Discrimination and Implementation of Emotions on Zoomorphic Robot Movements

Takafumi Matsumaru *

Abstract: This paper discusses discrimination and implementation of emotions on a zoomorphic robot aiming at designing emotional robot movements and improving robot friendliness. We consider four emotions; joy, anger, sadness, and fear. Two opposite viewpoints, performer and observer, are considered to acquire emotional movement data for analysis. The performer subjects produce emotional movements and movements that are easy to be recognized as expressions of the intended emotion are selected among the measured movements by the observer subjects. Discriminating the emotion embedded in a movement is tried using feature values based on the Laban movement analysis (LMA) and the principal component analysis (PCA). By the discrimination using PCA, the resultant rates of the correct discrimination are about 70% for all four emotions. The features of emotional movements are presumed from the coefficients of the discrimination function obtained in the emotion discrimination using PCA. Emotions are implemented by converting a setup for basic movements by employing the design principle based on the movement features. The result of the verification experiment suggests that four emotional movements are divided into two groups; the joy and anger group and the sadness and fear group. The emotional movements of joy or anger are dynamic, large-scale and frequent being relatively easy to interpret the intended emotion, while the emotional movements of sadness or fear are static, small-scale and little making difficult to understand the feature of movements.

Key Words: emotional movement, discrimination, implementation, friendliness, zoomorphic robot.

1. Introduction

This paper discusses discrimination and implementation of emotions on a zoomorphic robot aiming at designing emotional robot movements and improving robot friendliness since non-verbal communication is effective on human-robot social interactions [1]–[5].

Living creatures’ appearance models are usually used so that artificial objects can work on people physically, informatively, and emotionally like a robot partner and a robot pet. An artificial object can express its fictitious emotion and feeling by not only the static appearance but also the dynamic behavior, so we would like to make robots more friendly and familiar for users by emotional movements.

This paper is organized as follows: Section 2 surveys conventional works and explains our approach. Section 3 shows movement data acquisition for analysis. Sections 4 and 5 explain emotion discrimination using the Laban movement analysis and the principal component analysis. Section 6 discusses the feature extraction and its application. Section 7 presents conclusions.

2. Conventional Works and Our Approach

2.1 Conventional Works

Emotion has been a research subject in psychological and philosophical field, however recently, engineering approach becomes popular, e.g., human emotion discrimination based on facial expression [6]–[9], speech [10]–[13], both [14],[15], and face and/or speech and gesture [16]–[19]. Recognizing emotion only from gesture and/or body movement is also studied [20]–[24].

There are several researches on relation between artificial object’s bodily movement and user’s impression. Threat and biomorphic appearance of industrial robot are evaluated considering its speed, acceleration and distance to users [25],[26]. Physical feature of artificial object’s movement with user impression is examined on a dancing robot [27]–[29], a Bunraku puppet [30], and a mobile robot [31]. In [29], a set of physical feature values based on Laban movement analysis (LMA) [32]–[34] is proposed to evaluate and forecast user impressions produced by body expression. User impression of a dancing robot is analyzed and validity of the value set is verified.

Emotion implementation is studied mostly on speech synthesis [35]–[38] and robot face [39]–[41], but seldom on movement. This study aims at not operation of robot or agent based on emotion model [42],[43] but emotion implementation in operations [44],[45].

2.2 Our Approach

Two opposite viewpoints, performer and observer, are considered to acquire emotional movement data for analysis. Performer embeds emotion in movement, i.e., a subject produces emotional movements on a zoomorphic robot. Observer interprets emotion from movement, i.e., other subject observes the movement measured so that the movement easy to be recognized as expressing the intended emotion is selected.

The goal of this study is to establish a general technique to implement various emotions on general movement, and we take following steps as a preliminary study. Movement data is mea-
3. Emotional Movement Data

3.1 Emotion

We consider four emotions – joy (J), anger (A), sadness (S) and fear (F) – symmetrically arranged in the circumflex model of emotions by R. Plutchik [46],[47]. Human emotion is said to be a deviation and/or combination of several basic emotions, however, basic emotions are not completely determined even among psychologists.

