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Psychological Evaluation for Rough Shape and Biped Walking of Humanoid Robots Using Virtual Reality

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1. Introduction

Japan is becoming an aging society composed largely of elderly people, and the proportion of aged people in the population is increasing year by year. There is an increasing need for robots that can coexist with people and help them in their daily lives: housekeeping robots, nursing care robots, etc. Such robots are required to have "physical safety" and "mental safety". Physical safety means that robots do not injure humans. Mental safety means that humans do not feel fear or anxiety toward robots. In addition, it is important that humans do not have feelings of unpleasantness or aversion toward robots. Accordingly, when designing robots coexisting with people and planning their motions, it is necessary to consider the influences of the robots on human impressions and psychology. Mental safety has not yet been fully discussed. This is because the parameters of robots (shape, size, color, motion, speed, etc.) that may affect human psychology have not been clarified, and the method of measuring and evaluating human psychology for the robots has not been established.

There have been some researches on the evaluation of human psychology about robots and the interaction between robots and humans. Goetz et al. conducted questionnaire about matching between tasks and appearance of humanoid robots (Goetz et al., 2003). Robins et al. investigated the attitudes of autistic children for robots (Robins et al., 2004), and Woods et al. discussed the design of robots from children's viewpoint (Woods et al., 2004). Some psychological experiments for wheeled humanoid robot "Robovie" were conducted (Kubota et al., 2003; Kanda & Ishiguro, 2004; Sakamoto et al., 2004). Seal robot "Paro" was also psychologically evaluated worldwide (Shibata et al., 2003; Shibata et al., 2004). Kanda et al. investigated the impressions on real robots with different appearance by the semantic differential method when they did the same tasks (Kanda et al., 2005). These researches are significant because they evaluate the psychological suitability of the existent robots as partner robots or human-friendly robots. But they are not enough to analyze which parameters of robots bring desirable psychological effects.

For the purpose of clarifying the relationship between the parameters and their psychological effects, we have proposed the evaluation of human impressions and

psychology for robots coexisting with people using virtual reality (Nonaka et al., 2004; Inoue et al., 2005a; Inoue et al., 2005b; Ujiie et al., 2006; Inoue et al., 2007). CG robots are presented to human subjects using head-mounted displays or projection-based immersive 3D visualization system "CAVE" (Cruz-Neira et al., 1993), and the subjects and the robots coexist in the virtual world. The subjects answer questionnaire about their impressions or psychology for the robots and their motions; the questionnaire answers lead to the psychological evaluation. By using virtual reality, the parameters of robots can be easily changed and tested. It is also possible to experiment in various situations and environments. In the present article, we describe the recent two subjective evaluations about humanoid robots using CAVE: human impressions for rough shape of humanoid robots (Inoue et al., 2007) and human impressions for the way of biped walking (Ujiie et al., 2006) of one type of humanoid robot. Based on these results, we comprehensively discuss the rough shape and the way of biped walking of humanoid robots which bring desirable psychological effects as service robots.

2. Psychological evaluation of robots using virtual reality

When designing robots coexisting with people and planning their motions, it is necessary to consider the influences of the robots on human impressions and psychology. The purpose of the psychological experiments is to analyze the relationship between robot parameters (shape, size, color, motion, speed, etc.) and human psychology: what kind of psychological effects the parameters have. If we can obtain such knowledge, we can determine the parameters so that they may bring desirable psychological effects. For this purpose, it is required to investigate and compare human psychological reactions to many kinds of robots and their various patterns of motion. But, because we aim at designing new robots, real robots do not exist. Hence, if we perform psychological experiments using real robots, we must make many new robots with different parameters and control them only for the experiments, not for practical use. Making and controlling real robots, however, requires much cost and time. In addition, human psychology for the robots may depend on the situation. But preparing various real environments for the tests is difficult, and some situations are dangerous (e.g., on a street).

For these reasons, we have proposed to evaluate human impressions and psychology for robots using virtual reality. Fig. 1 shows the experimental system using CAVE. CAVE is one of immersive visualization systems. It consists of four screens and a projector for each. The screens are placed on the front, left, right and floor, thus surrounding a subject. The size of this space is about 3[m]x3[m]x3[m]. The projectors project 3D computer graphics on the screens. The subject wears stereoscopic glasses and stands inside the CAVE to see a stereoscopic view. By measuring the pose of the subject's head, the graphics seen from the point of view of the subject is always projected. As a result, the subject feels like he or she is existing inside the virtual world. CAVE can give a higher realistic sensation to humans than head-mounted displays. As shown in Fig. 1, a 3D CG robot in real scale is presented to a human subject using CAVE. The subject answers the questionnaire about his or her impressions or psychology about the robot; that leads to the psychological evaluation.

