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Motion Modification Method to Control Affective Nuances for Robots

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***Abstract*— In human–robot interaction, robots often fail to lead humans to intended reactions due to their limited ability to express affective nuances. In this paper, we propose a motion modification method that combines affective nuances with arbitrary motions of humanoid robots to induce humans to intended reactions by expressing affective states. The method is applicable to various humanoid robots that differ in degrees of freedom or appearances, and the affective nuances are parametrically expressed in a two-dimensional model comprised of valence and arousal. The experimental results showed that the desired affective nuances could be expressed by our method, but it also suggested some limitations. We believe that the method will contribute to interactive systems in which robots can communicate with appropriate expressions in various contexts.**

I. INTRODUCTION

Recently, many robots have been developed that provide services for humans at public facilities and private homes [15][16]. These robots are not only expected to provide physical assistance by carrying baggage, for example, but also to affect user emotions, such as encouraging the depressed or chastising those who have done something bad. How should robots act to realize such "touching" communication? To cite some cases, body entrainment with such robot motions as pointing and nodding plays an important role in human–robot communication [11][12].

Just as body entrainment affects observer behaviors through actor behaviors, affective expressions seem effective for changing the observer's affective state. For example, if a robot is approaching someone and frantically pointing, the person might sense a problem and mentally prepare for it. If the robot is pointing casually and happily, the person is prepared to offer an amicable response because the robot's behavior appears friendly(Fig.1). Thus, robots can induce humans to intended reactions by expressing affective states.

Humans evaluate the emotional states of others not only by their facial expressions but also by subtle changes of eye direction, voice tones, and bodily motions. In many studies, subtle expressions have been incorporated into robots and CG agents to intuitively and adequately transmit information about attitudes. For example, the attitudes of agents can be expressed by the intonations and duration of beeps or the velocity and trajectory of movements[8]. Display monitor

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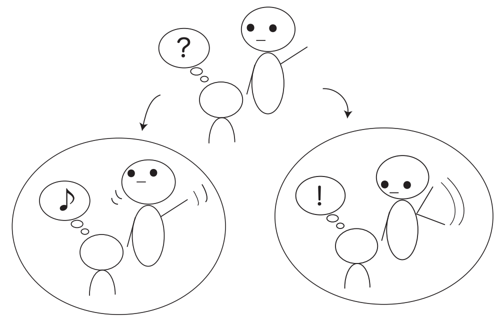

Fig. 1. Nuances of motions affect attitudes

"Roco" leads users to specific states of mind by expanding and directing its neck[3]. CG agent "Rea" informs changes of topic and shifts the conversation by such non-verbal cues as postures and eye gazing[4].

A. Purpose

We propose a method that expresses affective nuances by subtle expressions of humanoid robot motions that denote the expressions by subtle changes of the velocity and extensity of motions and posture from arbitrary motions.

In current methods for making robotic motions, one common procedure is setting all servo values for each pose and then playing the series of poses in order. With this method, however, gestures "waving hand sadly" and "waving hand happily" must be made as entirely different motions even though "waving hand" is shared by both motions. Furthermore, the expression of such affective changes as "gradually appears sad" must also be made as an independent motion. Making every single motion appropriate to various contexts is difficult, because a vast amount of work is required to make various affective expressions for all robot motions. We need a method for producing motions from a combination of arbitrary motions and desired affective nuances, or motion designers have to prepare all motions with various affective expressions.

CG studies include such approaches as an animation generator that adds nuances[10] or the extraction of motion styles from motion capture data[2]. These studies are based on the assumption that users evaluate the expressions of CG agents in the same way as humans since CG agents can accurately duplicate human motions and appearances therefore, few studies performed user evaluations.

In a study of robot expressions using body motions, Nakata[9] analyzed the impressions of the a robot's body expressions based on dance theory. In previous studies, the problem is that each method can only be applied to the

