Constructivist Approach to Human-Robot Emotional Communication - Design of Evolutionary Function for WAMOEBA-3 -

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Abstract- By applying a self-preservation function and communication capability, we investigated the emergence of the emotional behavior of robots to propose an "evaluation function for self-preservation," a " model of endocrine system," and a "MA model." We also developed a new hardware platform, WAMOEBA-3, to install our new knowledge into the robot. WAMOEBA-3, a wheel type, independent robot, was designed for easy maintenance and customization. As a new function for WAMOEBA-3, we introduced an evolutionary function for the acquisition of reactive motion that uses an interactive evolutionary computation method. We show the results of simulation experiments and discuss real world applications.

Keywords: Emotion, Communication, Interactive evolutionary computation

1. Introduction

Recently, humans have begun to assume that robot technology will perform such tasks as healthcare, housekeeping, nursing, and so on. To do so, robots must communicate with humans not only to receive commands but also to entertain people. In such cases, emotion is required for efficient and smooth communication.

Most communication robots have emotional models and behavior patterns that involve growth and/or learning processes based on the designer's psychological findings. These approaches are at present the most practical and fastest way of achieving the emotional communication between humans and robots. However, since the developer designs the connections between sensory inputs and emotional states, they are greatly influenced by his/her biases.

Instead of installing explicit emotional models into robots, we create implicit descriptions from which the robot generates its own emotion. We thought that emotion is the state of perceiving changes in bodily condition, derived from internal and external stimulation, caused by an autonomous system. To investigate a robot's own emotion, we focus on the self-preservation function [3].

According to the self-preservation function and emotion expression mechanisms, when people observe the robot's behavior, they may think as if the robot has its emotion. This is our working hypothesis.

We also discuss a method that judges the existence of emotion. For other systems (mainly human beings), the reactions of the system constitute the essential information for deciding the existence of emotion. Therefore, it is indispensable to equip the robot with such emotion expression mechanisms as a motor system, an active voice, expressions etc.

Based on this hypothesis, we've developed an emotional communication robot, WAMOEBA (Waseda Artificial Mind On Emotion Base), founded on a "behavior-based" approach. WAMEOBA can communicate; as other living organisms, it possesses such self-preservation functions like an autonomic nervous system and an endocrine system. Using these functions, WAMOEBA generates its own emotional behaviors based on its own hardware.

And also, we believe that complex behavior reflects not only the complexity of internal mechanisms but also that of the environment [1]. So, we proposed a reactive motion generator, named Motor Agent model[5]. In the Motor Agent model, each motor can move autonomously based on a summation of sensory inputs collected through a network in its body. Despite of the simple manner of each agent, the WAMOEBA can behave in various ways.

In this paper, we describe WAMOEBA-3, a new hardware platform robot, and an evolutionary approach for configuration of its behavior generation function. In the next section, we show the installation of our hypothesis. We introduce a self-preservation function for robots and a motion generation function. In part 3, we show the design of WAMOEBA-3's in detail. Many of WAMOEBA-3's functions derive from an early research platform, WAMOEBA-2Ri. We explain the design concepts and problems of WAMOEBA-2Ri and the improvements of WAMOEBA-3. In part 4, the evolutionary approach is described. Even though earlier research proposed various algorithms, their parameters reflected the biases of developers. Our approach solves this problem. In part 5, we discuss the problems of WAMOEBA-3 hardware and evolutionary functions. In the conclusion, we describe future works.

2. Design concept of WAMOEBA

2.1. *Self-preservation function*

Based on our hypothesis, it is necessary to imply a self-preservation function into a robot. Living organisms realize such a function by "autonomic nervous" and "endocrine systems." On the other hand, in order to realize a self-preservation function in a robot, we thought all sensory information must be efficiently integrated into an evaluation of hardware conditions. We have proposed an original evaluation method called the "evaluation function of self-preservation" that converts each sensory input, which is dimensionless between 0-100, into an evaluation value of durability (breakdown rate) of the robot between 0-1 [4]. When this value is close to zero, the state or "feeling" of self-preservation is high. If this value gets close to one, the state is low. This function has one minimum value that reflects the best state for self-preservation. The shape of this function depends on the basic hardware performance and degree of urgency. For example, the evaluation function of battery voltage, whose shape is shown in Fig.1, depends on the lowest voltage for the circuit drive and the standard voltage of the battery.

