Design and Evaluation of the new Emotional Expression Head for the ADL assistive Full-body Emotion Expression Humanoid Robot KOBIAN

N. Endo[A,*], S. Momoki[A], M. Zecca[B,C], *Member, ISG*, **K. Itoh[C,D], A. Takanishi[B,C,D,E]**, *Member, ISG*

***Abstract*— Personal robots and robot technology (RT)-based assistive devices are expected to play a major role in our elderly-dominated society, with an active participation to joint works and community life with humans, as partner and as friends for us. In particular, these robots are expected to be fundamental for helping and assisting elderly and disabled people during their activities of daily living (ADLs). To achieve this result, personal robots should be capable of human-like emotion expressions; in addition, human-like bipedal walking is the best solution for the robots which should be active in the human living environment. Although several bipedal robots and several emotional expression robots have been developed in the recent years, until now there was no robot which integrated all these functions. Therefore we developed a new bipedal walking robot, named KOBIAN, which is also capable to express human-like emotions. In this paper, we present the design and the preliminary evaluation of the new emotional expression head.**

I. Introduction

The average age of the Japanese population is rising fast because of an increased life expectancy and a reduced birth rate. Today there are about 2.8 workers per retiree; in fact, this figure is estimated to fall to 1.4 by 2050, when more than 35% of the population is expected to be over 65 [1]. Therefore, there is considerable expectation for a growing need for home, medical, and nursing care services to assist this aging society, both from the physical and psychological points of view [2].

In this elderly-dominated society, Personal Robots and Robot Technology (RT)-based assistive devices are expected to play a major role, both for joint activities with their human partners and for participation in community life. In particular, these robots are expected to be fundamental for helping and assisting elderly and disabled people during their activities of daily living (ADLs). These new devices should be capable of a smooth and natural adaptation and interaction with their human partners and the environment. They should also be able to communicate naturally with humans, especially in the case of home and personal assistance for elderly and/or handicapped persons. Moreover, these devices never should have a negative effect on their human partners, neither physical nor emotional.

Our group, in particular, is studying the fundamental technologies of service RT system that shares the living environment with elderly people and supports their comfortable life. We think that, for robots which share the environment with human and support their life, simple unilateral communication (e.g. operation, or programming) are not enough. Naturally, robots which receive influence from the human and have effect on human must have bilateral, human-like communication ability to naturally adapt to the partner and to the context.

In order to achieve communication ability similar to the one of the humans, the hardware itself should be as close to human as possible. However, it is has been reported that the affinity of robot decreases sharply when the similarity between the robot and human increases over a certain level [3]. If we realize a hardware which is totally similar to human, non-similarity except the appearance such as motion might give a negative, eerie impression to human. So a robot which closely resemble human may not be always the best solution.

Concerning the facial expression of emotions, there are several robots (androids) designed to have facial expression very similar to the humans'. One example is SAYA [4], but there are several others. We have developed the emotional expression humanoid robot series WE-4, capable of performing several facial expressions [5]. WE-4 has simplified and symbolic appearance, and let the estimation of the emotion be easy for human.

WE-4 is made as a platform for human-robot interaction experiments and possesses several degrees of freedom (59, in its current version) and sensory inputs (hearing, vision, touch, and smell); but it has only the upper body, and therefore it does not have mobility capability. Instead, we think that mobility is fundamental for the robot which has to be active in the human life space. Mobile robot can actively affect human; a robot that does not have mobility capability is only an

A. Graduate School of Science and Engineering, Waseda University, Tokyo, Japan
#59-308, 3-4-1 Okubo, Shinjuku-ku, Tokyo, 169-8555 Japan
Tel: +81-3-5286-3257, Fax: +81-3-5273-2209
noble@ruri.waseda.jp (N. Endo), takanisi@waseda.jp (A. Takanishi)
B. Institute for Biomedical Engineering, ASMeW, Waseda University, Tokyo, Japan
C. Italy-Japan Joint Laboratory on Humanoid and Personal Robotics "RoboCasa", Tokyo, Japan
D. Advanced Research Institute for Science and Engineering, Waseda University, Tokyo, Japan.,
E. Humanoid Robotics Institute (HRI), Waseda University, Tokyo, Japan

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ornament.

What kind of mobility is suitable for human living space? The human living environment is suitable for human beings; it is basically suitable for bipedal walking. Therefore it can be said that bipedal walking is the most suitable mobile form for human living environments.

