2008 IEEE International Conference on
Robotics and Automation
Pasadena, CA, USA, May 19-23, 2008

Development of Whole-body Emotion Expression Humanoid Robot

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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. The authors think that the emotion expression of a robot is effective in joint activities of human and robot. In addition, we also think that bipedal walking is necessary to robots which are active in human living environment. But, there was no robot which has those functions. And, it is not clear what kinds of functions are effective actually. Therefore we developed a new bipedal walking robot which is capable to express emotions. In this paper, we present the design and the preliminary evaluation of the new head of the robot with only a small number of degrees of freedom for facial expression**

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. 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. A robot prototype has also been developed to prove the concept.

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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, tact, and smell); but it has only the upper body, and therefore it does not have mobility capability. Instead, we think that mobility is a fundamental capability, necessary for the robot which has to be active in the human life space. Mobile robot can actively affect human; Robot which does not have mobility capability is only an 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.

Until now, at the best of our knowledge, there is no robot capable of fulfilling the above design specification for Interactive Robots in the human living environment. Therefore we developed a robot with all these functions. The name of the new robot is KOBIAN. Table I presents the comparison of KOBIAN with other robots.

There are several crucial aspects in the design of bipedal walking humanoid robots. The robot needs to be standalone about machine hardware and power supply system because of mobility capability; 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.

TABLE I
COMPARISON ABOUT ROBOT FUNCTION

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

II. KOBIAN

A. Project Requirement

As mentioned above, it is fundamental for the robot which is active in human living environment to be capable of biped walking. In addition, this kind of robot needs also the capability of moving in natural ways, as they share the living environment with human. Therefore, we developed the whole body emotion expression humanoid robot KOBIAN, based on the Biped Humanoid Robot WABIAN-2, which is capable of walking with stretched knee [8].

The robot needs also to comprehend 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 theYaw-axis. The robot also needs to see its steps, because there might be object posing obstacle to walking on the floor in the human living environment.

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.

A summary of the requirements is presented in Table II.

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).

TABLE II
DESIGN REQUIREMENTS

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	■ Perplexity ■ Happiness ■ No display of anger
Battery	■ Battery driven ■ Autonomous movement

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, 2, and 3.

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.

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 overview of the mechanism of the new KOBIAN's head is shown in Fig. 3.

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.

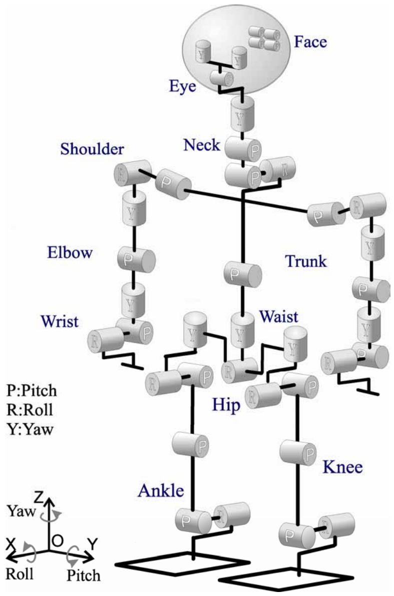


Fig. 1 DOF Configuration

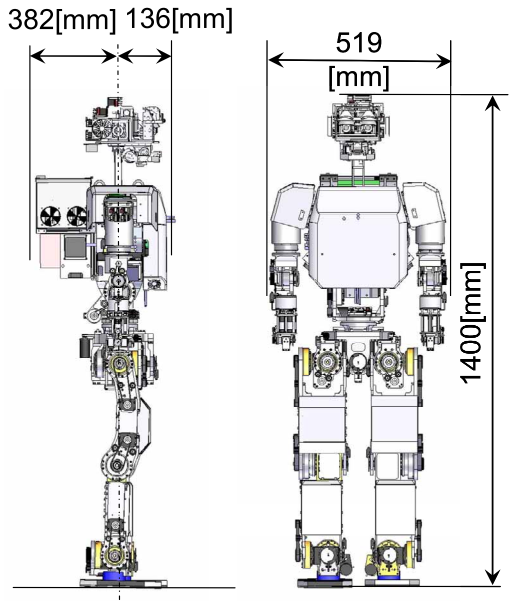


Fig. 2 Overview of KOBIAN

Fig. 3 Picture of KOBIAN

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).

The CAD drawing of the mechanism of the eyes and eyelids is shown in Fig. 4.

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.

