Effective Emotional Expressions with Emotion Expression Humanoid Robot WE-4RII

- Integration of Humanoid Robot Hand RCH-1 -

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Abstract- **The authors have been developing humanoid robots in order to develop new mechanisms and functions for a humanoid robot that has the ability to communicate naturally with a human by expressing human-like emotion. We considered that human hands play an important role in communication because human hands have grasping, sensing and emotional expression abilities. Then, we developed the the Emotion Expression Humanoid Robot WE-4RII (Waseda Eye No.4 Refined II) by integrating the new humanoid robot hands RCH-1 (RoboCasa Hand No.1) into the Emotion Expression Humanoid Robot WE-4R. Furthermore, we confirmed that RCH-1 and WE-4RII had effective emotional expression ability because the correct recognition rate of WE-4RII's emotional expressions were higher than the WE-4R's one. In this paper, we describe the mechanical features of WE-4RII.**

Keywords- Humanoid Robot, Robot Hand, Emotional Expression

1. Introduction

At present, industrial robots play an active role in various functions, such as assembly and conveyance, in manufacturing factories. And, industrial robots can take preprogrammed motion beforehand. Operators have to define the new robots' behavior with complex processes or methods. However, the personal robots anticipated to become popular in the future are required to be active in joint work and community life with humans. Whilst industrial robots require uniform motion, active behaviors and adaptation to partners or the environment are necessary for personal robots. Therefore, we have been developing new mechanisms and functions for a humanoid robot that has the ability to express emotions and to communicate with humans in a human-like manner.

Currently, active research is being conducted on the communication robots in the field of robotics. Brooks developed an expressive robotic creature, which expresses facial expressions using its eyes, eyelids, eyebrows and mouth. It can communicate with humans using visual information from CCD cameras [1]. Kobayashi developed a head robot that uses the fourteen Action Units of Ekman [2] [3]. It can express six basic facial expressions as quickly as human using 24-DOFs with air compressors for actuators. It can also recognize human facial expressions using CCD cameras and reciprocate the same facial expressions back [4] [5].

The authors have been developing the WE (Waseda Eye) series since 1995. Coordinated head-eye motion with Vestibular-Ocular Reflex, depth perception using the angle of convergence between the two eyes, adjustment to the brightness with the eyelids and four sensations (visual, auditory, cutaneous and olfactory sensation) were achieved. We also developed the 9-DOFs emotion expression humanoid arms and integrated them into our robots [6] [7]. And, the Emotion Expression Humanoid Robot WE-4R (Waseda Eye No.4 Refined) developed in 2003 could output its emotional expressions and behaviors with not only the face, but also the waist, arms and neck. On the contrary, we introduced a mental space with three

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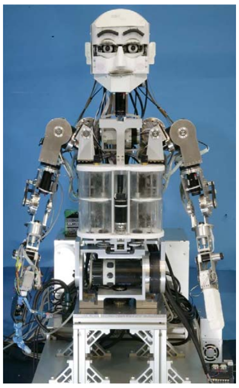
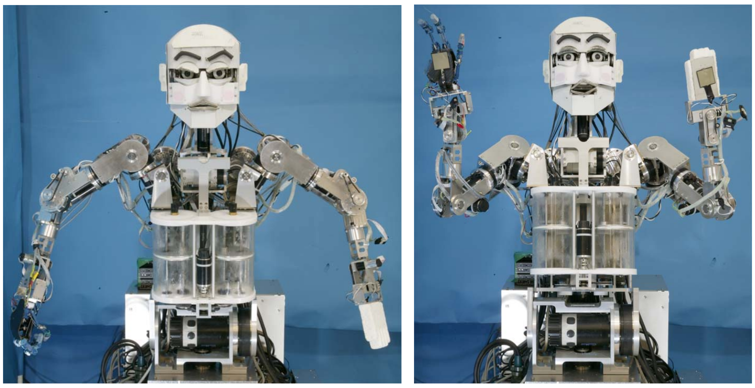


Fig. 1 WE-4R with RTR-2



(a) Anger (b) Surprise

Fig. 2 Emotional Expressions of WE-4R with RTR-2

independent parameters, the Learning System, the Mood Vector, the Second Order Equations of Emotion, the Robot Personality and the Need Model as the mental model for humanoid robots [8].