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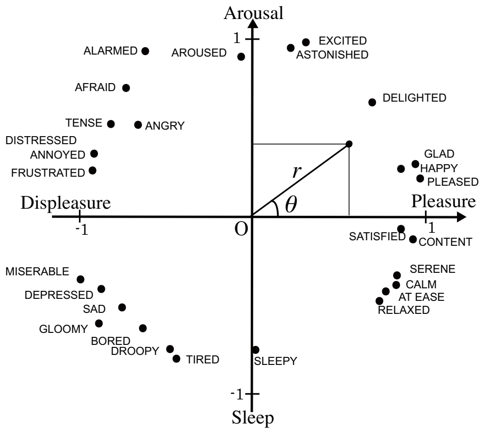
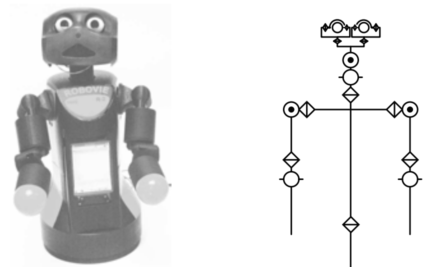


Fig. 2. Affective Nuance Model based on Russell's Circumplex Model



(a) Overview (b) Link mechanisms

Fig. 3. Desktop type Robot: Robovie-mini R2

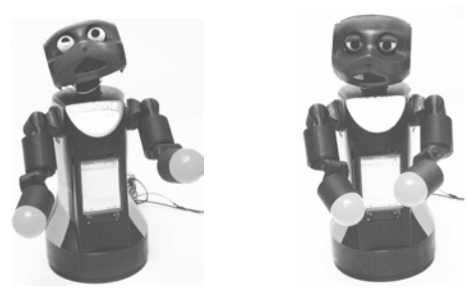


Fig. 4. Examples of basic postures: left: high valence, right: low valence

type of robot used in each study, so no result confirmed the method's effectiveness on several robots with different appearances.

In our study, we propose a motion modification method to control the affective nuances for humanoid robots, aiming to induce humans to intended reactions by expressing affective states. In particular, by controlling the posture, the velocity and the extensity of motions, our method modifies arbitrary motions to combine affective nuances. We conducted three experiments of user evaluations and verified the method's effectiveness.

II. Modification Method

A. Affective Nuance Model

There have been many studies of agent emotional expressions. The emotional models used in these studies were roughly divided into dimensional models and such categorical models as Ekman's six emotions: happiness, sadness, fear, surprise, anger and disgust. Our method adopts a dimensional model because it is adequate to gradually control motions. Some two-dimensional models have valence and arousal axes[13], and three-dimensional models have an additional intensity axis. Two-dimensional models can express a "core affect"[14]. On the other hand, such models express emotions too simplistically, making it difficult to distinguish "fear" from "anger"[6]. Since bodily expressions exhibit the gross affect rather than facial expressions[5], our first step is realizing the expression of a "core affect". For the above reasons, we adopt a two-dimensional model(Fig.2) in which vector direction and length determine the nature and the strength of the affective nuances respectively.

B. Assignment of Motion

We describe how to modify the motion for expressing affective nuances. The method uses three parameters, the velocity and the extensity of motion, and a basic posture, for modifying various motions without changing their meanings. The parameters do not depend on both DOFs and the arrangement of axes, so we can apply them to various robots. The mappings from the valence and arousal levels to the parameters are described below. An arbitrary motion (hereafter, original motion) is modified by the valence and arousal levels. Each parameter is mapped to either valence or arousal.

First, the velocity and the extensity of the motions of all the joints were assigned to arousal levels, which can be expressed by the contrast between moving actively or sluggishly. When an arousal level is high, the velocity of motion becomes high and the extensity of motion widens; when the arousal level is low, the velocity of motion becomes low and the extensity of motion becomes narrow.

Next, a basic posture is assigned to a valence level. The "Contraction" posture, characterized by a forward trunk, a bowed head, drooping shoulders and a sunken chest, gives a negative impression such as "depression" and "dejection", and the "expansion" posture, characterized by a backward trunk, a raised head and raised shoulders, gives such positive impressions as "joyful" and "receptiveness"[7]. So when the valence level is high, the head turns upward and the direction of the end of the arm turns away from the chest, and when the valence level is low, the head turns downward and the end of the arm turns inward.

For an application example, we explain with Robovie-mini R2(Fig.3), which was developed by ATR Intelligent Robotics and Communication Laboratories. Fig. 3(b) shows its arrangement of DOFs: four for each arm, three for its neck, two for each eye, one for each eyelid, and one for its waist.

