Personal Preference Analysis for Emotional Behavior Response of Autonomous Robot in Interactive Emotion Communication

Paper:

Personal Preference Analysis for Emotional Behavior Response of Autonomous Robot in Interactive Emotion Communication

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Robots must understand human intention flexibly before the two can live together, for example. Interaction Emotion Communication (IEC), bidirectional communication based on emotional behavior between human beings and robots, raises the personal affinity a robot has for human beings. IEC consists of three processes – (1) recognizing human emotion, (2) generating robot emotion, and (3) expressing robot emotion. We focus here on generating robot emotion. Emotional behavior patterns desirable in a robot vary with the person, so we also conducted individual preference analysis of emotional behavior.

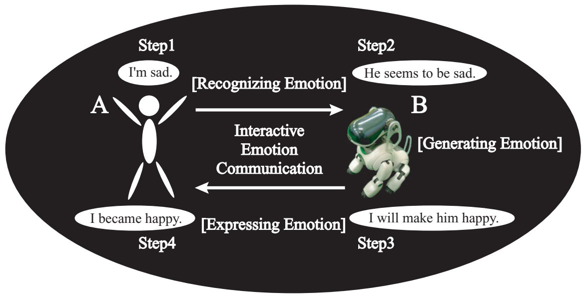

Fig. 1. Interactive emotion communication (IEC).

Keywords: emotion, communication, autonomous robot, fuzzy inference

1. Introduction

Despite increasing opportunities for contact between robots and human beings [1, 2], the technology for realizing interactive communication between the two remains surprising undeveloped, as does the flexible understanding of mutually emotion and intention required for them to live together and communicate smoothly. Some research into understanding human intent and expressing robot intent has used nonverbal information [3–7]. Nonverbal communication includes over 90% of the information concerning the emotion of the interlocutor [8]. Nonverbal communication may be by eye, voice, facial expression, or gesture. Robot facial expression like human beings gives us an uncanny feeling [9].

We have been studying nonverbal robot and human communication. We propose inferring emotion from human behavior [10], in Section 3, starting by extracting a subject's body features based on Laban's theory [11]. Using these extracted human body movement, we obtain the basic emotional degree through fuzzy inference [10]. We then evaluated the emotional value of human movement based on Russell's circumplex model [12].

Our research objective is to realize Interactive Emotion Communication (IEC) – emotion-based bidirectional human and robot communication. We aim to give high interpersonal affinity of robot to human. Moreover, we report on the impression of communication between a human and a robot. We would like to analyze the tendency of desirable robot reaction for emotional behavior through IEC. The aim of this research to inspect the individual preference analysis for robot emotional behavior.

2. Interactive Emotion Communication (IEC)

Our research assumes a bidirectional emotional communication model – Interactive Emotion Communication (IEC) – between human beings and robots as an example of nonverbal communication. Here, emotion refers to movement, e.g., gesture or dance [13] representing emotion directed toward a counterpart.

Assume human being A and robot B in an interaction in which A expresses an emotion to B through gestures. Upon recognizing A's emotion visually, B expresses an emotion to A. Recognizing IEC requires three IEC processes:

(1) recognizing human emotion,

(2) generating robot emotion,

(3) expressing robot emotion.

Because it remains difficult for robots – although easy for human beings – to communicate through language, we considered communication through emotions. Emotional robot behavior is decided based on an analysis of personal preference analysis, as detailed in Section 4 and shown in **Fig. 1**. Our eventual goal is to build robots able to recognize human emotion and express their own emotion by bidirectional communication based on an IEC model with high interpersonal affinity.

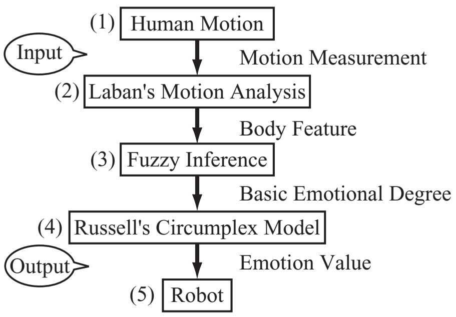

Fig. 2. Fuzzy emotion inference system (FEIS).