In 2004, we developed the Emotion Expression Humanoid Robot WE-4RII (Waseda Eye No.4 Refined II) by integrating the humanoid robot hands named RCH-1 (Robo Casa Hand No.1) to WE-4R in order to improve the robot emotional expression and realize interaction between human and robot. This paper describes the mechanical features of the Emotion Expression Humanoid Robot WE-4RII.

2. Human Hand

Human hands have five fingers and 22-DOFs each. And, a human can grasp objects, sense stimuli and express emotions with hands. Concerning the grasping ability, a human can grip, bite and pinch objects with the thumb and the other four fingers facing the thumb, and can hook objects with four fingers without the thumb. The sensibility on fingers is centralized on the finger tips. Finally, a human can express not only the hand signal but also its emotion using the finger motion and shape.

On the other contrary, grippers which can just open and close with 1-DOF to grasp objects are used for industrial robots. They are unsuitable to grasp complicated objects because they have two fingers. Some of them have several sensors such as the contact sensors and force torque sensors. But, generally, the complicated sensors are not implemented. Moreover, the grippers can't express any emotions. Therefore, we considered that the functionality of industrial robot hands was less than human's functionality. We also considered that we couldn't use the industrial robot hands to the emotion expression humanoid robots.

Therefore, we newly developed humanoid robot hand RCH-1 which has five fingers, grasping ability, sensing ability and emotion expression ability in order to realize interactive motion and various behaviors.

3. Preliminary Experiment on Robotic Hand

As a preliminary experiment, we integrated the robot prosthetic hand RTR-2 [9] developed by ARTS Lab. into the right hand of WE-4R in order to evaluate the effects of robot hand for the emotional expressions and interaction to human. RTR-2 has three fingers and two motors. All fingers can do extension and flexion movement and thumb also do abduction and adduction movement. And, RTR-2 can grasp an object mechanically following the object shape. Fig. 1 shows the Emotion Expression Humanoid Robot WE-4R with RTR-2.

Then, WE-4R with RTR-2 exhibited the emotional expressions. Fig. 2 shows the “anger” and “surprised” emotional expression. Because we changed only right hand of WE-4R, the right side of WE-4R could express the emotional difference by opening or closing its hand. But, the left hand of WE-4R was same even though the emotion was changed. The left side of the robot seemed to be much stranger than the right side. Therefore, we considered that the robot hand was effective to improve the emotional expression of the humanoid robot.

Moreover, WE-4R's behavior was limited because it couldn't grasp objects. But, WE-4R with RTR-2 could receive an object from a human partner using the CCD cameras on the WE-4R's head. We also considered that the integration of the robot hand could improve the robot behaviors or interactive motions.

4. Emotion Expression Humanoid Robot WE-4RII

Fig. 3 presents the hardware overview of the Emotion Expression Humanoid Robot WE-4RII developed in 2004. We integrated the humanoid robot hands RCH-1 into the