Each joint angle and its velocity are determined with the below procedure. First, position $(r \,|\, 0 \leq r \leq 1, \theta | \, 0 \leq \theta \leq 2\pi)$ on the circumplex model space is determined corresponding to the desired impression. This method modifies the original motions. Here, we assume that an original motion is described with joint angle positions $\mathbf{P^t} = \{P_1^t, \cdots, P_i^t, \cdots, P_m^t\}$ $(t = \{t_1, \cdots, t_k, \cdots, t_n\}, t_{i+1} = t_i + \Delta t_i)$ and transition time $(\Delta t = \{\Delta t_0, \cdots, \Delta t_j, \cdots, \Delta t_{n-1}\})$. n indicates the numbers of the poses whose original motion is composed and m indicates the numbers of joints. The modified motion is described with each joint angle position $\mathbf{P^t}' = \{P_1^t{}', \cdots, P_i^t{}', \cdots, P_m^t{}'\}$ and transition times $\Delta t' = \{\Delta t'_0, \cdots, \Delta t'_j, \cdots, \Delta t'_{n-1}\}$. $\mathbf{P^t}'$ and $\Delta t'$ are determined by the following equations:

$$
\begin{aligned}
\sigma &= a \cdot Ar(r,\theta) \\
\Delta t'_i &= \Delta t_i \cdot (1 - b \cdot Ar(r,\theta)) \\
P_i^{t_{j+1}}{}' &= \begin{cases} P_i^{t_j+\Delta t_j} + \sigma\Psi & (i \neq \{i_p, i_y\}) \\ P_i^{t_j+\Delta t_j} + \sigma\Psi + cR_i Pl(r,\theta) & (i = \{i_p, i_y\}) \end{cases} \\
Pl(r,\theta) &= r \cdot \cos(\theta) \\
Ar(r,\theta) &= r \cdot \sin(\theta)
\end{aligned}
$$

σ shows the displacement distance, Ψ shows a random variable following uniform distribution $U(0,1)$, and Pl, Ar show valence and arousal values from -1 to 1. i_p and i_y show the numbers of the joints of the robot's head pitch and elbow yaw respectively, and R_i is the difference between the maximum and the minimum of each joint angle value. The values of a, b, c are adjustment parameters that should be determined due to the joint axis locations of each robot. Fig.4 shows the examples of the basic posture modified by the above method. The difference in arousal changes both the velocity and extensity from the basic postures.

III. Experiments

A. Purpose

Our motion modification method enables seamless modification of arbitrary motions using two variables: valence and arousal however, the following questions must be confirmed: 1) How well do the parameters control affective nuances? 2) Do the modifications distort the meanings of the original motion? 3) Are the affective nuances identifiable between robots with different appearances? For each question, three experiments were conducted:
Experiment 1: evaluation of affective nuances
Experiment 2: conservation of original motions' meanings
Experiment 3: evaluation of affective nuances with heterogeneous robots
Through these experiments, we clarified the possibilities and limitations of our method.

B. Experiment 1: Evaluation of affective nuances

1) Purpose: The purpose of Experiment 1 is to evaluate the affective nuances expressed by modifying motions. We investigated the effect of the method that indicate the relative changes of the affective nuances from those of the original motions and the relationship between the evaluation results and the affective nuance model.

TABLE I
FACTOR MATRIX (VARIMAX ROTATED)

	Factor		Communality
	I	II	
Likable/Dislikable	**0.868**	0.115	0.77
Fun/Not fun	**0.865**	0.179	0.78
Amusing/Boring	**0.817**	0.333	0.78
Intense/Relaxed	0.081	**0.836**	0.71
Active/Passive	0.179	**0.786**	0.65
Strong/Weak	0.399	**0.739**	0.71

2) Method: [Subjects] The subjects were 24 students and lab members whose ages ranged from 19 to 38. The male/female ratio was 15:9. Their average age was 24.6, and the standard deviation was 5.4.
[Conditions] Robovie-mini R2 (Fig.3) was used in this experiment. The original motion was an idle motion that moves all of the robot's joints at certain speeds, amplitudes, and random directions. This motion did not have any specific meaning, so the effects of the method could be definitely observed. We prepared four types of motions by modifying the original motion with the following parameters:
$((r,\theta) = A(1, \frac{\pi}{4}), B(1, \frac{3\pi}{4}), C(1, \frac{5\pi}{4}), D(1, \frac{7\pi}{4}))$