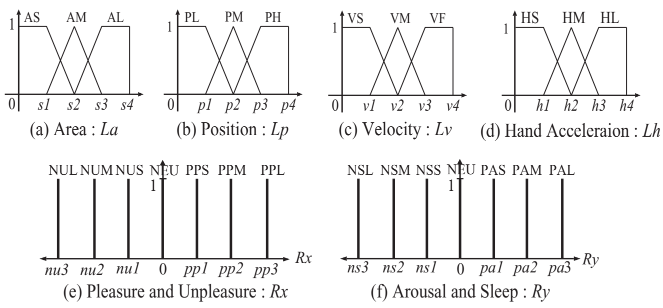

Fig. 3. Membership functions and singletons.

3. Fuzzy Emotion Inference in IEC

We explain the first step of IEC human emotion recognition used fuzzy inference to determine emotion from body features. We used Laban's theory and Russell's circumplex model to decrease fuzzy inference input and output and to simplify fuzzy rules.

3.1. Algorithm Flow

Figure 2 shows the Fuzzy Emotion Inference System (FEIS) flow we have proposed, which uses the following algorithm:

(1) measuring human emotion using a CCD camera,

(2) extracting body features from movement analyzed based on Laban's theory,

(3) calculating the basic emotional degree using fuzzy inference based on body features,

(4) obtaining an emotion value using Russell's circumplex model based on the basic emotional degree,

(5) expressing robot emotion based on the emotion value.

This research focuses on four basic emotions – joy (JOY), anger (ANG), sadness (SAD), and relaxation (REL) – in discussing human and robot emotions.

3.2. Laban's Theory

The theory [11] proposed by Rudolf Laban uses effort and shape to describe, interpret, and document human movement using three movement descriptions – effort-shape description, motif description, and structural description. Effort-shape description focuses on movement quality and expression meaning.

Laban theorized a bipolar system expressing movement based on fighting form – active, vivid movement – and indulging form – slow, gentle movement. These two forms are the core of effort-shape description.

Effort effectively classifies movement based on Kansei information. Shape shows overall static movement, including shape, which does not consider local movement.

Table 1. Fuzzy emotion inference rules.

		AS			AM			AL		
		PL	PM	PH	PL	PM	PH	PL	PM	PH
VS	HS	NUS NSL	NEU NSM	NEU NEU	NEU NSL	NEU NSL	PPL NSM	NEU NSL	PPL NSL	PPL NSL
	HM	NUM NSM	NUS NEU	PPM PAS	NEU NSL	NEU NSM	PPL NEU	NEU NSL	NEU NSL	PPL NSM
	HL	NUM NSS	NUM PAS	NUS PAM	NEU NSM	NEU NEU	PPM PAS	NEU NSL	PPM NSM	PPL NSM
VM	HS	NUM NSS	NUS NSS	PPS PAS	NEU NSM	PPM NSM	PPM PAS	PPM NSL	PPL NSM	PPL NEU
	HM	NUL NSS	NEU NEU	NUS PAM	NUM NEU	NEU NEU	PPM NEU	PPM NSM	PPL NEU	PPL PAS
	HL	NUL PAS	NUL PAM	NUM PAL	NUL NSS	NUM PAM	NEU PAM	NUS NSS	PPS PAS	PPM PAS
VF	HS	NUL PAM	NUM PAM	NUM PAL	NUM NSS	NEU NEU	NEU PAM	NUS NSM	PPM NSL	PPL PAS
	HM	NUL PAM	NUL PAL	NUM PAL	NUL NEU	NEU PAM	NUS PAL	NUM NSL	PPS PAS	PPM PAM
	HL	NUL PAL	NUL PAL	NUL PAL	NUL PAM	NUL PAL	NUM PAL	NUL PAS	NUM PAM	PPS PAL

