Evolutionary Personalized Robotic Doll: GomDoll

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***Abstract*—Genetic robot is one of artificial creatures and has its own genome in which each chromosome consists of many genes that contribute to defining its personality. By using the concept of genetic robot, this paper proposes personalized robotic doll by applying evolutionary process to generate unique propensity, defined by its genome. A genome population is evolved such that it customizes the genome satisfying a propensity desired by user based on Big Five personality dimensions. Robotic doll has emotion and motivation to reflect its internal state and to provide human friendly interaction. To demonstrate the effectiveness of this scheme, a bear-like robotic doll, GomDoll, is developed and the evolved genome is implanted to it to see its manner of internal and external responses to stimuli.**

I. Introduction

As the human-robot interaction has been realized more intelligently, the concept of sociable robot has been emerged. Robot researchers have been studied internal state module to build a sociable robot. The internal state module consists of motivation, homeostasis and emotion [1], [2]. Emotion can be used for generating more natural behaviors and interacting with user more intimately. Eventually, it will lead to a new prospect of accepting robot as an equal society member [3].

Although a lot of studies have obtained successful results for developing social robots, they focused more on external behaviors. To be truly sociable robot, however, the internal character needs to be considered by characterizing its personality. The significance of having a diverse personality was noted that "Personality is the engine of behavior." In other words, personality is crucial in building a believable social robot [4].

There were researches related to robot personality. Hiroyasu Miwa introduced a robot personality that consists of the Sensing Personality and the Expression Personality based on dynamic mental model [5]. Robot personality was also modeled by applying situation scene and designing the reaction of the robot [6]. However, they did not consider the concept of evolutionary process for desired personality.

Recently, the concepts of "Genetic Robot" and "The Origin of Artificial Species" were first coined by Kim et al. [7]. They are based on genome in which a unique personality is encoded. As per its personality the manner of internal and external responses to stimuli is different from each other. The responses include outward behaviors and change of internal state such as motivation, emotion and homeostasis. To demonstrate the feasibility of implementing genetic robot, Rity was developed in a 3D virtual world, which had its own genome defining its personality [8]. It was a software robot as a component of ubiquitous robot [9]. Evolutionary generation process was presented for a desired personality [10], [11] and it was extended to a multi-objective evolutionary generation process for specific personalities [12].

This paper focuses on generating robotic doll's propensity desired by user by applying evolutionary process, where the propensity is encoded in its computer-coded genome. The research on robot with its own propensity is to build a believable and interactive agent for a personal usage. Kim et al. defined genome as a set of chromosomes, where each chromosome was composed of three gene vectors: the fundamental gene vector (F-gene vector), the internal state related gene vector (I-gene vector) and the behavior related gene vector (B-gene vector) [8].

In this paper, only I-genes are considered for evolution, which encodes the relationship between perception and internal state. There are a large number of I-genes which contribute to defining the robot's propensity. It is difficult and time-consuming to manually assign the values of these genes to ensure reliability, variability and consistency for a specific desired propensity [8]. The evolutionary generating process for robot's propensity deals with these issues and provides a powerful tool for generating reliable genes in which the propensity is encoded. This paper presents architecture and evolutionary generating process for a desired propensity of robotic doll, GomDoll, which can sense stimuli on its body, posture and objects and express its internal state by facial and body motion [13].

This paper is organized as follows. Section II introduces research platform, which is a robotic doll, GomDoll. In Section III, evolutionary generation process for GomDoll's propensity is described. Experimental results are presented in Section IV, followed by the concluding remarks in Section V.

II. Research Platform

A robotic doll, GomDoll, is used as a research platform. It is specially designed for human-robot interaction, which 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. Touch, acceleration, tilt sensors and a camera are used to sense surrounding environment. Fig. 1 shows the emotional behaviors when it is happy, sad, angry, and fear, respectively. As the figure shows, GomDoll has the ability to

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express four different facial expressions.

(a) (b) (c) (d)

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

Fig. 2 is a screenshot of GomDoll's GUI program. In the figure, the upper left part is for showing vision input of GomDoll and the upper right part is for buttons to select one of Big Five personality models and other control purposes. The lower left part shows stimuli sensed by GomDoll and the lower right part shows the internal state values.