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 (Fig. 6). This means that it is easy to adapt various shapes of the cover

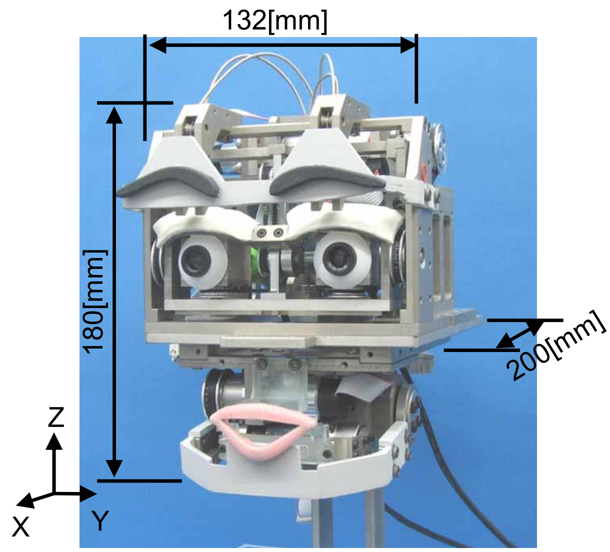


Fig. 3 Overview of Head

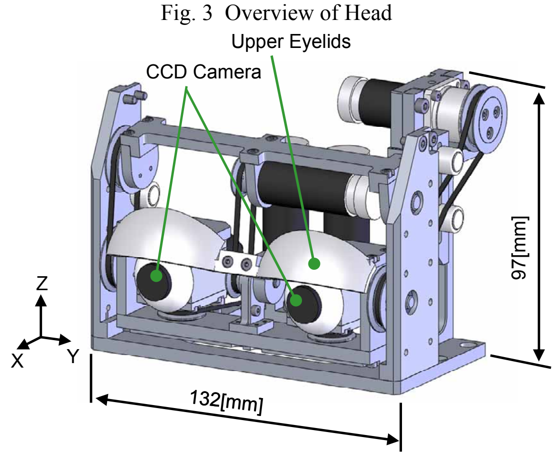


Fig. 4 Mechanical Design of Eyes and Eyelids

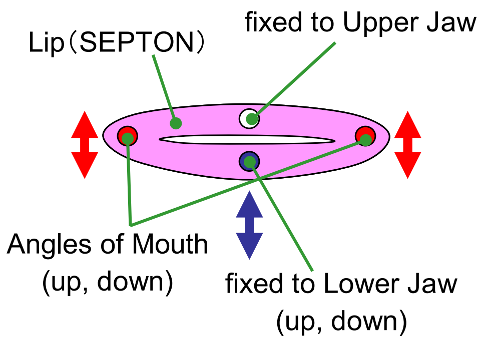
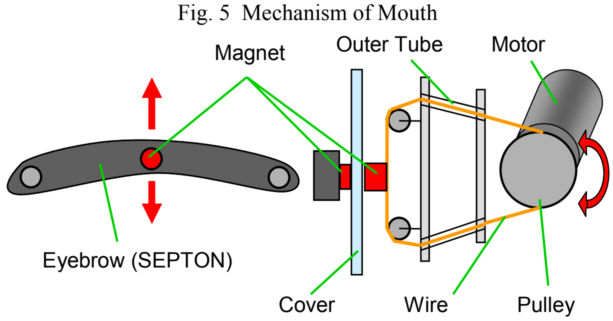
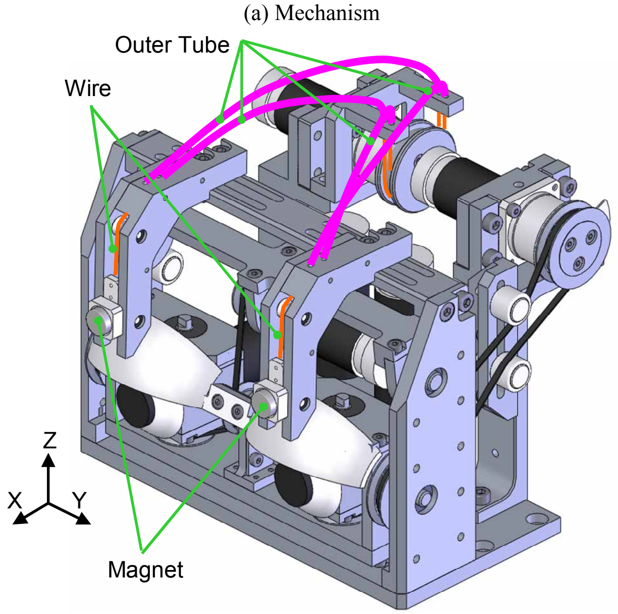


Fig. 5 Mechanism of Mouth



(a) Mechanism



(b) Mechanical Design

Fig. 6 Mechanism and Mechanical Design of Eyebrows

and eyebrow. The eyebrows are molded with SEPTON, and their shape is now much more natural looking than in WE-4.