(Upper Label: *Rx*, Lower Label: *Ry*)

Our research assumes that Time Effort (TE) is the speed of the body's center of gravity (COG), Flow Effort (FE) is manual (hand) acceleration, Table-Plane Shape (TPS) is body area, and Door-Plane Shape (DPS) is the height of the body's COG. TE, FE, TPS, and DPS are measured by a robot camera. We have excluded Laban's weight effort, shape effort, and wheel plane here because they are difficult to measure using a camera.

3.3. Fuzzy Emotion Inference

Figure 3 and **Table 1** show membership functions, singletons, and fuzzy rules used in FEIS. Tanabe et al. proposed the theory that basic emotional degrees extracted from movement analysis based on Laban's theory as fuzzy inference input are defined as pleasure/unpleasure and arousal/sleep based on **Table 1** to obtain an emotion value (Section 3.4) on Russell's circumplex model.

3.4. Russell's Circumplex Model

In 1980, J. A. Russell proposed the circumplex model [12] wherein all emotions are expressed as a circumplex on a plane defined by the two dimensions pleasure/unpleasure and arousal/sleep. Witvliet and Vrana [14, 15] further proposed the four basic emotions, joy (JOY), anger (ANG), sadness (SAD), and relaxation (REL), applied to each quadrant of this model (**Fig. 4**).

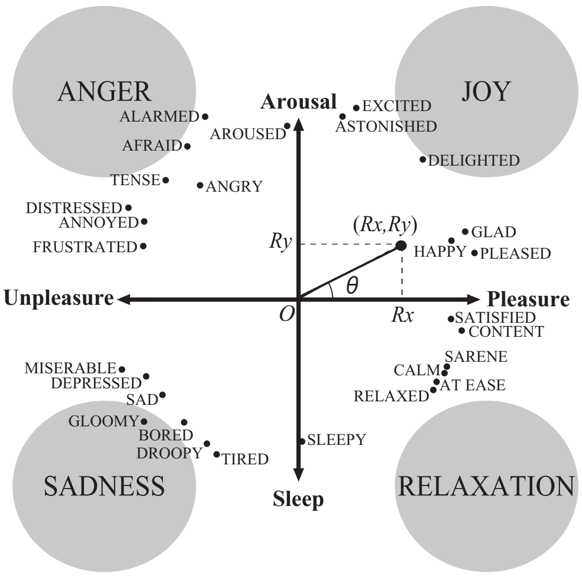

Fig. 4. Basic Russell's circumplex model emotions [12].

Human emotion is inferred from R_x (pleasure/unpleasure) and R_y (arousal/sleep) from FEIS. Human emotion is decided based on where the inference result (R_x/R_y) is. Emotion value (E_i : i = JOY, ANG, SAD, REL) means emotional strength. E_i is calculated as follows:

$$E_i = \sqrt{R_x^2 + R_y^2}\,|\sin(\pi - 2\theta)| \quad \quad (1)$$

$$\theta = \arctan\frac{R_y}{R_x} \quad \quad (2)$$

$$i = \begin{cases} \text{JOY} & 0 \le \theta < \frac{1}{2}\pi \\ \text{ANG} & \frac{1}{2}\pi \le \theta < \pi \\ \text{SAD} & \pi \le \theta < \frac{3}{2}\pi \\ \text{REL} & \frac{3}{2}\pi \le \theta < 2\pi \end{cases}$$

4. IEC Experiments

In inferring human emotions based on FEIS, we conducted interactive experiments between human subjects and a pet-type robot, defining human emotions as JOY-H, ANG-H, SAD-H, and REL-H, robot emotions as JOY-R, ANG-R, SAD-R, and REL-R, and emotion inferred from human emotional behavior by FEIS as JOY-F, ANG-F, SAD-F, and REL-F.