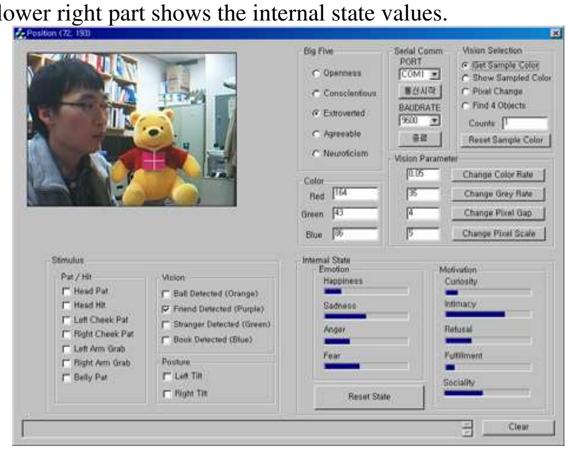

Fig. 2 Screenshot of GomDoll's GUI program

A. Architecture of GomDoll

Fig. 3 shows the overall architecture, composed of five modules: sensor, perception, internal state, behavior, and motor modules.

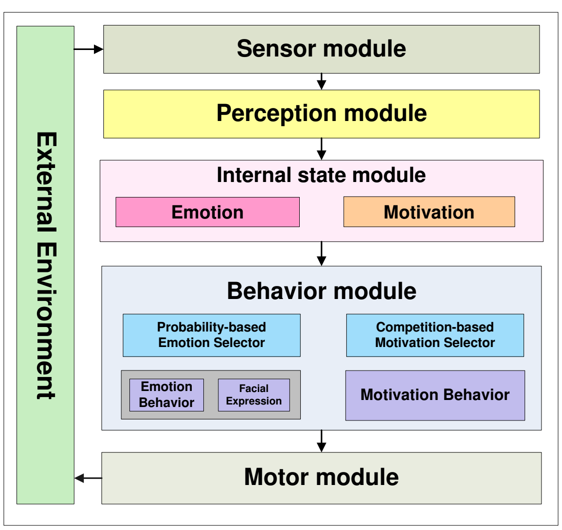

Fig. 3 Overall architecture of GomDoll

Sensor module consists of touch, tilt, acceleration and vision sensors. Touch sensor is attached underneath of GomDoll's skin, which can sense user's touch. Tilt sensor senses whether it is tilted left or right. Hitting is sensed by acceleration sensor and objects in the surrounding are detected by vision sensor. Perception module converts all the raw data from the sensor module to useful information for updating internal state. Internal state module consists of emotion and motivation, which are calculated by multiplying each of perception information and connection weights in between perception and internal state modules. These weights are encoded as I-genes. Behavior module selects a proper behavior and facial expression according to the current emotion and motivation state. Motor module is to physically execute the behavior. Perception, internal state and behavior modules are described in detail in the following.

1) *Perception Module*: It consists of stimuli on its body, posture and objects in the surrounding. As body stimuli, patting and hitting can be sensed by touch sensors attached on the skin and by acceleration sensor in the head of GomDoll. As posture stimuli, left and right tilts can be sensed by tilt sensor located at the center of GomDoll. Object stimuli are sensed by camera. Stimulus vector, S is defined as follows:

$$S = [s_1, s_2, \ldots, s_l] \tag{1}$$

where each element has a Boolean value, l represents the number of perceptions. Note that l equals 13 in GomDoll as shown in Table I. Stimulus vector is used to calculate the internal state values on emotion and motivation.

TABLE I
STIMULI AND PERCEPTIONS IN PERCEPTION MODULE

Stimulus	Perception
BODY	HEAD_PATTED, HEAD_HIT, LEFT_CHEEK_PATTED RIGHT_CHEEK_PATTED, LEFT_ARM_GRABBED RIGHT_ARM_GRABBED, BELLY_PATTED
POSTURE	LEFT_TILTED, RIGHT_TILTED
OBJECT	BALL_DETECTED, FRIEND_DETECTED STRANGER_DETECTED, BOOK_DETECTED

2) *Internal State Module:* The internal state module is composed of emotion state vector, E, and motivation state vector, M, where the state values are updated by stimulus vector, S, and weight matrices, W^E and W^M. These weights are encoded as I-genes for GomDoll. Emotion state includes four states: happiness, sadness, anger and fear. Motivation state is composed of five states: curiosity, intimacy, avoidance, control and sociality.

