How Humans Evaluate the Impression when Interacting Haptically with a Robot

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***Abstract*—It is necessary to analyze evaluation structure of impression of human for robot's natural interaction with human. In this paper, we assume hierarchy in evaluation structure of impression of human, and clarify the relationship between lower impression and higher impression in human-robot haptic interaction. Lower and higher stand for a strong and weak relationship to physical property of robot's motion. We divide robot's motions in haptic interaction into 16 basic motions. Through sensory evaluation and factor analysis, four lower impression factors and two higher impression factors are extracted. From the results of multiple regression analysis, we formulate the relationship between lower impression and higher impression.**

***Index Terms*—human-robot interation, haptic interaction, sensory evaluation, factor analysis, multiple regression analysis**

I. Introduction

Recently, there are numbers of researches on human-robot interaction. For robot's natural interaction with human, following two impressions should be the same. One is the impression robot should give to human using robot's motion. The other one is the impression human obtains from robot's motion. Therefore robot needs to generate the motion which gives human the impression robot should give. To generate these motions, the relationship between robot's motion and human's impression should be revealed.

The relationship between AIBO's neck motion and human's impression given by AIBO's motion was studied by Saito et al [1]. Mori et al. studied on the impression human obtains from the motion of a red ball displayed on a screen [2]. Hayashi et al. analyzed the relationship between human's motion and impression [3]. These researches reveal the relationship between robot's or human's motion and human's impression.

Though in these researches human's impression is considered as a whole, there are thought to be two kinds of impressions. One is the impression directly related to physical properties of robot's motion. In this paper, we call these impressions ”lower impression”. The impressions such as ”speedy” or ”large” are lower impression. Another one is the impression not directly related to physical properties. These impressions are called ”higher impression”. The impressions such as ”gentle” or ”fun” are higher impression. Higher impressions are thought to be formed by lower impressions. That is to say lower impression and higher impression form hierarchical structure. Though previous researches reveal the relationship between robot's motion and human's impression, these researches did not analyze the relationship between lower impression and higher impression. In this paper, we call the relationship between lower and higher impression “evaluation structure of impression“, and analyze this structure.

In addition to that, previous researches deal with only non-haptic interaction. However, robot is getting closer to human, and robot and human often contact with each other. In the near future, robot would use haptic interaction to express its intention and emotion. Therefore it is necessary to analyze the evaluation structure of impression of human haptically interacting with robot.

In this research, we analyze the evaluation structure of impression in haptic interaction. First, robot's motions in haptic interaction are classified to select proper motions in sensory evaluation. Next, sensory evaluation is conducted to quantify the human's impression. Then, lower impression factors and higher impression factors are extracted by factor analysis. After that, we analyze the relationship between the lower impression and the higher impression. From the above results, the evaluation structure of impression is obtained.

II. Classification of Motion

In this research, we focus on the interaction in which human and robot shake hands with each other. We quantify human's impression given by robot's motion using sensory evaluation. Robot's motions used in sensory evaluation need to cover whole motion conducted in shake-hands interaction [4]. To select proper motions used in sensory evaluation, robot motions should be classified.

In shake-hands interaction, robot's motions are divided into two main branches, motions not related to human's motion and motions depending on human's motion. ”Circular motion”, ”reciprocating motion”, and ”random motion” are selected as the motion not related to human's motion. The motion depending on human's motion is thought to be divided into motions depending on position of the tip of human's arm and motions depending on velocity of the tip of human's arm. ”Pull”, ”push”, ”imitation”, and ”rewind” are selected as motion depending on position of the tip of human's arm. In ”pull” motion, robot's arm pulls the tip of human's arm into certain point. On the other hand, robot's arm pushes the tip of human's arm out of certain point in ”push” motion. In the case of ”imitation”, the tip of robot's arm draw the same trajectory as the tip of human's arm did. In the case of ”rewind”, robot's arm inversely draw the same trajectory as the tip of human's arm did. As motions depending on velocity of the tip of