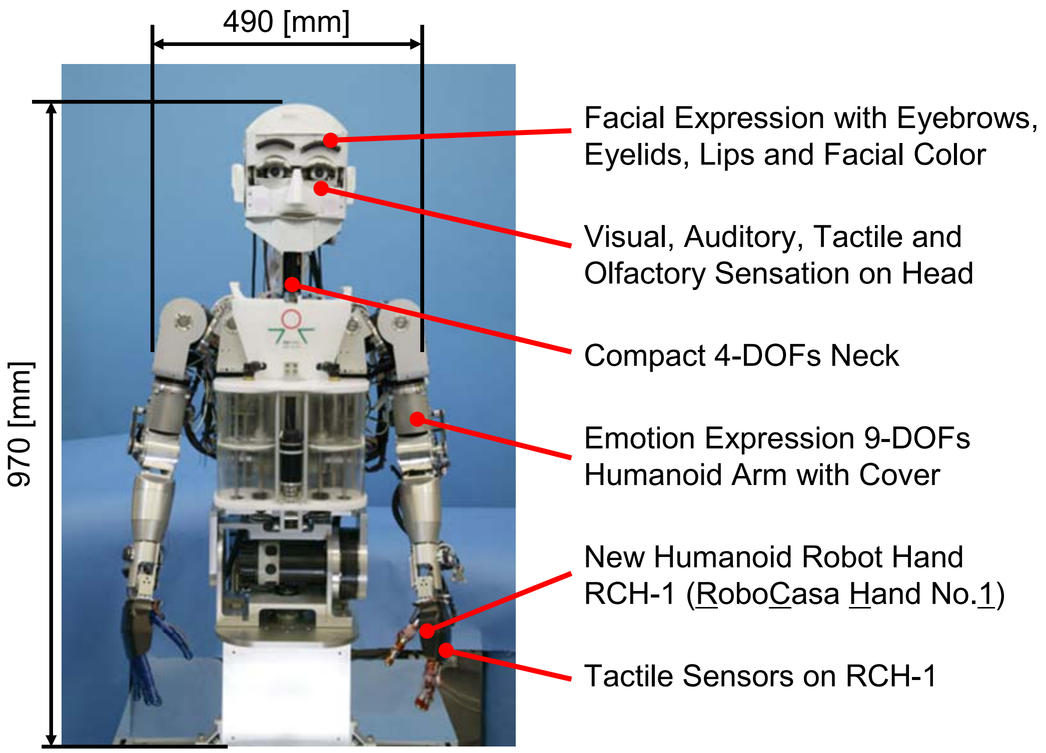


Fig. 3 Mechanical Features of WE-4RII

Table 1 DOF Configuration

Part	DOF
Neck	4
Trunk	2
Base Shoulders	4
Shoulders	6
Elbows	2
Wrists	6
Eyes	3
Eyelids	6
Eyebrows	8
Lids	4
Jaw	1
Lungs	1
Hands	12
Total	59

Table 2 Sensors on WE-4RII

Part	Sensation		Device	Quantity
Head	Visual		CCD Camera	2
	Auditory		Microphone	2
	Cutaneous	Tactile	FSR	26
		Temperature	Thermistor	1
		Weight	Current Sensor	2
	Olfactory		Semiconductor Gas Sensor	4
Hand	Cutaneous	Tactile	Contact Sensor	16
		Tactile	FSR	4
		Force	3D Force Sensor	2

WE-4R. WE-4RII is 0.97 [m] tall and weigh 59.3 [kg]. And, WE-4RII has 59-DOFs (Degrees of Freedom) as shown in Table 1 and has sensors shown in Table 2, which serve as sense organs for extrinsic stimuli. In the following section the detailed descriptions of each part are presented.

4.1 Humanoid Robot Hand RCH-1

Fig. 4 shows the humanoid robot hand RCH-1 developed in 2004 [10]. RCH-1 has five fingers and six active DOFs and 10 passive DOFs. Each finger has 1-DOF for extension and flexion movement. Moreover, the thumb has one more DOF for abduction and adduction movement. Extension and flexion motions are driven by single cable actuated by a DC motor. RCH-1 can grasp an object following the object shape by special mechanisms [9]. So, we don't need to independently control all joints. And, because all fingers have the same design, there are not any differences between each joint. Abduction and adduction motion are driven by direct driven mechanism with a DC motor mounted inside the palm. RCH-1 is designed and developed by ARTS Lab, Scuola Superiore Sant'Anna.