There are several crucial aspects in the design of bipedal walking humanoid robots. The robot needs to be autonomous (hardware and power supply system) because of mobility; there is also a severe weight limit because of weight ratio power of available actuator. Therefore it is important to balance several requirements of the design such as weight, size, power supply, number of actuators, the degree of freedom configuration, etc. Depending on the case, it may be difficult to assign a lot of degree of freedom for facial expression to the head.

In this paper, we describe the design and the evaluation of the robot head that has the ability for an effective facial emotion expression with only a small number of degrees of freedom.

II. KOBIAN

A. Project Requirements

As written above, the main requirements for such interactive a robot are: mobility; bipedal walking; interaction; and emotion expression.

In addition, the robot also needs to understand the relative position of an object, to execute a task to support humans in their living environment. Therefore the vision must be able to sense depth. To do that, it is required that each eye part has a camera that can separately move around the Yaw-axis. The robot also needs to see its steps, because there might be an object posing hindering the walk in the human living environment.

Category	Specification
Size	Human-like shape and size
Mobility	Biped walking Stretched knee
Vision	Relative position of objects Possibility to see its own steps
Emotions	Happiness Perplexity
Battery	Battery driven Autonomous movement

Table 1: Summary of the requirements for the new robot.

Concerning the interaction at emotional level, a mechanism to tell the user whether the robot understand human words or not is important for a smooth communication and interaction. In addition, it is necessary to transmit emotion for the emotional communication. Therefore the robot should be capable of facial expression for promotion of interaction, communication of meaning of the sensitivity, and indication of internal states. In particular, smile that indicates the robot feel pleasant and perplexity that indicates the robot cannot understand human words are essential. All the above requirements are summarized in Table 1.

Name	Mobility	Bipedal Walking	Interaction	Emotion Expression
WE-4RII [5]	NO	NO	YES	YES
SAYA [4]	NO	NO	YES	YES
Robovie-IV[6]	YES	NO	YES	NO
ASIMO[7]	YES	YES	YES	NO
WABIAN-2[8]	YES	YES	NO	NO
KOBIAN	YES	YES	YES	YES

Table 2: Comparison about Robot Function.

Until now, however, there was no robot capable of fulfilling all the above design specification for interactivity in the human living environment. Therefore we developed the whole body emotion expression humanoid robot KOBIAN. Table 2 presents the comparison of KOBIAN with other robots. The details of the development of the robot are presented in the following sections.

B. Mechanical Design

We designed and developed KOBIAN based on WABIAN-2 and WE-4 to meet above-mentioned requirements.

Starting from WABIAN-2, we removed the Yaw axis of the ankle and the Roll axis of the trunk. To balance the size and weight of the head to the size of the body (both for aesthetic reasons but also to make the bipedal walking possible), a new emotional expression head had to be designed. At the same time, we are developing a new, lighter version of artificial hands (not ready at the time of the preparation of this paper).

The basic concept of the design of the head is lightweighting and downsizing of the head of WE-4 in order to mount it on the body of WABIAN-2. In addition, we decided to reduce the DOF as much as possible because of the limits of power supply system and the I/O port. The DOF configuration and overview of KOBIAN are shown in Fig. 1, and Fig. 2; Fig. 3 shows the picture of the first prototype. *Table 3* summarizes the main data.

1) Design of the head

The weight of WE-4's head is 7.5 kg; the maximum weight for KOBIAN's head, instead, is 3.5 kg. Concerning the size, WE-4's head is big in comparison with the human head; instead, KOBIAN's head should be as close to the human head as possible, because the size of the body is at the same level as a human body.

About the expression, we focused the design on the capability to express happiness and perplexity. This is because we thought that it is useful to express whether a robot is able to understand human instructions during the interaction.