Because we do not have to make real robots, the proposed method allows us to change the parameters of robots easily and to evaluate many kinds of robots and their different motions

in various situations. We do not have to measure the locations of the robots using some sensors or measurement systems. We can keep the same experimental conditions and display the same motions repeatedly; this is suitable for the experiments which require many subjects. Accordingly, this method is suitable to evaluate new robots and to analyze the psychological effects of the robot parameters. On the other hand, this system cannot deal with situations where the subject has physical contact with the robot: for example, a nursing-care robot. The movable area of the subject is limited inside CAVE.

As we mentioned, this method applies virtual reality to the problem where experiments using real objects are difficult to perform. But, in order to obtain similar results to human psychology in real world, experimental settings using virtual reality should resemble real case as much as possible. Especially when we evaluate robots which work around people, the robots should be displayed to subjects in correct size and 3-dimensionally, and the distance between the robots and subjects should be the same as real case. Accordingly this method uses CAVE as the virtual reality environment.
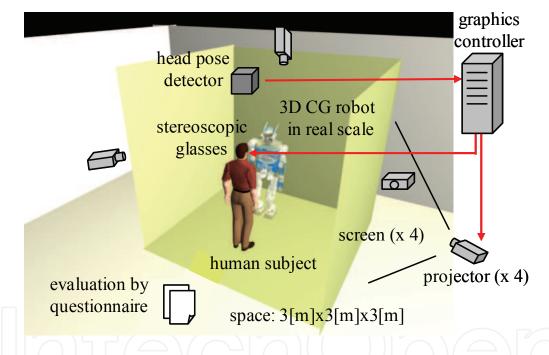

Fig. 1. Psychological evaluation of robots using CAVE

In the previous work (Nonaka et al., 2004), we evaluated holding-out motion of humanoid robots: a robot reaches out for the cup placed on a side table, and holds out it for a subject sitting in front of the robot (this experiment used a head-mounted display). Then we showed the effects of the rotation of the robot's head and body on the human psychology. In the previous work (Inoue et al., 2005a), we evaluated passing-by motion of humanoid robots: a robot approaches a subject from the front and passes near him or her in a corridor. Then we showed the effects of the head motion and walking speed on the human psychology; these could be a sign of indicating that the robot is aware of the subject. The work (Inoue et al., 2005b) compared virtual and real mobile manipulators.

Humanoid robots are candidates for robots coexisting with people because they have human-like structures. We describe the recent two experiments about humanoid robots.

3. Psychological evaluation for rough shape of humanoid robots

3.1 Robot model

Appearance is an important factor for impressions. Here we investigate human impressions for rough shape of humanoid robots.

The appearance of a humanoid robot is determined by a large number of parameters: height, width, ratio of links, ratio of link thickness, shape of links, color, material, and so on. But it is impossible to change all parameters. In this study we select a) thickness of head, b) thickness of body, and c) thickness of legs. The thickness of arms is changed together with the thickness of body. Thus the parameter b) includes the thickness of arms. We call these parameters a), b) and c) "rough shape parameters".

When we investigate psychological effects of rough shape parameters, it is better to reduce the influences of the other parameters on human psychology. From this reason, we make 3D CG robot models in real scale by combining simple solid elements: gray spheres and cylinders. We change the thickness of head, body and legs by changing the diameters of the spheres and cylinders. The purpose of this experiment is to find how human impressions change when the rough shape parameters change. It is not absolute impressions on the simplified robot models. Accordingly we define a standard robot and make other robots with different thickness of head, body and legs. Then we evaluate the impressions for these robots relative to the standard robot.
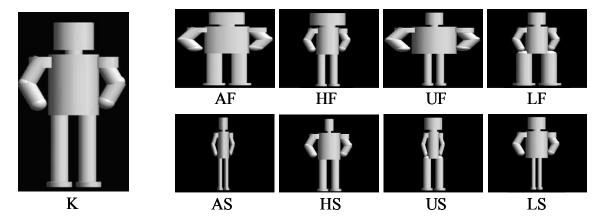

