# Factors of Gestures of Robots for Smooth Communication with Humans

Hisayuki Narahara
School of Integrated Design Engineering
Keio University ,Yokohama, JAPAN
Email: narahara@a8.keio.jp

Takashi Maeno
Department of Mechanical Engineering
Keio University ,Yokohama, JAPAN
Telephone: +81-45-566-1516
Email: maeno@mech.keio.jp

***Abstract*—Four steps of research are conducted in order to analyze a relationship between robot's actions and human's emotions who is taking a look at an acting robot. First, 138 physical properties of robot's movements are measured by using a simple humanoid robot with upper half of the body with three degrees of freedom (DOF) in each arm and three DOF in head. Second, from the 138 physical properties, ten typical physical properties are selected by use of hierarchical cluster analysis. Third, sensory evaluation is conducted to extract three emotional factors by use of factor analysis. Finally, the relationship between three emotional factors and ten typical physical properties are analyzed by use of multi regression analysis. By conducting those steps, a model is made explaining the relationship between the physical properties of gesture and the human's emotions. This model is expected to be used to generate gestures that can give rise to desired emotions of humans.**

## I. INTRODUCTION

In old days, robots have been used only for manufacturing. However, in recent days, they are used for various purposes. For example, robots are used for entertaining people, for treating people having mental illness and for helping education of infants. In those fields, robots are expected to be able to communicate with humans smoothly. For smooth communication between robots and humans, it is said that robots have to have an ability to express their emotions in the way human can feel expressed emotions correctly [1]. However, gestures of recently developed robots are not designed so as to give rise to human's emotions correctly. Therefore, emotions designers expect robots to give human and the emotions human feels by robot's actions are not quite the same. It makes it difficult a smooth communication between robots and humans. To realize a smooth communication between robots and humans, it is necessary to establish a method of designing robots that give rise to human expected emotions by their actions. To establish the method, first, we should analyze the relationship between robot's actions and human's emotions. It is difficult to analyze the relationship between robot's actions and human's emotion because there are tremendous numbers of robot's actions, verbalization, movement and pause. In those actions, we assume that movement is the most important way to express emotions. Because, movement such as gesture is the most primitive way to express emotions which humans conduct from infant stage [2].

There are several previous studies analyzing the relationship between robot's movements and human's emotion. Nakata [3] analyzed a relationship between robot's movements and human's emotions. Analyzing these relationship, first, he measured robot's movements with some physical properties based on Laban System. Then, he analyzed the relationship between physical properties of robot's movements and human's emotions by use of factor analysis. In his result, relationship between the physical properties of robot's movements and the human's emotions is shown. However, his research is obscure in some respects. One is that he decided human's basic emotions subjectively. He only selected human's basic emotions of joy, surprise, sad and anger. However, it is not covering all the emotions of human's. Another problem is that he decided to measure robot's movements by six physical properties that were defined by Laban System. Measuring robot's movement by only six physical properties is not enough.

To establish a method of designing robots that give human proper emotions by their movements, the quantitative relationship between physical properties of robot's movements and human's emotions should be clarified. In the present study, we analyze a relationship between robot's movements and human's emotions quantitatively. First, physical properties of robot's movements are measured by using a simple humanoid robot having upper half of the body with movement of three DOF in each hand and three DOF in head. Second, over one hundred physical properties of the robot are measured. From the result, ten typical physical properties are selected by use of hierarchical cluster analysis. Third, sensory evaluation is conducted to extract emotional factors by use of factor analysis. Finally, the relationship between the emotional factors and the physical properties are analyzed by use of multi regression analysis. By conducting those steps, a model is made that can explain the relationship between the physical properties of gesture and the human emotions.

## II. METHODS OF ANALYSIS

We describe a concrete methods to quantify the relationship between the robot's gestures and the human's emotions below. In order to understand the human's recognition, semantic differential (SD) method is effective. It has been used to quantify human's emotions statistically. Therefore, we use SD method to analyze the relationship between robot's gestures and human's emotions. To evaluate human's emotions, we

ROBOCOMM 2007, 14th – 16th Oct 2007, Athens, Greece.