4.1. Experimental Setup

The pet-type robot was the dog-like AIBO (SONY ERS-7), chosen for its "high interpersonal affinity." The AIBO program is read and written via personal computer using an exclusive memory stick. Joints have 20 degrees of freedom (DOF).

The experimental environment is shown in **Fig. 5** using

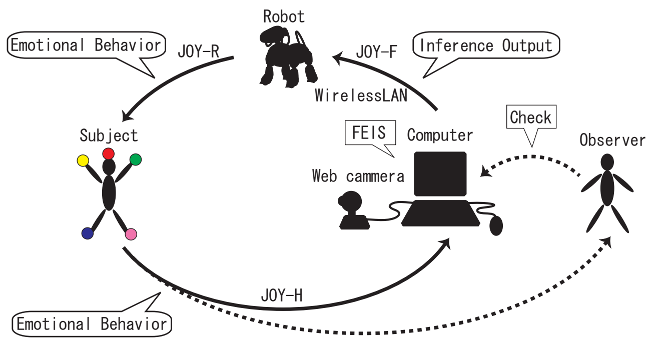

Fig. 5. Experimental JOY-H environment.

Table 2. Membership functions and singleton values.

La	*Lp*	*Lv*	*Lh*
$s1 = 150$	$p1 = 85$	$v1 = 5$	$h1 = 20$
$s2 = 300$	$p2 = 170$	$v2 = 10$	$h2 = 45$
$s3 = 450$	$p3 = 200$	$v3 = 25$	$h3 = 90$
$s4 = 700$	$p4 = 300$	$v4 = 150$	$h4 = 200$
Rx		*Ry*	
$pp1 = 100$	$nu1 = -100$	$pa1 = 100$	$ns1 = -100$
$pp2 = 200$	$nu2 = -200$	$pa2 = 200$	$ns2 = -200$
$pp3 = 300$	$nu3 = -300$	$pa3 = 300$	$ns3 = -300$

Table 3. Emotional situations imaged by two subjects.

Subjects	Emotions	Situations
A	JOY-H	Trial thing was successful.
	ANG-H	Trial thing was unsuccessful.
	SAD-H	Precious item was broken.
	REL-H	He takes some hot drink.
B	JOY-H	His desire was satisfied.
	ANG-H	He felt insulted.
	SAD-H	He was betrayed.
	REL-H	He absorbed himself in hobby.

the example JOY-H. **Table 2** shows membership function (see **Fig. 3**). Subjects expressed different behavior and filled out questionnaires determining membership functions and singleton values.

FEIS was constructed on a computer to collect image data – 3 to 5 frames/s – on human expression. FEIS output is sent to the robot through via a wireless LAN. We also appointed an observer to evaluate FEIS accuracy.

4.2. Preconditions

This experiment was cooperated with two subjects – two university students of 20 generations. Subjects attached five markers – head, both hands, and both foots so that computer extracts body features, and each color was different – red, yellow, green, blue, and pink. We made subjects perform emotional behavior freely without restrictions of expression. Subject expresses his emotional behavior while he images various situation as shown in **Table 3**. In order to realize a kind of natural situation, we question two subjects about when they easily imaged each emotion. **Table 3** shows the emotional situations imaged by two subjects.

Emotions of subjects were measured using a camera connected to a personal computer (see **Fig. 5**). Human emotion was recognized by FEIS. The observer checked FEIS output in real time. FEIS output was sent to the robot through a wireless LAN, and the robot expressed emotion based on FEIS output.

Robot emotion was limited to 4 patterns – JOY-R, ANG-R, SAD-R, and REL-R expressed in 3-6 seconds. Subjects observed the robot in front of him as well and filled out questionnaires on robot emotion based on the patterns above.

Experiments were as follows:

Step 1: The subject extracts a situation in which emotion is easily expressed.