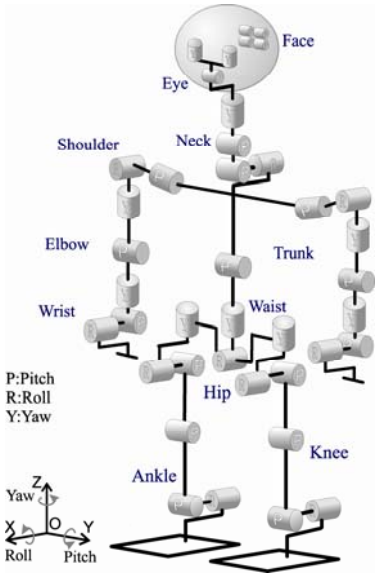


Fig. 1: Distribution of the DOFs

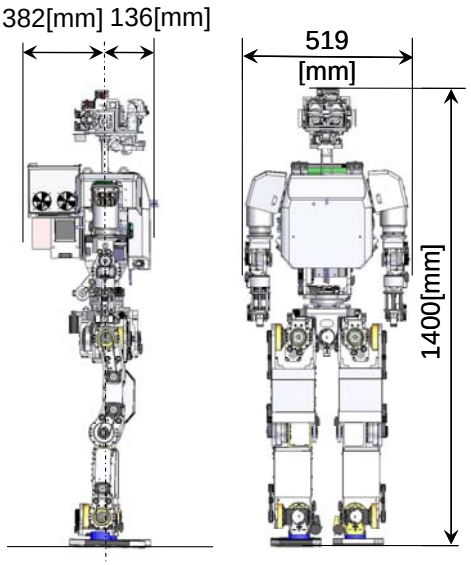


Fig. 2: Schematic Overview of KOBIAN

Fig. 3: Picture of KOBIAN

KOBIAN		
Height	1400 mm	
Weight	58 kg	
DOFs	48, distributed as follows:	
	Head	7
	Neck	4
	Arm	7x2
	Hand	4x2
	Trunk	1
	Waist	2
	Leg	6x2
Sensors	6-Axis Force/Torque Sensors Photo Sensors Magnetic Encoders	
Actuators	DC Servo Motors	
Reduction Mechanism	Harmonic Drive Gears Timing-belt/Pulleys	
Batteries	Li-ion Battery	

Table 3: KOBIAN main data.

At first we assumed that the facial expression which KOBIAN express is symmetric. As for this, the basic facial expression is expressed by symmetric movement. Moreover, we think that the robot which has simplified appearance like comics expression is more effective than the robot looking just like human; therefore the facial expression of the robot has not to be realized with the same mechanism and shape as human.

The direction of eyes is useful to communicate the attention and the intention. In addition, the distance between the robot and the observed object can be obtained. Therefore the eyes of KOBIAN have 3 DOFs (both eyes Pitch and each eyes Yaw) as well as WE-4.Concerning the mechanism of the Yaw of the eye, WE-4 uses antagonist wires and torsion spring. However, assembly and maintenance are quite difficult. Therefore a new mechanism using pulleys has been developed for KOBIAN.

Because quantity of movement was comparatively small, the DOF of the opening and shutting of lower eyelids is omitted. KOBIAN has 1DOF of the opening and shutting of upper eyelids. The eyelids are molded with Hitohada gel (Exseal Co., Ltd.) because rigid eyelids interfere in mechanism of eyes. In addition, the Pitch axis motion of the upper eyelids is mechanically synchronized with the Pitch axis motion of eyes (same mechanism as in WE-4). Fig. 4 shows the picture of KOBIAN's head.

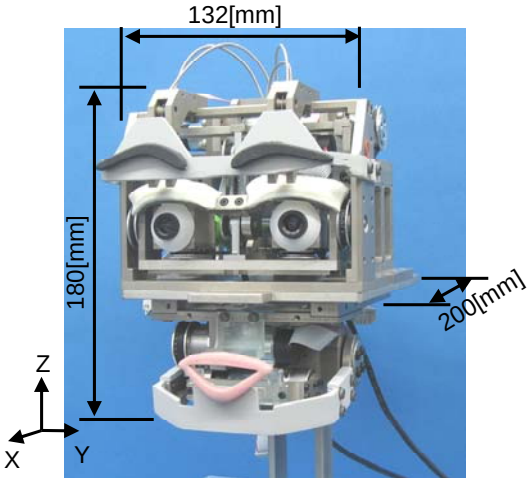


Fig. 4: Picture of KOBIAN's head

WE-4 has 5 DOFs at the mouth (pitch axis motion at the jaw, extending, up and down at the angles of mouth). The lip is made by using springs of spindle type and actuated by wires, and has high expression performance. However, assembly and maintenance are hard. KOBIAN has 2 DOFs at the mouth (pitch axis motion at the jaw, up and down at the angles of mouth). The lip is molded with thermoplastic resin SEPTON (KURARAY Co. Ltd.). The mechanism of the mouth is shown in Fig. 5. This mechanism is much easier to assembly and maintain than the previous one.