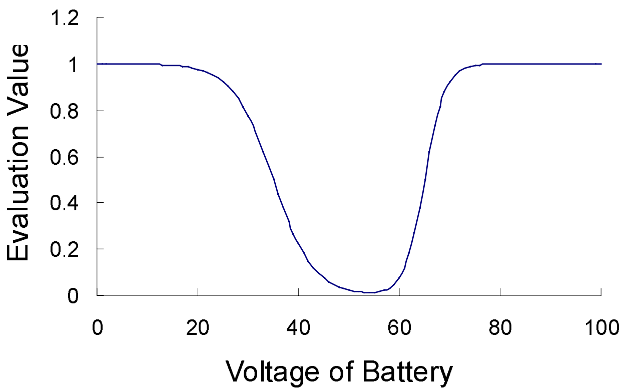

Fig. 1. Evaluation function of voltage of battery

There are various evaluation functions of self-preservation E_i, according to each sensor. Therefore, near vector $\mathbf{x} = (E_1, E_2, \cdots, E_i, \cdots .E_n)$, the following value can be calculated by each step cycle.

$$P = |\mathbf{x}| = \sqrt{\sum E_i^2} \tag{1}$$

This is an absolute value that expresses the good/bad evaluation of the self-preservation of robots.

We also propose a machine model of an endocrine system. In WAMOEBA's self-preservation system, 4 hormonal parameters are calculated by using P values that correspond to 4 conditions: mood, or whether the evaluation value is good or bad; arousal, or whether the value changes dynamically.

In humans, the endocrine system influences such body parts or functions as the metabolism of internal organs, the muscles, the reflection of pupils, etc. In robots, such functions correspond to sensor gain, motor output, circuit temperature, energy consumption, etc. Table 1 shows the influences of internal secretions in the machine model of the endocrine system.

The $H1$ and $H4$ are secreted in the situation when the P increases and decreases dynamically, and the $H2$ and $H3$ are secreted in the situations when the absolute

Table 1. Affects of the hormonal parameters of WAMOEBA

		$H1$	$H2$	$H3$	$H4$
Actuator Speed		Up	Down	Down	Up
Cooling Fan Output		Down	Up	Up	Down
Camera Viewing Area		Down	Up	Up	Down
Sensor Range		Down	Up	Up	Down
Sound	Volume	Up	Down	Down	Up
	Speed	Up	-	Down	Up
	Pitch	Down	Down	Up	Up
LCD Color		Red	Blue	Yellow	
Emotion		Anger	Sadness	Pleasure	Expect

value of P is very high, and very low. We defined these hormonal influences in view of the self-preservation. For example, if the P is increasing, the robot must excape from its current situation. So we think it is quite natural that the $H1$ hormone makes its motion faster. The influences of the other hormones are configured based on these manners.

Table 2. Expressions of WAMOEBA by Hormone Parameters

Radical Unpleasantness	cause	Bumper switches, Ultra sonic range sensors (radical approach)
	expression condition	Decrease of the viewing angle, Increase of the motor speed, Red color expression on the LCD and Low voice
Unpleasantness	cause	Temperature of the motors and the electrical circuits, Ultra-sonic range sensors
	expression condition	Increase of the viewing angle, Decrease of the motor speed, Blue color expression of the LCD
Pleasantness	cause	charge
	expression condition	Decrease of the viewing angle, Decrease of the motor speed, Yellow color expression on the LCD

In addition, these are not fixed but are changed by the mixture condition of the four hormone parameters. This model can generate some intermediate emotions. These intermediate emotions make the variety of the behavior very rich.

2.2. *Behavior generation function*

Here, the methodology by which WAMOEBA generates its behavior for emotional communication is discussed. A conventional model-based robot behaves according to its environmental model implemented a priori. Those manners of motion generation require an accuracy of sensor input, an optimal environment, and a large amount of calculation. On the other hand, R. Brooks proposed a "behavior-based approach" with behavior models that correspond to tasks [2]. Not every behavior module requires higher level behavior planning. However, the varieties of behavior are limited because only combinations of each behavior module are fixed a priori. Since humans can easily predict robot behavior while communicating during experiments, they quickly become tired. Designing a behavior module for communication with humans is extremely difficult.

