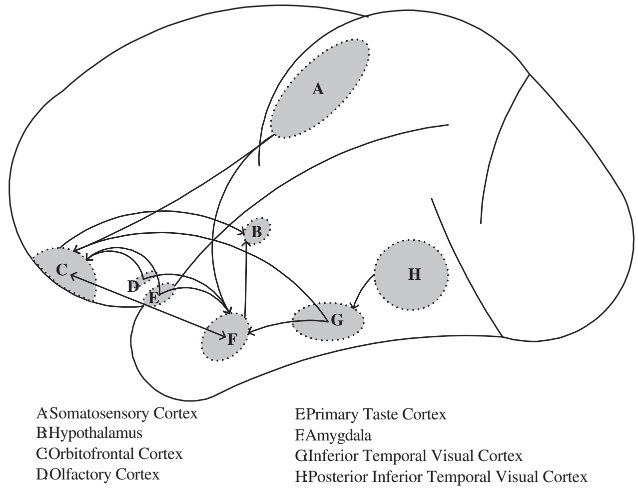
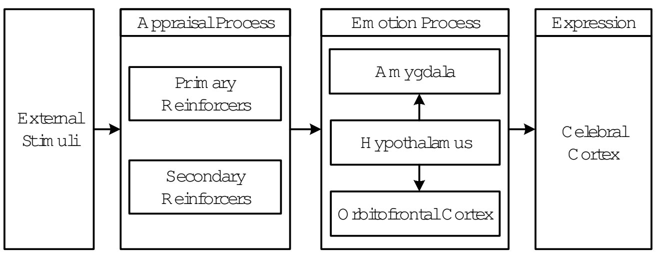


(a) Lateral view of the macaque monkey brain



(b) Diagram of the macaque monkey brain

Fig. 1. Brain of the macaque monkey

and cognitive science. Section III describes the proposed robot affective system based on Section II. The experimental result and the conclusion are presented in Section IV and Section V, respectively.

II. AN AFFECTIVE SYSTEM IN A HUMAN BRAIN

Since the temporal lobe and the prefrontal cortex have undergone considerable development [8], [9], humans can feel several emotions simultaneously, and have various ways of expressing them. For example, when you are competing with your best friends for a contest, and finally you get the first prize. Then you can feel both joy and grief because of your success as well as the failure of your friend. There have been several efforts to discover the emotion processing mechanism in humans to date. In this section, we introduce a neuroscientific approach to human affective system.

Since the triune brain model [1] had been proposed, many people assumed that the limbic system is the source of emotions. However, according to the recent neuroscientific studies [8], [9], [10], the emotion involves not only with the limbic system but also with the neocortex such as the orbitofrontal cortex. The amygdala and the orbitofrontal cortex are responsible for perception, appraisal, and learning of environmental stimuli such as visual or acoustic sensory stimuli. The hypothalamus is in charge of homeostasis, i.e., maintaining the body's status quo. It controls body temperature, hunger, thirst, and other circadian cycles, and alters the emotion to obtain the desired stimuli.

Fig. 1 (a) shows how the primate brain responds to the environmental stimuli. In primates, the external stimuli are decoded as a reward or a punishment. Rewards are stimuli for which an animal will work, and punishers are stimuli that the animal will work to avoid. For example, in the primate taste system, the reward decoding occurs after several processing stages. The first stage is the primary taste cortex, which identifies the taste. According to that result, the secondary taste cortex in orbitofrontal cortex evaluates the reward value. This value is decreased by feeding to satiety, because neurons in the orbitofrontal cortex decrease their responses as the reward value of the food decreases.

Since an animal performs any actions to obtain the reward or to avoid the punisher [8], rewards and punishers can be defined as reinforcers. As shown in Fig. 1 (b), there are two types of reinforcers: primary reinforcers, and secondary reinforcers [9]. The primary reinforcer (e.g., the taste of food or pain) is unlearned, and has innate reinforcing properties. The secondary reinforcer (e.g., the auditory or visual stimulus) develops its reinforcing properties through learning its association with primary reinforcement. For example, fear might be produced by a sound (i.e., the conditioned stimulus) that has been previously associated with a painful stimulus (i.e., the primary reinforcer). This type of learning is referred to stimulus-reinforcement association learning," [9] and involves with the amygdala and the orbitofrontal cortex. For example, the association learning in the amygdala is realized as modifiable synapses between visual or auditory neurons and neurons from taste, olfactory or somatosensory primary reinforcers [9].