A is the combination of high arousal and high valence, B is the combination of high arousal and low valence, C is the combination of low arousal and low valence, and D is the combination of low arousal and high valence. Evaluation was conducted under these four conditions.
[Procedure] In the experiments, subjects sat on chairs and faced the robot on a desk at a distance of one meter. The experiment consisted of habituation and evaluation parts. In the habituation part, they watched the original motion that equaled a not-affected motion $((r,\theta) = (0,0))$ for 20 seconds. In this part, they did not evaluate the motion, but merely watched it. In the evaluation part, subjects were presented one of the four types of modified motions (A,B,C, or D) for 15 seconds soon after being shown the original motion for 5 seconds (a total of 20 seconds for each motion). The motions were presented randomly, and the subjects filled out questionnaires after each motion was presented. Showing the original motion is important for the experiment because we wanted subjects to relatively evaluate the stimuli by comparison with the original motion.
[Evaluation] After each motion was presented to the subjects, they evaluated them on a 1-to-5 scale by questionnaire that consisted of the following six pairs of adjectives. The adjectives for valence are: "likable/dislikable," "fun/not fun," and "amusing/boring" The adjectives for arousal are: "intense/relaxed," "active/passive" and "strong/weak." The question: "What do you assume about the robot's feelings?"

3) Results: The six items were subjected to a maximum likelihood factor analysis with a varimax rotation. Two factors were extracted as illustrated in Table I; the cumulative proportion was 73.2% (first factor: 39.5%, second factor: 33.7%). The first factor was called "valence" because the contributing adjectives were "Likable" "Fun" and "Amusing." The second factor was called "arousal" because the

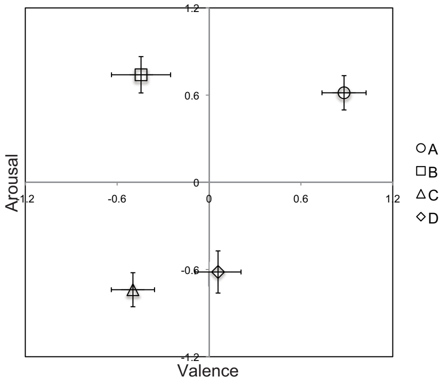


Fig. 5. Average factor scores: error bar: SE

TABLE II
COMPARISON AMONG FOUR CONDITIONS

Motion	FactorI(Valence)
A–B	$p < .01^{**}$
A–C	$p < .01^{**}$
B-D	$p = 0.35$
C–D	$p = 0.03^{*}$
ANOVA Results	$p =< .01^{**}$
$(F(3, 69))$	$F = 18.33$

contributing adjectives were "Intense" "Active" and "Strong."

Fig.5 shows the averages and the standard errors of the valence and arousal scores for each robot. A multiple analysis of variance (MANOVA) was conducted on the factor scores. A significant main effect of valence was found for the valence scores as well as a main effect of arousal for the arousal scores ($F(1, 23) = 40.03$, $p < .01$. $F(1, 23) = 99.59$, $p < .01$). There was no interaction for the arousal scores between valence and arousal, indicating significant differences between AB–CD. However, there was an interaction for the valence scores, so an analysis of variance (ANOVA) was performed to test for differences among the four conditions (A,B,C and D). There was a significant difference ($F(3, 69) = 18.33$, $p < .01$), and the Bonferroni method provided a multiple comparison among A, B, C and D. The result showed significant differences in A–B, A–C, and C–D and no significant difference in B–D(Table II) indicating that the interaction for valence scores was caused by the lack of differences between the score of D and those of B.

4) Summary: The factor analysis result showed that the evaluation scores could be described with two factors (valence and arousal). [A, D]–[B, C] could be distinguished by the valence level and [A, B]–[C, D] could be distinguished by the arousal level so that subject evaluations accord with the affective nuance model. Then the results showed that the evaluations agreed with the model without the valence score in B–D. As a result of the experiment, the settings of the parameters accorded with the affective nuances on the model, and therefore the method can control the expressions in conditions A, B, and C, although the expression of the arousal level was inadequate in the high valence/low arousal condition (D).

(a) Pointing to right (A)

(b) Pointing forward (B)

(c) Waving hand (C)

Fig. 6. Examples of modified motions: Experiment 2

C. Experiment 2

1) Purpose: One of the method's concepts is using existing motions as original motions, so it must be confirmed that after modifying the method, the motions retained the meaning of the original motions. So the purpose of Experiment 2 is to confirm whether the gestures (motions with specific meanings) modified by the method are perceived as having the same meaning as before the modification.