Each internal state is updated by its own weights, which connect the stimulus vector to itself and are also represented as a vector. The internal state values are updated as follows:

$$\begin{aligned} e_i(t+1) &= e_i(t) + S \cdot W_i^{E} + \lambda_E (Y_S - 1) \\ m_i(t+1) &= m_i(t) + S \cdot W_i^{M} + \lambda_M (Y_S - 1) \\ \text{where} \quad E &= [e_1, e_2, \cdots, e_{N_E}] \\ M &= [m_1, m_2, \cdots, m_{N_M}] \end{aligned} \tag{2}$$

$e_i(t)$ and $m_i(t)$ are the i-th emotion and motivation state respectively, and W_i^E and W_i^M are the weight matrix connecting stimulus vector, S, to the i-th emotion and motivation state. 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. Internal state values are decreased by the ratio of λ_E and λ_M until they become 0 in a normal state. Thus, λ_E and λ_M are decrement constants, which represent how fast the emotion and motivation values decrease when there is no external stimulus. N_E and N_M are the number of emotion and motivation states, respectively.

3) Behavior Module: It selects a proper behavior and facial expression in order to show GomDoll's emotion. GomDoll expresses its emotion and motivation based on their values.

The probability-based emotion selector selects an emotion state depending on each emotion state probability. The probability of each state is relatively defined by comparing the sum of all emotion state values. Based on selected emotion, facial expression (Table II) and emotion behavior (Table III) are chosen. Facial expression can be expressed through GomDoll's eyebrow, eye color and ear position, which are independent of body behavior.

TABLE II
FACIAL EXPRESSION FOR EMOTION

Internal state	Facial expression
Happiness	shake both ears, yellow LED on the eyes
Sadness	lower both ears, lower both of inner eyebrows, green LED on the eyes
Anger	shake both ears fast, raise both of outer eyebrows, red LED on the eyes
Fear	shake both ears fast, lower both of inner eyebrows, green LED on the eyes

TABLE III
BEHAVIOR FOR INTERNAL STATE

Internal state	Behavior
Happiness	dance, rotate legs slowly sway head up and down slowly
Sadness	lower head
Anger	shake arms up and down fast
Fear	sway head left and right fast
Curiosity	observe curious object, rotate legs fast, move arms toward the object
Intimacy	observe intimate object, shake arms outside and inside
Avoidance	shake head fast, look away
Control	observe desired object, sway head up and down
Sociality	observe strange object, shake arms up and down slowly

The competition-based motivation selector selects a motivation state depending on each motivation state value. In other words, the motivation having the highest value gets chosen. Motivation behavior is chosen to express GomDoll's selected motivation. From selected motivation and emotion behaviors, only one behavior can be chosen. If only one emotion behavior comes out of selectors which mentioned above, it will be selected with facial expression. But if both motivation and emotion behavior comes out of selectors, motivation behavior will be selected instead of emotion behavior because emotion can still be expressed by facial expression.

B. *Focus Selection*

GomDoll's focus changes depending on the object detected, which appears on the camera, and motivation state at the moment. As shown in Table IV, each of four objects stimulates different motivation state. If there are more than one object in the sight of GomDoll, the object having the highest motivation will be selected. For example, if a ball and a book are shown at the same time to GomDoll with openness propensity, its curiosity will increase higher than control and it will focus on the ball. However, if the ball disappears, even though curiosity value is higher than control value at that moment, the focus will change to the book because there is no ball anymore. By observing GomDoll's focus, the propensity can be demonstrated.

TABLE IV
OBJECTS AND STIMULATED MOTIVATION

Object	**Stimulated Motivation**
Ball	Curiosity
Friend	Intimacy
Stranger	Avoidance, Sociality
Book	Control

III. PROPENSITY GENERATING METHOD

I-genes, connection weights between perception module and internal state module of GomDoll, are trained to generate GomDoll's propensity desired by user based on Big Five personality dimensions. Training procedure is as follows: initially generate perception scenario, then train I-genes for generating desired one of Big Five personality models, finally implant trained I-genes to GomDoll.

The perception scenario is generated, which consists of a sequence of virtual stimuli for a time period [10]. Each stimulus is interpreted as perception information in the perception module at each time step and after applying all stimuli to the perception module, averages of each internal state are calculated. All of internal state averages are compared with preference values, which are defined by user who sets one of Big Five personality dimensions through GUI. After training all I-genes for the desired propensity, they are applied to GomDoll.