Emotions are defined as affective states produced by rewards and punishers [9]. For example, a pleasure could be produced by an occurrence of the rewards such as an admiration of others or a pleasant touch; and frustration or anger could be produced by the termination of a reward such as the death of a loved one. As shown in these examples, the affective states involve the occurrence, termination, or omission of the rewards (or punishers). As a result, Fig. 2 shows that some emotions are associated with both the contingency of reinforcer and its intensity [8].

The affective states are classified as primary and secondary emotions. The primary emotions are innate, and involve the primary reinforcers. For example, when you are surprised by a loud noise, the surprise is related to the primary reinforcer such as an acoustic sensory stimulus. On the other hand, the secondary emotions involve the secondary reinforcers, and depend on results of the stimulus-reinforcement association

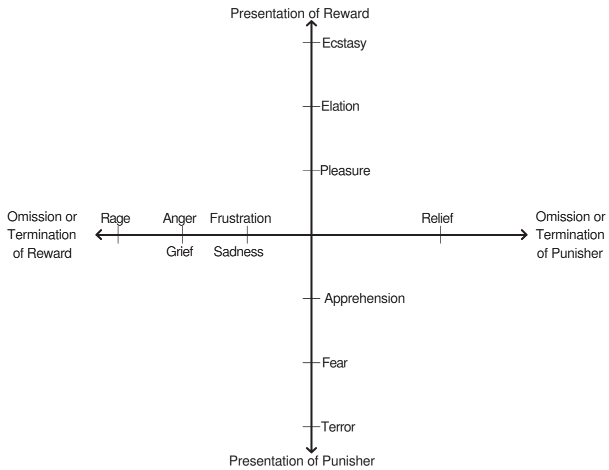


Fig. 2. Emotions associated with reinforcement contingencies

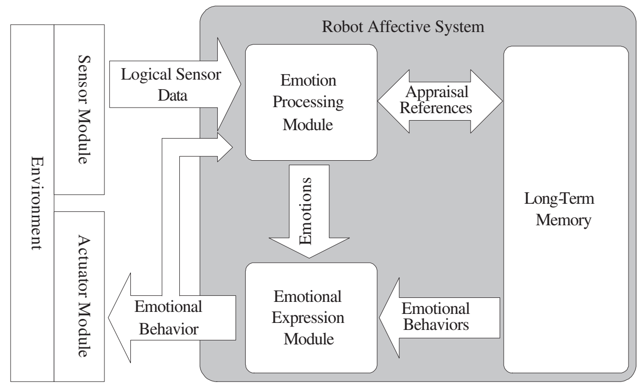


Fig. 3. Framework for the robot affective system

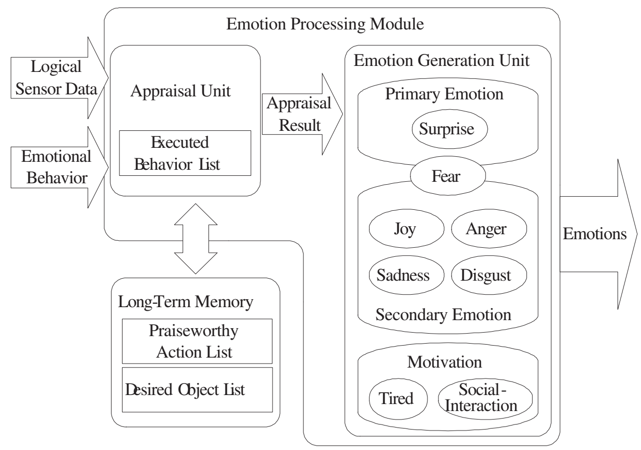


Fig. 4. Emotion processing module of the robot affective system

learning.