4.2 Integration of RCH-1

In order to integrate RCH-1 into WE-4R, the actuation system for extension and flexion of RCH-1 has been mounted inside the forearm of WE-4RII (Fig. 5), thus mimicking the position of *flexor digitorum* and *extensor digitorum* in the human forearm. The motors are connected with the motors by using thin wire with

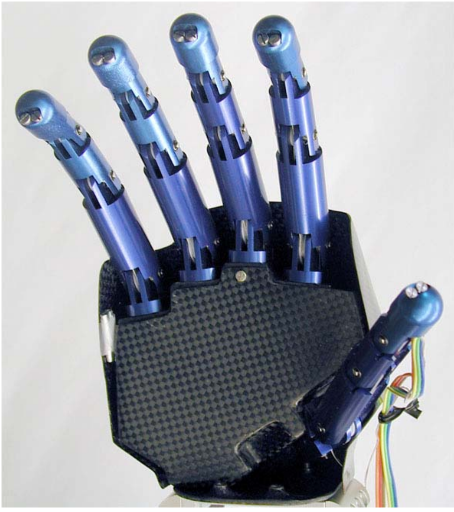


Fig. 4 RCH-1

BODEN CABLE which was an outer tube for endoscopes.

On the other contrary, the wrist joints of WE-4R were driven by DC motors with planetary gear system. So, the hand motion of WE-4R wasn't stable because there was too much backlash. Moreover, we had to redesign the forearms to mount the finger's motors. Therefore, we changed the gear system to small harmonic drive systems in order to reduce the backlash and miniaturize the wrist mechanism. Especially, we designed the link mechanism shown in Fig. 6 for the pitch axis of the wrist. The link mechanism transmits the motor power with the two links, which were supported by four ball bearings to reduce the slant caused between inner and outer rim.

4.3 Sensors on WE-4RII

WE-4RII has visual, auditory, tactile and olfactory sensors on its head, and tactile sensors on its hands.

Regarding visual sensor, WE-4RII has two color CCD cameras (CS6550, Tokyo Electronic Industry Co. Inc.) in its eyes. WE-4RII calculates the gravity and area of the targets. And, it can recognize any color as the targets and it can recognize eight targets at the same time. WE-4RII also can recognize the distance of the targets using the angle of convergence between the two eyes. If there are multiple target colors in the robot's view, WE-4RII follows the target which is autonomously selected by the robot in a 3D space. Regarding auditory sensor, WE-4RII has condenser microphones (BL1994, Knowles Electronics Japan) in each ear. It can localize the sound direction from its loudness and the phase difference in a 3D space. For olfactory sensation, we set four semiconductor gas sensors (SB-19, SB-30, SB-AQ1A and SB-E32, FIC Inc.) in WE-4RII's nose. WE-4RII can quickly distinguish the smells of alcohol, ammonia and cigarette smoke. And,