Step 2: The subject expresses emotional behavior based on the 5 color markers worn.

Step 3: The camera images the subject's emotional behavior recognized by FEIS.

Step 4: The computer sends the human emotion to the robot based on FEIS output.

Step 5: The robot expresses emotional behavior for all human emotion combinations.

Step 6: The subject observers the robot while expressing emotional behavior.

Step 7: Experiment steps 2-4 are repeated within 40 seconds.

Step 8: Questionnaires on subjects' impressions of robot emotional behavior were checked after experiments.

Experiments used the 16 pattern shown in **Fig. 6**. The robot expressed emotional behavior based on FEIS output. To simplify experiments, we assumed the following emotional robot expressions:

JOY-R: The robot raises both hands.

ANG-R: The robot drops both hands to the ground.

SAD-R: The robot hangs its head.

REL-R: The robot stretches its legs.

Subjects were informed in advance of what each robot action mean to.

4.3. Robot Emotion Impression

To evaluate all combinations of robot and human behavior, we used 6 adjectival pairs – animal-like–mechanical (S_1), interesting–boring (S_2), complex–simple (S_3), familiar–unfamiliar (S_4), natural–unnatural (S_5), and likable–dislikable (S_6). Subjects evaluated robot reactions using 7 scores (-3 to 3). Adjectival pairs were selected as Kansei word referring to past references [17, 18].

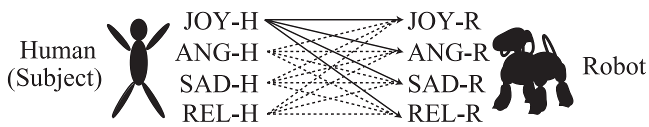

Fig. 6. 16 experimental patterns.

Table 4. Evaluation of experimental results.

		JOY-R	ANG-R	SAD-R	REL-R
JOY-H	σ_A	0.90	0.40	0.55	0.20
	σ_B	1.90	1.90	−1.58	−1.40
	ρ	0.57	0.71	−0.77	0.10
ANG-H	σ_A	−0.40	0.20	0.05	−0.25
	σ_B	−2.05	−1.18	0.48	−1.83
	ρ	0.10	−0.33	−0.62	0.42
SAD-H	σ_A	0.85	0.25	0.55	0.25
	σ_B	1.90	1.18	1.25	1.23
	ρ	0.71	−0.15	0.45	0.33
REL-H	σ_A	−0.25	0.05	0.40	1.50
	σ_B	0.80	1.40	−2.68	1.18
	ρ	0.25	0.00	−0.58	−0.33

We defined evaluation value σ to detect the likability degree of subjects. σ, which is the weighted sum of subject's evaluation score S_i ($i = 1, \ldots, 6$) in questionnaire, is calculated as shown in Eq. (3).

$$\sigma = \sum_{i=1}^{6} \alpha_i S_i \quad \ldots \ldots \ldots \ldots \quad (3)$$

We asked both subjects the significance weight α_i ($i = 1, \ldots, 6$) for 6 adjectival pairs in questionnaire to calculate σ. In advance, we questioned two subjects about the percentage of significant factor for each adjectival pair. The weights α_i are expressed with the percentage for "Animal-like (α_1)," "Interesting (α_2)," "Complex (α_3)," "Familiar (α_4)," "Natural (α_5)," and "Likable (α_6)."

After experiments, we obtained (α_1, α_2, α_3, α_4, α_5, α_6) = (0.15, 0.05, 0.15, 0.15, 0.0, 0.5) for subject A, (0.15, 0.1, 0.025, 0.1, 0.125, 0.5) for subject B as the weight of score S_i. By using these weights, we calculate the evaluation value for questionnaire. Subject A's and subject B's evaluation values (σ_A, σ_B), which were calculated with Eq. (3), were useful when we make a comparison between the personal preference.