Table III presents the comparison between DOF configurations of KOBIAN and WE-4 heads.

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.

TABLE III
DOF Configurations of KOBIAN and WE-4

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

127 subjects (118 men and 9 women, average age: 23; SD: 2.82) participated to the evaluation after giving the informed consent to the experiment. We showed 17 pictures of KOBIAN (1 neutral and 16 emotional, Figure 7) and 7 pictures of WE-4 (1 neutral and 6 emotional, Figure 8). Each emotional picture was shown side by side with the picture of the Neutral expression as a reference (Figure 7(a), Figure 8(a)). To reduce the influence of outer covering, KOBIAN was using a cover resembling WE-4's face. The pictures were shown in random order, varying from subject to subject. The subjects were asked to choose the emotion that they thought the picture of the robot was expressing among a predetermined list (“anger”, “happiness”, “surprise”, “disgust”, “sadness”, “fear”, “perplexity”, and “other”).

Finally, we compared the recognition rates of KOBIAN and WE-4. The results are summarized in Table IV. In yellow the emotion with the highest recognition ratio for WE-4; in green the emotion with the highest recognition rate for KOBIAN. The best recognition rates for each emotion for the two robots are summarized in Fig. 9.

As a whole, the recognition rate of KOBIAN’s facial expression is low, and the impressions that the subject takes is disperse compared to WE-4. Considering the maximum recognition rate for each picture, the average for WE-4 is 71.5%, while it is only 57.0% for KOBIAN.

Concerning the specific emotions, the recognition rate for “happiness” is 94.0% in case of WE-4; it is only 68.4% for KOBIAN, falling by almost 26%. The recognition rate for “surprise” is 84.2%, falling by almost 5%. The recognition rate of “perplexity” is 46.1%, but that of WE-4 is much lower (28.5%). Which of course is not a surprise, as WE-4 was not designed to express “perplexity”. The recognition rate of “anger” is 97.4% in WE-4, but only 12.8% in KOBIAN. But in this case, the low recognition rate was not a problem because of the basic design requirement (see Table II). No picture of KOBIAN was labeled as “sadness” or “fear”, as expected.

These results are the natural outcome of the reduced number of DOFs of the head of KOBIAN (7 vs 22 of WE-4). In addition, WE-4 can also express the emotions by changing its facial color, but KOBIAN cannot (at least in the present version). However, we think that the recognition rate can increase by using other communication media such as sound, movement, arms, and whole body together.

Interestingly enough, no picture of WE-4 was correctly identified as "fear" or "disgust" (maximum recognition rate for "fear" is only 10.3%; maximum recognition rate for disgust is only 15.5%). Conversely, several pictures of KOBIAN has been labeled as "disgust", although their recognition rate is not particularly high (ranging from 45.2% to 65.0%). 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".

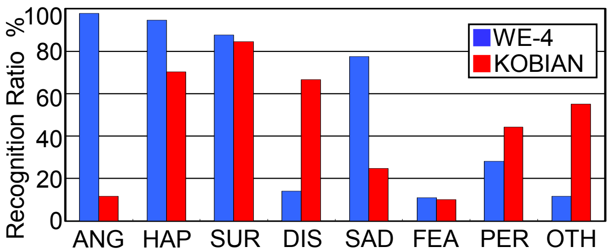


Fig. 9 Summary of the Evaluation Results

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, in particular for happiness (68.4%) and anger (12.8%). The second one, however, was a specific design requirement.

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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Acknowledgment

This research was commissioned by The New Energy and Industrial Technology Development Organization (NEDO)

and conducted at Humanoid Robotics Institute, Waseda University, and a part of it was supported by a Grant-in-Aid for the WABOT-HOUSE Project by Gifu Prefecture.

KOBIAN has been designed by 3D CAD software "SolidWorks". Special thanks to SolidWorks Japan K.K. for the software contribution, and KURARAY Co., Ltd. for the SEPTON contribution.