A. *Propensity model*

Big Five personality dimensions are employed to classify GomDoll’s propensity. They are classified as follows: openness, conscientious, extroverted, agreeable, and neuroticism [14], [15]. From these, in this paper all of them are engineered for GomDoll to demonstrate the feasibility of the propensity generation process by using evolutionary algorithm. By the objective function composed of internal state values and desired preference values, the propensity can be evaluated.

B. *Implementation*

1) Setting preference value: The preference values on each internal state decide propensity of GomDoll, which are assigned by user. For example, openness personality has high curiosity about novel objects so it has high curiosity value, 0.8. On the other hand, conscientious personality has insensible character so that it has only 0.1 of curiosity level. Note that the range of preference value is from 0 to 1. These values are used for the desired values of propensity.

TABLE V
PREFERENCE VALUES

Internal State \ Personality	Openness	Conscientious	Extroverted	Agreeable	Neuroticism
Happiness	0.30	0.15	0.75	0.45	0.45
Sadness	0.20	0.15	0.10	0.20	0.40
Anger	0.20	0.15	0.10	0.20	0.45
Fear	0.20	0.15	0.05	0.10	0.40
Curiosity	0.80	0.10	0.20	0.20	0.15
Intimacy	0.20	0.10	0.45	0.40	0.10
Avoidance	0.10	0.10	0.05	0.10	0.80
Control	0.15	0.80	0.10	0.10	0.15
Sociality	0.15	0.15	0.80	0.55	0.05

2) Perception scenario: The important issue for generating the perception scenario is that each of internal states should be stimulated evenly among all. There are positive stimuli, which increase happiness state such as patting head, belly, etc. and decreases sadness, anger and fear. There are also negative stimuli, which are on the opposite of positive stimuli such as hitting head and tilting. If the perception scenario is randomly generated with uniform distribution and the total number of positive and negative stimuli in GomDoll's system is different, the perception scenario would not be proper for training I-genes because of unbalanced number of positive and negative stimuli.

For example, GomDoll has 6 positive stimuli and 3 negative stimuli, so if they are randomly selected with uniform distribution, positive stimuli are more likely to be chosen. By this reason, positive internal state such as happiness is more likely to be added and less likely to be substituted by positive stimuli and the opposite to the negative internal state. Thus, if the preference values for positive and negative internal states are the same, the I-genes which connect between positive stimuli and positive internal states are smaller than the I-genes which connect between negative stimuli and negative internal states. Note that it is essential for designing the perception scenario to select the same number of positive and negative stimuli for all of the internal states.

In this paper, number of time steps for the perception scenario is 50 and total number of positive and negative stimuli in perception scenario is set to 25. Masking matrix is multiplied before the virtual stimuli are applied to the perception module.

3) Gene masking: To build a truly believable one, it is required to have proper I-genes, which leads to generating plausible internal states showing a specific character [10]. In this regard, a gene masking process is needed to train proper I-genes. Elements of the masking genes are +1, -1 and 0. For example, positive stimuli such as 'head patting' are connected with positive internal states with masking value with +1, but connected with negative value with -1. In contrast, negative stimuli such as ‘head hitting’ are connected on the opposite way.

TABLE VI
MASKING MATRIX FOR BODY AND POSTURE STIMULI AND EMOTION STATE

Stimulus \ Emotion	Happiness	Sadness	Anger	Fear
HEAD_HIT	-1	+1	+1	+1
HEAD_PATTED	+1	-1	-1	-1
LEFT_CHEEK _PATTED	+1	-1	-1	-1
RIGHT_CHEEK _PATTED	+1	-1	-1	-1
LEFT_ARM _GRABBED	+1	-1	-1	-1
RIGHT_ARM _GRABBED	+1	-1	-1	-1
BELLY_PATTED	+1	-1	-1	-1
LEFT_TILTED	-1	+1	+1	+1
RIGHT_TILTED	-1	+1	+1	+1

TABLE VII
MASKING MATRIX FOR OBJECT STIMULI AND MOTVATIION STATE

Stimulus \ Motivation	Curiosity	Intimacy	Avoidance	Control	Sociality
BALL_DETECTED	+1	0	0	-1	0
FRIEND_DETECTED	0	+1	-1	0	-1
STRANGER_DETECTD	0	-1	+1	0	+1
BOOK_DETECTED	-1	0	0	+1	0

Table VI and VII represent the masking matrix between stimuli and internal states. It is assumed that the body and posture stimuli effect only on emotion state, but not on motivation state and the objects stimulate motivation state, but they do not stimulate emotion state. By separating stimuli for effecting emotion and motivation states, it can be clearly observed that which stimulus effects on which internal state and how much it effects.