4.4. Experimental Results

Table 4 shows evaluations for subjects A (σ_A) and B (σ_B). In this table, ρ means Spearman rank correlation coefficient, detailed later. **Fig. 7** shows differences of impressions between the two subjects. With impressions consistent between subjects, we arranged favorable adjectives at left side and unfavorable at right. These impressions were graded with 7 scores for 6 items. The better the impression, the farther left it is (subject A: solid line; subject B: broken line). Results are summarized as follows:

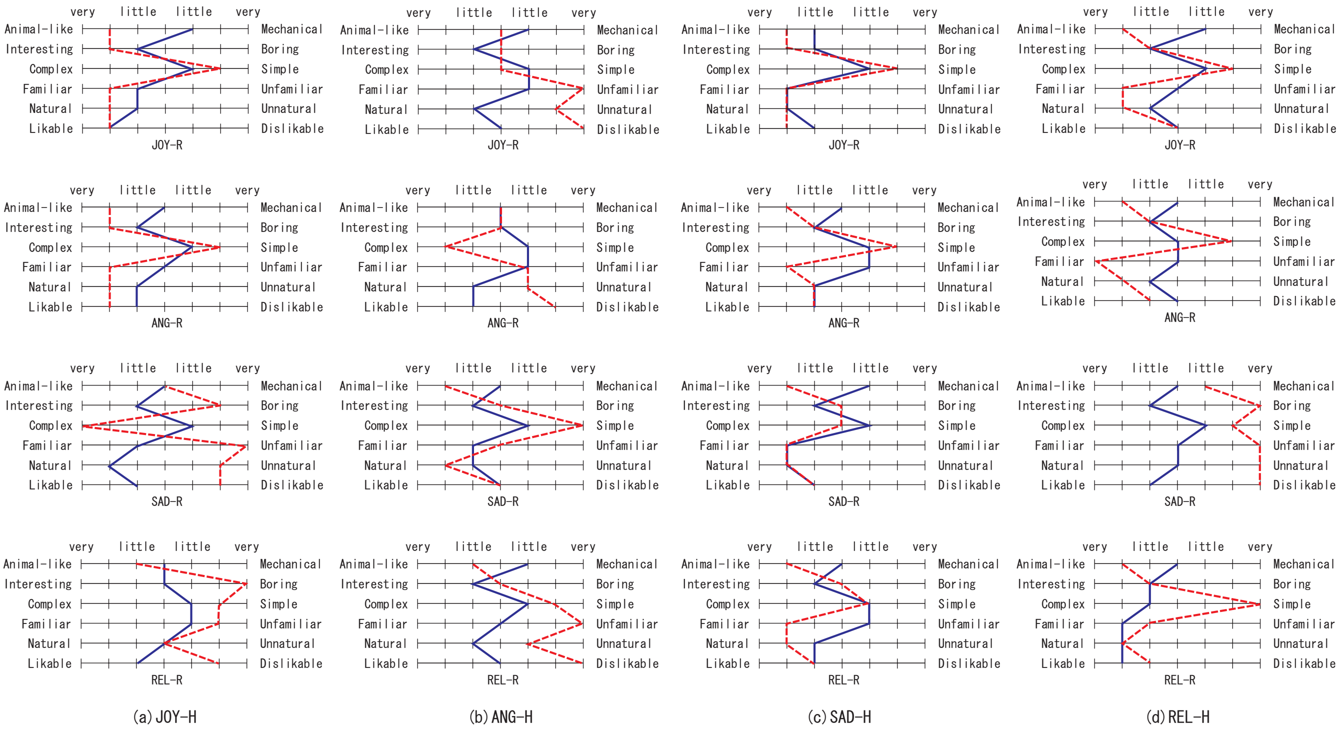

Fig. 7. Impressions.

JOY-H Subject A evaluated likable–dislikable highly in all combination (JOY-R, ANG-R, SAD-R, and REL-R vs. JOY-H). Subject A did not feel bad impression to robot when he was in joy. Subject B's preferences are clear, especially in contrast to subject A's, when they were opposed, as in JOY-H vs. SAD-R.