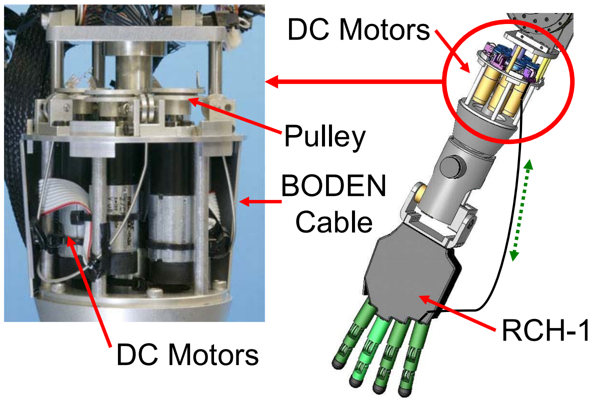


Fig. 5 Integration of WE-4R and RCH-1

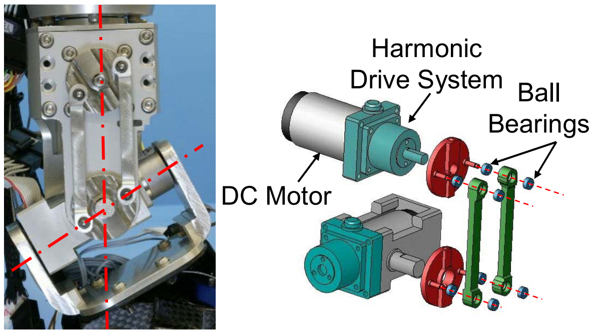


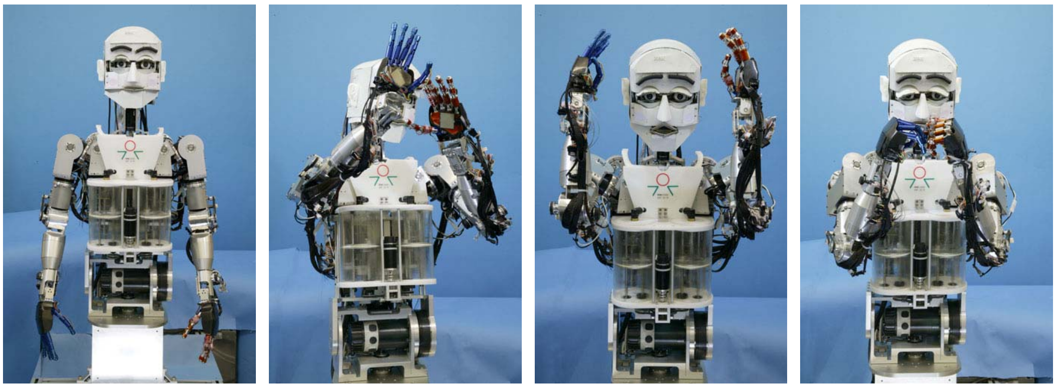
Fig. 6 Wrist Mechanism of WE-4RII

WE-4 has tactile and temperature sensations. For tactile sensation, we used FSRs (model 406, Interlink Electronics, Inc.) and set them on the cheeks, forehead, top of the head and side of the head of WE-4RII. WE-4RII can recognize the difference in touching behaviors such as "push," "hit" and "stroke". For the temperature sensation, we used a thermistor and a heat sheet, and we set them on the forehead [6].

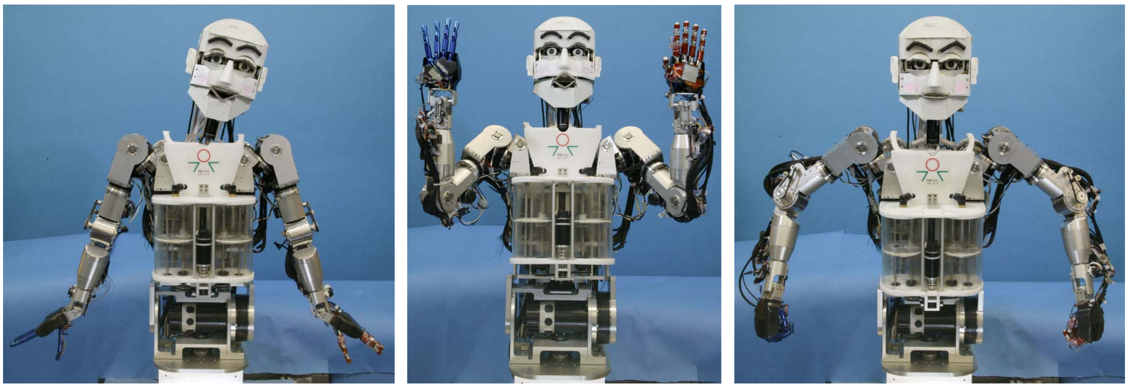
Meanwhile, WE-4RII has on/off contact sensors and FSRs. The on/off contact sensors which are film shaped switch, detect contact with the objects for the grasping. And, we set FSRs on the dorsum of RCH-1. They are the same sensors as the FSRs on the head. We use them for interaction with a human.

4.4 Emotional Expressions

WE-4RII could express its emotion using the upper-half body motion including the facial expression, arms, hands, waist and neck motion. And, we considered that the motion velocity was as important as the posture in emotional expression. Therefore, we controlled both the posture and the motion velocity to realize the effective emotional expression. For example, WE-4RII quickly moves its body for surprise emotional expression, but it slowly moves its body for sadness emotional expression. Fig. 7 shows the emotional expressions exhibited by WE-4RII.



