Reflex and Emotion-based Behavior Selection for Toy Robot

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Abstract— ***This paper presents a robotic doll with emotional and reflexive behaviors. The robotic doll imitates an animal's appearance to provide comfort in human interaction. Emotion is considered to show more natural behaviors and to interact with user more intimately. Behavior is selected based on reflex-ness and emotion. A bear-like robotic doll, GomDoll is developed with the full use of the available degrees of freedom, sensors, and emotional and reflexive architecture implemented on a micro-controller. Experimental results demonstrate the effectiveness of the proposed architecture.***

I. Introduction

There have been numerous studies on the robot which has mimicked not only animal's appearance but also its internal state. Robot whose appearance looks like animals has an advantage in providing comfort in human interaction [1]. Also considering natural interaction, robot researchers have been implementing an internal state module to the robot [2][3], where internal state consists of motivation, homeostasis and emotion. Emotion can be used for generating more natural behaviors and to interact with user more intimately. As the human-robot interaction has been realized more intelligently, the concept of sociable robot has been emerged. It will lead to a new prospect of accepting robot as an equal society member [4].

These days research has been extended even to develop a robot for elderly people or for therapy for people with a mental disease [5]-[9]. The therapeutic robot can be also used to gather personal information on health over a long period of interaction and report it to a separate computer placed at the nurse's station [10][11].

Although they have obtained the successful results either as a toy or for therapy, there still exist difficulties for general public, in particular children to use these robots popularly because of the cost and complexity. Considering a consumer market, they need to be produced with a comfortable price to purchase and the operations need to be simple for elderly people or children.

This paper introduces a bear-type robotic doll, called GomDoll, which means a male cub in Korean. To make it cost-effective, an 8-bit microcontroller is employed as a control processor to implement architecture for processing sensor data and for selecting proper behaviors. An emotional and reflexive architecture, which is suitable for the microcontroller-based robot, is proposed to focus on how to respond naturally and diversely in regard to usual interaction with user. Thus, in addition to reflexive behaviors, emotional behaviors are expected. As it can respond with different behaviors depending on its emotion even with respect to the same repeated stimuli, user may not easily get bored in playing with it. For example, if a user grabs its left arm, it turns its head to left gently with a curious look when it is in a normal state, but it will act unkindly with angry face if it is in an angry state.

This paper is organized as follows: Section II describes the hardware system of GomDoll. Section III presents the emotional and reflexive architecture with three sub-systems: perception system, internal system, and behavior system. Section IV presents experimental results and concluding remarks follow in Section V.

II. Hardware Description

Robotic doll, GomDoll is controlled by the microcontroller, which supports ISP (In System Programming) and has 8-channel A/D converter for converting analog outputs of the sensors. The two 16 bit timer/counters are also useful to control servo motors. GomDoll has four types of sensors. Light sensors are used on the both sides of cheeks and forehead to recognize petting motion. An acceleration sensor is located on the head so that hit can be felt. Two flex sensors are placed on each arm to find out if someone grabs the arm. A tilt sensor is equipped on the chest for cognizing slant. GomDoll has total 14 degrees of freedom: three for a neck, four for two arms, two for two ears, three for two eyebrows, and two for two legs. Ears, eyebrows, and pupils (implanted LEDs) are used to show facial expressions and emotion states.

Figure 1 shows five emotional behaviors of GomDoll by facial and body expressions. The pupils are brown when it is in a normal or happy state. But when it feels sad or fear, pupils illuminate green. When it gets angry, they change to red. It also lowers its head if it is sad and raises its hand if it is angry.

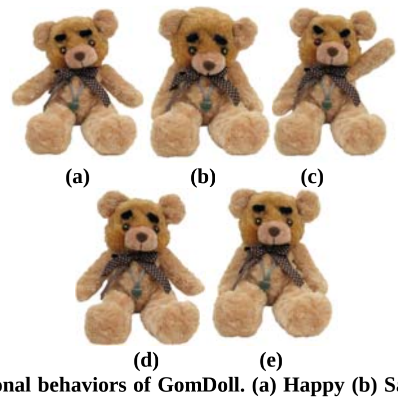

Fig. 1 Emotional behaviors of GomDoll. (a) Happy (b) Sad (c) Angry (d) Fear (e) Normal

Considering reflexive action and emotional expression, total 47 behaviors are currently developed for GomDoll as shown in Table I, where 'L', 'R' and 'M' represent left, right and middle, respectively and 'N' means negative feeling on the perceived stimulus. 'Grab' denotes a behavior when its arm is grabbed. Similarly, each behavior is named following the perceived stimulus or emotional state.