ISBN 978-963-9799-08-0
DOI 10.4108/ICST.ROBOCOMM2007.2154

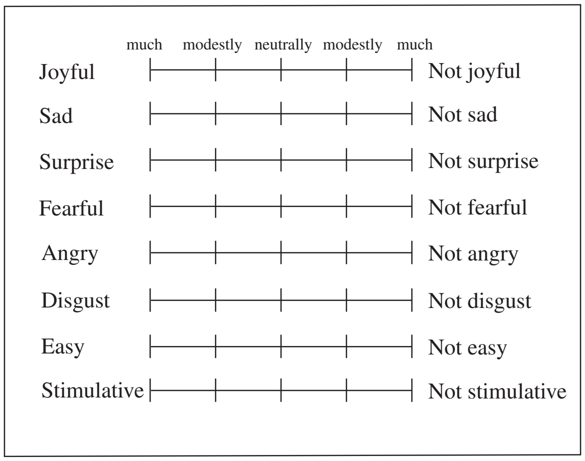


Fig. 1. Evaluation sheet

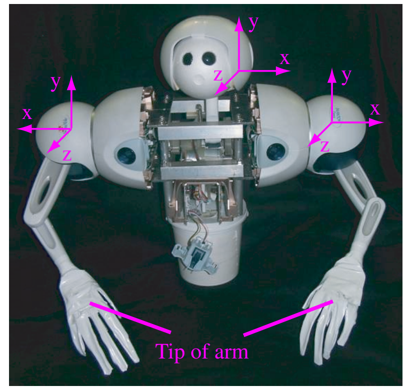


Fig. 2. Gesture robot

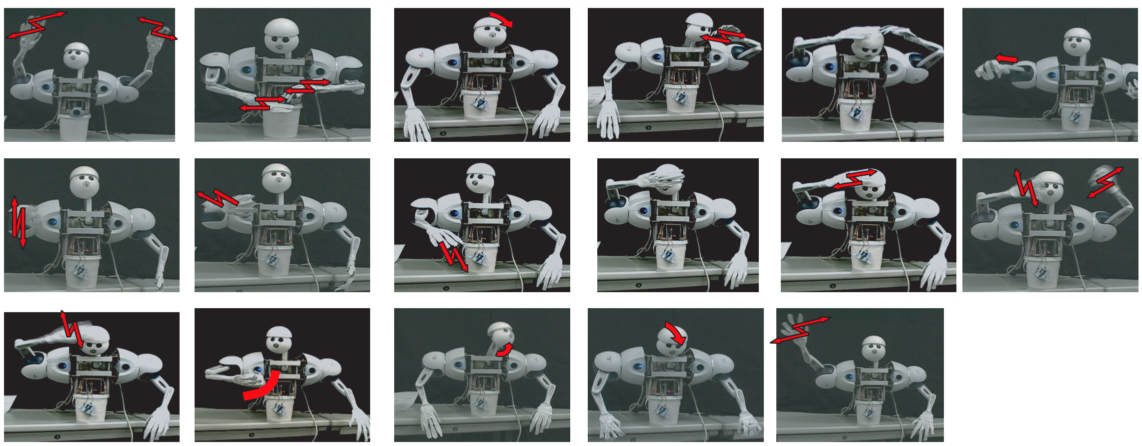

Fig. 3. Selected gestures

must prepare some adjectives which indicate human's emotions. It is important to select adequate adjectives because it directly affect on the result of SD method. Therefore, we select adjectives referring to psychology of emotion. In psychology of emotion [4], there are numbers of eminent researchers. Each researcher selected different kinds of human basic emotions. However, most of the researchers selected six emotions which Ekman suggested, 'joy', 'surprise', 'fear', 'sadness', 'anger' and 'disgust', as human basic emotions. Hence, we use those six emotions. In addition to those, we select another two emotions, 'easy' and 'stimulative'. Those two emotions are suggested by Yokoyama [5] for research on animal assisted therapy (AAT) by introducing robots to medical field instead of animals. He suggested that in AAT, human felt comforted by communicating with animals and the comfort was brought by a good balance of a human's feelings between 'easy' and 'stimulative'. With selected the eight adjectives, we evaluate human's emotions by five-point scale as shown in Fig. 1. From the result of the evaluation, we conduct factor analysis in order to extract the human's potential emotions as factors. Then, we conduct multiple regression analysis to analyze statistically the relationship between the factors of human's emotions and the physical properties of robot's gestures. In multiple regression analysis, the factors of human emotions are used as objective variables, as well as the physical properties of robot's gestures are used as explaining variables. Executing those processes, we quantify the relationship between the robot's gesture and the human's emotion.

## III. Preparation of Analysis

### A. Production of gesture robot

We produced a gesture robot shown in Fig. 2 whose shape is designed by imitating human's upper body. The reason why we imitate the human's upper body is that in communication, human makes gestures mostly using only upper body. The robot has nine DOF. Each arm has three DOF and the head has three DOF, respectively. The arms and the head are made by use of haptic device, PHANToM (manufactured by SensAble Technology).