2) Method: [Subjects] The subjects were 20 university students whose ages ranged from 18 to 25. The male/female ratio was 11:9. Their average age was 20.6, and the standard deviation was 1.91.

[Conditions] Three types of gestures were used as original motions: gesture 1: waving hand gesture 2 : pointing to right and gesture 3: pointing forward. Gestures 1, 2, and 3 were modified in the four conditions that were the same as in Experiment 1. The examples of modified motions are shown in Fig.6. Subjects evaluated these twelve kinds of motions.

[Procedure] First, subjects watched a modified motion(test stimuli) on a TV monitor, and four motions were simultaneously displayed as possible answers.

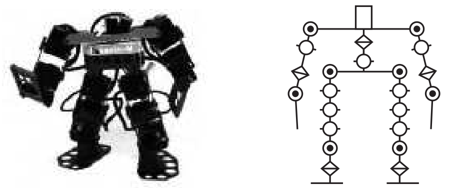
[Evaluation] Subjects answered this question: "Which gesture is identical to the first one?" They either selected an answer from the four motions displayed after the test stimuli or "not applicable." The four motions were the three original motions (gesture 1, 2, and 3) and a shaking head gesture as a dummy. The dummy gesture was a marker to indicate whether the subjects were concentrating on the experiment.

3) Results: Table III shows the accuracy rate of each gesture. The accuracy rate average of 89.6% shows that

TABLE III

ACCURACY RATE: EXPERIMENT 2

	Waving hand				Pointing to right				Pointing forward			
	A	B	C	D	A	B	C	D	A	B	C	D
correct	17	14	16	20	19	18	18	19	17	18	19	20
incorrect	2	0	0	0	0	1	0	0	0	0	0	0
not applicable	1	6	4	0	1	1	2	1	3	2	1	0
accuracy rate	0.85	0.70	0.80	1.00	0.95	0.90	0.90	0.95	0.85	0.90	0.95	1.00
(average)	(0.84)				(0.93)				(0.93)			



(a) Overview (b) Link mechanisms

Fig. 7. Biped humanoid robot: Robovie-M

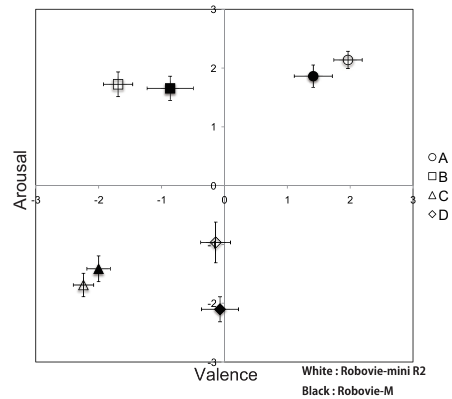


Fig. 8. Evaluation scores: error bar:SE

subjects could choose the correct answers for almost all gestures. There was no significant difference among the three types of gestures ($F(2, 6) = 2.33$, $p = 0.17$), or also among the four conditions($F(3, 6) = 2.71$, $p = 0.13$).

D. Experiment 3

1) Purpose: In Experiment 1, only one type of robot Robovie-mini R2 was used. But in this experiment, we used two types of humanoid robots with different appearances to confirm whether the expressions were properly evaluated. We used "waving hand" as an original motion because the evaluation of a modified "waving hand" motion might be difficult for subjects since the motion has such specific meanings, as "Hello" or "I'm here," unlike the original motion used in Experiment 1. We intended to apply the method to various motions, so we chose it as a severe condition.

2) Robot: We use two types of robots: Robovie-mini R2 and Robovie-M (Fig.7). Robovie-M is our biped humanoid robot developed by ATR that has four DOFs for each arm and two DOFs for its waist and chest. This robot does not have any DOFs for its neck, so the waist and chest work as alternative axes to the neck.

3) Method: [Subjects] The subjects were 30 university students whose ages ranged from 18 to 25. The male/female ratio was 14:16. Their average age was 20.4, and the standard deviation was 1.82.

[Condition] In this experiment, "waving hand" was used as an original motion for two types of humanoid robots: Robovie-mini R2 and Robovie-M. Evaluations were conducted with four conditions for each robot. The conditions were the same as in Experiment 1.

[Evaluation] The question was: "What do you assume about the robot's feelings?" In this experiment for the evaluations, we used Self-Assessment Manikin (SAM)[1] which is an evaluation method that simply measures valence, arousal and dominance using pictograms; we used the valence and arousal parts.