We believed that the generation of diverse behaviors should be described not at the level of the "task" but at the "motor activity". So we proposed a Motor Agent (MA) model as WAMOEBA's behavior generation mechanism [5]. MA model is an autonomous distributed control algorithm that regards each motor as an autonomous agent that connects with neighboring agents and collects all sensor information and other motor drive conditions through networks in the robot hardware (Fig.2). Based on this information, each motor acts autonomously. The motion command M_i of motor i is calculated as follows:

$$a_i = \sum_{j \neq i} \omega_{ji}^{m} M_j + \sum_{k} \omega_{ik}^{s} S_k \qquad (2)$$

Here, the input value of sensor k is defined as S_k, the output of motor j is M_j, and the activity of motor i is a_i. The commands for motor i are generated using the absolute value and the positive and negative values of a_i. In this design, the morphology of the behavior depends on weight value ω in which the descriptions are not explicit. The initial value of ω depends on the physical arrangement of the motors and the sensor; i.e., ω is a large value when the distance between the sensors and the motors is small. In this stage, ω is adjusted by a designer who observes the behaviors of WAMOEBA.

According to these implicit expressions, the MA model, WAMOEBA, generates behavior using the entire body: imitation of the movement area, the origin of sound, and avoidance behaviors, etc.

3. WAMOEBA-3

3.1. *Total design concept*

In our early research, we developed a robot that can communicate emotionally, WAMOEBA-2 (Fig.3). It is a wheel type, independent robot equipped with a built-in battery and a control system. WAMOEBA-2 has appeared at many events at which we've carried out numerous experiments. Self-preservation functions and MA models have been installed in WAMOEBA-2 [5].

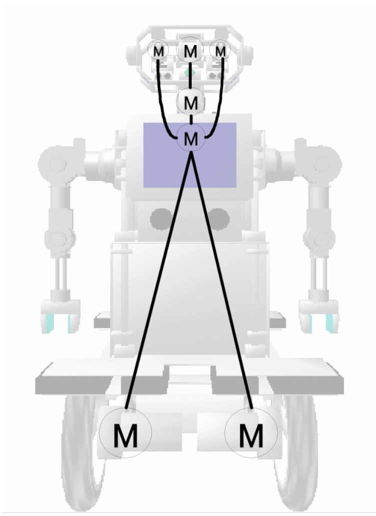

Fig. 2. Concept diagram of motor agent

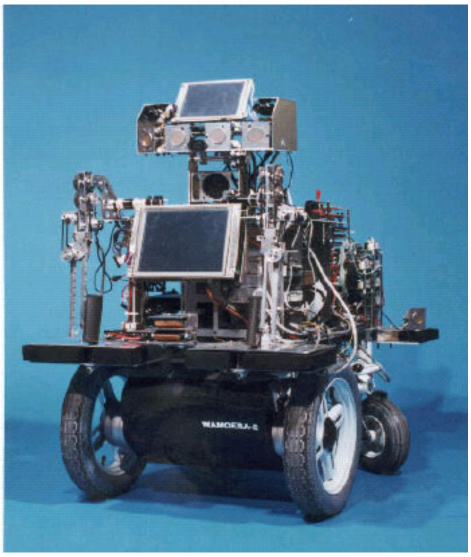

Fig. 3. WAMOEBA-2 (1995-1999)

According to many comments in the questionaire experiments, WAMOEBA-2 was improved its arm systems and head system. WAMOEBA-2Ri was developed as a advance version of WAMOEBA-2 (Fig.4).