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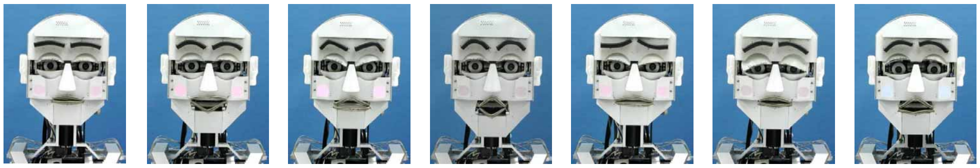
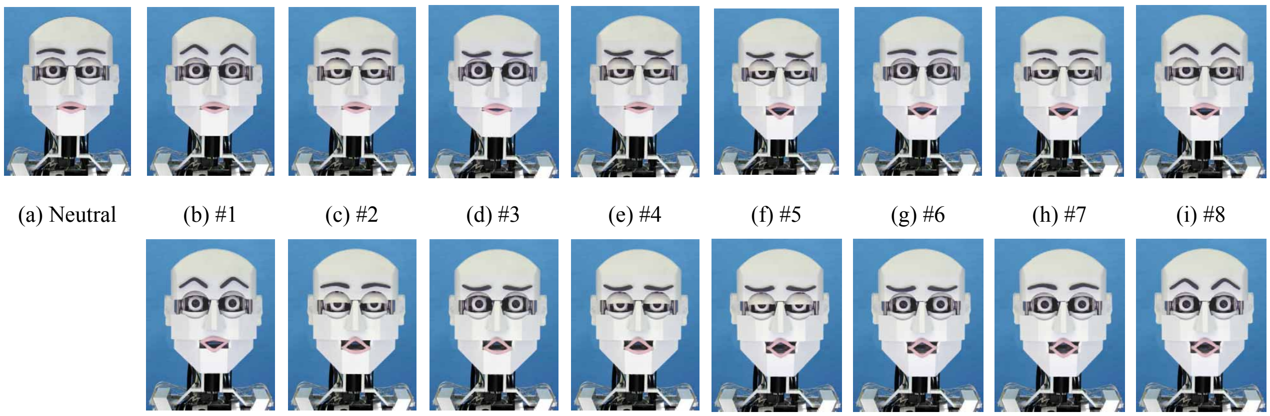


(a) Neutral (b) #1 (c) #2 (d) #3 (e) #4 (f) #5 (g)#6

Fig. 7 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. 8 Facial Expressions of KOBIAN

TABLE IV
RECOGNITION RATES OF FACIAL EXPRESSIONS (%)

picture	Anger	Happiness	Surprise	Disgust	Sadness	Fear	Perplexity	Other
WE-4 #1	0.00	94.02	2.56	0.00	0.00	0.00	0.85	2.56
WE-4 #2	97.44	0.00	1.71	0.85	0.00	0.00	0.00	0.00
WE-4 #3	0.00	7.69	88.89	0.00	0.00	0.85	0.85	1.71
WE-4 #4	17.24	0.00	0.86	15.52	25.00	6.03	28.45	6.90
WE-4 #5	0.00	0.00	0.00	1.71	76.07	0.00	9.40	12.82
WE-4 #6	0.00	2.59	43.97	8.62	12.07	10.34	16.38	6.03
KOBIAN #1	2.59	5.17	64.66	0.00	0.00	0.00	2.59	25.00
KOBIAN #2	9.40	0.00	0.00	39.32	1.71	0.00	4.27	45.30
KOBIAN #3	3.42	0.00	5.13	6.84	26.50	7.69	46.15	4.27
KOBIAN #4	8.55	0.00	0.00	61.54	6.84	0.00	13.68	9.40
KOBIAN #5	7.69	0.85	0.00	46.15	1.71	1.71	17.09	24.79
KOBIAN #6	0.00	68.38	22.22	0.00	0.00	0.85	0.00	8.55
KOBIAN #7	4.27	2.56	1.71	30.77	0.00	0.00	5.98	54.70
KOBIAN #8	1.71	35.04	6.84	7.69	0.85	0.00	1.71	46.15
KOBIAN #9	0.85	58.12	38.46	0.00	0.00	0.00	0.00	2.56
KOBIAN #10	12.82	0.00	0.85	46.15	0.00	0.00	4.27	35.90
KOBIAN #11	10.26	0.00	12.82	10.26	11.97	6.84	40.17	7.69
KOBIAN #12	8.55	0.00	0.00	64.10	2.56	0.00	12.82	11.97
KOBIAN #13	10.26	0.00	0.00	64.96	3.42	0.00	10.26	11.11
KOBIAN #14	11.97	0.00	8.55	13.68	7.69	8.55	43.59	5.98
KOBIAN #15	0.00	11.11	77.78	0.00	0.00	0.00	0.85	10.26
KOBIAN #16	2.36	11.81	84.25	0.00	0.00	0.00	0.00	1.57