4) Generating Propensity: Evolutionary algorithm was used to generate I-genes for desired propensity. Each individual has 117 I-genes for the connection weights between 13 perceptions and 9 internal states. Mutation equation and standard deviation are as follow:

$$x_{i+\mu} = x_i + N(0,\sigma_i^2) \qquad \sigma_i = \frac{\sqrt{f_{Pi}}}{\mu} \tag{3}$$

where x_i is the i-th individual and μ is the number of individuals. $N(0,\sigma_i^2)$ is a vector of independent random Gaussian numbers with a mean of zero and standard deviation, σ_i. By adding $N(0,\sigma_i^2)$ to the individuals, offspring are generated. f_{Pi}, which will be shown in equation (4), is the objective value of the i-th individual which decides how far it explores and how deep it exploits. If f_{Pi} is large, it means that i-th individual is still far to converge to the desired propensity and need to explore broadly. And if f_{Pi} is small, it can be interpreted in the other way.

The trained individuals are compared with each other and the number of wins of each individual is incremented when it has smaller objective value than opponent individual. All of the individuals are rearranged by their number of wins and upper half of them are selected as parents of the next generation.

The objective function evaluates the objective of trained I-genes by comparing the average value of internal states after perception scenario and preference value, defined as follow:

$$S_E = \sum_{i=1}^{N_E} E_i^P \qquad S_M = \sum_{i=1}^{N_M} M_i^F \qquad \Phi_{E_i}^P = \frac{E_i^P}{S_E} \qquad \Phi_{M_i}^P = \frac{M_i^P}{S_M}$$

$$\Phi_{E_i}^C = \frac{\sum_{j=1}^{T_s/\Delta T} E_i^C(j\Delta T)}{\sum_{j=1}^{T_s/\Delta T}(\sum_{i=1}^{N_E} E_i^C(j\Delta T))} \qquad \Phi_{E_i}^C = \frac{\sum_{j=1}^{T_s/\Delta T} M_i^C(j\Delta T)}{\sum_{j=1}^{T_s/\Delta T}(\sum_{i=1}^{N_M} M_i^C(j\Delta T))}$$

$$f_P = \sum_{i=1}^{N_E}(\Phi_{E_i}^P - \Phi_{E_i}^C)^2 + \sum_{i=1}^{N_M}(\Phi_{M_i}^P - \Phi_{M_i}^C)^2 \qquad (4)$$

where E_i^P is the i-th preference value of emotion, M_i^P is the i-th preference value of motivation, N_E is the number of emotion states, N_M is the number of motivation states, $E_i^C(j\Delta T)$ is calculated the value of i-th emotion state at j-th time step, $M_i^C(j\Delta T)$ is calculated the value of i-th motivation state at j-th time step, $\Phi_{E_i}^C$ is calculated i-th emotion average value, $\Phi_{M_i}^C$ is calculated i-th motivation average value, $\Phi_{E_i}^P$ is the desired i-th emotion average value, $\Phi_{M_i}^P$ is the desired i-th motivation average value, S_E is the total sum of preference values of emotion states and S_M is the total sum of preference values of motivation states. f_P is the objective function for comparing trained propensity and the desired propensity which is the preference value in Table V, where a big number N is introduced to make a maximization problem. By maximizing objective value, GomDoll can get a desired propensity.

IV. Experimental Results

Trained I-genes for each propensity were applied to GomDoll and two experiments were carried out. Total 600 individuals were used and the generation was terminated when the objective value is less than 0.01.

The first experiment was for comparing how emotion state changes among five propensities by applying body and posture stimuli and the second experiment was comparing motivation differences among five propensities when four different objects were detected. For representing four objects (ball, friend, book and stranger) four different color patches were used.

A. Body and posture stimuli experiment

The body and posture stimulus experiment was for comparing the change of emotion states among five different propensities.

The first graph of Fig. 4 shows the change of stimuli and four different stimuli were applied continuously with the same interval. Other four graphs show each emotion state for all five characters for comparing each other. When GomDoll's head was patted and left arm was grabbed, the value of happiness of extroversion was higher than other propensities.