WAMOEBA-2Ri can communicate with humans in various ways. However, it is

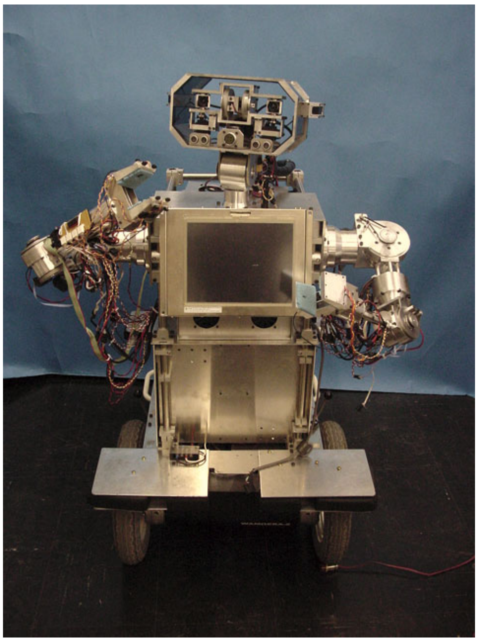

Fig. 4. WAMOEBA-2R*i* (2000-)

difficult to customize the hardware because the form of WAMOEBA-2Ri is shaped by the repetition of experiments and improvements. Its system is too complicated to receive any new equipment.

WAMOEBA-3, shown in Figure 5, was designed to solve this problem. Its design and size is based on an average Japanese child: 656 mm long, 825 mm wide, 1316 mm tall, and approximately 105 kg. Its upper body is equipped with two arms and a head with many sensors such as CCD-cameras. WAMOEBA-3 is also equipped with an omnidirectional vehicle for locomotion.

WAMOEBA-3 is designed for easy maintenance. For example, sliding mechanisms are installed on the battery case and power supply unit to allow easy access. We reduced the number of cables trailing behind the robot, since WAMOEBA-3 has a distributed control system constructed of 6 microcomputers and a Dos/V PC. Furthermore, the distributed control system contains enough redundancies to customize the robot in the future.

3.2. *Arm system*

At the '97 International Robot Exhibition, we conducted an experiment with a WAMOEBA-2 that had two simple arms for making gestures and other emotional expressions [6]. A questionnaire from participants included such comments as "I cannot understand the arm motions," and "the arm feels broken when I touch it." Thus,

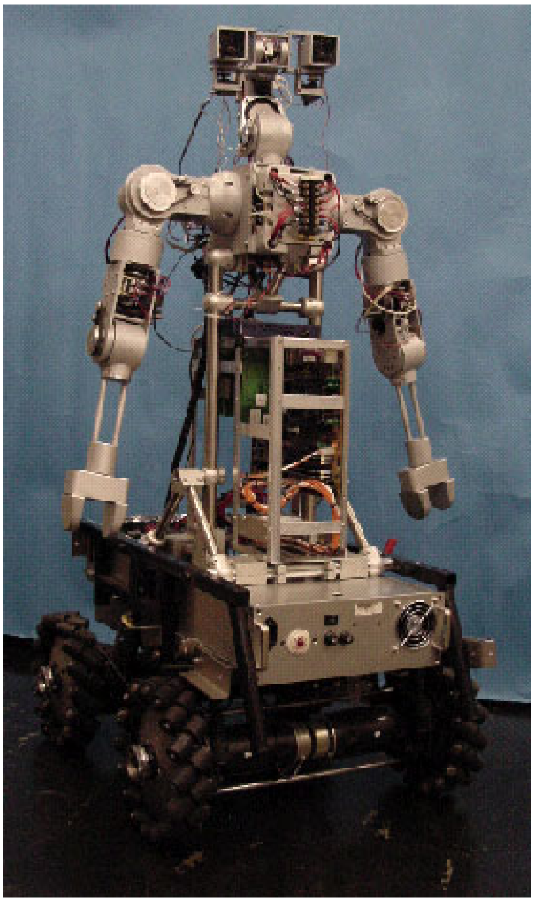

Fig. 5. WAMOEBA-3

an arm system is important from the viewpoint of human-robot communication as well as robot intelligence. Based on the comments, we developed a new arm system.

Regarding physical interaction between robots and humans, each manipulator actuator should control its own torque to measure stress and for maintenance. The end-effectors, with 6-axis torque sensors, limit interaction positions.

On the other hand, installing a torque sensor in each joint is a more efficient measurement of the stress on the arm. It doesn't limit the contact position, and it is less expensive than pasting sensors all over the entire body. Instead, we only need to install a torque sensor in each joint. Actually, in the WAMOEBA-2Ri's arm system, each joint contains a torque sensor to sense stress on the joint. The WAMOEBA-2Ri arm can successfully manage such human-robot physical interaction as shaking hands.