Behavior	Behavior Description
Pat_L(_R) 1,(2,3)	Tilting head to left (right) and chafing face (nose, or sniffing) gently
N_Pat_L(_R) 1,(2,3)	Looking left (right) and shaking head up and down(left and right, rotating head) fast with angry face
Tilt_L(_R) 1,(2,3)	Looking left (right) and waving arms up and down (right and left, up right and right left)
N_Tilt_L(_R)1,(2,3)	Looking left (right) and shaking arms (lifting one arm, both arms)fast with angry face
Grab_L(_R) 1,(2,3)	Looking left (right) and flapping ears (shaking right (left)arm up and down, left and right)
N_Grab_L(_R) 1,(2,3)	Looking left (right) and pulling head down (shaking head up and down, left and right) with angry face
Grab_M	Shaking head left and right gently
N_Grab_M	Moving head up and down fast with angry face
Pat_M	Shaking head up and down gently
N_Pat_M	Shaking head left to right fast with angry face
Wonder	Looking around gently
Fear	Pulling eyebrows and shaking head with fearful face
Sad	Pulling head down and shaking head with sad face
Angry	Lifting arms up and down fast with angry face
Happy1,(2,3)	Waving head and arms (Lifting arms and head Dancing with arms and legs)

TABLE 1.SYMBOLS AND CORRESPONDING BEHAVIORS

III. EMOTIONAL AND REFLEXIVE ARCHITECTURE

Figure 2 shows overall architecture, composed of three systems: perception system, internal system and behavior system [12] [13]. Perception system senses all stimuli such as patting and hitting through outside sensor information.

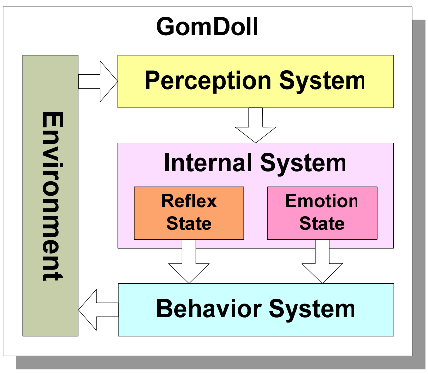

Fig. 2 Overall architecture of GomDoll

These stimuli are symbolized as Boolean values for classification. The internal system consists of emotion state and reflex states, which are calculated by multiplying their symbolized value and connecting weights. The behavior system selects one of the behaviors based on the emotion and reflex states of GomDoll. Each of the systems is summarized in the following.

A. Perception System

Perception system consists of a sensor module and a symbolization module as shown in Figure 3. In the figure, 'Val_L1', 'Val_T2' and 'Val_F2' represent the threshold values of each sensor. If the sensor value is bigger than its threshold value, the stimulus value becomes *'1'*, or if not, it becomes *'0'*.

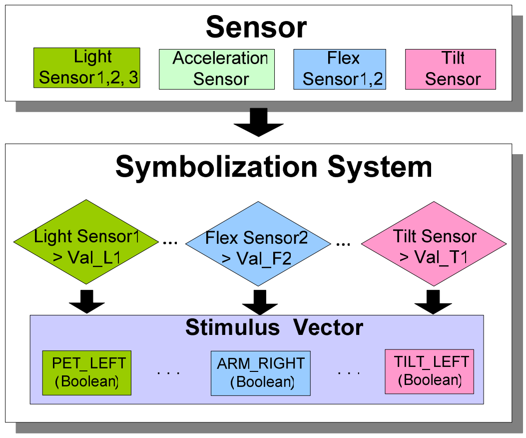

Fig. 3 Perception system with sensor and symbolization modules

In the sensor module, there are four kinds of sensors: light sensor, acceleration sensor, flex sensor and tilt sensor. The light sensor (CdS sensor), A90.09 is to sense patting behavior by checking the shadow of the user's hand. Using light sensor gives some benefits such as reduced cost and ease of interfacing. However, it is not sufficiently enough for GomDoll to distinguish between user's hand and close object which makes shadow on its face. Future design may thus utilize thermal sensors together with light sensors.