Fig. 2. Standard robot "K" and eight robots to be evaluated

robot	head	body	legs
K	standard	standard	standard
AF	**fat**	**fat**	**fat**
AS	*slim*	*slim*	*slim*
HF	**fat**	standard	standard
HS	*slim*	standard	standard
UF	standard	**fat**	standard
US	standard	*slim*	standard
LF	standard	standard	**fat**
LS	standard	standard	*slim*

Table 1. Rough shape parameters of eight robots

Fig. 2 shows the standard robot "K". Its height (1.54[mm]) and the ratio of the links are the same as those of existing humanoid robot "HRP-2"(Kaneko, 2004). Notice that the standard robot does not mean a typical humanoid robot. It defines standard for relative evaluation of impressions. We generate eight robots shown in Fig. 2 by doubling the thicknesses of head, body and legs of the standard robot or reducing them to half. All robots have the same height of the standard robot. In this figure, the first symbol represents the changed parameter: "A" = all parameters, "H" = head, "U" = body, "L" = legs. The second symbol represents thickness: "F" = fat (double), "S" = slim (half). Table 1 summarizes the rough shape parameters of these robots. Changing three parameters (head/body/legs) in three levels (standard/flat/slim) generates 27 robots in total. But evaluating all of them by psychological experiment requires too much time per subject; it is impossible because of subject's fatigue. Thus we select 8 robots to see the effects of each parameter and overall thickness.
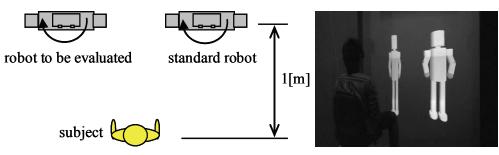

Fig. 3. Setting of experiment for evaluating rough shape

3.2 Experimental method

Fig. 3 shows a bird's-eye view of the setting of the virtual environment and a scene of the experiment using CAVE. Each of the eight robots and the standard robot stand upright and side by side. Each subject sits on a chair in front of the robots; the distance between the robots and the subject is 1[m]. The relationship between the height of the robots and the eye level of the subject may affect his or her impression. Sitting on the chair reduces the differences of the eye level among the subjects and makes all subjects look up at the robots. The robots are rotating so that the subject can see them from all angles. The standard robot is always displayed, and the eight robots are displayed one by one. All subjects see the eight robots. In order to cancel out the order factor, the eight robots are presented in randomized order for each subject. The subjects are 8 men and 17 women (total 25 subjects) between the ages of 19 and 66.

3.3 Psychological evaluation

After seeing each of the eight robots, the subject answers the questionnaire about his or her impression of the presented robot relative to the standard robot. The questionnaire by the semantic differential method consists of 38 adjective pairs, summarized in Table 2. We pick up some of these adjective pairs from those already used in the similar psychological experiments, and add the others which seem suitable to this experiment. The subject evaluates each adjective pair according to seven rating grades. In this table, positive adjectives are arranged on the left side. Some adjective pairs in the questionnaire sheet are swapped so that the pairs may be balanced. The sheet is written in Japanese.

