Emotional Communication Between Humans and the Autonomous Robot
Which has the Emotion Model

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ABSTRACT
This study discusses the communication between autonomous robots and humans through the development of a robot which has an emotion model. The model refers to the internal secretion system of humans and it has four kinds of the hormone parameters to use to adjust various internal conditions such as motor output, cooling fan output and sensor gain. We surveyed 126 visitors at '97 International Robot Exhibition held in Tokyo, Japan (Oct. 1997) in order to evaluate psychological impressions of the robot. As a result, the human friendliness of the robot was confirmed and some factors of the human-robot emotional communication were discovered.

1. INTRODUCTION
In recent years, interactive simulation games have become very popular. Human beings enjoy communication with machinery which is not controlled by operators but behaves autonomously in ways which the observers cannot anticipate. These machines will be successful in the future.

Robot hardware and virtual agents have been developed to date using the above considerations. Bates developed a virtual agent that mimics the behavior of living things using animation [1]. SONY proposed "Robot Entertainment," and developed a pet robot with 4 legs [2]. Moreover, there is some research which has applied robot behavior to human-machine interface. F. Hara proposed "Active Human Interface (AHI)," and made a robot which makes the facial expressions to indicate the conditions at the machinery [3].

Most of these robots or agents have original feeling models. The feeling model not only improves the autonomy of the robot but also affects the smoothness of human-robot communication. In general, feeling models are structured based on the taxonomy of feeling in psychology, and is constructed using a static rule such as finite-state-automatos etc. However, there is no common theory on the classification of feeling, because all theories depend on individual human experiences.

R. Pfeifer noted that the simple behavior of robots can be interpreted as "feelings" by observers [4] referring to the "Fungus Eater" proposed by M. Toda [5]. He regards feelings as emergent phenomena.

We focused on the "internal secretion system" as a biological mechanism which generates the body conditions recognized as feelings. Research shows that feelings accompany various bodily changes caused by the autonomic nervous system and the internal secretion systems, e.g. tension in muscles, shrinkage of pupils, and rise in temperature, etc. We call these objective phenomena an "emotion" in order to distinguish the feelings experienced subjectively. In other words, "emotion" is the subordinate concept of feelings.

This study proposes a new model of feelings based on the basic concept, "emotion," in order to realize the human-robot emotional communication for use in human-machine interface fields. To date, the model of the internal secretion system using fuzzy set theory has been proposed and implemented in an autonomous robot, WAMOEBA-1R (Waseda Amoeba, Waseda Artificial Mind On Emotion BAse) [6]. This paper describes the three functions of an independent autonomous robot WAMOEBA-2, which improved version of WAMOEBA-1R. The first function is hardware for the human-interface, the second is a method for emotional expressions generated by the proposed model of the internal secretion system, and the third is a behavior generation algorithm based on human psychology in communication. Moreover, the factors in emotional communication of robots are described by referring to the results of a questionnaire at the '97 international robot exhibition held at Tokyo Big-Site, Japan, Oct., 1997.
2. AUTONOMOUS ROBOT: WAMOEBA-2

WAMOEBA-2 has been developed to investigate a robot emotional communication with humans, and it focused on the emergence of intelligence for communication. It is a completely independent robot which has the batteries and the control computers (Pentium 233 MHz and 200 MHz) into the body, respectively. The dimensions are 983 (L) x 862 (W) x 1093 (H) [mm], and the weight is around 60 [kg]. The characteristics of the robot hardware are 1) communication functions, 2) model of the internal secretion system, and 3) behavior generation algorithm.

2.1 COMMUNICATION FUNCTIONS

From the perspective of being "human friendly," the arrangement of the sensors and the motors refers to the morphologies of the creatures represented by human beings. WAMOEBA-2 has two arms for emotion expressions using gestures. In addition, it has two LCDs on the head and the chest to indicate internal conditions. It is important for WAMOEBA-2 to detect visual, sound, and tactile information, because human beings can generate this information directly. WAMOEBA-2, therefore, has various sensors, e.g. four ultrasonic range sensors, two color CCD cameras, two microphones (right and left), two touch panels (the head and the chest), and eight tactile sensors on the vehicle. The motor chair is adapted to the vehicle part, so that WAMOEBA-2 can acquire a wide activity area, so it does not have to stay indoors. WAMOEBA-2 can driven for about 30 [min.] using the battery in the motor chair.