The WAMOEBA-3 arm system was designed for physical interaction with hu-

Table 3. Specifications of WAMOEBA-3

Dimensions	mm	1316(H)×825(L)×656(W)
Total Weight	kg	105
Max speed	km/h	3.5
Payload	kgf/hand	5.0
Drive member	Camera DOF	1+1×2=3
	Neck DOF	3
	Vehicle DOF	3
	Arm DOF	6×2=12
	Hand DOF	1×2=2
Outside Sensors	Vision	CCD Color camera × 2 (10×Optical zoom, 4×Degital zoom)
	Sound input	microphone×2 (Directional hearing, Voice recognition)
	Sound output	SpeekeriVoice synthesisj
	Distance	Ultra sonic sensor
	Collission	Bumper switch
	Joint stress	Torque sensor×14
	Obstacle	Infra-red sensor×20
	Grip stlength	Tactile sensor×6
Inside Sensors	Electric voltage	Battery voltage
	Electric current	motor current
	Temperature	cercuit temperature sensor
Structural material		Extra super duralumin Titanium alloy(Ti-6Al-4V) aluminium(52S)
CPU		Pentium4(3.2GHz)

mans, making gestures, and doing easy tasks. The length of links and the degrees of freedom were designed by considering the overall balance. Fig.6 shows an assembly drawing of a WAMOEBA-3 arm with six degrees of freedom and a maximum payload of 5 kg in the critical posture. The end-effecter speed is set at a maximum of 0.3 m/s, so that people will not be startled by its movements. Each joint has a more miniaturized torque sensor than WAMOEBA-2Ri.

3.3. *Head system*

In an earlier study using WAMOEBA-2Ri, independently moving cameras helped communication [7]. Therefore, WAMOEBA-3's head also has moving eyes, shown in Figure 7. We also added a joint that allows the robot to cock its head and look thoughtful.

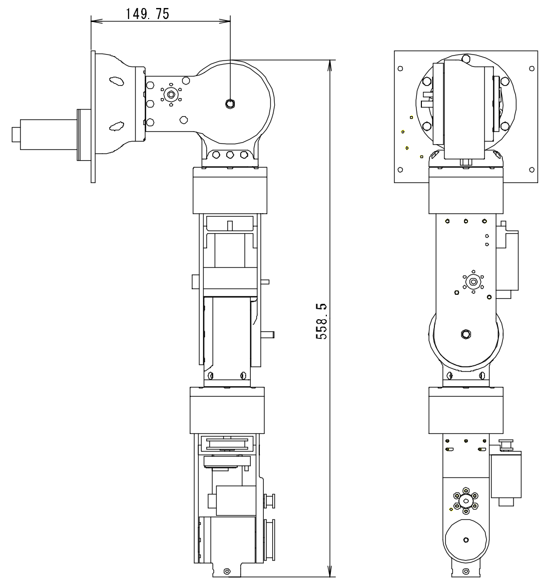

Fig. 6. Assembly of WAMOEBA-3 arm

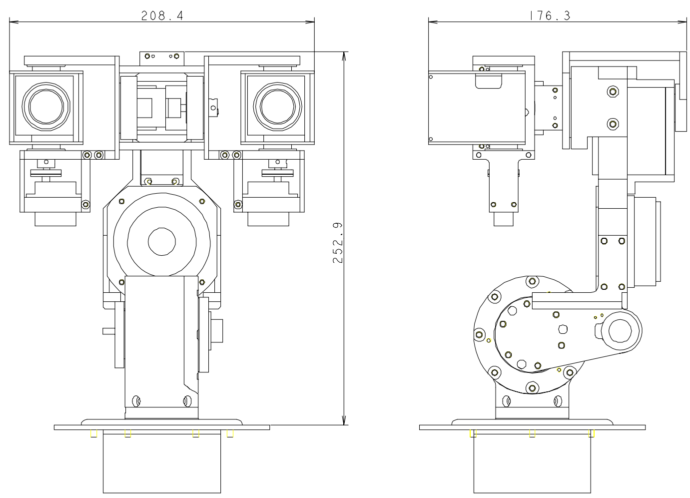

Fig. 7. Assembly of WAMOEBA-3 head

3.4. *Locomotion mechanism*

Another improvement of WAMOEBA-3 is its locomotion mechanism. A vehicle is an appropriate locomotion mechanism for a communication robot because of its stability. WAMOEBA-2Ri vehicle is an ordinary, two-wheel drive type vehicle, so it can make stable physical interactions with humans and the environment. However, the amount of space required when turning is so large that the robot is dangerous when surrounded by many people.