3.2 Zoomorphic Robot

A zoomorphic robot, IP Robot PHONE (IPRP) by Iwaya Co. (Fig. 1) [48], is used. IPRP has three links, right arm, left arm, and head connected to its body at a joint with two degree-of-freedom (DOF) respectively, and IPRP has totally six axes (Table 1). Six-axis movement can be recorded while back-driven manually and reproduced as driven by electric motors.

3.3 Data Measurement

We have a subject create ten-second IPRP movement showing IPRP emotional state by operating three links by his/her hands. Movement is recorded firstly on both arms and secondly on head, and the recorded movement of three links is simultaneously shown to the subject. Recording and showing are repeated until the subject is satisfied on the movement. IPRP acquires six-axis angle data every five milliseconds, and 12,000 angle data is recorded at six axes on a ten-second movement. Fifty subjects attended the measurement (Table 2).

3.4 Data Selection

Emotion embedded in a movement is discriminated using feature values, so the movement data by fifty subjects is selected to raise discrimination accuracy based on experimental observation. We had three subjects, other than previous subjects, observe two hundred IPRP movements in random order and reply the emotion which the movement expresses. Movements from which two or more subjects correctly understand the intended emotion are selected. 36 data on joy, 28 data on anger, 27 data on sadness, and 26 data on fear are remained and those are used in the emotion discrimination.

4. Emotion Discrimination Using Feature Values Based on LMA

This section shows the result of a trial to discriminate emotion embedded in a movement using feature values based on Laban movement analysis (LMA) by reference to [29]. Emotion discrimination using these feature values is examined in two ways, using deviation score and using discrimination analysis.

4.1 Feature Values Based on LMA

LMA, widely used for human movement analysis, draws on R. Laban’s theories of effort and shape to describe, interpret and document human movements. Effort means dynamic feature of operation, i.e. quality of movement, and it is formulated according to IPRP mechanism [49]. Shape means geometric feature of overall body configuration, and we use two-dimension shape as [29] considering not only spread but also deviation [50].

4.1.1 Weight effort

Weight effort (WE), originally meaning the forcibleness degree of body movement, is formulated as a square sum of joint angular velocity assuming weighted summation of motion energy of links per unit time. Weight M is defined as $M_{\text{right}} = M_{\text{left}} = 1$ and $M_{\text{head}} = 3$ considering apparent mass and attention to each link.

$$WE = \frac{1}{N} \sum (M_{\text{right}} \theta_{\text{right}}^2 + M_{\text{left}} \theta_{\text{left}}^2 + M_{\text{head}} \theta_{\text{head}}^2)$$ (1)

4.1.2 Time effort

Time effort (TE), originally meaning the bustle degree of movement modification, is formulated as a summation of joint angular velocity of all links.

$$TE = \frac{1}{N} \sum (|\theta_{\text{right}}| + |\theta_{\text{left}}| + |\theta_{\text{head}}|)$$ (2)

4.1.3 Space effort

Space effort (SE), originally meaning the directional deviation degree of body movement, is formulated as a summation of angle among three links considering coincidence degree of link direction.

$$SE = \frac{1}{N} \sum (\theta_{\text{right}} + \theta_{\text{left}} + \theta_{\text{head}})$$ (3)

4.1.4 Positional deflection

Positional deflection (PD) shows the eccentricity degree of tips from body center. PDx in front-back direction (x direction) is formulated as below in coordinates with their origin at body center. PDy in right-left direction (y direction) and PDz in up-down direction (z direction) are formulated similarly.

Table 1 IPRP specifications.