Adjective pairs in Japanese		Factor 1	Factor 2	Factor 3
yasashii	kowai	-0.391	**0.678**	0.263
ningentekina	kikaitekina	-0.152	0.412	0.276
kouitekina	tekitaitekina	-0.354	**0.705**	0.240
karui	omoi	-0.526	0.148	**0.732**
chiseitekina	chiseinokaita	-0.119	0.382	**0.661**
shigekitekina	taikutsuna	0.598	0.061	0.102
yoi	warui	0.111	**0.665**	0.353
atarashii	furui	0.022	0.229	0.589
chiisai	ookii	-0.567	0.113	**0.683**
anshin-na	fuan-na	0.390	0.469	-0.234
hakkirishita	bonyarishita	0.531	-0.079	-0.096
yuukan-na	okubyouna	**0.774**	-0.111	-0.500
sensaina	soyana	-0.512	0.351	**0.653**
shitashimiyasui	shitashiminikui	-0.021	**0.754**	0.078
kimochinoyoi	kimocihnowarui	-0.058	**0.756**	0.226
youkina	inkina	0.517	0.329	-0.236
uchitoketa	katakurushii	0.144	**0.683**	0.195
chikazukiyasui	chikazukigatai	-0.076	**0.778**	0.211
yukaina	fuyukaina	0.149	**0.654**	0.029
sukina	kiraina	0.150	**0.824**	0.211
hayai	osoi	-0.081	0.109	**0.785**
subayai	noroi	-0.117	0.150	**0.759**
hadena	jimina	**0.608**	-0.141	0.020
binkan-na	donkan-na	-0.272	0.063	**0.787**
sekkyokutekina	shoukyokutekina	**0.801**	-0.061	-0.030
surudoi	nibui	-0.134	0.198	**0.776**
anzen-na	kiken-na	-0.150	**0.660**	-0.050
utsukushii	minikui	-0.020	0.567	0.462
omoiyarinoaru	wagamamana	-0.118	**0.604**	0.048
nigiyakana	sabishii	**0.664**	0.095	-0.219
tsuyoi	yowai	**0.718**	-0.129	-0.559
katudoutekina	fukappatuna	**0.711**	0.116	0.059
rippana	hinjakuna	**0.747**	0.014	-0.441
danseiteki	joseiteki	0.546	-0.274	-0.552
tanomoshii	tayorinai	**0.702**	0.008	-0.465
odayakana	hageshii	-0.541	0.517	0.228
shihaitekina	fukujuutekina	**0.678**	-0.403	-0.300
namerakana	gikochinai	-0.016	0.497	0.481

Table 2. Adjective pairs and factor loadings for rough shape experiment

3.4 Factor analysis

We quantify the results of the questionnaire in the range of 1 to 7 so that the positive adjective has higher score. Then we apply factor analysis. Factor analysis is a statistical data reduction technique used to explain variability among observed variables in terms of fewer unobserved variables called factors. The observed variables are modeled as linear combinations of the factors:

$$x = Af + e \tag{1}$$

$$x = [x_1, x_2, \cdots, x_n]^T \tag{2}$$

$$f = [f_1, f_2, \cdots, f_m]^T \tag{3}$$

$$e = [e_1, e_2, \cdots, e_n]^T \tag{4}$$

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nm} \end{bmatrix} \tag{5}$$

where $x_i (i = 1, \cdots, n)$: observed variable, $f_j (j = 1, \cdots, m)$: common factor, $e_i (i = 1, \cdots, n)$: specific factor, $a_{ij} (i = 1, \cdots, n; j = 1, \cdots, m)$: factor loading. In this case, the observed variable is score of adjective pair, and n=38.

After extracting factors by the repetitive principal factor method, we determine that a three-factor solution, m=3, is suitable based on the following factors and the difference in eigenvalues. Table 2 summarizes the factor loadings of factor 1, 2, and 3 after normalized Varimax method. Focusing on the adjective pairs whose absolute value of factor loading is 0.60 or more, we interpret the meanings of the three factors.

(a) The adjective pairs which have higher factor loadings of factor 1 and lower factor loadings of the other factors are divided into two groups. The first group contains "rippana (grand)", "tanomoshii (dependable)", etc. This group is related to the impression of leaders. The second group contains "sekkyokutekina (aggressive)", "katsudoutekina (active)", etc. This group is related to the impression of active person. Hence we call factor 1 "leadership-activity" factor.

(b) Factor 2 has higher factor loadings for "sukina (favorite)", "chikazukiyasui (accessible)", "kimochinoyoi (amiable)", etc. Accordingly, we interpret factor 2 as a familiarity with or good feelings about the robot, and call factor 2 "friendliness" factor.

(c) The adjective pairs which have higher factor loadings of factor 3 and lower factor loadings of the other factors are "hayai (fast)", "subayai (quick)", "binkan-na (sensitive)", etc. These are related to the speed of the motion; we call factor 3 "quickness" factor.