WAMOEBA-3 is equipped with an omnidirectional vehicle that can move in any direction without actually turning at any stage. WAMOEBA-3 can also move in a narrow space.

3.5. *Self preservation function*

According to our working hypothesis, the robot must be equipped with sensors that monitor its internal condition to generate the emergence of emotional behavior. At the same time, the robot must also have hardware preservation functions. WAMOEBA-3 is equipped with many sensors that observe its internal condition: thermal sensors, a battery voltage sensor, and an electric consumption sensor. In addition WAMOEBA-2Ri has cooling fans and power switches controlled by the built-in PC. WAMOEBA-3's power switches can also turn off such circuit modules as left or right arm, head, vehicle, etc.

3.6. *Other equipments*

WAMOEBA-3 has CCD Cameras, microphones, ultra sonic sensors, and bumper switches. Since WAMOEBA-2Ri couldn't distinguish humans from its environment, WAMOEBA-3 is equipped with pyroelectric sensors.

3.7. *Control system*

WAMOEBA-2Ri has two PC/AT convertible PCs. One processes its posture control, and the other controls self-preservation functions and the model of endocrine system. The two PCs are connected to the Ethernet and realize the distributed control system. However, the PCs contain many interface boards so that the control system takes over most parts of the body. WAMOEBA-3 has a distributed control system constructed of 6 microcomputers and a Dos/V PC. Each microcomputer is placed near the modules it controls.

4. Evolutionary function

4.1. *Interactive evolutionary computation*

In previous research, we proposed self-evaluation functions, a model of endocrine system, and an MA model. Even though these algorithms enabled the robot to behave in a variety of ways, the sensory input's influence on the secretion rates were set a priori based on designer's preference. This is also true for the weights of the combinations between different motor agents. These tasks of configurations are very tough works. And also the reason why the robot behaves in such manners is sometimes questionable for its users. We think these parameters of motions should be configured through the interactions between a robot and human(s). Therefore, we aim to configure the parameters by using machine learning.

Although there are numerous learning algorithms, we chose evolutionary computation (EC) because it is suitable for exploring a large search area and can generate a number of possible solutions. An additional advantage is that EC doesn't require models of the system.

In a conventional EC, each individual is evaluated using a given fitness function. However, it is more difficult to evaluate communicative behavior quantitatively rather than qualitatively. Therefore, we decided to use interactive evolutionary computation (IEC), which combines evolutionary computation and interactive learning[9]. IEC does not require defining a fitness function explicitly; that task is performed by human assessors.

4.2. *Fitness Prediction Function*

The biggest problem with applying IEC is human fatigue. Since assessors cooperate with a computer to evaluate individuals, the IEC process spends huge length of time. To minimize human fatigue, we need to reduce the number of individuals and generations. This results in poorer and slower EC learning capability.

To solve this problem, we used a method for predicting the fitness values of genes automatically. Our proposed algorithm to apply the IEC into human-robot communication is shown in Figure 8. First, to select the genes that have distant datasets from each other, the newest genes are analyzed with a self-organizing map (SOM) algorithm, and seven genes are selected. The selected gene is translated into pheno-type (motor agent network) and installed into the WAMOEBA-3. Then, WAMOEBA-3 interacts with an assessor, who evaluates them. Unselected genes are automatically evaluated by the prediction system based on the results of manual evaluation. Thus, in this way, we can increase the population size in IEC without increasing human fatigue. When all genes have been evaluated both automatically and manually, the EC applies genetic operators (selection, crossover, and mutation) to the gene pool and generates more appropriate genes.