<table>
<thead>
<tr>
<th>Joint</th>
<th>Angle deg</th>
</tr>
</thead>
</table>
| Head  | HP: -50 ~ +40 (90)
|       | HY: -80 ~ +60 (140) |
| Right arm | RP: -15 ~ +195 (210)
|         | Ry: -80 ~ +60 (140) |
| Left arm | LP: -15 ~ +195 (210)
|        | Ly: -80 ~ +60 (140) |

Table 2 Subject.

<table>
<thead>
<tr>
<th>Age</th>
<th>10–19</th>
<th>20–29</th>
<th>30–39</th>
<th>40–49</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>4</td>
<td>34</td>
<td>0</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>Female</td>
<td>2</td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>total</td>
<td>6</td>
<td>41</td>
<td>3</td>
<td>3</td>
<td>50</td>
</tr>
</tbody>
</table>
4.1.5 Distance between parts

Distance between parts (DP) shows the spatial spread of tips. \( DP_{xy} \) on horizontal plane (xy plane) is formulated as below by regarding it as a perimeter of triangle formed by tips projected on horizontal plane. \( DP_{yz} \) on vertical plane (yz plane) and \( DP_{zx} \) on sagittal plane (z-plane) are formulated similarly.

\[
DP_{xy} = \frac{1}{N} \sum (PD_{xright} + PD_{xleft} + PD_{xhead})
\]

\[
DP_{xy} = \frac{1}{N} \sum (DP_{xy_{left}} + DP_{xy_{right}} + DP_{xy_{head}})
\]

4.2 Emotion Discrimination Using Deviation Score

Data location in distribution is expressed using deviation score (DS) when a data set maintains normal distribution. Data of all feature values about four emotions, we obtained the distribution center. The deviation scores about four emotions are usually set at fifty, but we set the score at zero meaning that, when the deviation score is small, it locates closer to the distribution center. The deviation scores for each emotion are calculated on a movement data, and the emotion with lowest deviation score is supposed to be expressed in the movement.

When a data is located at distribution center, the deviation score \( \bar{x} \) is used as an estimate value of unknown average vector, and \( S \) is used as an estimate value of variance-covariance vector \( \Sigma \).

\[
\bar{x} = [\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_g]
\]

\[
S = \frac{1}{n-g} \sum_{i=1}^{g} (n_i - 1)S_j
\]

In this discrimination, the values selected as \( F > 2.0 \) by the forward selection method – \( WE, TE, PD \) (xy and z directions), and \( DP \) (xy, yz, and zx planes) – are used.

The result is shown in Table 4 in which high rate of correct discrimination is obtained – about 60% at anger and about 70% at other emotions. This result shows that emotional movement can be correctly discriminated with more than 60% by using discrimination analysis.

4.3 Emotion Discrimination Using Discrimination Analysis

Discrimination analysis (DA) is a technique to acquire the discrimination function to distinguish the group to which a new data belongs when some data given in advance is clearly divided into several groups. A new data \( x = [x_1, x_2, \ldots, x_g] \) is placed in a group of which the Mahalanobis distance \( d_i \) \((i = 1, 2, \ldots, g)\) [52] from the center of gravity is the minimum, where \( \mu = [\mu_1, \mu_2, \ldots, \mu_g] \) is an average vector of parent population.

\[
d_i^2 = (x - \mu)^T \Sigma^{-1} (x - \mu)
\]

In practice, \( \bar{x} \) is used as an estimate value of unknown average vector, and \( S \) is used as an estimate value of variance-covariance vector \( \Sigma \).

\[
\bar{x} = [\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_g]
\]

\[
S = \frac{1}{n-g} \sum_{i=1}^{g} (n_i - 1)S_j
\]

In this discrimination, the values selected as \( F > 2.0 \) by the forward selection method – \( W_E, T_E, P_D \) (xy and z directions), and \( D_P \) (xy, yz, and zx planes) – are used.