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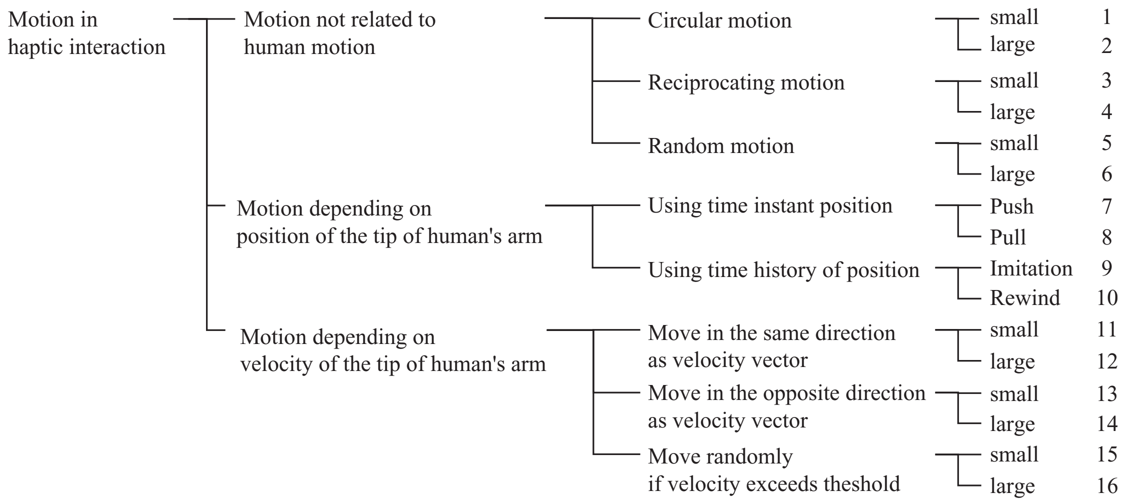


Fig. 1. Classification of robot's motion in human-robot haptic interaction

TABLE I
CHARACTERISTICS OF PHANToM'S MOTION

Motion	Characteristic	Motion	Characteristic
1	Radius: 20mm, Period: 1sec	9	Positional control
2	Radius: 50mm, Period: 0.5sec	10	Positional control
3	Amplitude: 30mm, Period: 0.5sec	11	Output force: 0.001*velocity
4	Amplitude: 60mm, Period: 0.5sec	12	Output force: 0.002*velocity
5	Output force: 1-3N, Interval: 200-500msec	13	Output force: -0.001*velocity
6	Output force: 2-7N, Interval: 100-300msec	14	Output force: -0.002*velocity
7	Output force: 200/(distance from reference point)	15	Output force: 0.5-1N, Threshold speed: 102mm/s
8	Output force: -1*(distance from reference point)	16	Output force: 50-80N, Threshold speed: 102mm/s

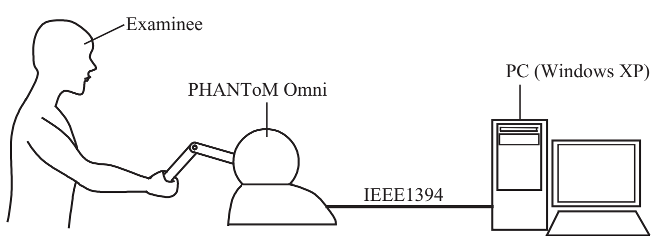


Fig. 2. Scene of the experiment

TABLE II
EVALUATION ITEMS

Lower impression		Higher impression
Viscous	Heavy	Gentle
Speedy	Heady	Familiar
Stable	Powerful	Calm
Selfish	Large	Non-boring
Compliant	Smooth	Fun
Voluntary	Hard	Fresh
Complex		