2.2 MODEL OF INTERNAL SECRETION SYSTEM

The original characteristic of WAMOEBA-2 is internal mechanism architecture for modeling the internal secretion system of humans. The internal secretion system controls the entire state of the living organism using hormones. It is thought that, for robot hardware, these organisms correspond to the control mechanisms of electric power consumption and circuit temperature, etc. WAMOEBA-2 receives the battery voltage and the driving current. Moreover, using temperature sensor IC, it can...
acquire eight positions of temperature, which are the motors (the head, the neck, the shoulder, the elbow, and the motor chair) and the circuits (the image processing board and A/D boards etc.). It can control the output of the cooling fans, and the switch the power supply of each motor on or off by itself.

WAMOEBA-2 controls these internal mechanism using the hormone parameters calculated by the original algorithm “Self-Preservation Evaluation Function.” This function is one kind of fuzzy set membership function which converts sensor input into the evaluation values of durability (breakdown rate) of robot hardware between 0-1. Each function consists of two sigmoid function in order to simulate the properties of human senses, and it has one minimum value which stands for the best state for the self-preservation of the robot. When this value is close to zero, the state of self-preservation is positive, and if this value gets close to one, the state is negative. WAMOEBA-2 has seven kinds of self-preservation evaluation functions that correspond to eleven internal and external sensors. The shapes of these functions are chosen depending on the basic hardware specs. For example, the evaluation function of the voltage of battery is shown in Fig.3. In this case, the shape of the function is decided depending on the lowest voltage of the circuit drive, the standard voltage of the battery. WAMOEBA-2 calculates the output of the hormone parameters using total value \( P \) of all self-preservation evaluation functions in every program cycle as follows;

\[
\frac{dH}{dt} = \alpha \cdot (P - P^s) \cdot e^{\beta \cdot \frac{dP}{dt} + \gamma \cdot (H - H^s)}
\]

where, \( \alpha, \beta \) and \( \gamma \) are coefficients that correspond to the potential, the change quantity, and the stabilization. \( \alpha \) represents if the hormone output is continuous. \( P^s \) and \( H^s \) represent the standard values about \( P \) and \( H \). \( \sigma(x) \) is the sigmoid function which suppresses \( \frac{dP}{dt} \) within the range of 0-1. There are four kinds of the hormone parameters \([H1 \text{ to } H4]\) corresponding to four conditions: if the evaluation value \( P \) is positive or negative (mood), and if \( P \) changes dynamically or not (arousal). These hormone parameters affect many hardware conditions such as sensor gains, the motor outputs, the temperatures of the circuits and energy consumption in parallel. The affects of each hormone are decided referring to the physiology [7] shown in Table 1, Table 2 shows examples of the correspondences between the morphologies of the emotional expressions caused by the hormone parameters, however, these are not fixed but are changed by the mixture condition of the four hormone parameters.

### Table 1 Affects of the Hormone Parameters of WAMOEBA-2

<table>
<thead>
<tr>
<th></th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
<th>H4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuator Output</td>
<td>Up</td>
<td>Down</td>
<td>Down</td>
<td>Up</td>
</tr>
<tr>
<td>Cooling Fan Output</td>
<td>Down</td>
<td>Up</td>
<td>Up</td>
<td>Down</td>
</tr>
<tr>
<td>CCD Camera Viewing Angle</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
<td>Decrease</td>
</tr>
<tr>
<td>Ultrasonic Sensors Sensing Area</td>
<td>Narrow</td>
<td>Wide</td>
<td>Wide</td>
<td>Narrow</td>
</tr>
<tr>
<td>Volume</td>
<td>Up</td>
<td>Down</td>
<td>Down</td>
<td>Up</td>
</tr>
<tr>
<td>Speed</td>
<td>Up</td>
<td>Down</td>
<td>Down</td>
<td>Up</td>
</tr>
<tr>
<td>Loudness</td>
<td>Down</td>
<td>Down</td>
<td>Up</td>
<td>Up</td>
</tr>
<tr>
<td>LCD Color</td>
<td>Red</td>
<td>Blue</td>
<td>Yellow</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2 Outline of the Affects of a Hormone model

<table>
<thead>
<tr>
<th></th>
<th>cause</th>
<th>Bumper switches, Ultra-sonic range sensors (radical approach)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unpleasantness</td>
<td>expression condition</td>
<td>Decrease of the viewing angle, Increase of the motor output, Red color expression on the head LCD and Low voice</td>
</tr>
<tr>
<td>Pleasenntness</td>
<td>expression condition</td>
<td>Decrease of the viewing angle, Decrease of the motor output, Yellow color expression on the head LCD and High voice</td>
</tr>
</tbody>
</table>

### 2.3 MOTORAGENT

Next, the methodology by which WAMOEBA-2 generate its behavior for emotional communication should be discussed. We considered some algorithms of robot behavior as follows.