3.5 Discussions about effects of rough shape on human impressions

Fig. 4 shows the mean value of the standard factor score for each of the eight robots with respect to each factor. The meanings of the symbols in the graphs are described in 3.1 and Table 1. We apply the T-test (5% level) to all combinations of these results.
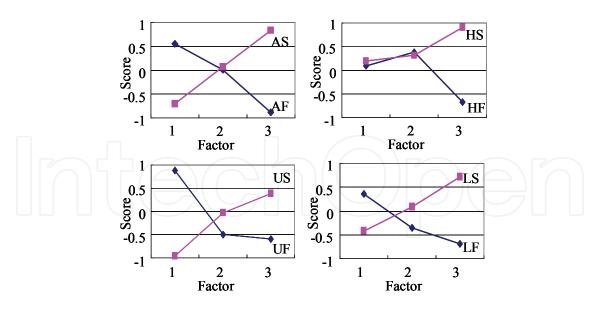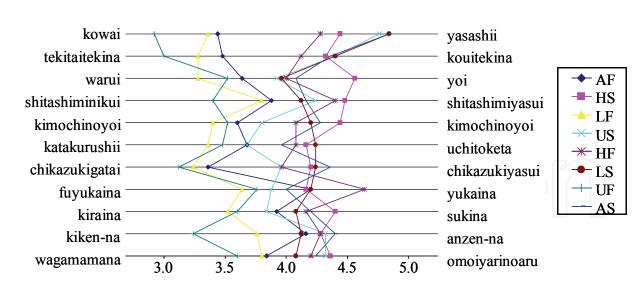
Fig. 4. Standard factor scores of eight robots

(a) With respect to the quickness factor (factor 3), the fat one (F) and the slim one (S) differ significantly for all parameters (A, H, U, L). Regardless of the parameters, the slim one (S) gives the impression of higher quickness than the standard robot "K", and the fat one (F) gives the impression of lower quickness than the standard robot "K". When the overall thickness of robot (A) is changed, the difference between the fat robot "AF" and the slim robot "AS" is largest.

(b) With respect to the leadership-activity factor (factor 1), changing the thickness of head (H) makes little difference. For other parameters (A, U, L), the fat one (F) and the slim one (S) differ significantly. The fat one (F) gives the impression of higher leadership-activity than the standard robot "K", and the slim one (S) gives the impression of lower leadership-activity than the standard robot "K". When the thickness of body (U) is changed, the difference between the fat body "UF" and the slim body "US" is largest. That is more effective than changing the overall thickness of robot (A).

(c) With respect to the friendliness factor (factor 2), the difference between the fat one (F) and the slim one (S) is smaller than the cases of the quickness and leadership-activity factors. Only for the legs (L), the fat legs "LF" and the slim legs "LS" differ significantly.

(d) When the overall thickness of robot (A) is changed, the factor scores of the friendliness nearly equal zero. It means that the impressions for the fat robot "AF" and the slim robot "AS" are almost same as the standard robot "K". This result suggests that keeping the ratio of the overall thickness gives little influences on the friendliness factor.

(e) The slim body "US" and the slim legs "LS" give almost the same impression of the friendliness as the standard robot "K". But the fat body "UF" and the fat legs "LF" give the impression of lower friendliness than the standard robot "K".

(f) Both the fat head "HF" and the slim head "HS" have greater factor scores of the friendliness than zero. They give the impression of higher friendliness than the standard robot "K". Fig. 5 shows the average rating grades of each robot on the adjective pairs related to the friendliness factor. The slim head "HS" gets high grade with respect to "yoi (good)", and the fat head "HF" gets high grade with respect to "yukaina (pleasant)". Accordingly the reason why the friendliness increases is different when the head is made fat (F) and slim (S).

Fig. 5. Rating grades of eight robots on adjective pairs related to friendliness

4. Psychological evaluation for biped walking of humanoid robots

4.1 Purpose of experiment

When robots are introduced into human society in the future, the robots and humans will pass each other frequently. Hence, it is important that the humans do not feel uncomfortable or insecure around the moving robots. While the work (Inoue, 2005a) investigates the head motion and walking speed as a sign of awareness, this experiment evaluates the way of biped walking for its own sake. The walking motion of current humanoid robots is mainly intended for stable walking. But various walking motions will be possible for humanoid robots: walking with the knees bent, walking with the body swaying, walking with long strides, and so on. How do the differences in walking motions influence human impressions? If we can obtain some knowledge on this relationship, this knowledge will be useful for designing and planning suitable walking motions for the humanoid robots which will move around in our society.

It is not easy to develop a new method of biped walking and to make real humanoid robots walk stably. This is because the performances of current humanoid robots are limited and the effects of a disturbance (e.g., irregularity of the ground) must be compensated. But psychological experiments aim at investigating visual effects of walking motions on human psychology. For these reasons, we evaluate human impressions for biped walking of humanoid robots using virtual reality.