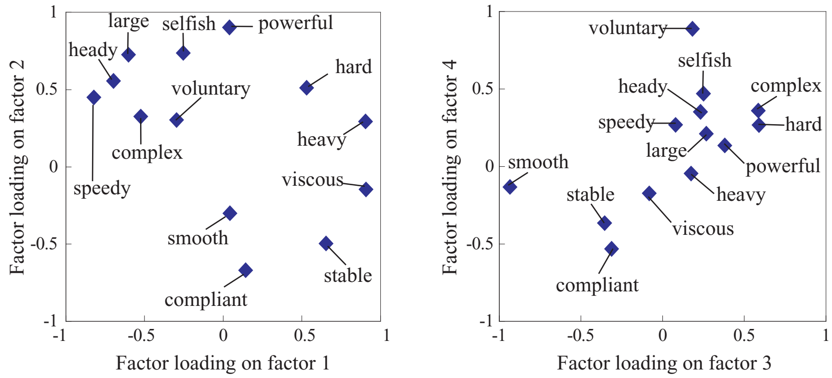
human's arm, we select following three motions: (1) move in the same direction as velocity vector of the tip of human's arm, (2) move in the opposite direction as velocity vector of the tip of human's arm, and (3) move randomly if velocity of the tip of human's arm exceed threshold. Furthermore the motion not related to human's motion ("circular motion", "reciprocating motion", and "random motion") and the motion depending on velocity of the tip of human's arm are divided into "large" type and "small" type based on spacial extent or output force.

Fig. 1 shows the classification of robot's motion in shake-hands interaction. The numbers on the right side of the motion's name are motion number, which will be used later.

III. SENSORY EVALUATION

In order to quantitatively estimate human's impression given by robot's motion in shake-hands interaction, we conduct sensory evaluation using semantic differential (SD) method [4]. In the sensory evaluation, we use a haptic device, PHANToM Omni, from SensAble Technologies. PHANToM is controlled by a computer (Windows XP), and conducts motions shown in Fig. 1. The characteristics of PHANToM's motion are shown in Table I. "Distance" and "velocity" used in Table I show distance and velocity of the tip of PHANToM. In the sensory evaluation, examinees are asked to hold the tip of PHANToM's arm and freely move it. After enough interaction with PHANToM, they are asked to estimate the impressions given by PHANToM's motion in five levels. To eliminate the order effect, PHANToM's motions are presented in random order. Examinees are ten males in their twenties. The scene of the experiment is shown in Fig. 2.

In this research, we reveal the relationship between lower impression and higher impression. Therefore thirteen evaluation items concerning lower impression and six evaluation items concerning higher impression are selected. Evaluation items are selected based on researches on robot's motion [1][2][3] and researches on haptic interaction [5][6]. Selected evaluation items are shown in Table II.



(a) Factor loadings on factor 1 and factor 2

(b) Factor loadings on factor 3 and factor 4

Fig. 3. Factor loadings of lower impression

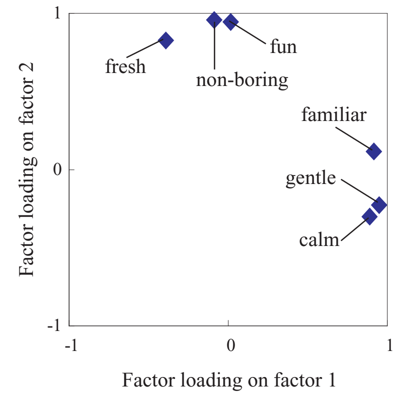
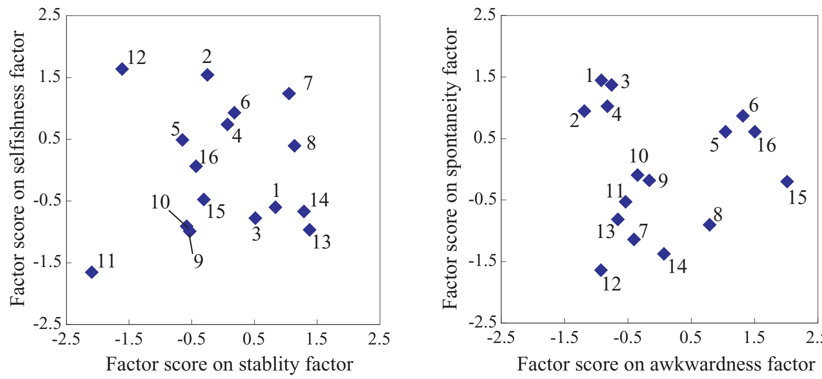