A conventional model-based robot behaves based on the environmental model given a priori. It requires accu-
rate sensor input, an optimal environment, and a large amount of calculation. R. Brooks proposed a "behavior based approach" [8] which has some behavior modules that correspond to the tasks. Each behavior module does not require higher level behavior planning.

However, there is a limitation on the variety of behavior, because there are only the combinations of each behavior module which are fixed a priori. In communication, humans can easily forecast robot behavior through the experiments, and would then become tired. It is an extremely difficult problem to design a behavior module for communication with humans.

We thought that the behavior should be described not at the level of the "task" but at "motor activity" in order to generate the diversity of the behavior. R. Brooks has developed a humanoid robot, "Cog," which moves its arms based on oscillators in the motors [9].

As the first step, we proposed the behavior reflection system of WAMOEBA-2 named "motor agent." In the motor agent algorithm, each motor acquires all sensor information and other motor drive conditions through the network in the robot hardware. Based on this information, each motor decides its actions autonomously. Motion command $M_i$ of motor $i$ is calculated as follows:

$$a_i = \sum_p w_p S_p + \sum_j w_j M_j$$

(2)

Here, the input value of sensor $p$ is defined as $S_p$ (e.g. the sound volume and the visual moving area etc.), 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 architecture, the morphology of the behaviors depends on weight value $w$, in which descriptions are not explicit. The initial value of $w$ depends on the physical arrangement of the Motors and the Sensor; i.e., $w$ is a large value when the distance between the sensors and the motors is small. In this stage, $w$ is adjusted by a designer who observes the behaviors of WAMOEBA-2. Table 3 shows some connections, which have a large $w$ value between the sensors and the motors.

Based on only implicit expressions, the "motor agent," WAMOEBA-2 generates the behavior using the whole body, e.g. imitation of the movement area, the sound origin, and avoidance behavior, etc. Although the $w$ value is fixed a priori, the hormone parameters affect all motor activity: $a_i$. That is, hormone parameters $H_x$ and $H_y$ (which cause the exciting conditions in WAMOEBA-2) increase the $a_i$, and, on the other hand, $H_z$ and $H_w$ (which cause the calm conditions) decrease $a_i$. As the results, the forms of the behavior change as follows: for example, when WAMOEBA-2 is quiet due to the low battery etc., it imitates moving object by the head only. In the exciting conditions however, it follows the object using the arms and/or the vehicle. The behaviors based on motor agent are expected to surprise observers.

### Table 4 Speaking Words of WAMOEBA-2

<table>
<thead>
<tr>
<th>WORDS</th>
<th>Stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Hello, my name is WAMOEBA-2.&quot;</td>
<td>Start of the program</td>
</tr>
<tr>
<td>&quot;Auch!&quot;</td>
<td>Bumper Touch Sensors</td>
</tr>
<tr>
<td>&quot;Delicious&quot;</td>
<td>Charging</td>
</tr>
<tr>
<td>&quot;I'm sleepy.&quot;</td>
<td>Increase of H2 Hormone Parameter</td>
</tr>
<tr>
<td>&quot;Good Morning!&quot;</td>
<td>Decrease of H2 Hormone Parameter</td>
</tr>
<tr>
<td>&quot;Good bye!&quot;</td>
<td>End of the program</td>
</tr>
</tbody>
</table>

3. COMMUNICATION USING WAMOEBA-2

3.1 EMOTIONAL EXPRESSION OF WAMOEBA-2

This chapter outlines the communication between WAMOEBA-2 and humans in actual experiments. Humans can communicate with WAMOEBA-2 by hand waving, clapping, calling, touching the tactile sensors etc. WAMOEBA-2 makes various reactions such as approaching, escaping, making sounds, eye tracking, and arm stretching. These actions are generated by the motor agent. In addition, WAMOEBA-2 changes the motion speed, volume/speed/loudness of sounds, and color output on LCD by hormone parameters. WAMOEBA-2 speaks some English according to the behavior shown in Table 4.

3.2 CHARACTERISTICS OF COMMUNICATION

Most conventional emotion models have a limited ability to communicate with humans. Usually, a human being...
observes and judges the expressions of the emotion model, and the recognition rate is the evaluation of the model. In communication between WAMOEBA-2 and humans, there is no scenario like this. The psychological impressions at humans change dynamically according to the behavior of the robot and/or the humans. The characteristics of WAMOEBA-2 communication are as follows.