4.3. *Application of the IEC into Communication System*

First, we've carried out an experiment to confirm the successfulness of the fitness prediction function. We used a simple MA network model for a motion generation function. Although in the original MA model every possible connection was built, the MA network in this experiment was constructed of only five kinds of connections. The structure of the motor agent network is shown in Figure 9. Black circles and white circles represent the sensor agent and the motor agent respectively. Arrows express the connection's direction. The connection between neck motor and vehicle motor agents is bilateral.

To acquire reactive motions using IEC, the weights of these connections are encoded to genes. The data of genes are represented by numerical data, which are

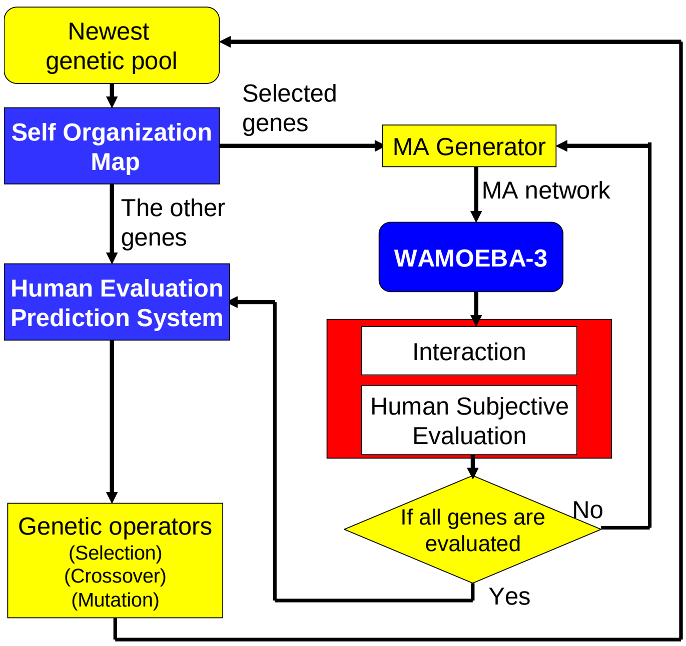

Fig. 8. Proposed Algorithm

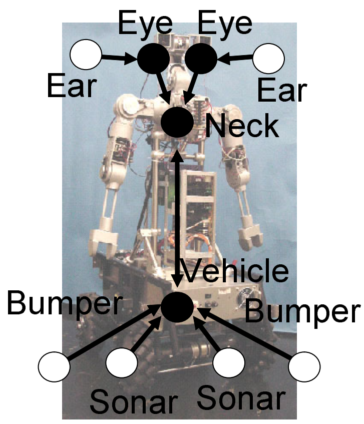

Fig. 9. Motor-Agent network

easy to analyze. The dimension of the dataset of a gene is 28.

We developed the interaction simulator (Fig.10) in which an assessor used a joystick equipped with a force feedback mechanism to interact with a robot. In the environment, there were no objects, obstacles, or textures that could influence the assessor: only two robots, the assessor's and one controlled by the program (MA). The assessor could control his robot freely in the environment and generate synthesized voice by pushing a button. He also could shock the other robot, prompting various physical interactions. On the other hand, the program could "hear" sound with its "ears", "feel" collisions with its bumper switches, sense distances with ultrasonic sensors; he could generate various reactions.

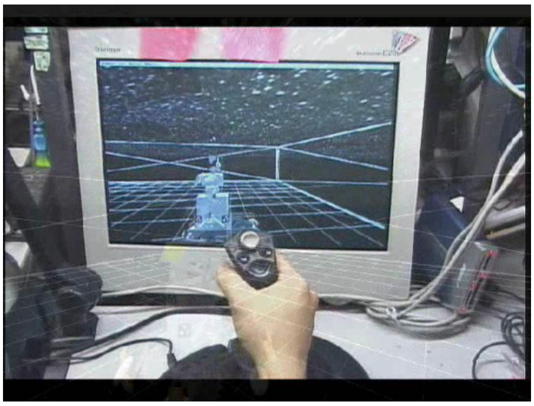

Fig. 10. Interaction simulator

Usually, a communication has its own goal. In this experiment, however, since we wanted to acquire a variety of behaviors, we did not prepare communication tasks in advance. Concerning the evaluation method, we did not supply any adjectives for the evaluation dialogue that took place at the end of each interaction. Assessors were simply informed of the abilities of the robot and allowed to evaluate the behavior freely.