The result is shown in Table 4 in which high rate of correct discrimination is obtained – about 60% at anger and about 70% at other emotions. This result shows that emotional movement can be correctly discriminated with more than 60% by using discrimination analysis.

4.4 Remarks on Emotion Discrimination

Remarks on emotion discrimination using feature values based on LMA is made from the trial. Joy movement frequently has up and down motion of both arms simultaneously like banzai. Anger movement is wrongly discriminated compared with other emotional movements because anger movement is highly individual, so we may introduce new feature value to discriminate more correctly. Most of sadness and fear movements are small and those are sometimes confused each other, so it is difficult to distinguish them correctly and we should try to use a robot with more DOFs.

5. Emotion Discrimination Using Principal Component Analysis

This section shows the result of a trial in which feature values are extracted using principal component analysis (PCA) [53] and an emotion embedded in a movement is discriminated using linear discrimination analysis (LDA) [54].
5.1 Dimension Reduction
Dimension reduction [55] is introduced because the measured data is time-series of six axes and the amount of calculation and the number of items to examine increase when comparing in every axis. When the dimension is reduced, the calculation becomes simple, the movement feature distributed on each axis is aggregated, and the feature extraction becomes easy. We use PCA for dimension reduction.

PCA is one of the multi-variable analysis which aggregates data from high-order to low-order without losing information as much as possible. Specifically, a new variable is set as linear combination of original variables in such a way that the distribution might be the maximum. PCA is originally used for multi-variable analysis, but it is applicable to time-series multi-variable data. First principal component is expressed as follows, where $X = [x_1, x_2, ..., x_p]$ is an observation value and $a$ is the maximum eigenvector of variance-covariance matrix of $X$.

$$Y = a'X$$

(10)

Only the first principal component is used for analysis because the purpose of applying PCA is dimension reduction. Significance of principal component does not matter due to the same reason.

5.2 Variables for Discrimination
The movement data is individually examined to develop guidelines to perform PCA and it is found that the first principal component is classified as below (Fig. 3):

- Type-1: cyclic, high frequency (> 0.3Hz), large amplitude
- Type-2: cyclic, high frequency, small amplitude
- Type-3: cyclic, low frequency (< 0.3Hz)
- Type-4: almost constant
- Type-5: no recognizable pattern

Many movement data indicates cyclic variation of the first principal component as type-1, -2, and -3 in Table 5 which shows the rate of type of all movement data at each emotion, so it is found that frequency analysis could be used for emotion discrimination. There are many type-1 movement at joy and anger while sadness and fear movements are fewer in type-1 and more in type-2, -3, and -4, so the amplitude should also be used as a feature value.

According to the result of fast Fourier transform (FFT), frequency components of the first principal component are lower than 3Hz in general as shown in Fig. 4, so we set the components from 0Hz to 3.0Hz in every 0.1Hz as feature value candidates for emotion discrimination. Variables for discrimination are selected so as to $F > 2.0$ by the forward selection method from 32 candidates – 31 frequency elements of the first principal component from 0Hz to 3.0Hz and the total amplitude as maximum-minimum difference. Variables definitely selected are following ten units – the frequency elements of 0.0, 0.1, 0.2, 0.3, 0.6, 0.8, 1.2, 1.3 and 3.0Hz and the amplitude.

5.3 Emotion Discrimination
LDA is applied as well as the emotion discrimination using feature values based on LMA in 4.3. The discrimination belonging to the group from which the Mahalanobis distance $d_i$ is the minimum means the same as the discrimination belonging to the group in which the linear function $u_i(i = 1, 2, ..., g)$ is the maximum.

$$u_i = x'S^{-1}x_i - \frac{1}{2}x_i'S^{-1}x_i$$

(11)

Probability that an observed value is belong to a group $i$ can be calculated from the upper probability of Mahalanobis distance $d_i$, because Mahalanobis distance has a chi-square distribution of degree-of-freedom $p$ (number of independent variables, 10).