The human emotion processing involves with both reinforcers and current states of neuromodulation [11]. Neuromodulation refers to the action of a neuromodulator on nerve cells. The neuromodulator, such as dopamine, serotonin, and opioids, is released by a neuron and end up spending a significant amount of time in the cerebrospinal fluid and modulating the overall activity level of the brain. Thus, a neuromodulator can change the way of computation between single neurons and synapses, either enhancing or damping their activities. As described above, the environmental stimuli are evaluated in terms of the primary or secondary reinforcers including the neuromodulators, and then the affective states are dynamically generated by the contingencies and intensity of these reinforcers. Hence, human can have several emotions simultaneously and express them in various ways. Therefore, we propose a dynamic affective system inspired from neuroscientific researches for a robot to be more human-like and friendly.

III. THE ROBOT AFFECTIVE SYSTEM

For a robot to have more natural emotion, we propose a robot affective system inspired from neuroscience such that it can have various emotional states at the same time and express those combined emotions just like humans do. Our affective system is shown in Fig. 3. The sensor module translates external stimuli into logical sensor information, similar to the orbitofrontal cortex or primary taste cortex. The logical sensor data is an abstraction of the external stimuli (e.g., a name of an object). The actuator module realizes emotional behaviors of a robot.

The robot affective system is responsible for generating and expressing affective states according to the external or internal stimuli. The robot affective system comprises three modules: an emotion-processing module, an emotional expression module, and a long-term memory. As amygdala and hypothalamus generates emotions in accordance with external or internal stimuli, the emotion-processing module determines which stimuli are rewards or punishers and generates affective states. The emotional expression module controls the sequential or parallel execution of emotional behaviors such as the facial expressions or text-to-speech of the robot. Lastly, the long-term memory contains the information for the emotion-processing module and the emotional expression module.

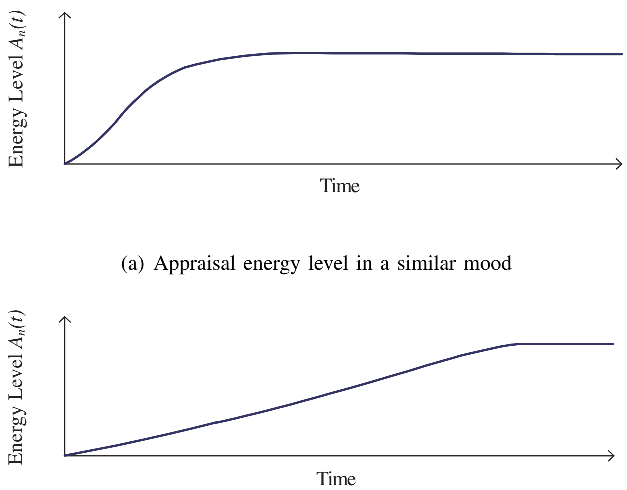
A. Emotion Processing Module

As shown in Fig. 4, the emotion-processing module comprises an appraisal unit, an emotion generation unit, and an external long-term memory. The long-term memory contains a praiseworthy action list and a desired object list for the appraisal unit. The praiseworthy action list and the desired object list are an appraisal reference for the praiseworthiness of the robot action and the attractiveness of the recognized

TABLE I

APPRAISAL RESULT OF APPRAISAL UNIT

Catetory	Appraisal result	
	Positive	Negative
Recognized object	Like	Dislike
Robot action	Praiseworthy	Blameworthy
Facial expression of a user	Good	Bad
Consequence of a robot action	Success	Fail



(a) Appraisal energy level in a similar mood

(b) Appraisal energy level in a different mood

Fig. 5. Characteristic graph of moods

object, respectively.

1) Appraisal Unit: The appraisal unit assesses external stimuli (e.g., logical sensor data and emotional behaviors) in accordance with the long-term memory. As shown in TABLE I, the external and the internal stimuli are classified into four categories in the appraisal unit. When a recognized object is in the desired object list; or an action of the robot itself is in the praiseworthy action list; or the facial expressions of a user is good, the appraisal result is positive. When the robot executes an emotional behavior, it is included in the executed behavior list of the appraisal unit. If the listed behavior receives its expected result within the specified time interval, it is a positive appraisal result.