The acceleration sensor is to sense a hitting stimulus. When user hit GomDoll, the impact makes it accelerate for a sudden period of time. Therefore, by checking the acceleration of GomDoll's body, a hitting stimulus can be sensed. Triaxial acceleration sensor, MMA7260Q, is used and currently only one direction is considered in the implementation.

The flex sensor is attached on both arms to sense grasping. The sensor changes its resistance when it is bent. Since it is bent when the arm is grabbed, the grasping stimulus can be checked by sensing the change of its resistance. If there are no sensors attached, the arm manipulation mechanism may malfunction or get damaged when the user grabs its arm while it is moving. Two flex sensors, FLX-01, are used for each arm.

The tilt sensor is to check whether it is tilted. Since the tilted angle changes the corresponding output voltage of the sensor, it can verify whether the body is swinging left or right. An inclinometer made by DAS is used as the tilt sensor. Table II summarizes the applied stimuli and percepts in perception system.

Stimulus	Percept
Patting and Hitting	PET_LEFT, PET_RIGHT, PET_BOTH, PET_HEAD, HIT
Grasping	ARM_LEFT, ARM_RIGHT, ARM_BOTH
Tilting	TILT_LEFT, TILT_RIGHT

TABLE 2.STIMULI AND PERCEPTS IN PERCEPTION SYSTEM

Symbolization system maps the sensor data into Boolean stimulus vector by comparing each data to the reference value. Stimulus vector is defined as S and each element has a Boolean value as follows:

$$S = [s_1, s_2, ..., s_l] \quad (1)$$

l represents the number of symbols. Note that in this paper $l = 10$ as Table II shows. The stimulus vector is used to calculate the reflex and emotion state values of the internal system.

B. Internal System

Internal system is composed of reflex state vector, R and emotion state vector, E, where the state values are updated by stimulus vector, S, and weight matrices, W^R and W^E as shown in Figure 4.

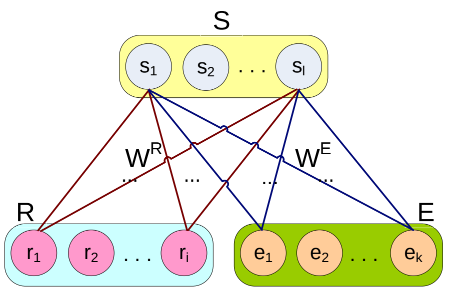

Fig. 4 Weights between stimulus vector and reflex and emotion states

The reflex value is used to react directly to the reflex stimuli. For example, when GomDoll is tilted or its arm is grasped while moving, it should react quickly to protect itself regardless of the emotion. As mentioned in the previous sub-section, the reflexive behaviors are activated to the eight applied stimuli: 'patting left cheek', 'patting right cheek', 'patting both cheeks', 'grasping left arm', 'grasping right arm', 'grasping both arms', 'tilting left', and 'tilting right'. Each stimulus is matched with the reflexive behaviors.

If we define i as the number of the reflexive behaviors, r_n is the n-th reflex value, and W_n^R is the connection weight between the stimulus vector S and the n-th reflex value r_n. Then the reflex values are calculated from the following equations:

$$\begin{aligned} r_1 &= S \cdot W_1^R \\ r_2 &= S \cdot W_2^R \\ &\vdots \\ r_i &= S \cdot W_i^R \\ R &= [r_1, r_2, \cdots, r_i] \end{aligned} \quad (2)$$

As both the elements of stimulus vector and the connection weight, W_i^R are represented as a Boolean value, reflex values are also Boolean. When GomDoll responds with a reflexive behavior to the corresponding stimulus, the reflex value resets itself to be ready for the next stimulus.

Unlike the reflex value, emotion value affects GomDoll's behavior indirectly. In this implementation, only four emotion states are considered: 'happy', 'sad', 'fear' and 'angry'. When k is defined as the number of emotion states, $e_n(t)$ is the n-th emotion value at time step t. The emotion state values are updated as follows:

$$\begin{aligned} e_1(t+1) &= e_1(t) + S \cdot W_1^E + \lambda_E (Y_S - 1) \\ e_2(t+1) &= e_2(t) + S \cdot W_2^E + \lambda_E (Y_S - 1) \\ &\vdots \\ e_k(t+1) &= e_k(t) + S \cdot W_k^E + \lambda_E (Y_S - 1) \\ \text{where } E &= [e_1, e_2, \cdots, e_k] \end{aligned} \quad (3)$$