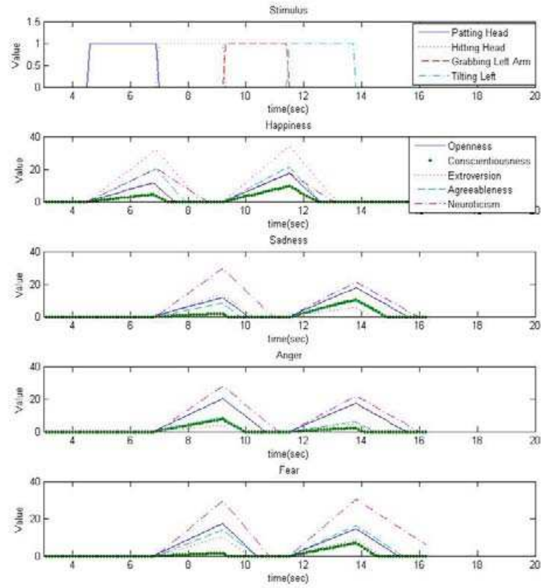

Fig. 4 Body, posture stimuli and the change of emotion states for different propensities

It demonstrated that extroversion has high tendency to be happy. But when GomDoll's head was hit and left tilted, the value of negative emotion state of neuroticism was higher than other propensities. It showed that neuroticism has high tendency to feel negatively. For overall stimuli, the emotion states of conscientiousness were less likely to be changed because its propensity was insensitive to the stimuli from environment.

B. Object stimuli experiment

The objects change motivation states of GomDoll and the changing rate of motivation states are different in each propensity. Each object stimulates its own related motivation states. By using these differences, all propensities can be compared to each other.

The first graph of Fig. 5 shows the change of detected objects for given time steps. On the first graph, the objects were applied as follows: ball → ball & friend → friend → friend & book→ book → book & stranger→ stranger. The purpose of showing two different objects at the same time was for showing which object GomDoll prefers for different propensity. The other five graphs represent the motivation states of Gomdol with the propensity of openness, conscientiousness, extroversion, agreeableness and neuroticism.

When a ball was shown to GomDoll, the one with the propensity of openness had the fastest increment of curiosity.

It demonstrated that GomDoll with the openness propensity has the highest tendency to feel curiosity for novel objects.

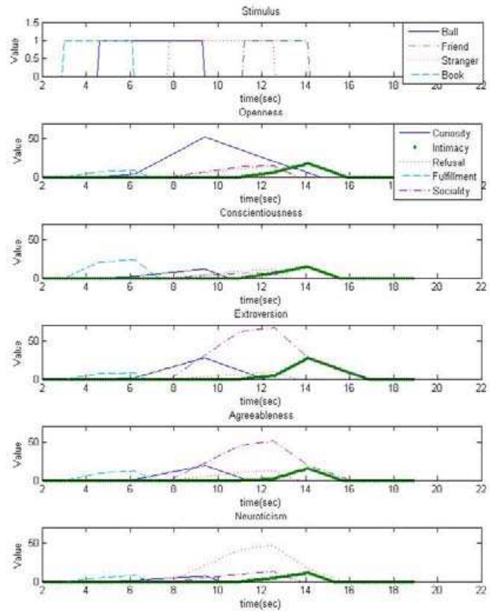

Fig. 5 Object stimuli and the change of motivation states for each propensity

When a friend was shown to GomDoll, the extrovert one had the fastest increment of intimacy. It showed that extrovert one has the highest tendency to feel intimacy for friendly objects. And when a book was shown to GomDoll, the conscientious one had the fastest increment of control. It showed that the one with conscientious propensity has high desire for control. When a stranger was shown to GomDoll, the one with the propensity of extroversion had high increment of sociality but neurotic one had high tendency of avoidance than sociality. It represented that the extroverted GomDoll has high sociable manner than avoidance but neurotic GomDoll has the opposite character.

V. CONCLUSIONS

This paper proposed an evolutionary generating process for robotic doll's propensity encoded in its I-genes. I-genes for five propensities were generated and applied to the robotic doll, GomDoll. The experimental results showed that the changing rate of internal states for body, posture and object stimuli were different in each of propensities. It was verified that the proposed robot propensity generating process was applicable to robotic doll. By using this process, a robot which possesses user desired propensity could be built based on user defined preference values.

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