(a) Neutral (b) Disgust (c) Fear (d) Sadness



(e) Happiness (f) Surprise (g) Anger

Fig. 7 Emotional Expressions of WE-4RII

4.5 Behavior

We improved the behavior and interactive motion of WE-4RII using its hands and the co-operating motion with visual sensation.

At first, WE-4RII calculates the position of the human face, the human hand or the target in a 3D space using the visual sensation on the head. Then, WE-4RII autonomously moves its arms and hand to interact to the partner. For example, WE-4RII could receive an object from a human partner and give the objects to the partner using its hands. Moreover, the WE-4RII could shake its hand with the partner following the partner's face with its eyes and head.

On the other contrary, we also increased the robot behavior. We gave the robot motion patterns as the robot behaviors. WE-4RII autonomously selects its behavior according to the situation. To make the motion pattern, we have to define the positions, postures and time of the tip of the robot hands, and calculate the hand trajectory with 3D spline function. Then, the trajectories were divided in each 33 [ms]. The robot calculates the joint angle from divided trajectory using the inverse kinematics [8]. Because WE-4R had the same movable range as human, WE-4RII could output human-like motions by defining the motion patterns. We defined the various patterns such as throwing a ball and shaking a maraca.

4.6 Total System Configuration

Fig. 8 shows the total system configuration of WE-4RII. We used three computers (PC/AT compatible) connected by Ethernet. PC1 (Pentium 4 3.0 [GHz], Windows XP) captures the visual images from CCD cameras and it calculates gravity and brightness of the target, and sends them to PC2. PC2 (Pentium 4 2.6 [GHz], Windows XP) obtains and analyzes the outputs from the olfactory and cutaneous sensations using 12 [bit] A/D boards and the sounds from microphones using a soundboard. Then, PC2 determines the mental state. In addition, PC2 controls DC motors excepting RCH-1. Then, PC2 sends control information of RCH-1 to PC3. PC3 (Pentium III 1.0[GHz], Windows 2000) obtain and analyze the sensor information of RCH-1 and control DC motors on RCH-1. PC3 sends the sensor information to PC2.

5. Experimental Evaluation

We evaluated the recognition rate of the emotional expression of WE-4RII. We showed 18 subjects (averaged