W_n^E is the connection weight between the stimulus vector S and emotion state. It shows how strongly the stimuli act to each emotion value. For example, when GomDoll's left cheek is touched, happy emotion value gets increased to a magnitude of *3*. When the robot is being hit, the angry, sad and fear emotion values get increased to the magnitude of *6*, *5*, and *4*, respectively. All of these values are defined in the weight matrix, W_n^E . Y_S is set to *1* if any of external stimuli exist, if not, *0*. When there are external stimuli from outside, (Y_S *-1*), becomes *0*. With no stimuli, it becomes *-1*. Then, emotion values are decreased by 'λ_E' until they become *0* to be in a normal state. Thus, λ_E is a decrement constant which represents how fast the emotion value decrease when there is no external stimulus.

C. Behavior System

The behavior system directly connects to the behavior with the reflex stimulus, and indirectly connects to the behavior with the emotion state, respectively. Significantly, the reflexive behaviors have a higher priority compared to the emotional behaviors because the reflexive stimulus implies that the robot may be in an urgent situation. For example, it should balance its body when one tilts the robot, whereas it is in sad state. However, its behavior may be different depending on its emotion.

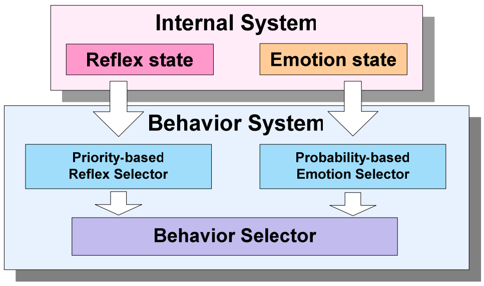

Fig. 5 Behavior selector of GomDoll

Figure 5 shows a behavior selection mechanism, where the left side is for reflex-based behavior selection and the right side is for emotion-based behavior selection. On the left side, as all reflex values are Boolean numbers, either *0* or *1*, only one of them is selected by the priority-based reflex selector based on the priority of stimuli as shown in Table III. The problem is that if the robot always responds with the same behavior on a same reflexive stimulus, the user might get bored because he/she can predict the outcome when a certain stimulus is applied. Thus, it should be combined with probability-based emotion selector.

Stimulus	Priority
Grasping both arms	1
Grasping left (right) arm	2
Tilting left (right)	3
Patting both cheek	4
Patting left (right) cheek	5

TABLE 3.PRIORITY OF STIMULI FOR REFLEX SELECTOR

On the right side, the probabilistic emotion identifier identifies an emotion state depending on each emotion's probability. The probability of each state is relatively defined by comparing to the sum of the all emotion state values (sum_E). Since sum_E is set as the maximum range and each state is arranged in a straight line with its own probability, happy state is more likely to be chosen by the selector if its value is bigger than other states and covers bigger range in the scale. For example, if happy state value is 10, sad is 4, angry is 3 and fear is 5, then sum_E is 22. The probability of happy emotion is 10/22, which has the highest probability to be chosen of all states. However, it does not necessarily mean that the happy state must be chosen by the identifier because the emotion is chosen probabilistically. By using this method, it is not easy for a user to predict what the robot will act next. Thus, the robot can stimulate the user and draw her/his interest.

An important feature in the architecture is that the emotion state also does an important role to select behaviors. This is summarized in Table IV. Note that behavior descriptions are in Table I. For example, if the robot is tilted when it is in happy state, the reflexive behavior becomes gentle and brown color appears on its pupils. However, if it is tilted when it is in angry state, the corresponding reflexive behavior becomes unkind and red color appears on its pupils.

Stimulus	Emotion	Behavior
Patting left (right) cheek	Normal Angry	Pat_L(_R) 1,(2,3) N_Pat_L(_R) 1,(2,3)
Patting both Cheeks	Normal Angry	Pat_M N_Pat_M
Tilting left (right)	Normal Angry	Tilt_L(_R) 1,(2,3) N_Tilt_L(_R)1,(2,3)
Grasping left (right) arm	Normal Angry	Grasp_L(_R) 1,(2,3) N_Grab_L(_R) 1,(2,3)
Grasping both arms	Normal Angry	Grasp_M N_Grasp_M

TABLE 4.BEHAVIORS WITH RESPECT TO STIMULUS AND EMOTION

IV. EXPERIMENTAL RESULTS

The proposed architecture and GomDoll's performance can be shown through the experiment results by analyzing its behaviors. The experiments are mainly divided into two. The first experiment focuses on how diverse behaviors are activated with the same stimulation in normal state. In contrast, the second experiment is to see what happens if it is in the different emotion state with the same stimulation as the previous case.