The result of emotion discrimination is shown in Table 6. Compared with the result by distinction analysis using feature
Table 6 Discrimination result using principal component analysis.

<table>
<thead>
<tr>
<th>Intended emotion</th>
<th>Discriminated emotion</th>
<th>Number of data</th>
<th>Rate of correct discrimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joy</td>
<td>J A S F</td>
<td>36</td>
<td>72.2%</td>
</tr>
<tr>
<td>Anger</td>
<td>5 19 2 2</td>
<td>28</td>
<td>67.9%</td>
</tr>
<tr>
<td>Sadness</td>
<td>0 0 19 8</td>
<td>27</td>
<td>70.4%</td>
</tr>
<tr>
<td>Fear</td>
<td>2 1 5 18</td>
<td>26</td>
<td>69.2%</td>
</tr>
</tbody>
</table>

Table 7 Coefficients of linear discrimination function.

<table>
<thead>
<tr>
<th>Emotional movement</th>
<th>Joy</th>
<th>Anger</th>
<th>Sadness</th>
<th>Fear</th>
</tr>
</thead>
<tbody>
<tr>
<td>max-min</td>
<td>1.1E-01</td>
<td>1.4E-01</td>
<td>4.0E-02</td>
<td>6.0E-02</td>
</tr>
<tr>
<td>0Hz</td>
<td>-1.1E-02</td>
<td>-6.0E-02</td>
<td>-2.2E-02</td>
<td>-4.1E-03</td>
</tr>
<tr>
<td>0.1Hz</td>
<td>-1.2E-04</td>
<td>-1.4E-04</td>
<td>-9.1E-06</td>
<td>-4.5E-05</td>
</tr>
<tr>
<td>0.2Hz</td>
<td>-7.8E-05</td>
<td>-1.7E-07</td>
<td>1.3E-04</td>
<td>-3.6E-05</td>
</tr>
<tr>
<td>0.3Hz</td>
<td>8.1E-05</td>
<td>-3.9E-06</td>
<td>-4.9E-05</td>
<td>9.1E-05</td>
</tr>
<tr>
<td>0.6Hz</td>
<td>9.2E-05</td>
<td>-1.7E-05</td>
<td>6.9E-06</td>
<td>-7.5E-06</td>
</tr>
<tr>
<td>0.8Hz</td>
<td>9.7E-05</td>
<td>-6.8E-05</td>
<td>3.8E-06</td>
<td>1.2E-05</td>
</tr>
<tr>
<td>1.2Hz</td>
<td>2.1E-04</td>
<td>3.3E-05</td>
<td>2.6E-05</td>
<td>3.2E-05</td>
</tr>
<tr>
<td>1.3Hz</td>
<td>1.2E-04</td>
<td>2.7E-04</td>
<td>6.5E-05</td>
<td>8.5E-05</td>
</tr>
<tr>
<td>3.0Hz</td>
<td>-1.2E-03</td>
<td>1.6E-03</td>
<td>3.7E-04</td>
<td>1.1E-04</td>
</tr>
<tr>
<td>const</td>
<td>-8.6</td>
<td>-8.8</td>
<td>-2.0</td>
<td>-2.6</td>
</tr>
</tbody>
</table>

values based on LMA (Table 4), better results are obtained except that it is slightly worse at fear, and about 70% of correct discrimination is obtained at all four emotions.

6. Feature Extraction and Its Application
6.1 Feature Extraction from Discrimination Function

The coefficients of variables of the linear discrimination function obtained in the emotion discrimination using PCA are shown in Table 7 in which we can find that principal component of movement data expressing each emotion has the following features:

**Feature of principal component**
- Joy: large amplitude, many 1.2 and 1.3Hz elements
- Anger: large amplitude, many 1.3 and 3.0Hz elements
- Sadness: small amplitude, many 0.2 and 3.0Hz elements
- Fear: small amplitude, many 0.3 and 3.0Hz elements

These features of principal component of movement data aggregated from six-axis angle data may be applicable to both the original movement in each axis and the full-body movement:

**Feature of movement**
- Joy: large-scale and a little fast
- Anger: large-scale and fast
- Sadness: small-scale and slow
- Fear: small-scale and a little slow

We design emotional movement based on these features.