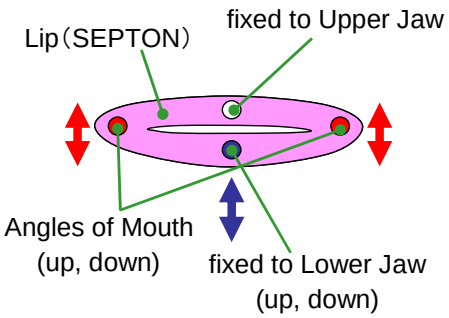


Fig. 5: Mechanism of the mouth.

The control points of the eyebrows of WE-4 are two points at both ends and two internal points equally spaced of the eyebrow. The wires actuate these points up and down. However, the cover and the mechanism are not separated so that it is not easy to remove and change the eyebrows. As a result, assembly and maintenance are quite difficult. In the mechanism of the eyebrows of KOBIAN, the eyebrows and the cover and the drive mechanism are separated. This means that it is easy to adapt various shapes of the cover and eyebrow. The eyebrows are molded with SEPTON, and their shape is now much more natural looking than in WE-4.

Table 4 presents the comparison between DOF configurations of KOBIAN and WE-4 heads. More details on the development of the head are presented in [9].

Part	WE-4	KOBIAN
Eyes	3	3
Upper Eyelids	4	1
Lower Eyelids	2	0
Eyebrows	8	1
Jaw	1	1
Lip	4	1
Total	22	7

Table 4: DOF Configurations of KOBIAN and WE-4.

III. Experimental Evaluation

We conducted a questionnaire of what a kind of impression people get about the facial expression of KOBIAN's head. Objectives of this evaluation are:

1. assessment of the recognition rate of KOBIAN's facial expressions
2. proof that KOBIAN is capable of expressing "perplexity", and incapable of expressing "anger"
3. comparison of the recognition rate of KOBIAN with the one of WE-4.

Two groups of users participated to the preliminary evaluation after providing the informed consent:

- Group A: 127 young subjects (118 men and 9 women, average age: 23.0; SD: 2.82);
- Group B: 17 elderly subjects (average age: 68.0; SD: 12.8).

We showed 7 pictures of WE-4 (1 neutral and 6 emotional, Fig. 6) and 17 pictures of KOBIAN (1 neutral and 16 emotional, Fig. 7). Each emotional picture was shown side by side with the picture of the Neutral expression as a reference (Fig. 6(a), Fig. 6(a)). To reduce the influence of outer covering, KOBIAN was using a cover resembling WE-4's face. All the pictures were shown in random order, varying from subject to subject. In case of Group A, an online questionnaire was used; in case of Group B, all the pictures were printed on A4 paper (1 emotion per page) and shuffled before the presentation. The subjects were asked to choose the emotion that they thought the picture of the robot was expressing among a predetermined list.

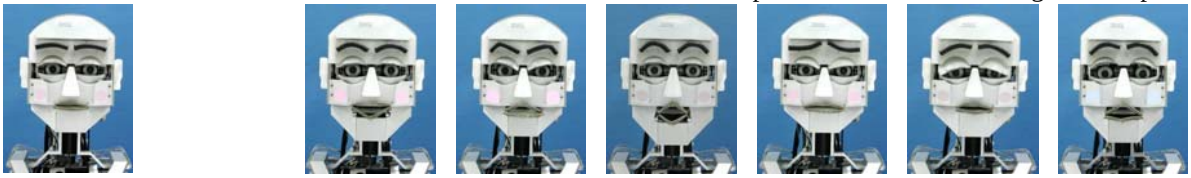
Finally, we compared the recognition rates of KOBIAN and WE-4. The results are summarized in Table 5 and Fig. 8 for Group A, and Table 6 and Fig. 9 for Group B. In those tables and figures the following abbreviations are used: ANG: Anger; HAP: Happiness; SUR: Surprise; DIS: Disgust; SAD: Sadness; FEA: Fear; PER: Perplexity; OTH: other.

Overall, the recognition ratio of KOBIAN's face is lower than WE-4, as expected because of the extreme reduction of DOFs (22 DOFs used for facial expressions in WE-4, while only 7 are used in KOBIAN). The only exception is "disgust", for which KOBIAN's face seems to be far more expressive both for young and for elderly people.