ANG-H Both subjects had relatively unfavorable impressions of ANG-H. Subject A felt sympathetic but subject B was troubled in case of ANG-H vs. ANG-R. Both were displeased when the robot expressed pleasure – JOY-R and REL-R – after subject expressed ANG-H.

SAD-H Both subjects had a good impression when the robot expressed JOY-R for SAD-H. We think that the robot expressing JOY-R is happy, but both subjects felt encouraged by the robot. Subjects' evaluations were comparatively similar.

REL-H Subjects A and B clearly had different preferences. Subject A evaluated REL-H vs. REL-R the highest due to feeling sympathy for the robot's emotion. In contrast, subject B evaluated REL-H vs. ANG-R the highest due to feeling that the robot was sulky and anger although robot actually wanted to be friends.

Figure 8 show FEIS output and movement timing expressing robot emotion for the best combination with high evaluation in **Table 4**. **Fig. 8** graphs show subject B's high evaluation combination. The X-axis is time for one experiment (40 seconds) and the Y-axis emotion value (E_i). Vertical lines show average FEIS output per second. The robot expressed emotion 3 to 5 times within 40 seconds, and FEIS output JOY-F, ANG-F, SAD-F, and REL-F inference results successfully. Robot JOY-R, ANG-R, SAD-R, and REL-R emotion complied with inference results.

Vertical bold lines show the timing of robot emotion. Robot emotion frequency is important for evaluating human impression. We confirmed that the personal preference was appeared for various robot emotional behavior. In the next step, we should perform the experiment that we investigate tendency of the general personal preference.

4.5. Discussion

Subject impressions confirmed what they feel regarding robot emotion, e.g., they were cheered by JOY-R when they feel sadness. This has very important implications for further development. We calculated Spearman rank correlation coefficient ρ (**Table 4**) to inspect these impressions referencing [16]. $|\rho| \geq 0.6$ shows strong correlation between two subjects' impressions. The strongest negative correlation was in JOY-H vs. SAD-R, while the strongest simultaneous positive correlation was JOY-H vs. JOY-R and SAD-H vs. JOY-R. In the case of JOY-H vs. SAD-R, the two subject's impressions differed markedly. In this case, two subjects' impressions were reverse plus and minus though same robot's reaction. Through robot emotional reactions, we confirmed that robot emotion affects to human's impression.

Results of this experiment confirmed that robot emotion gives different impressions. It is important because