4) Results: Fig.8 shows the averages and the standard errors of the valence and arousal scores for each robot. The scores range from -3 to 3 on a 7-point scale.

A MANOVA was conducted on the valence and arousal scores. There were no significant main effects of the robot factor for the valence score ($F(1, 28) = 0.80$, $p = 0.38$) and marginally significant main effects for the arousal score ($F(1, 28) = 3.69$, $p = .07$). There was an interaction for the arousal scores between the robot and the valence($F(1, 28) = 11.67$, $p < .01$). An ANOVA was conducted on the arousal scores of all conditions, and a significant difference was found in the D(high valence / low arousal) condition ($F(1, 29) = 11.59$, $p < .01$).

Similar to the results of Experiment 1, there was a significant main effect of valence for the valence scores ($F(1, 28) = 165.60$, $p < .01$) and of arousal for the arousal scores ($F(1, 28) = 545.89$, $p < .01$), and there was an interaction for the valence scores between the valence and arousal levels($F(1, 28) = 8.43$, $p < .01$). An ANOVA was performed to test for differences in the four conditions (A, B, C and D). A significant difference was found, and the Bonferroni method provided a multiple comparison among A, B, C and D. The result showed significant differences with Robovie-mini R2 in A–B, A–C, C–D, and B–D at the valence levels. With Robovie-M, there were significant differences in A–B, A–C and C–D, and no significant difference in B–D ($p = .72$).

5) Summary: The result shows that the difference between robots did not affect user evaluations. An interaction was found for the arousal score, and there were no significant differences among A, B, and C. So, the interaction was caused by the difference between the robots in D.

IV. Discussion

The experiment results suggest the following conclusions:

1) The results of Experiment 1 showed that affective nuances can be controlled by our method, although the expression of the arousal level was inadequate in the high valence/low arousal condition (D).
2) In Experiment 2, modification did not distort the meaning of the original motion.
3) In Experiment 3, the subjects evaluated the motions modified from the original "waving hand" motion with two robots that have different appearances. The evaluation result resembled Experiment 1, even though the appearances were different.

In Experiments 1 and 3, our method failed to express the affection in the fourth quadrant (high valence / low arousal combination) because no category is applicable to the fourth quadrant when the principle emotional categories (for example, Ekman's six emotions) are arranged in a two-dimensional model. Therefore, the expressions of emotions in the domain were not treated in the studies of robot's expressions using categorical models. This means that the state may not be clearly represented in expressions although a state of high valence / low arousal does exist.

In Experiment 2, the method did not distort the meaning of the original motion, but the accuracy rate of "waving hand" was relatively low (83.8%), especially in the low valence / high arousal condition (70.0%). The subjects might have interpreted the motion as "brushing off" instead of "waving hand angrily" because the combination of "angry" and "waving hand" was unnatural. "Waving hand" is usually used in friendly situations and almost never in anger. The experiment was conducted under a condition without context or interaction, so such misunderstandings might be resolved in specific situations. Our next goal is to induce humans to an intended reaction by affective motions, so we need detailed investigation under specific situations.

V. Conclusion

We proposed a motion modifying method for controlling the affective nuances of communication robots. The target expression was treated as a two-dimensional space that consisted of valence and arousal. Our method modified an original motion with three parameters: velocity, extensity of motion, and a basic posture. We confirmed that our proposed method could modify the original motion for expressing affective nuances that correspond to three combinations: high valence / high arousal, low valence / high arousal, and low valence / low arousal. We also confirmed that the modification retains the original motion's meaning and that we can apply it to humanoid robots with different appearances, although the method remains inadequate to express the high valence / low arousal combination.

Our research aims to realize human–robot communication that induces users to intended reactions by expressing affective states. In this paper, we proposed a modification method to control the affective nuances as the basis for the expressions of affective states. Robot expressions of affective states can affect human affective states and subsequent behavior, and such effects are expected to be applied to various contexts. Since these experiments were conducted without contexts or interactions, future work will consider specific behavior that effectively induces the intended context by expressions in interactive situations. Our method can gradually change the affective nuances, and the transitions of affects might be more effective to such induction than merely expressing an specific affect. Additionally, because not only motions but also verbal communication are necessary for service robots, the designs of multimodal expressions must be considered using motions and voices.

VI. ACKNOWLEDGMENTS

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