Fig. 5. Factor loadings of higher impression



(a) Factor scores on stablity factor and selfishness factor

(b) Factor scores on awkwardness factor and spontaneity factor

Fig. 4. Factor scores of lower impression

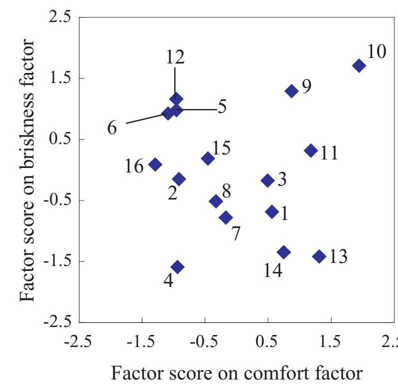


Fig. 6. Factor scores of higher impression

IV. Analysis on Impression Evaluation Structure

A. Factor Analysis of Lower Impression

After the sensory evaluation, we conduct factor analysis of the lower impression to extract potential factors. As a result of factor analysis, cumulative contribution rate of four factors reaches 90%. Therefore we can conclude that the lower impression could be explained by the four factors. The result of factor analysis is shown in Fig. 3. Fig. 3 (a) shows factor loading on factor 1 and factor 2 of the lower impression. Fig. 3 (b) shows factor loading on factor 3 and factor 4 of the lower impression. Plots in these figures show evaluation items concerning the lower impression. As for factor 1, you can find the factor loadings of ”heavy”, ”viscous”, and ”stable” are very large. So we name factor 1 ”stability” factor. Based on the factor loading on each factor, factor 2, 3, and 4 are named ”selfishness” factor, ”awkwardness” factor, and ”spontaneity” factor. ”selfishness” and ”awkwardness” are the impressions given not by seeing a robot but by touching a robot. Therefore, these two factors are the unique factors being able to be extracted in haptic interaction.

Fig. 4 shows factor scores of the lower impression. Fig. 4 (a) shows factor scores on ”stability” factor and ”selfishness” factor. Fig. 4 (b) shows factor scores on ”awkwardness” factor and ”spontaneity” factor. Each number on the plot in these figures represents PHANToM's motion number described in chapter II. As shown in Fig. 1, motion 1 and 2 are both ”circular motion”. Motion 3 and 4 are ”reciprocating motion”. Motion 11 and 12 are the same type of motion. However, looking at factor scores on ”selfishness” factor in Fig. 4 (a), we find the significant difference between motion 1 and 2, motion 3 and 4, and motion 11 and 12. This indicates the size of motion, spacial extent or output force, has larger effect on ”selfishness” factor than the type of motion.

Motion 13 and 14 obtain high factor scores on ”stability” factor. This is because, in motion 13 or 14, PHATNToM gives examinee reaction force in the opposite direction as velocity vector of the tip of examinee's arm. That is to say, PHANToM moves to decrease the velocity of the tip of examinee's arm, and examinee feels ”stability”.

In Fig. 4 (b), Motion 1-6 have high factor scores on ”spontaneity” factor. As discribed in chapter I, motion 1-6 are not related to human's motion, and PHANToM moves whether examinee moves his arm or not. Thus examinee felt ”spontaneity” from motion 1-6.