1) **Adaptability in real world**
   Since WAMOEBA-2 is an independent and behavior based robot, it is not necessary to standardize its environment. Moreover, there is no limitation for humans in the standing position and/or motion, etc.

2) **Diversity of the ways to communicate**
   Human beings can communicate without special interface tools. Moreover, neither "words" nor "gestures" etc. for communication are specified, and preliminary knowledge is not needed.

3) **Development of communication**
   Communication is developed according to the behavior of humans and WAMOEBA-2 in real-time. There is no "story" and/or "scenario" set beforehand by a designer.
   It is believed that the "freedom degree" mentioned above (where humans are not restrained in communication with robots) is an important element in order to realize robot-human emotional communication.

4. **EXPERIMENTS**
   In order to evaluate WAMOEBA-2, demonstrations and questionnaires experiments were done at the '97 international robot exhibition held in "Tokyo Big Site," Oct. 1997, where about 150,000 people attended. The objective of this experiment is to investigate the general psychological impressions of human beings that communicated with the autonomous robot.

To make the questionnaires, we referred to research [10] about an evaluation of human subjectivity from robot behavior. The questionnaires consisted of free comments and a seven-step evaluation of five adjective pairs. Answers were obtained from 126 visitors, which involve many men (88%), engineers (17%) and people in there twenties (50%). The reason for the about percentages is the exhibition focused on industrial robots.

Experimental procedure was as follows: first, we explained the research background and the functions of WAMOEBA-2 to the testee operating the WAMOEBA-2. Next, we had the testee actually make interactions, and did the questionnaire. Fig.4 shows the results of the adjective pairs in the questionnaire, "Goodwill or Hostile", "Hate or Like", and "Untame or Tame". These adjective pairs are related to the emotional impressions of testees.

WAMOEBA-2 was given the impressions of "Goodwill", "Like", and "Tame" generally.

About the free comments, since there were no orders to testees, the contents of the comments involve various topics. We categorized these topics as follows. The ratio for the entire answer is described in parentheses.

a) External design (20.2%)
   b) Mechanical / Electrical hardware structure (9.3%)
   c) Software involving Algorithms (39.5%)
   d) Objective and/or methodology of the research, etc. (21.7%)

As the results of the arrangement of the questionnaires, the factors that affects human psychological impressions are as follows:

1) **Robot Design and Form**
   There was a resemblance between the robot and living things caused by the arrangement of the sensors and motors influences the psychological impressions of the testee. Moreover, the testee drew various opinions about the design and the covering of WAMOEBA-2.

2) **Behavior**
   There were many testees who were interested in the

![Fig.4 Results from Questionnaire 1](image-url)
changes of the reaction of the robot. There were more testees who try to understand the English words, which WAMOEBA-2 said. The importance of language was clarified again.

3) Responsibility

Many testees were sensitive to the responsibility of WAMOEBA-2. Though the robot was designed to search for the moving area and sound origin that are thought to represent human beings, there was a lot of sensory noise in the exhibition hall. It is important for robots, who communicate with human beings to detect the stimulus caused by human intentions.

In addition, Fig. 5 shows the results of the adjective pairs, "Intentional - Meanless" and "Animal like - Machine like." The answers here showed a tendency to separate into two groups largely. This tendency was not related to whether the testee is male or female, the age of the testee, and the job. These questionnaire results are thought to show the important and inevitable problem when human beings interpret these concepts and/or words in robotics.

5. CONCLUSION AND FURTHER RESEARCH

This study examined the emotional communication between an autonomous robot and human beings. The autonomous robot WAMOEBA-2 has been developed by implementing the emotion model by referring to the internal secretion system, and the motor agent which generates various behavior based on implicit descriptions in the network. The questionnaire examined the human psychological impressions from robot and done at the '97 International robot exhibition, and the human-friendliness of the robot was confirmed. Further, from the questionnaire, some factors and problem in the robot's emotional communication were clarified, represented by "humans freedom of degree."

The communication between an autonomous robot and human being discussed in this paper is a new concept which is different from conventional robot-human communication which only focused on the cost and the efficiency. However, the autonomy and/or the intelligent of robots will advance, and they will be used in homes and hospitals, etc. There, the communication discussed here will be indispensable, and has many problems, e.g. methods to maintain human-friendliness and the human empathy to robots etc.

In the future, the emotion model of WAMOEBA-2 should be optimized from the perspective of the kinds of hormone parameters and their effects. Further, there are many comment concerning with the "will" of WAMOEBA-2 in the questionnaire. It is thought that WAMOEBA-2 should equip more intelligent functions for human-robot emotional communication.

**REFERENCES**