A. Behavior Selection in Normal State

In the first experiment, all reflex and emotion state values were set as zero before the experiment because this experiment was to see various reactions in one emotion state. For example, when one pats the robot's head, happy state value will go up and then the robot will act based on happy state (chosen by the probabilistic selector). Once the emotion state is selected, one of the behaviors based on the selected emotion state will be chosen by behavior selector. Thus, if happy emotion value increases then one of the behaviors which express happy emotion will be activated.

When the robot's head was patted, happy state was increased to *6*. One of 'Happy1', 'Happy2' and 'Happy3' behaviors was selected by behavior selector. The results are shown in Figure 6.

Fig. 6 Selected behaviors when the robot's head is patted

When the robot's cheek was patted, 'Patting_Left_Cheek' value in reflex state was set to true and at the same time the happy emotion value is increased to *3*. Thus, one of the 'Pet_Left' reflexive behaviors was selected by behavior selector. After then, the selector continuously chose a behavior related to happy state. Thus there were total of 9 possible behaviors to be chosen as shown in Figure 7. On the x-axis, '1', '2' and '3' correspond to 'Pat_L1', 'Pat_L2' and 'Pat_L3'. 'H', 'H2' and 'H3' represents 'Happy1', 'Happy2' and 'Happy3', respectively.

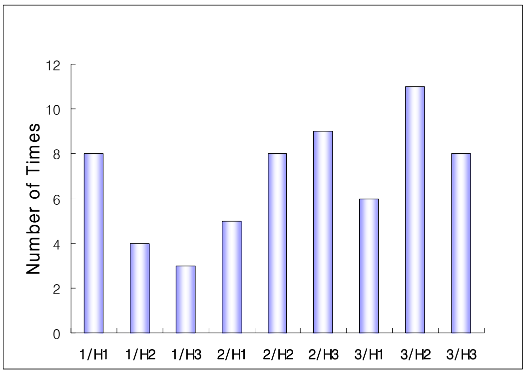

Fig. 7 Selected behaviors when the robot's cheek is patted

Grasping left arm stimulus was similar compared to patting left cheek. When the robot's arm was grabbed, 'Grasping_Left_Arm' value in reflex state was set and happy value was increased to 2. Thus, one of the 'Grasp_Left' reflexive behaviors was selected by probabilistic selector. Then it continuously chose a behavior related to happy state (Happy1, Happy2 and Happy3). In fact, the stimulus like grasping arms is not a positive stimulus for GomDoll because of motor load problem. As for users, however, grasping GomDoll's arm usually means expressing their intimacy toward it. Thus happy emotion value is increased by grasping stimulus. Similarly, there were total of 9 possible behaviors to be chosen and Figure 8 proves its effectiveness. On the x-axis, '1', '2' and '3' correspond to 'Arm_L1', 'Arm_L2' and 'Arm_L3', respectively.

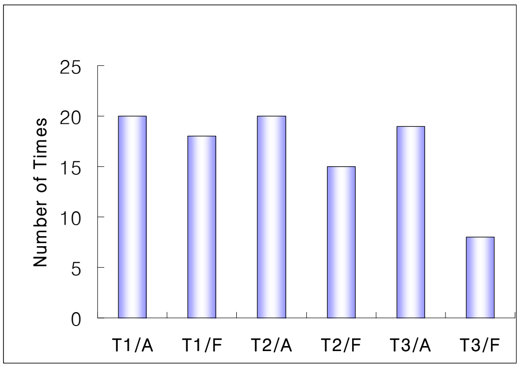

Fig. 8 Selected behaviors when the robot's left arm is grasped

Tilting stimulus was also similar to patting cheeks and grasping arms. A reflexive behavior against tilting stimulus was activated at first and then an emotion-related behavior (angry and fear) followed. Thus, total of 6 behaviors were possible and the result shows as expected in Figure 9. On the x-axis, 'T1', 'T2' and 'T3' correspond to 'Tilt_L1', 'Tilt_L2' and 'Tilt_L3', respectively.