4.2 Experimental method

Fig. 6 shows the model of humanoid robot HRP-2 used in the experiment and a bird's-eye view of the settings. The robot is 1.54 [m] in height and 0.62 [m] in width. A 3D CG model of this robot in real scale is presented to subjects through CAVE. The width of the virtual corridors is 2.3 [m]. Each subject sits on a chair placed at the intersection of two corridors. The robot starts from the position of 1 [m] in front and 3 [m] on the left of the subject, and it cuts in front of him or her along the corridor. The distance between the subject and the robot's path is 1 [m]. The subject sees the walking robot from its side (not from the front) so

that he or she can see the whole body motion of the robot. The walking speed is constant at 0.17 [m/s]. The sound of the robot's walking, which is a recording of a real HRP-2, is also presented.
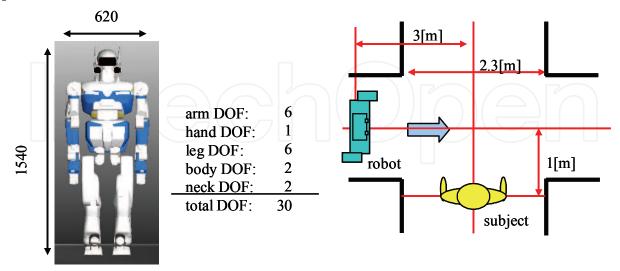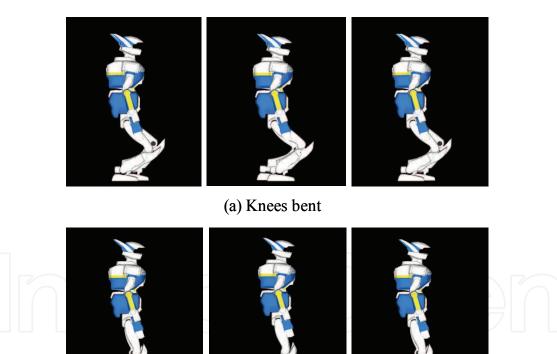

Fig. 6. Humanoid robot HRP-2 and setting of experiment for evaluating biped walking
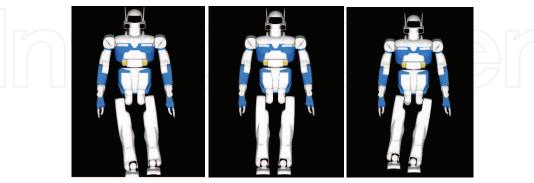

(a) Knees bent

(b) Knee stretched
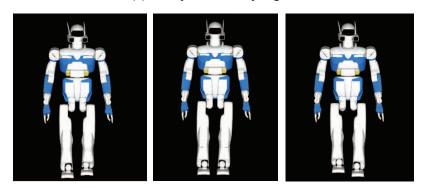
Fig. 7. Biped walking motions with knees bent or stretched

There are many parameters that define biped walking motion. In this experiment, the following two parameters, which are commonly seen in the walking of current humanoid robots, are selected: 1) the knees are bent or stretched, and 2) the body is side-swaying or in

an upright posture. Fig. 7 illustrates the difference in (a) knees bent and (b) knees stretched. Fig. 8 illustrates the difference in (a) body side-swaying and (b) body in an upright posture. Combining them, we generate four walking motions. In all motions, the head and body are facing in the walking direction. All subjects see these four walking motions. In order to cancel out the order factor, these are presented to subjects in randomized order.

(a) Body side-swaying

(b) Body in upright posture

Fig. 8. Biped walking motions with or without body side-swaying

4.3 Psychological evaluation

After seeing each motion, the subject answers the questionnaire about his or her impression on the robot's motion. The questionnaire by the semantic differential method consists of 29 adjective pairs, summarized in Table 3. Each adjective pair is evaluated according to five rating grades. In this table, positive adjectives are arranged on the left side. Some adjective pairs of the questionnaire sheet are swapped so that the pairs may be balanced. The sheet is written in Japanese.