### B. Selection of gestures

Human uses wide variety of gestures in communication. Therefore, we should classify gestures based on a clear idea. Psychologist Kita [6] proposed a theory of classification of gesture. In his theory, gestures are divided into two categories. One is Emblem. Gestures that are classified into this category are independent from speech. Hence these gestures are used separately in communication. The other is spontaneous gesture. Gestures classified into this category are independent from speech. Hence these gestures are used with speech in communication. In our research, we assume that gestures are used independently in communication. Therefore, gestures selected in our study belong to Emblem. We selected seventeen gestures from numbers of gestures described in dictionary [7] that are classified into Emblem. All gestures are shown in Fig. 2. As shown in Fig. 3, the gestures do not have obvious meanings.

### C. Measurement of gesture

In order to conduct sensory evaluation, we recorded the robot's gestures. When we recorded the robot's gestures, we also measured the physical properties of the robot. The measured physical properties are position, velocity, angle and angular velocity. Measured points are tip of both arms and center of head as shown in Fig. 3. Physical properties are measured in three axial directions and measured with time interval of a millisecond. From the measured physical properties, we calculated 138 physical properties for each gesture.

### D. Selection of physical properties

As mentioned above, we calculated 138 physical properties. However, it is difficult to quantify the relationship between all of calculated physical properties of the robot's gestures and the emotions of human. Therefore, we need to select several physical properties indicating features of robot's movements well. In order to select physical properties, first, we conducted hierarchical cluster analysis and classified the physical properties into twelve groups. Then, we selected the typical physical properties of each group. After that, we calculated a correlation coefficient between each physical property and conducted determination of significance by use of t-test. The level of significance was 1%. From the result of determination of significance, we determined ten physical properties.

### E. Sensory evaluation

In order to evaluate human's emotions when they are observing robot's gestures, we conducted sensory evaluation. In our sensory evaluation, examinees are thirteen men and women in their twenties. Experimental procedures are as follows: First, we show movies of all the gestures of the robot to the examinees. Then, the examinees recorded their emotions in evaluation sheet shown in Fig. 1. From the result, we calculated the sum of all the examinees in each adjective.

## IV. Analysis on human's emotions

The human's emotions when the human observes the robot's gestures are represented as several factors of emotions. In our research, we conduct maximum likelihood common factor analysis to calculate factors of emotions.

The result is shown in Table I. In Table I, if absolute figures of factor loadings are larger than 0.7, the cells are colored. In Table I, the sum of contributing rate of three factors became 90%. So we can conclude that the human's emotions were described by three factors. From factor loadings of the adjectives, we named each factor. Factor 1, 2, and 3 were named 'fear', factor, 'sadness' factor and 'aggravation' factor, respectively.

## V. Analysis between physical properties of gestures and emotions

In order to analyze the relationship between the physical properties of gestures and the factors of emotions, we conducted multiple regression analysis. In the multiple regression analysis, the factors of emotions were used as objective variables, as well as the physical properties were used as explaining variables. The result is shown in Table 2. In Table II, each 'X' shows physical property. 'X1' is a 'maximum velocity of top of left arm', 'X2' is a 'average velocity of tip of left arm(x) ', 'X3' is a 'maximum velocity of tip of right arm', 'X4' is a 'average velocity of tip of right arm(x)', 'X5' is a 'maximum width', 'X6' is a 'maximum height', 'X7' is a 'average angular velocity of head(x)', 'X8' is a 'maximum angular velocity(y)', 'X9' is a 'maximum angular velocity(z)' and 'X10' is a 'sum of kinetic energy of head'. x, y and z are directions of movements which are shown in Fig. 2. The maximum width X5 is a maximum distance in x direction between tips of both arms. The maximum height X6 is a maximum distance in y direction between center of head and bottom of robot. In Table II, if a standard partial regression coefficient is larger than 0.5, the cell is colored. From F value, the level of significance of factor of 'fear' is 0.5% and the level of significance of factor of 'sadness' is 10%. Therefore, it is confirmed that the relationship between ten physical properties and those two factors are assumed to be linear. On the other hand, the level of significance of 'aggravation' factor is 40%. Therefore, the relationship between ten physical properties and the 'aggravation' factor is not linear. This result indicates that there are any causes but physical properties that affect 'aggravation' factor.

The standard partial regression coefficient of the 'fear' factor shows that the average velocity of tip of right arm(x) negatively contribute to the factor.The 'fear' factor is also positively affected by the average angular velocity of head (x).

The standard partial regression coefficient of the 'sadness' factor shows that the average velocity of tip of left arm (x) and the maximum velocity of tip of right arm negatively contribute to the factor and the maximum velocity of head (y) positively contribute to the factor.