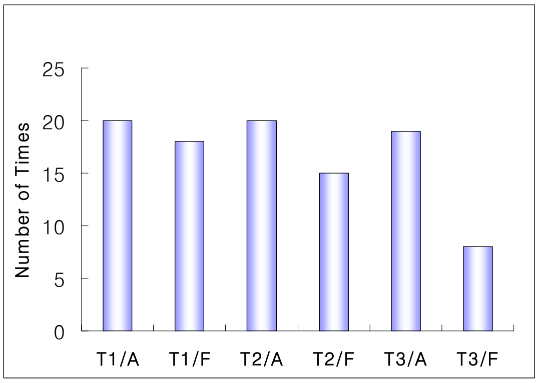

Fig. 9 Selected behaviors when the robot's is tilted

The hitting stimulus affect emotion values, that are angry, sad, fear values were increased to *6*, *5*, and *4*, respectively. If one of three states was selected by the probability based emotion selector, one of three behaviors was chosen as shown in Figure 10. There is only one behavior each implemented for angry, sad and fear state now, however, more various behaviors will be provided in the future work.

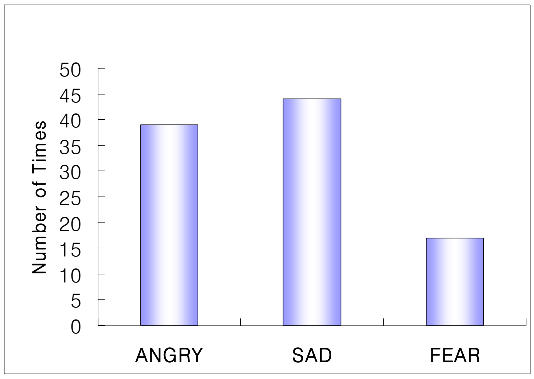

Fig. 10 Selected behaviors when the robot's head is hit

B. Behavior Selection in Emotion State

This experiment tests if the robot acts differently even with the same stimulus by the situation that the emotion states are different. For example, it will act violently even when one pats it when the robot is already in a great angry state. This shows that the robot does not act directly according to the stimulus from outside, but rather act based on the emotion state like a real creature.

In the first experiment, all inner values were reset before the experiment, after then hitting stimuli were given five times at every ten seconds. The angry, sad and fear emotion values were increased to *6*, *5*, and *4*, respectively by the hitting stimuli. Once hitting was finished, robot's arm was grabbed. When grabbed, the happy state value was increased to *2*. Figure 11 demonstrates all emotion state changes during this time period. The figure shows a saw-toothed shape because when there is no stimulus, the emotion values are decreased by λ_E as shown in equation (3). Angry, sad and fear states grew gradually, which means that the robot is near negative emotion state. But when the user grabbed the arm at *60* second, happy state was increased as shown in the figure. Even though the grabbing stimulus increased the happy emotion value, the dominant emotion was the angry emotion. Thus the probability-based emotion selector chose the angry emotion for representing Gomdoll's state. The behavior selector inspected the 'left arm grabbed' reflex value and 'angry' emotion state. Therefore, the behavior selector selected one of Neg_Arm_L1, L2 or L3 actions.

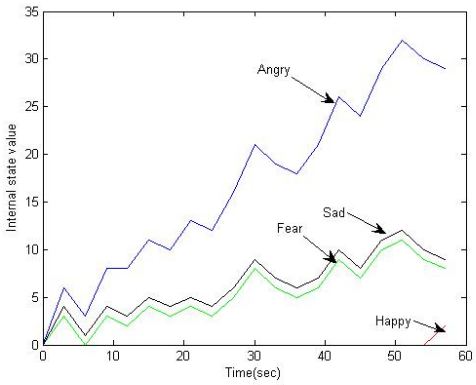

Fig. 11 Emotion changes when hitting stimulus is given

In the second experiment, head patting stimulus was given five times at intervals of every ten seconds. When Gomdoll's head was patted, happy state value was increased to *6*. After patting is finished, robot's arm was grabbed. As shown in Figure 12, the happy emotion was increased by patting Gomdoll's head and grabbing stimulus which came after 5 times of the patting stimulus also increased the happy emotion. Thus the probability-based emotion selector chose the happy emotion for representing Gomdoll's state and the behavior selector inspected the 'left arm grabbed' reflex value and 'happy' emotion state. Therefore the combined reaction was one of Arm_L1, L2 or L3 actions. The two experiments show that the same inputs could cause different behaviors according to the current emotion state.