The subjects are 34 men and 13 women between the ages of 14 and 32; they do not get a chance to see real humanoid robots.
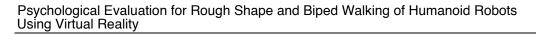
4.4 Factor analysis

We quantify the results of the questionnaire in the range of 1 to 5: the positive adjective is 5, and the negative adjective is 1. Then we apply the factor analysis. After extracting factors by the repetitive principal factor method, we determine that a three-factor solution is suitable based on the following factors and the difference in eigenvalues. Table 3 summarizes the

factor loadings of factor 1, 2, and 3 after Varimax normalized. Focusing on the adjective pairs whose absolute value of factor loading is 0.60 or more, we interpret the meanings of the three factors.

(a) Factor 1 has high factor loadings for many adjective pairs. Among them, the factor loadings of other factors for "shitashimiyasui (friendly)," "kawairashi-i (lovable)," and "yukaina (pleasant)" are small. Accordingly, we call factor 1 the "friendliness" factor.

(b) Factor 2 has high factor loadings for "hayai (fast)," "subayai (quick)," and "binkan-na (sensitive)," which concern the speed of the robot motion; we call factor 2 the "quickness" factor.

(c) Factor 3 has high factor loadings for "hageshi-i (intense)" and "hadena (showy)," which concern the activity of the robot motion; we call factor 3 the "activity" factor.

Adjective pairs (in Japanese)		Factor 1	Factor 2	Factor 3
Yasashi-i	Kowai	0.699	0.039	-0.299
Kanji no yoi	Kanji no warui	0.641	0.188	-0.165
Shitashimiyasui	Shitashiminikui	0.600	0.085	0.004
Anzen-na	Kiken-na	0.410	0.177	-0.447
Atatakai	Tsumetai	0.673	0.021	0.106
Kawairashi-i	Nikurashi-i	0.608	-0.014	-0.017
Uchitoketa	Katakurushi-i	0.648	0.052	0.173
Anshin-na	Fuan-na	0.436	0.279	-0.408
Chikazukiyasui	Chikazukigatai	0.714	0.215	-0.158
Akarui	Kurai	0.630	0.188	0.172
Omoiyari no aru	Wagamamana	0.455	0.025	-0.338
Ningentekina	Kikaitekina	0.436	0.348	0.046
Shizukana	Souzoushi-i	0.126	-0.145	0.724
Chu-uibukai	Fuchu-uina	0.589	0.119	0.277
Yukaina	Fuyukaina	0.716	0.065	-0.016
Sukina	Kiraina	0.675	0.090	-0.135
Kyoumibukai	Taikutsuna	0.380	0.094	0.151
Yoi	Warui	0.588	0.180	-0.147
Kouritsutekina	Muda no o-oi	0.026	0.490	-0.363
Hayai	Osoi	-0.066	0.735	0.183
Subayai	Noroi	-0.003	0.804	0.184
Hageshi-i	Odayakana	-0.292	0.065	0.697
Sekkyokutekina	Shoukyokutekina	0.264	0.374	0.542
Noudoutekina	Jyudoutekina	0.134	0.294	0.480
Hadena	Jimina	0.042	0.112	0.691
Karoyakana	Omo-omoshi-i	0.183	0.499	0.070
Binkan-na	Donkan-na	0.124	0.677	0.137
Kashikoi	Orokana	0.177	0.551	-0.216
Shizen-na	Fushizen-na	0.312	0.563	-0.122

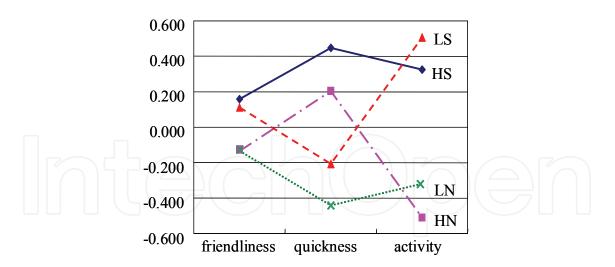Table 3. Adjective pairs and factor loadings for biped walking experiment

Fig. 9. Standard factor scores of four biped waking patterns

4.5 Discussions about effects of biped walking on human impressions

Fig. 9 shows the mean value of the standard factor score for each walking motion with respect to each factor. Here "L" means knees bent, "H" means knees stretched, "S" means body side-swaying, and "N" means body in an upright posture. Thus, the four walking motion patterns are expressed as "LS," "LN," "HS," and "HN."

It seems that the walking motions are divided into two groups with respect to each factor. We apply the T-test (5% level) to these results.