In the appraisal unit, the human neuromodulatory system is implemented as moods. Thus, the energy level of each appraisal result $A_n(t)$ depends on time and mood, as shown in Fig. 5. In a good mood, the energy level of the positive appraisal result increases more rapidly than that of the negative one, and vice versa. The mood $Mood(t)$ is defined as (1).

$$Mood(t) = \sum_{k=1}^{A} e_k \times E_k(t-1) \qquad (1)$$

where $E_k(t)$ is the activation level of the k_{th} emotion, A is the number of the emotion, and e_k is a gain parameter of the k_{th} emotion. If the activation level $E_k(t)$ is the positive emotion, then e_k is defined as positive value, and vice verse. When the value of mood $Mood(t)$ is positive, the mood of the system is positive.

2) Emotion Generation Unit: The emotion generation unit comprises three parts: the primary emotion part, the secondary emotion part, and the motivation part (see Fig. 4). The primary emotions involve the primary reinforcers. They are linked directly to the logical sensor data, since the primary reinforcers are unlearned stimuli. On the other hand, the secondary emotions involve the secondary reinforcers. Therefore, they depend on the results from the appraisal unit. The motivation part implements homeostatic regulations in the hypothalamus of the human brain, such as tired and social interaction.

According to a psychological research on emotion [12], we express our elemental emotions in the same ways, and can recognize these emotions in the face of another: anger, disgust, fear, joy, sorrow, and surprise. Thus, we propose that the affective state of the robot is the blending of the six basic emotions. In the emotion generation unit, the activation level of each emotion is continuously updated. When the activation level exceeds a threshold value, the emotion is activated. All emotions above the thresholds are active in contrast to the winner-take-all scheme that allows only one emotion to be active at a time.

The activation level of the i_{th} primary emotion $E_i(t)$ at time t depends on the level of logical sensor data as in (2).

$$E_i(t) = E_i(t-1) + \sum_{m=1}^{M} w_m \times S_m(t) - \delta(t) \qquad (2)$$

where S_m is the level of the m_{th} logical sensor data, w_m is the weight of the mth sensor data, $\delta(t)$ is the decay factor of the emotion, and M is the number of logical sensors related to the emotion. For example, if the emotion ‘surprise’ depends on the microphone level, the robot is surprised by a loud noise. In this system, the elements of the surprise are a loud noise and an abrupt change in the visual stimulus.

On the other hand, the secondary emotions depend on the appraisal result of the appraisal unit, because it is related to the stimulus-reinforcement association learning of the secondary reinforcers. The activation level of the j_{th} secondary emotion at time t, $E_j(t)$, is affected by the energy level of appraisal result $A_n(t)$ and that of the motivation $M_l(t)$ as in (3).

$$E_j(t) = E_j(t-1) + \sum_{n=1}^{N} a_n \times A_n(t) + \sum_{l=1}^{L} c_l \times M_l(t) - \delta(t) \qquad (3)$$

where a_n is the weight of the n_{th} appraisal result, c_l is the weight of the l_{th} motivation, N is the number of related appraisal results, and L is the number of related motivations.

The motivation unit implements homeostatic factors, such as ‘tired’ for taking a rest and ‘social interaction’ for interacting with people. In the emotion-generation process, as shown in (3), the activation level of the emotion $E_j(t)$ is affected by the activation level of the motivation $M_l(t)$. The motivation level $M_l(t)$ increases gradually when internal or external stimuli do not satisfy the desired stimuli of each motivation. As shown in (3), the motivation controls the emotion to execute appropriate actions, and consequently tries to obtain the required stimuli.

B. Emotional Expression Module

The emotional expression module controls the emotional actions of the robot. It determines appropriate emotional behavior using the long-term memory to express the affective states. The long-term memory contains a set of emotional behaviors of which there are two types: concurrently executable behaviors, and sequentially executable behaviors. An execution of a sequential behavior depends on which activation level of the emotion is the highest. The execution of sequential behavior related to the highest activation level has priority over the others. In the concurrently executable behaviors, all behaviors that exceed the thresholds are performed. For example, the eye lid position of the robot $D_{EyeLid}(t)$ is defined as in (4).