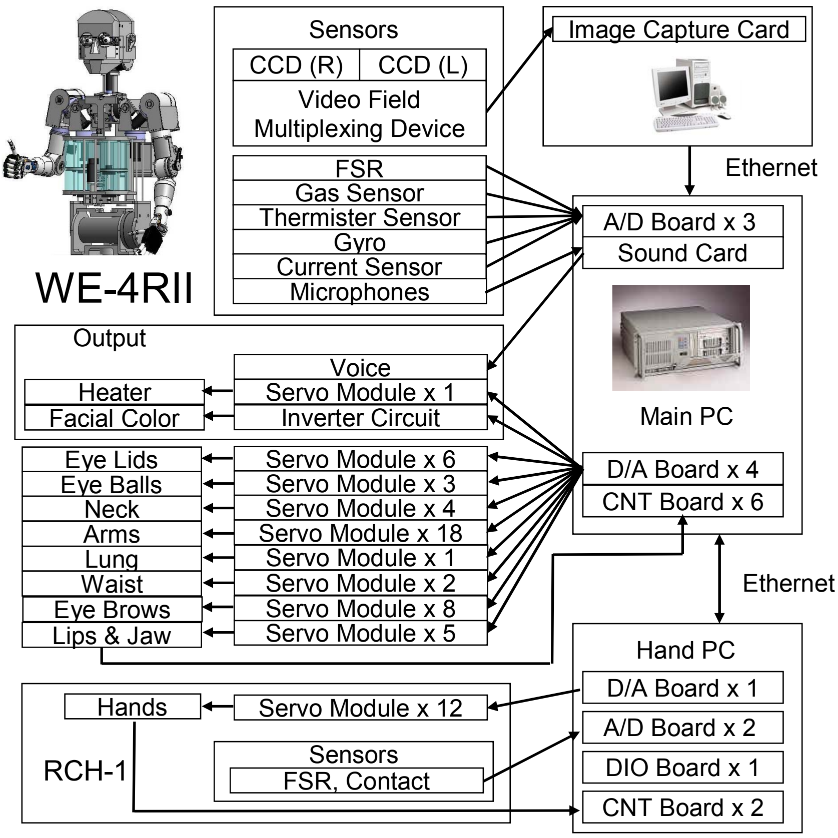


Fig. 8 System Configuration

age: 21) the movies of the six basic emotional expressions exhibited by WE-4R and WE-4RII. In the movies, emotional expressions of WE-4RII and WE-4R were the same excepting the hand motion. WE-4RII expressed the postures shown in Fig. 7. Next, the subjects chose an emotion that they thought the robot expressed. Then, we examined the recognition rates of those emotional expressions. Finally, we compared the recognition rates of WE-4RII to WE-4R. The experimental results are presented in Fig. 9.

As a result, the recognition rate of "Happiness" facial expression was 5.5 [points] higher than WE-4R. And, all subjects correctly recognized the "Surprised", "Sadness", "Anger" and "Disgust" emotional expressions. However, the recognition rate of the "Fear" was 5.5 [points] lower than WE-4R's rate because the some subjects considered the "Fear" emotional expression as "Disgust" emotional expression. In total, the averaged recognition rate of all emotional expressions of WE-4RII was 2.8 [points] higher than the WE-4R's averaged recognition rate. As described before, the difference between emotional expressions of WE-4RII and WE-4R are only hand motion. Therefore, we considered that the RCH-1 had effective emotional expression ability. And, we also considered that these emotional expressions except "Fear" emotional expression were sufficiently effective.

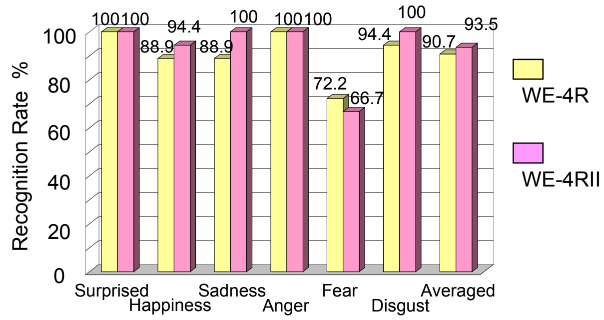


Fig. 9 Experimental Evaluation

By the way, human's emotional expressions are always different even if the human emotion is same. So, we defined several extra emotional patterns. And, we measured the recognition rate of them. The experimental results are shown in Table 3. The subjects felt the particular emotion to pattern 1, 2, 4 and 5. But, they answered that pattern 3 had several emotion or meaning according to the situation. Therefore, we confirmed that WE-4RII could express its emotions by several ways by using its facial expressions, neck, arms, hands and waist motion.

6. Conclusions and Future Work

(1) We integrated RTR-2 into the Emotion Expression

Table 3 Experimental Result of Additional Emotional Expression

	Anger	Happiness	Surprise	Disgust	Sadness	Fear	Other
Pattern 1	0	0	0	0	91.7	0	8.3
Pattern 2	0	0	91.7	0	0	0	8.3
Pattern 3	0	25	0	0	0	0	75
Pattern 4	100	0	0	0	0	0	0
Pattern 5	0	75	0	0	0	0	25

Humanoid Robot WE-4R in order to confirm the effects of robot hand on humanoid robots for emotional expressions and interaction.

(2) We developed the Emotion Expression Humanoid Robot WE-4RII (Waseda Eye No.4 Refined II) by integrating the humanoid robot hands RCH-1 (Robo Casa Hand No.1) into WE-4R.

(3) We confirmed that RCH-1 and WE-4RII had effective emotional expression ability through the experiments with questionnaires.

In this paper, we improved the WE-4RII's emotional expression. And, WE-4RII could interact with human using RCH-1. In the future, we would like to increase the emotional expression patterns and robot behaviors. And, we also would like to introduce the behavior model which autonomously determines and outputs the most suitable behavior or emotional patterns according to the situation.

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