Adaptive Motions by the Endocrine System Model in An Autonomous Robot

Tetsuya OGATA* *and* Shigeki SUGANO**
Department of Mechanical Engineering, Waseda University
3-4-1, Okubo, Shinjuku-ku, Tokyo 169-8555, Japan
Phone: +81-3-5286-3264, Fax: +81-3-5272-0948
E-mail: {ogata*, sugano**} @paradise.mech.waseda.ac.jp

ABSTRACT: *This paper describes an application of the model of human's endocrine system in a real robot hardware. The robot has four kinds of hormone parameters to adjust to various internal conditions such as motor output, cooling fan output and sensor gain etc. As the result of the experiments, the hormone parameters enabled the robot to adjust its conditions (homeostasis) and generate primitive adaptive motions.*

1. INTRODUCTION

To date, various “emotion models” have been proposed in fields of the human interface (HI) in order to realize human friendliness of machines etc. [1] In these studies, some explicit emotional states are implemented to the emotion models by designer a priori, such as “anger,” “pleasure” and “sadness” etc. The research theme of these studies is to determine the methodology to categorize emotion, the methodology to express each emotion, the methodology to change the emotional state in the model, and the methodology to improve the recognition rate for human to observe the emotion model etc.

Recently, much attention is paid to the application of the emotional mechanism into autonomous robots [2-4] in some fields represented by the “New AI.” These studies do not treat the emotional states categorized explicitly, but the intelligent behaviors which are similar to “emotional behaviors” of living creatures. The motivation for these studies is to construct the machine intelligence rather than the human interface. Therefore, the research theme for these studies is to propose the architecture of a variety of emerging behavior.

The behavior variety of living creatures (human) are assumed to emerge from biological changes in the body, for example, respiratory rhythm, muscle tension, pupils diameter, and skin temperature, etc. These biological changes do not depend on the reflection system such as the spinal cord and the brainstem but the autonomic nervous system and the endocrine system.

The objective of this study is to realize an emotion model without the need of defining the classified emotional states, but introducing a model based on the endocrine system. To date, we have developed an autonomous mobile robot named WAMOEBA-1R (Waseda Amoeba, Waseda Artificial Mind On Emotion BAse), and implemented the software of the endocrine system using fuzzy set theory, and some effects of the system were confirmed based mainly on the obstacle avoidance simulation experiments. [5, 10] Through the experiments, it was clarified the importance of the consideration of the robot hardware architecture such as the internal sensors and the internal adjusters which are the components of “the endocrine system” in order to realize the environment adaptability of the robot.

Based on above consideration, this paper discuss the robot hardware architecture which refers to human biological system. WAMOEBA-2R developed in this study obtained two possible functions by introducing the engineering model of the endocrine system. One is the adjustment function of the internal condition, and the other is the emotional expression function.

2. MORPHOLOGY OF THE ENDOCRINE SYSTEM IN ROBOTS

In this chapter the outline of the autonomic nervous system and the endocrine system is described. [6] The human nervous system is categorized into two nerve systems. One is the ‘motor system’ which has been conventionally implemented into robots as the joint servo control, and second is the autonomic nerve system and the endocrine system for the adjustment of the body.

These systems do not belong to a reflection system but a limbic system such as the amygdala and the hypothalamus in human brain where all sensing information are integrated. These parts of the brain are comparatively old;

they appeared after the reflection systems such as the brainstem and the vertebras. The endocrine system posses hormones to adjust various internal organs.

The autonomic nervous system and the endocrine system has two principle functions. One function is called 'homeostasis,' which maintains the internal condition of the living organisms. The other function is adjustment of body states in order to drive primitive emotions such as "anger" and "fear," so the being will survive in its environment. [7]

It is thought that the criteria of this adjustment would be the most primitive instinct of creatures; "self-preservation." [8] For example, when the conditions of the environment and/or the body change rapidly, the hormones, such as the noradrenaline and the dopamine etc. are secreted and the sympathetic nervous system is driven. Then, the muscles are tense, the pupils shrink and the activity of the internal organs are suppressed. As the result of these effects, the states of the body are prepared for the "fighting or flighting" behavior. [9]

If such endocrine systems are introduced into a robot, it is expected for the robot to adapt the environmental changes by the adjustments of the motor outputs, the viewing angles of the cameras, and the circuit temperatures, etc. As a result of these effects, the robot is expected to generate more flexible behaviors than the simple reflection systems that behavior based robots [10] generate in future. Furthermore, the behavior morphology of the robot has the possibility to become extremely similar to emotional expressions of human. For example, even the changes of the motor outputs are expected to cause psychological impressions to the observer in a sense of "excitement" or "quietness," for example.