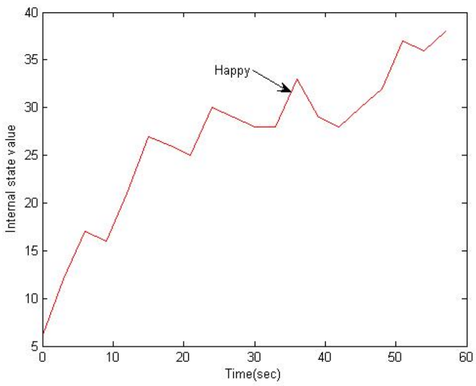

Fig. 12 Emotion changes when patting stimulus is given

V. CONCLUSION

In this paper, cost-effective robotic doll, GomDoll was developed using a microcontroller as a control processor. For the natural interaction with user, an emotional and reflexive architecture was presented and implemented on GomDoll. The experimental results demonstrated that GomDoll acted based on reflex and emotion state values such that it responded naturally and variously in regard to usual interaction with the user. GomDoll could be used for elderly people in hospital for mental therapy and for children for entertainment who are allergic to animals.

As future works, the light sensor should be combined with thermal sensor to distinguish between human's tactual and other objects. Also, learning module should be included to make the robot intelligent. It can be learned from its user by altering each weight of the internal weight matrices.

The video clip of GomDoll is available at http://rit.kaist.ac.kr/~ritlab/research/Artificial_Creatures/RoboticDoll.wmv

REFERENCES

[1] T.L. Anderson and M. Donath, "Animal behavior as a paradigm for developing robot autonomy," *ROBOT. AUTONOMOUS SYST.* vol.6, no.1-2 , pp. 145-168, 1990.

[2] R.C. Arkin, M. Fujita, T. Takagi and R. Hasegawa, "Ethological modeling and architecture for an entertainment robot," *in Proceedings of the IEEE International Conference on Robotics and Automation* , pp. 453-458, 2001.

[3] M. Fujita and H. Kitano, "An Development of an Autonomous Quadruped Robot for Robot Entertainment", *Autonomous Robots*, Vol.5, pp.7-18, 1998.

[4] C. Breazeal, "Function Meets Style: Insights From Emotion Theory Applied to HRI," IEEE Transactions on system, man, and cybernetics, vol.34, no.2, pp. 187-194, May. 2004

[5] Libin, A. V.and E. Libin, "Person-Robot Interactions From the Robopsychologists' Point of View: The Robotics Psychology and Robotherapy Approach." *Proceedings of the IEEE*, vol.92,no.11, pp 1-15, 2004.

[6] Tamura, T., S. Yoshimitsu, et al, "Is an Entertainment Robot Useful in the Care of Elderly People with Severe Dementia?," *The Journal of Gerontology*, vol.59A, no.1, pp. 83-85, 2004.

[7] K. Wada and T. Shibata, "Robot Therapy in a Care House – Its Sociopsychological and Physiological Effects on the Residents," *in Proceedings of IEEE International Conference on Robotics and Automation*, pp. 3966-3971, 2006.

[8] A. Yokoyama, "The Possibility of the Psychiatric Treatment with a Robot as an Intervention -From the Viewpoint of Animal Therapy-," *Proc. of Joint 1st Int'l Conf. on SCIS and ISIS*, paper number 23Q1-1, in CDROM Proc., 2002.

[9] E. Libin, and A. Libin, "Robotherapy: Definition, Assessment, and Case Study," *Proc. of the 8th Int. Conf. on Virtual Systems and Multimedia*, pp.906-915, 2002.

[10] W.D. Stiehl, J. Lieberman, C. Breazeal, L. Basel, L. Lalla, and M. Wolf , "Design of a Therapeutic Robotic Companion for Relational, Affective Touch," *IEEE International Workshop on Robots and Human Interactive Communication*, pp. 408-415, 2005.

[11] Wada, K, T. Shibata, et al. "Effects of Robot Assisted Activity for Elderly People at Day Service Center and Analysis of Its Factors,." *4th World Congress on Intelligent Control and Automation*, Shanghai, P.R. China, 2002

[12] J.H. Kim, K.H. Lee and Y.D. Kim, "The Origin of Artificial Species: Genetic Robot," *International Journal of Control, Automation, and Systems*, vol. 3, no.4, pp. 564-570, Dec. 2005.

[13] J.H. Kim, K.H. Lee, Y.D. Kim and I.W. Park, "Genetic Representation for Evolvable Artificial Creature," *in Proceedings of IEEE Congress on Evolutionary Computation*, pp. 6838-6843, 2006.