(a) With respect to the friendliness factor, the motions seem divided into the group (HS, LS) and group (HN, LN). This means that the friendliness factor depends on the body side-swaying. But, according to the results of the T-test, all pairs for the four motions are not significantly different.

(b) With respect to the quickness factor, the pairs HS-LS, HS-LN and HN-LN differ significantly; but the pair HN-LS is not significantly different. Hence, the motions are generally divided into the group (HS, HN) and group (LS, LN).This means that the quickness factor mainly depends on knee bending. Furthermore, walking with the knees stretched (H) has a higher quickness than walking with the knees bent (L).

(c) With respect to the activity factor, the pairs HS-LS, HS-LN, HN-LS and HN-LN differ significantly. Hence, the motions are divided into the group (HS, LS) and group (HN, LN). This means that the activity factor depends on body side-swaying. Walking with the body side-swaying (S) has a higher activity than walking in an upright posture (N).

Because significant differences cannot be seen directly in the friendliness factor, we calculate the mean value of the grade for each walking motion with respect to each of 10 adjective pairs related to the friendliness factor. The results are shown in Fig. 10, where the horizontal axis represents the mean value of the grade. With respect to "uchitoketa (relaxed)," the motion HN is different from the others. Thus, combining the knee stretched and the upright posture gives a relaxed impression. With respect to the pair "akarui (cheerful)," the motions seem divided into the group (HN, LN) and group (HS, LS). Hence, body side-swaying gives a more cheerful impression than does an upright posture. With respect to "kawairashi-i (lovable)," the motion LS is different from the others. Thus, combining the knees bent and body side-swaying gives a lovable impression.
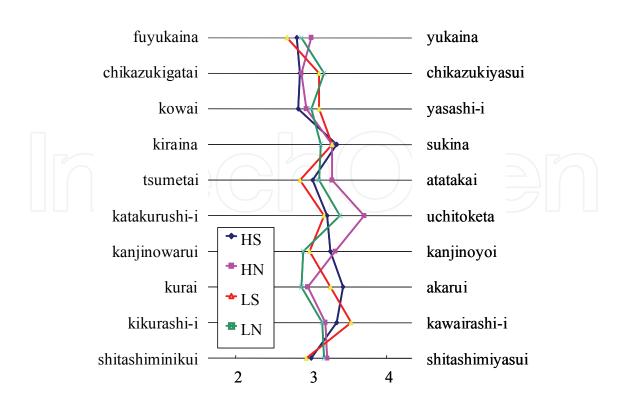
Fig. 10. Rating grades of four biped walking patterns on adjective pairs related to friendliness

5. Summary

Human impressions of humanoid robots are investigated using immersive 3D visualization system CAVE. In the first experiment, human impressions for rough shape parameters (thickness of head, body and legs) of humanoid robots are investigated. In the second experiment, human impressions for walking humanoid robots are evaluated, because robots and humans will pass each other frequently in future human-robot coexisting society.

Notice that factor analyses found the similar factors of the impressions for appearance (rough shape parameters) and motion (way of biped walking): friendliness, quickness and (leadership-)activity. Among them, the friendliness factor is an important property for robots coexisting with people. We obtain the following knowledge on the friendliness factor, which will be useful to design rough shape of humanoid robots as service robots and to generate their biped walking motion:

(a) Making the overall thickness of robot fat or slim (or keeping the ratio of the thickness of head, body and legs) gives little influences on the friendliness.
(b) Making the body or legs fat deceases the friendliness.
(c) Making the head fat or slim increases the friendliness. The reason why the friendliness increases is different for the fat head and slim head. The slim head gives good impression, and the fat head gives pleasant impression.
(d) Combining the knees stretched and the upright posture gives a relaxed impression, and combining the knees bent and the body side-swaying gives a lovable impression. The body side-swaying gives a more cheerful impression than does the upright posture.

These experiments limit the parameters of humanoid robots to two or three. The reason is to reduce the time of the experiment per subject and to make the difference between the robot shapes clearly understandable. In the future, we will continue with experiments on the influences of other parameters on human impressions.

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The aim of this book is to provide new ideas, original results and practical experiences regarding service robotics. This book provides only a small example of this research activity, but it covers a great deal of what has been done in the field recently. Furthermore, it works as a valuable resource for researchers interested in this field.

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