In case of elderly people (Fig. 8) the recognition ratio is also generally lower than the one of younger people (Fig. 9), which might be related to their impaired perception due to their age and/or their poor health conditions. This might suggest that for elderly people a more empathized emotional expression is needed. Despite of this, however, this evaluation proved the effectiveness of emotion expression even with a reduced number of DOFs.

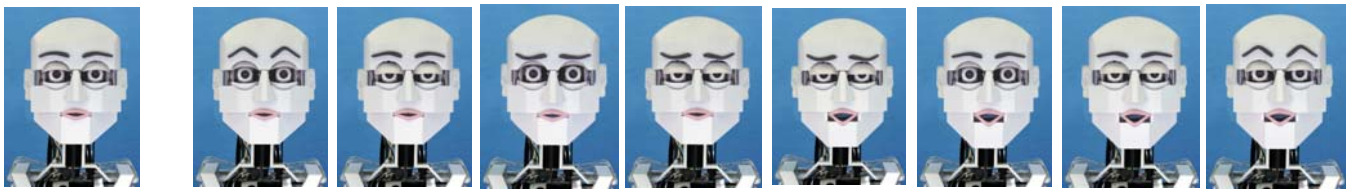
Concerning WE-4, only 4 emotions ("Anger", "Happiness", "Surprise", and "Sadness") were correctly labeled by both groups, although with different recognition ratios. For example, "Anger" was correctly identified by 97.7 % of Group A, but only by 56.2% for Group B; "Surprise" was well recognized by Group A (87.6%), while Group B mixed it (46.1%) with "Happiness" (29.4% for the picture WE-4 #3) or "Fear (46.1% for the picture WE-4 #6).

"Perplexity" received a very low score: 28.1% for Group A, 17.5% for Group B. Which of course is not a surprise, as none of the pictures of WE-4 was designed to express this emotion.

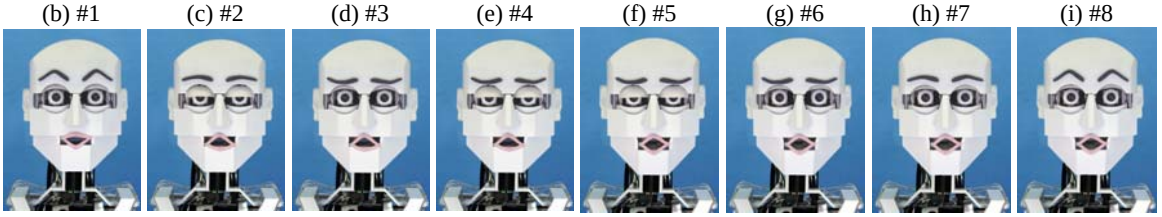


(a) Neutral (b) #1 (c) #2 (d) #3 (e) #4 (f) #5 (g)#6

Fig. 6: Facial Expressions of WE-4.



(a) Neutral (b) #1 (c) #2 (d) #3 (e) #4 (f) #5 (g) #6 (h) #7 (i) #8



(j) #9 (k) #10 (l) #11 (m) #12 (n) #13 (o) #14 (p) #15 (q) #16

Fig. 7: Facial Expressions of KOBIAN.

	ANG	HAP	SUR	DIS	SAD	FEA	PER	OTH
WE-4 #1	0.00	**94.57**	2.33	0.00	0.00	0.00	0.78	2.33
WE-4 #2	**97.67**	0.00	1.55	0.78	0.00	0.00	0.00	0.00
WE-4 #3	0.00	9.30	**87.60**	0.00	0.00	0.78	0.78	1.55
WE-4 #4	16.41	0.00	0.78	14.06	28.13	6.25	28.13	6.25
WE-4 #5	0.00	0.00	0.00	1.55	**77.52**	0.00	9.30	11.63
WE-4 #6	0.00	2.34	42.97	8.59	13.28	10.94	15.63	6.25
MAX	*97.67*	*94.57*	*87.60*	*14.06*	*77.52*	*10.94*	*28.13*	*11.63*
KOBIAN #1	2.34	6.25	**65.63**	0.00	0.00	0.00	2.34	23.44
KOBIAN #2	9.30	0.00	0.00	39.53	1.55	0.00	4.65	44.96
KOBIAN #3	3.10	0.00	6.20	7.75	24.81	8.53	44.19	5.43
KOBIAN #4	7.75	0.00	0.00	**62.79**	6.98	0.00	13.18	9.30
KOBIAN #5	6.98	1.55	0.00	47.29	1.55	1.55	17.05	24.03
KOBIAN #6	0.00	**70.31**	21.09	0.00	0.00	0.78	0.00	7.81
KOBIAN #7	3.88	2.33	1.55	31.01	0.78	0.00	5.43	**55.04**
KOBIAN #8	1.55	34.11	6.20	7.75	0.78	0.00	2.33	47.29
KOBIAN #9	0.78	**57.36**	39.53	0.00	0.00	0.00	0.00	2.33
KOBIAN #10	11.63	0.00	0.78	46.51	0.00	0.00	3.88	37.21
KOBIAN #11	9.30	0.00	11.63	10.08	11.63	7.75	41.86	7.75
KOBIAN #12	7.75	0.00	0.00	**66.67**	2.33	0.00	11.63	11.63
KOBIAN #13	9.30	0.00	0.00	**65.12**	4.65	0.00	10.08	10.85
KOBIAN #14	11.63	0.00	9.30	12.40	8.53	10.08	42.64	5.43
KOBIAN #15	0.00	12.40	**77.52**	0.00	0.00	0.00	0.78	9.30
KOBIAN #16	2.33	11.63	**84.50**	0.00	0.00	0.00	0.00	1.55
MAX	*11.63*	*70.31*	*84.50*	*66.67*	*24.81*	*10.08*	*44.19*	*55.04*