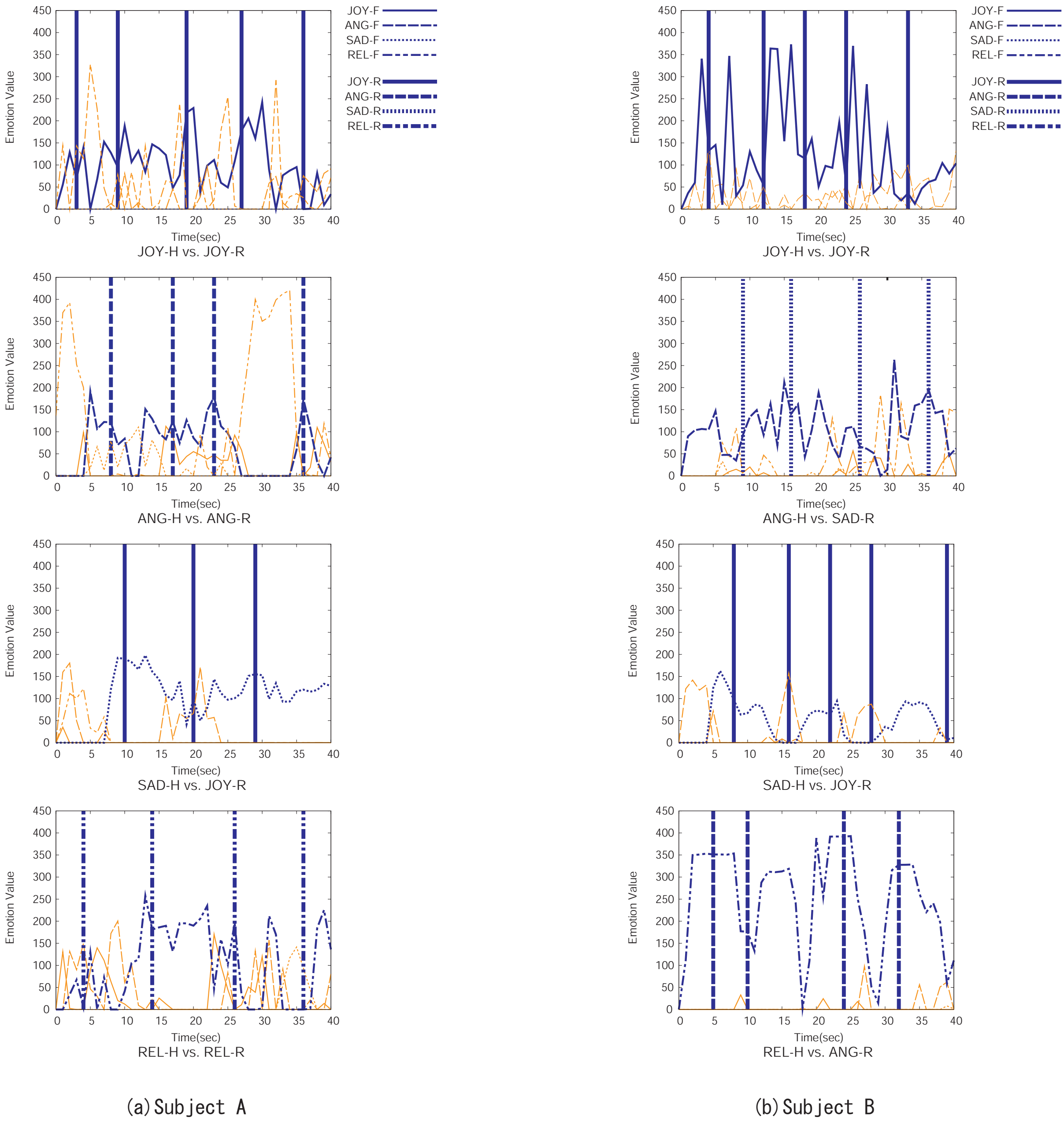

Fig. 8. FEIS output in high evaluation.

impressions include the variety of human preference. We thus must construct a way to transform robot emotion impression correctly through emotional behavior.

5. Conclusions

We have constructed basic IEC-based communication between human beings and robots, and have analyzed the human impression for the actual robot through emotional behavior. We confirmed that the robot reaction for human emotional behavior gives different impression to subjects. Experimental results suggest guidelines for raising interpersonal affinity between the two. Human beings and robots express emotional behavior in IEC, so we hope that IEC may effectively improve human expression in conditions such as autism and major depression, thereby lowering stress in daily life.

We plan to construct a system in which the robot conducts all processes. Because fuzzy rule parameter tuning takes much time for individual subject adaptation, we must develop a system making fuzzy rules easy to construct even in cases of experiments with involving large numbers of subjects.

Acknowledgements

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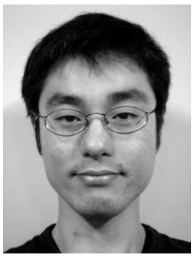

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Membership in Academic Societies:
- The Robotics Society of Japan (RSJ)
- Japan Society for Fuzzy Theory and Intelligent Informatics (SOFT)
- The Japanese Society for Artificial Intelligence (JSAI)
- The Institute of Electrical and Electronics Engineers (IEEE)