6.2 Emotional Movement Designing

Emotion is implemented by converting a setup basic movement employing the design principle based on the movement features:

- **Design principle**
  - Movement amplitude: anger ≥ joy ≥ fear ≥ sadness
  - Movement speed: angry > joy ≥ fear ≥ sadness
  - Standard position: It is decided referencing the movement in which emotion is correctly discriminated.

Four types of emotional movement are produced from a simple basic movement applying the design principle.

**Movement produced**
- Basic movement: Both arms move up and down, and its head shakes from side to side.
- Joy movement: Both arms move widely at almost the same speed as the basic movement. Standard position of arms and head is a little upward.
- Anger movement: Both arms and head move widely and very quickly. Standard position of arms and head is a little upward.
- Sadness movement: Both arms and head move slightly and slowly. Standard position of arms and head is downward.
- Fear movement: Both arms and head move slightly and a little slowly. Standard position of arms and head is downward.

6.3 Verification Experiment

Whether an observer can interpret intended emotion from produced movement is verified.

6.3.1 Procedure

Eight kinds of ten-second movement, two kinds at four emotions, are produced to implement an emotion to basic movement (Table 8). One for each emotion (odd number) has high probability of expressing the intended emotion and the probability is greatly different from that of other emotion. The other (even number) has relatively low probability of expressing the intended emotion and the probability is slightly different from that of other emotion. The basic movement and four emotional movements produced are shown in Fig. 5 as still pictures at regular intervals. Probabilities of expressing a specified emotion shown in Table 8 are computed from the Mahalanobis distance from the center of gravity of the movement data group acquired for the emotion as explained in 5.3. The computed probability varies significantly with delicate difference of movement, and it takes a lot of trial and error to produce a movement with intended probability. We had subjects observe the eight movements in random order and reply the emotion interpreted from the movement – joy, anger, sadness, fear, or no idea.

6.3.2 Result

The result by fifteen subjects is shown in Table 9.

- Joy movement: Percentage of correct answers is high in both movements.
- Anger movement: Percentage of correct answers is high in the movement with high anger probability, but that is low with low probability confusing with joy.
Table 8 Movement produced.

<table>
<thead>
<tr>
<th>Movement data number</th>
<th>Intended emotion</th>
<th>Probability of expressing emotion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>J</td>
</tr>
<tr>
<td>1</td>
<td>Joy</td>
<td>98.0%</td>
</tr>
<tr>
<td>2</td>
<td>Joy</td>
<td>38.9%</td>
</tr>
<tr>
<td>3</td>
<td>Anger</td>
<td>18.4%</td>
</tr>
<tr>
<td>4</td>
<td>Anger</td>
<td>31.9%</td>
</tr>
<tr>
<td>5</td>
<td>Sadness</td>
<td>15.8%</td>
</tr>
<tr>
<td>6</td>
<td>Sadness</td>
<td>0.4%</td>
</tr>
<tr>
<td>7</td>
<td>Fear</td>
<td>25.2%</td>
</tr>
<tr>
<td>8</td>
<td>Fear</td>
<td>31.0%</td>
</tr>
</tbody>
</table>

Table 9 Experimental result.