Table 5. Recognition ratios for WE-4RII's and KOBIAN's pictures (Group A – young subjects).

	ANG	HAP	SUR	DIS	SAD	FEA	PER	OTH
WE-4 #1	0.00	**64.71**	11.76	0.00	5.88	17.65	0.00	0.00
WE-4 #2	**56.25**	6.25	12.50	0.00	6.25	12.50	6.25	0.00
WE-4 #3	0.00	29.41	47.06	11.76	0.00	11.76	0.00	0.00
WE-4 #4	31.25	6.25	0.00	12.50	6.25	25.00	12.50	6.25
WE-4 #5	0.00	17.65	0.00	0.00	**52.94**	11.76	17.65	0.00
WE-4 #6	0.00	0.00	47.06	5.88	23.53	11.76	11.76	0.00
MAX	*56.25*	*64.71*	*47.06*	*12.50*	*52.94*	*25.00*	*17.65*	*6.25*
KOBIAN #1	0.00	20.00	**66.67**	6.67	0.00	0.00	6.67	0.00
KOBIAN #2	0.00	5.88	5.88	11.76	29.41	11.76	23.53	11.76
KOBIAN #3	0.00	5.88	35.29	0.00	5.88	11.76	35.29	5.88
KOBIAN #4	18.75	0.00	6.25	31.25	25.00	0.00	18.75	0.00
KOBIAN #5	5.88	0.00	5.88	35.29	17.65	0.00	35.29	0.00
KOBIAN #6	0.00	29.41	41.18	0.00	5.88	11.76	11.76	0.00
KOBIAN #7	5.88	11.76	5.88	17.65	23.53	5.88	11.76	17.65
KOBIAN #8	11.76	29.41	29.41	0.00	0.00	5.88	11.76	11.76
KOBIAN #9	0.00	**52.94**	23.53	11.76	0.00	0.00	11.76	0.00
KOBIAN #10	0.00	0.00	11.76	29.41	35.29	0.00	17.65	5.88
KOBIAN #11	5.88	0.00	35.29	11.76	5.88	35.29	5.88	0.00
KOBIAN #12	5.88	0.00	5.88	35.29	29.41	5.88	11.76	5.88
KOBIAN #13	25.00	0.00	0.00	25.00	18.75	12.50	18.75	0.00
KOBIAN #14	6.25	0.00	**50.00**	6.25	12.50	12.50	12.50	0.00
KOBIAN #15	0.00	23.53	**70.59**	0.00	0.00	0.00	0.00	5.88
KOBIAN #16	0.00	23.53	**64.71**	5.88	0.00	0.00	5.88	0.00
MAX	*25.00*	*52.94*	*70.59*	*35.29*	*35.29*	*35.29*	*35.29*	*17.65*

Table 6. Recognition ratios for WE-4RII's and KOBIAN's pictures (Group B – elderly subjects).