Figure 11 shows the evolution process of the experiments. Circles and triangles represent maximum fitness values of the system with the prediction function (prediction) and that without the prediction function (non-prediction) respectively. Squares and X plots represent population averages of the prediction and those of the non-prediction.

At first, the fitness values are increasing gradually. However, as the experiment continues for some time, the assessor may grow weary and change his/her criteria for interaction. In the middle period of this experiment, the non-prediction system couldn't keep the fitness function. The fitness value tended to drop. On the other hand, our proposed system, prediction system can adapt to the changes.

5. Discussion

WAMOEBA-3 is developed to investigate human-robot communication. Therefore, WAMOEBA-3 is better for communication with humans than WAMOEBA-2Ri

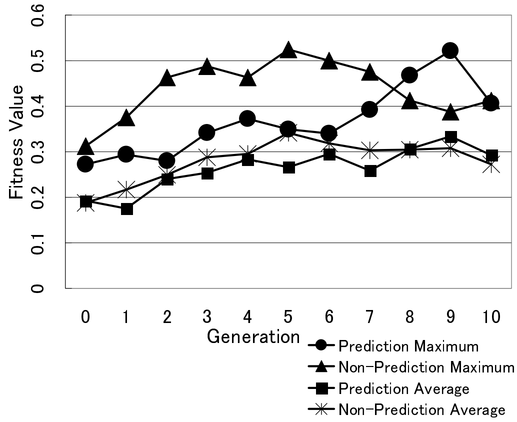

Fig. 11. Fitness value of IEC

because its pyroelectric sensors enable it to distinguish humans from the environment. However, WAMOEBA-3 does have some job performance problems. The body has no joints, so it cannot pick up objects from the floor. We're now discussing the improvement of appending a joint into the body of WAMOEBA-3. Since the WAMOEBA-3 body is constructed with very simple structure, the improvement can be built easily.

On the other hand, the evolutionary approach is very useful to acquire reactive motions for WAMOEBA-3. For example, it is unnatural for a wheel type robot to move sideways, although an omni-directional vehicle can move in any direction. In this case, an interactive evolutionary approach is effective because the assessor can configure the robot's motion without explicit programming. Above all, the purpose of using an evolutionary approach is "emergence". We hope that unique and ingenious motions have emerged through the experiment.

For that purpose, we need to continue work on the techniques required for applying IEC to the real world. As described above, the biggest problem of this experiment is human fatigue. The simulator experiment took about 90 minutes on average, and one evaluation of an individual took about 90 seconds. Therefore, the experiment may take more than two hours. In this case, it is worried that the robot hardware breaks down many times. However, we designed the WAMOEBA-3 for easy maintenance, so WAMOEBA-3 is the appropriate hardware platform for our proposing algorithm, IEC.

6. Conclusion and future works

In this paper, we introduced our working hypothesis for investigating the emotion for robots. In WAMOEBA, self-preservation is realized by a function that evaluates self-preservation and the model of endocrine system. The motion generation function of WAMOEBA is based on an MA model that is a distributed autonomous agent algorithm.

Next, we demonstrated a new hardware platform, WAMOEBA-3, designed to solve many of WAMOEBA-2Ri's problems. WAMOEBA-3 has many improvements that lighten the stress of maintenance and customization. Many of its features are derived from WAMOEBA-2Ri. WAMOEBA-3 is more appropriate for human-robot communication than WAMOEBA-2Ri.

In addition, since WAMOEBA-3's motion generation function is configured with an IEC approach, it can circumvent the problem of developer bias. An evolutionary function using IEC works correctly in simulation experiments. Though many problems remain before application of the evolutionary function into an actual robot, WAMOEBA-3 is suitable to applying the IEC because it allows easy-maintenance.

Now we continue to develop WAMOEBA-3, extending the evolutionary experiment into the real world by designing bumper switches and an auricle for the ears designed to improve sound collecting capability and directivity to sound.

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