B. Factor Analysis of Higher Impression

In addition to lower impression, we conduct factor analysis of the higher impression. As a result of factor analysis, cumulative contribution rate of two factors reaches 89%. Therefore

TABLE III
STANDARD PARTIAL REGRESSION COEFFICIENT AND F-VALUE OF MULTIPLE REGRESSION ANALYSIS

	Stability	Selfishness	Awkwardness	Spontaneity	F-value
Comfort	0.13	-0.81	-0.40	-0.24	24.4
Briskness	-0.69	0.01	0.24	0.02	4.37

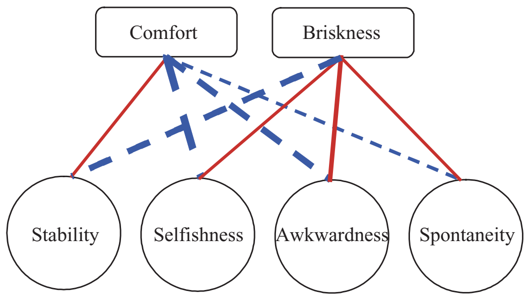


Fig. 7. Factor loadings of higher impression

we can conclude that the higher impression could be explained by two factors. The result of factor analysis is shown in Fig. 5. In Fig. 5, horizontal and vertical axes are factor loadings on factor 1 and 2, respectively. As for factor 1, factor loadings of ”gentle”, ”familiar”, and ”calm” are very large. So we name factor 1 ”comfort” factor. Factor 2 are named ”briskness” factor because factor loading of ”fresh”, ”non-boring”, and ”fun” are very large.

Caltech perception psychologist Shinsuke Shimojo said attraction consisted of familiarity and novelty. The two factors extracted in this research, ”comfort” factor and ”briskness” factor, are thought to represent familiarity and novelty, respectively. Therefore the result of factor analysis of the higher impression is thought to be valid from psychological standpoint.

Fig. 6 shows factor scores of the higher impression. In Fig. 6, horizontal and vertical axes are factor scores on ”comfort” factor and ”briskness” factor, respectively Factor scores on ”comfort” factor of motion 1-6 and motion 11-16 show that the large motions, whose spacial extent or output force are large, have lower factor scores on ”comfort” factor than the small motions. This result agrees with the prevailing view that wild motions do not give human comfort.

C. Multiple Regression Analysis of Lower Impression and Higher Impression

In order to analyze the relationship between lower impression and higher impression, we conduct multiple regression analysis. In multiple regression analysis, we use factor scores of higher impression as objective variables, and factor scores of lower impression as explaining variables. Standard partial regression coefficient and F-value (variance ratio) are shown in Table III. The multiple regression equation of ”comfort” factor is statistically significant at the 0.01 level in terms of the standard F test. The multiple regression equation of ”briskness” factor is significant at the 0.05 level.

The standard partial regression coefficient of ”comfort” factor shows that ”selfishness” factor and ”awkwardness” factor make a negative contribution to ”comfort” factor. So to give comfortable feeling to human, robot needs to move its own arm smoothly (not awkwardly) and follow the movement of human's arm (do not be selfish).

The standard partial regression coefficient of ”briskness” factor shows that ”stability” factor makes a negative contribution to ”briskness” factor. Therefore to give brisk impression to human, robot needs to move unsteadily, or lightly.

From the factor analysis and multiple regression analysis, we establish the evaluation structure of impression of human haptically interacting with robot. The obtained sturcture is shown in Fig. 7. In Fig. 7, full line and broken line show positive and negative standard partial regression coefficient, respectively. Line thickness shows the absolute value of the standard partial regression coefficient.

V. CONCLUSION

In this paper, we have discussed the analysis of evaluation structure of impression of human haptically interacting with robot. First of all, robot's motions in shake-hands interaction were classified. Human's impressions were quantified through sensory evaluation using haptic device PHANToM. The result of factor analysis shows that lower impression could be explained by four factors, ”stability”, ”selfishness”, ”awkwardness”, and ”spontaneity”. Higher impression could be explained by two factors, ”comfort” and ”briskness”. The result of the multiple regression analysis shows that ”selfishness” factor and ”awkwardness” factor negatively contribute to ”comfort” factor, and ”stability” factor negatively contributes to ”briskness” factor. Thus we revealed the evaluation structure of human impression in shake-hands interaction.

In future works we will analyze the relationship between lower impression and physical property of robot's motion to generate the proper motion. Then we will develop a robot system that can conduct proper motion to give human the impression robot should give.

VI. ACKNOWLEDGEMENT

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