TABLE I
FACTOR LADING MATRIX

| | Factor1 | Factor2 | Factor3 | Independent factor |
|---|---|---|---|---|
| Stimulative | 0.95 | -0.05 | 0.30 | 0.03 |
| Easy | -0.77 | -0.48 | -0.29 | 0.26 |
| Surprize | 0.90 | -0.18 | 0.15 | 0.25 |
| Fear | 0.72 | 0.35 | 0.33 | 0.01 |
| Sadness | -0.08 | 0.84 | 0.18 | 0.01 |
| Joy | -0.14 | -0.85 | -0.48 | 0.01 |
| Disgust | 0.41 | 0.46 | 0.78 | 0.10 |
| Anger | 0.40 | 0.35 | 0.84 | 0.14 |
| Charasteristic number | 5.01 | 1.83 | 0.37 | |
| Accumulative contributing rate | 0.63 | 0.85 | 0.90 | |

TABLE II
MULTIPLE REGRESSION ANALYSIS BETWEEN PHYSICAL PROPERTIES AND FACTORS OF EMOTIONS

| | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | $R^2$ | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fear | -0.05 | -0.10 | 0.45 | -0.57 | 0.08 | 0.18 | 0.63 | 0.10 | 0.13 | -0.15 | 0.95 | 11.87 |
| Sadness | -0.17 | -0.88 | -0.71 | -0.02 | 0.45 | -0.32 | 0.31 | 0.71 | -0.08 | 0.47 | 0.84 | 3.22 |
| Aggravation | 0.41 | 0.10 | -0.11 | 0.35 | -0.65 | -0.16 | 0.39 | -0.71 | 0.00 | -0.39 | 0.68 | 1.26 |

## VI. DISCUSSION

From the result of factor analysis, three factors are calculated. For example, 'stimulative' , 'easy' , 'surprise' and 'fear' are strongly-correlated to 'aggravation' factor. Hence, those four adjectives are on the same axis. Likewise, 'sadness' and 'joy' are on the same axis and 'anger' and 'disgust' are on the same axis. Therefore we can conclude that human evaluate the robot by three axes.

From the result of multiple regression analysis, the relationship between the emotional factors of human and the physical properties of robot's gestures are quantitatively related.

The average angular velocity of head(x) positively contribute to the 'fear' factor. Therefore, we can assume that the horizontally directed swaying motion of head affects the 'fear' factor and as the horizontally directed swayng motion become faster, human's 'fear' emotion become larger.

The average velocity of the tip of left arm(x) and the maximum velocity of tip of right arm are negatively contribute to the 'sadness' factor. Therefore, we can assume that the velocity of arm affects the 'sadness' factor and as the velocity of arm becomes larger, human's 'joy' emotion becomes larger. The Maximum angular velocity of head(y) positively contribute to the 'sadness' factor. Therefore we can assume that the vertically directed swaying motion of head affects 'Sadness' factor and as the vertivally directed swaing motion of head becomes faster, human's 'sadness' emotion becomes larger.

## VII. CONCLUSION

In the present research, we made a model for explaining the relationship between physical properties of robot's gestures and the factors of human's emotions. The result of factor analysis shows that the human's emotions when human observes the robot's gestures are explained by three factors. The result of multiple regression analysis shows that 'fear' factor and 'sadness' factor are described by several physical properties of robots. By using our model, we can generate gestures of robots that give rise to desired emotions of human.

## VIII. AKNOWLEDGEMENT

This work is supported in part by Grant in Aid for the 21st century center of Excellence for "System Design: Paradigm Shift from Intelligence to Life" from the Ministry of Education, Culture, Sport, and Technology in Japan.

## REFERENCES

[1] Research Committee on Human Friendly Robot, "Technical Targets of Human Friendly Robots", *J. of the Robotics Society Japan*,Vol.16,No.3,pp.288-294,1998.

[2] Raffler-Engel,W.V,*Nonverbal communication*. Tokyo:Taisyuukannsyotenn Publishers, 1981.

[3] T. Nakata, T. Mori and T. Sato, "Quantitative Analysis of Impression of Robot Bodily Expression based on Laban Movement Theory", *J. of the Robotics Society Japan*, Vol.19, No.2, pp.252-259, 1998.

[4] H. Hana, N. Suzuki and Y.Hana, *Introduction to Emotional Psychology(in Japanese)*. Tokyo: Saiensu sha Co.,Ltd.Publishers, 2001.

[5] A. Yokoyama,"Possibility of Psychiatric Medicine to which Robot is Applied: From a Viewpoint of Animal Therapy", *Journal of Newest Psychiatric Medicine*, Vol.7, No.5, pp.439-447, 2002.

[6] S.Kita, *Gesture(in Japanese)*. Tokyo: Kanekosyobo Publishers, 2002.

[7] Y. Higasiyama and L. Ford, *Body movements*. Tokyo: Sanseido Publishers, 2003.