<table>
<thead>
<tr>
<th>Movement data number</th>
<th>Intended emotion</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>J A S F no-idea</td>
</tr>
<tr>
<td>1</td>
<td>Joy</td>
<td>15 0 0 0 0</td>
</tr>
<tr>
<td>2</td>
<td>Joy</td>
<td>14 0 0 0 1</td>
</tr>
<tr>
<td>3</td>
<td>Anger</td>
<td>0 14 0 1 0</td>
</tr>
<tr>
<td>4</td>
<td>Anger</td>
<td>11 3 0 1 0</td>
</tr>
<tr>
<td>5</td>
<td>Sadness</td>
<td>0 0 7 7 1</td>
</tr>
<tr>
<td>6</td>
<td>Sadness</td>
<td>0 0 9 6 0</td>
</tr>
<tr>
<td>7</td>
<td>Fear</td>
<td>1 7 2 4 1</td>
</tr>
<tr>
<td>8</td>
<td>Fear</td>
<td>0 0 7 6 2</td>
</tr>
</tbody>
</table>

- Sadness movement: Percentage of correct answers is low in both movements confusing with fear.
- Fear movement: Percentage of correct answers is low in both movements, i.e., the movement with high fear probability is usually confused with anger and that with low is confused with sadness.

6.3.3 Discussion

Four emotional movements are divided into two groups, the joy and anger group and the sadness and fear group, and the percentage of correct answers at two groups is greatly different especially in the movement with both high probability of expressing the intended emotion and greatly-different probability of expressing other emotions. The emotional movement of joy or anger is dynamic, large-scale and frequent while that of sadness or fear is static, small-scale and little making difficult to understand the feature of movement.

Produced movement with many erroneous answers usually has small difference between the highest and the second probabilities of expressing emotion as no. 5 and 7 in Table 9. Therefore, to make the percentage of correct answers high, we should not only produce a movement with high probability of expressing the intended emotion but also make the probability different from other emotions. At sadness and fear, however, it is difficult to produce a movement with great different probability from others.

7. Conclusion

This paper discussed discrimination and implementation of emotions on a zoomorphic robot aiming at designing emotional robot movements and improving robot friendliness. We considered four emotions; joy, anger, sadness, and fear. Two opposite viewpoints, performer and observer, were considered to acquire emotional movement data for analysis. The performer subjects produce emotional movements and movements that are easy to be recognized as expressions of the intended emotion are selected among the measured movements by the observer subjects. Discriminating the emotion embedded in a movement was tried using feature values based on the Laban movement analysis (LMA) and the principal component analysis (PCA). By the discrimination using PCA, the resultant rates of the correct discrimination were about 70% for all four emotions. The features of emotional movements were presumed from the coefficients of the discrimination function obtained in the emotion discrimination using PCA. Emotions were implemented by converting a setup for basic movements by employing the design principle based on the movement features. The result of the verification experiment suggested that four emotional move-
ments are divided into two groups; the joy and anger group and the sadness and fear group. The emotional movements of joy or anger were dynamic, large-scale and frequent being relatively easy to interpret the intended emotions, while the emotional movements of sadness or fear were static, small-scale and little making difficult to understand the features of movements.

The following are issues to be solved: (a) We should improve the accuracy of discriminating emotions embedded in a movement by, for example, referring to body parts and feature values on which people usually pay attention. (b) Although emotional movements are produced by a trial and error in the verification experiment, we should examine the technique to generate emotional movements from a certain movement automatically. (c) It is necessary to verify whether the proposed technique is applicable to other robots and various movements, or we have to improve and establish more general techniques extendable to various operations and systems.

We should consider the combination of a bodily movement with a facial expression, an audio information, and others, because it is difficult even for people to discriminate an emotion only from the movement and people feel discomfort from zoomorphic and humanoid robots without a facial expression. We would like to reveal information other than emotions which can be acquired from a movement and develop a technique to design movements including such information with practical applications.

Acknowledgments

Gratitude is expressed to laboratory members with self-sacrificing dedications, especially to Mr. Shigehisa Suzuki (now, at Sumitomo Metal Industries, Ltd.) and Mr. Shoya Tano (now, at Mitsubishi Motors Corp.) who greatly contributed especially on the measurement and analysis of the movement data.

References

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