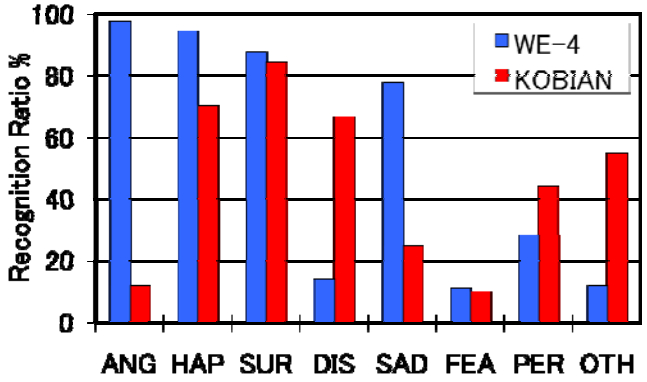


Fig. 8: Summary of the evaluation results (Group A – young subjects).

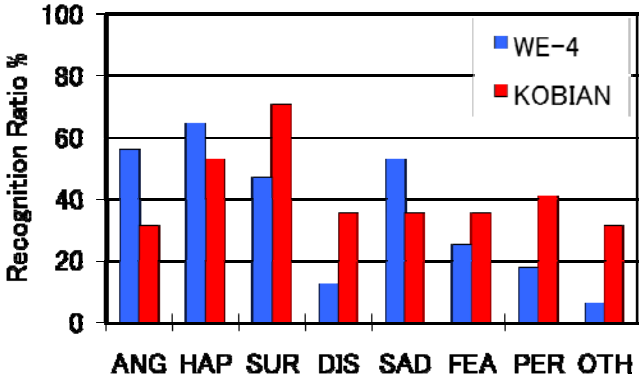


Fig. 9: Summary of the evaluation results (Group B – elderly subjects).

Interestingly, no picture of WE-4 was correctly identified as “Fear” or “Disgust” (maximum recognition rate for “Fear” is only 10.9% for Group A, 25.0% for Group B; maximum recognition rate for “Disgust” is only 14.1% for Group A, 12.5% for Group B). However, in a previous study [5] the difference was much more clear. This might be due to the use of the movements of the neck, which are absent in these pictures. In our future work we will clarify this aspect.

Concerning KOBIAN, the recognition ratio was usually lower than WE-4, for both Group A and Group B. These results are the natural outcome of the reduced number of DOFs of the head of KOBIAN. In addition, WE-4 can also express the emotions by changing its facial color, but KOBIAN cannot (at least in the present version).

As for the specific emotions “Happiness” and “Surprise” are usually well recognized, although the picture that received the higher score depends on the group (see Table 5 and Table 6). The recognition rate of “Anger” is only 11.6% for Group A and 25.0% for Group B. However, the low recognition ratio is not a problem because of the basic design requirement (see Table 1). No picture of KOBIAN was labeled as “sadness” or “fear”, as expected.

Interestingly, several pictures of KOBIAN has been labeled as “Disgust”, although their recognition rate is not particularly high (ranging from 45.2% to 65.0% for Group A, 31% to 35% for Group B). It is also very interesting to observe that picture #6 of WE-4 (Fig. 7(g)), which is supposed to represent “fear”, is actually recognized mostly as “surprise”. Picture #4, instead, is recognized as “perplexity” instead of “disgust”.

IV. Conclusions

In this elderly-dominated society, Personal Robots and Robot Technology (RT)-based assistive devices are expected to play a major role, both for joint activities with their human partners and for participation in community life. So far, several different personal robots have been developed. However, it is not clear what kind of ability is necessary to personal robot. We think that emotion expression of robot is effective for joint activities of human and robot. In particular, the robot should express in particular happiness and perplexity, which we thought being fundamental for a smooth and natural interaction with humans.

In this paper, we presented the design and development of a new robot named KOBIAN, and its new head capable of performing different facial expressions with only 7 DOFs. This new robot is based on the previously developed Biped Humanoid Robot WABIAN-2 for the lower body, and on the Emotion Expression Humanoid Robot WE-4R for the head.

We evaluated the emotional performance of the new head by investigating the recognition rate of its different facial expressions, and we compared it with the facial expressions of WE-4R. The preliminary results of this evaluation show that the recognition rates of the emotions expressed by KOBIAN are lower compared to the one of the WE-4R,

The important result, however, is that KOBIAN can perform the specific facial expressions even with a very limited number of DOFs.

In the future, we will conduct questionnaire for people of various nationality and various generations. In addition, we will investigate the influence of outer covering and the effects of sound, movement, arms, and whole body. Furthermore, we will investigate what kind of robot is effective in human living environment by human-robot interaction experiment.

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