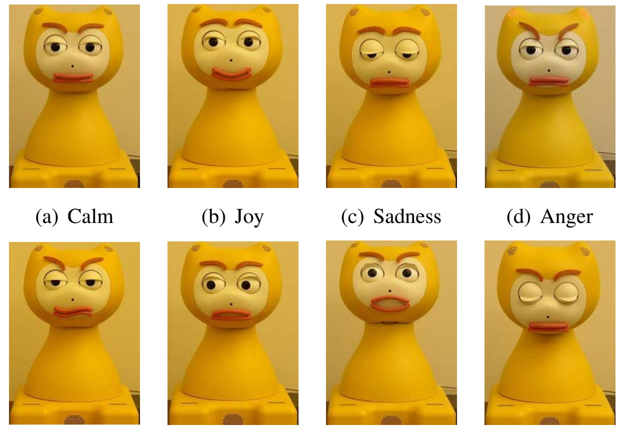
$$D_{EyeLid}(t) = \sum_{a=1}^{A} \mu_a \times E_a(t) \times P_a(t) \quad (4)$$

where A is the number of emotions, $P_a(t)$ is the eyelid position designated for a_{th} emotion, $E_a(t)$ is the activation level of the a_{th} emotion, and μ_a is the weight of $P_a(t)$.

The emotional expression module should deal with competing rewards, goals, and priorities. Furthermore, the selection process between the emotional behaviors can respond to many different types of reward. Therefore, the emotional behavior has properties, such as the expected result, if any; the processing type (e.g., sequential execution or parallel execution); and the waiting time. The expected result is the available stimulus from the emotional behavior, and the waiting time is the maximum time allowed to receive the expected stimulus from the environment.

IV. EXPERIMENTAL RESULTS

To evaluate the proposed system, it was applied to the Philips iCat, which is an experimentation platform for the HRI. The iCat has four touch sensors, two microphones, a CCD camera, and 13 servos for facial postures. The robot affective system runs on a 3 GHz PC running Windows, and communicates with the iCat through a USB port. The robot affective system produces the robot's emotional states



(a) Calm (b) Joy (c) Sadness (d) Anger

(e) Disgust (f) Fear (g) Surprise (h) Tired

Fig. 6. The basis facial postures of the iCat

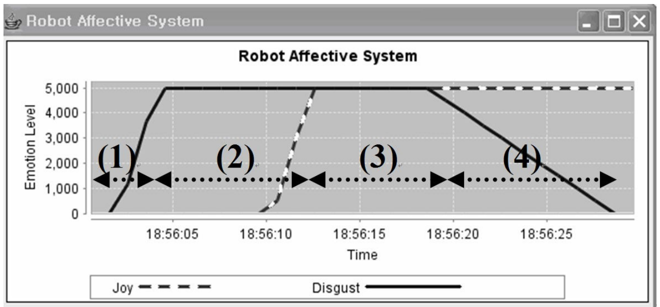
TABLE II
DATA STORED IN THE LONG-TERM MEMORY

Data category	Data
Desired object list	Apple, bananas, red-color, toy
Praiseworthy action list	Make laugh, smiling, nod
Emotional behavior	8 basis facial posture, exclamations, wink

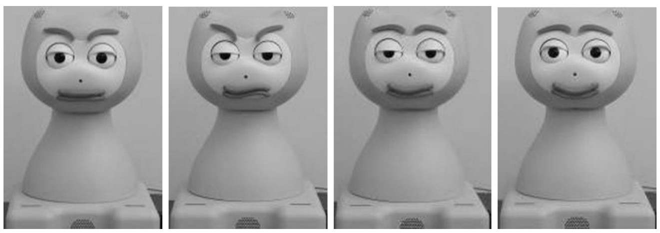
in accordance with the internal stimuli; and external stimuli such as interactions between the user and the iCat (e.g., the touch sensors of the iCat). The iCat's basis facial postures, based on its emotional states, are shown in Fig 6 and stored in the long-term memory. As shown in TABLE II, the long-term memory contains the praiseworthy action list, the desired object list, and the emotional behaviors such as eight basis facial postures.

The robot's facial expression is defined as a blending of basis facial postures (see Fig. 7). For example, when the robot likes red color and dislikes blue color, the robot detects a blue object at the beginning of (2) in Fig. 7 (a), and then the activation level of disgust increases. The facial expression of disgust is also shown in (2) of Fig. 7 (b). As shown in (3) of Fig. 7 (a), the joy is activated because of the recognition of a red object. The facial expression in (3) of Fig. 7 (b) is a blending of two basis facial postures (joy and disgust). As shown in (4) of Fig. 7 (a), when the blue object has disappeared, the activation level of disgust decreases, and the emotional expression is in (4) of Fig. 7 (b).

Fig. 8 describes an emotion processing associated with the reinforcement contingencies. As shown in Fig. 2, the termination (or omission) of rewards involves with the grief or anger in the human emotion processing. Similarly, the emotion processing in the proposed system is associated with a presentation as well as termination (or omission) of reinforcement. Therefore, when an attractive object is

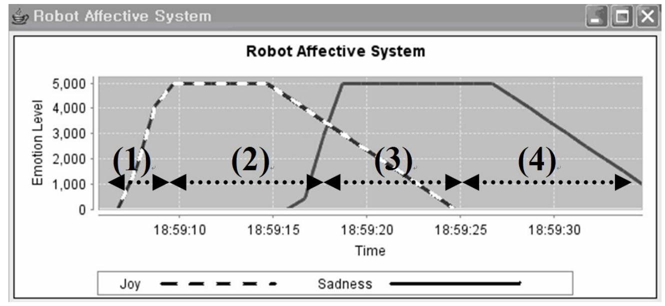


(a) Activation level of joy and disgust

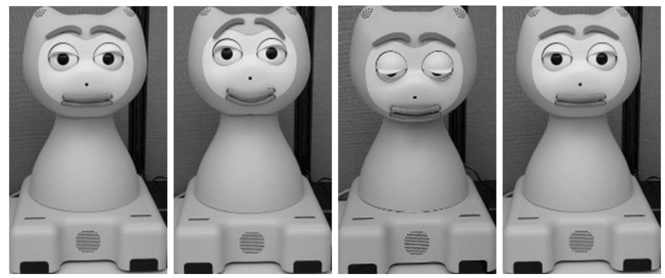


(b) Sequence of facial postures in accordance with (a)

Fig. 7. Activation level of emotions and facial postures



(a) Activation level of joy and sadness



(b) Sequence of facial postures in accordance with (a)

Fig. 8. Emotion associated with the reward contingencies

unexpectedly disappeared at the end of (2) in Fig. 8 (a), the terminated rewards affects the level of sadness.

As described above, the facial expression of the iCat is a blending of basis facial postures. In this system, in accordance with the emotion activation level, the emotional expression is the sequential execution, or a linear combination of the parallel behaviors. In contrast to previous work, the proposed system is able to express various emotional behaviors continuously. According to the affective states of the robot, the robot generates various combinational behaviors, such as facial expressions, and sequential behaviors, such as emotional exclamations and simple text-to-speech.

V. CONCLUSION

We have presented a robot affective system inspired from neuroscience with reinforcer intensity and contingency focused. The proposed robot affective system produces simultaneously various emotions in accordance with the appraisal of external stimuli as well as the contingencies of reinforcement. In addition, emotions decrease, increase, or changes to another emotion seamlessly as time pass, what we believe more real-life like. The facial expression of the system is not a predefined emotional behavior, but the blending of concurrently or sequentially executable behaviors.

In future, we intend to implement personality and association learning into the affective system. Personality has an important role in emotion processing and can change the emotional reaction to the environment. Therefore, emotional robots should have characteristic personality. Furthermore, we will also focus on the association learning for the emotional response of unknown objects.

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