3. THE MODEL OF THE ENDOCRINE SYSTEM

3.1 HARDWARE OF WAMOEBA-2R

In this chapter, an autonomous mobile robot developed in this study: WAMOEBA-2R shown in Fig. 1, 2 is described. WAMOEBA-2R is an independent robot into which the batteries and the control systems are built. The dimensions are 990 (L) x 770 (W) x 1390 (H) [mm], and the weight is approximately 130 [kg]. Since a motor powered wheel chair is adopted to the mobile vehicle of WAMOEBA-2R, the activity area is wide and not limited to the indoors. Moreover, using the battery equipped in the motor powered wheel chair, the total system of WAMOEBA-2R can be driven for about half an hour.

To detect the external information, the head is equipped with four ultrasonic range sensors, two color CCD cameras, two microphones, and the vehicle is equipped with eight touch sensors.

The breast portion of WAMOEBA-2R's body has two arms which has four D. O. F. (degree of freedom) with gripper which has one D. O. F. Total reach of this arm is 450 [mm] , the weight is 3.8 [kg], and the electric consumption is 50.5 [W]. Each arm can hold an object with a maximum weights of 2 [kg], and make emotional expressions by making gestures. A strain gage is installed directly on each joint axis to detect the torque of each joint.

Further, the head and breast are each equipped with the LCD for the expression of emotional information, monitoring of technical parameters and command inputs, etc.

However, the characteristic unique to WAMOEBA-2R are not the sensors or D.O.F. but the internal mechanisms for modeling the human's endocrine system. The endocrine system, control the entire state of the living organism. It is thought that, in the case of robot hardware,

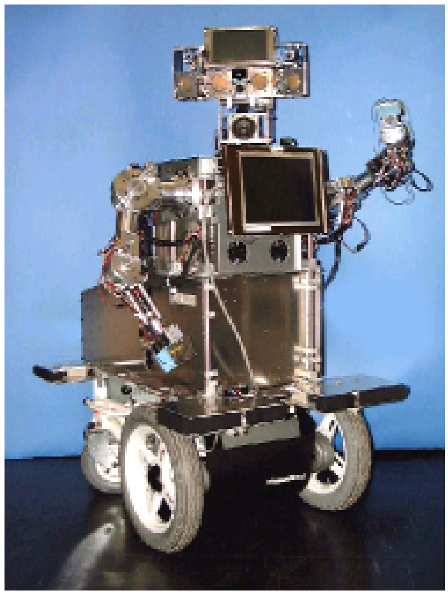

Fig. 1 WAMOEBA-2R (Photgraph)

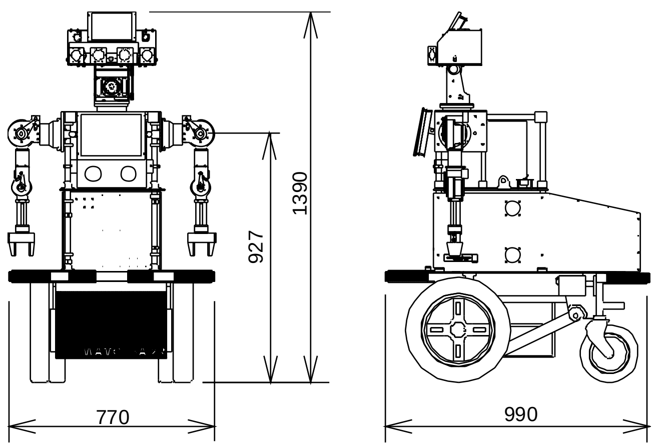

Fig. 2 Assembly Drawing of WAMOEBA-2R

Table 1 The correlation between the autonomic nervous system and Robot hardware mechanisms

Influence of Autonomic Nervous System in Human	Mechanical System		
	Influenced Part	Input Information	Adjustor
Heart Beat Sugar Density in Blood	Actuator Battery	Torque Sensor Voltage, Current Sensor	Actuator Output
Gastrointestinal Activity	Battery	Battery Load (Fruid Level Sensor)	Charging Current
Sweat, Cowlick Musclar tiredness	CPU, Electiric Curcuit, Actuator	Temperature Sensor	Cooling Fan
Arousal	Program Cycle Speed	Data Processing Times	Occupaton Memory
Pupillary Light Reflex	Camera	Optical Sensor	Squeezing
Excretion	Structural Part Electric Curcuit	Rust and/or Dirt	-
Self-Restoration of Organization	Wiring	Test for continuity (Tester, Voltmetor)	-
	Structural member	Deformations (Strain Gage etc.)	-
	Sensors	Referrence to Input Information	-

Table 2 Specification of WAMOEBA-2R

Dimensions		1390(H) x 990(L) x 770(W) mm
Weight		Approx. 130 kg
Operating Time		Approx. 50 min
Max speed		3.5 km/h
Payload		2 kgf/hand
External DOF	Neck	2
	Vehicle	2
	Arm	4 x 2 = 8
	Hand	1 x 2 = 2
Internal DOF	Cooling Fan	10
	Power Switches	4
External Sensors	Image Input Audio Input Audio Output Distance Detection Joint Torque Grip Detection Object Detection	CCD Cameras x 2 Microphones x 2 Speaker Ultrasonic Sensors x 4 Torque Sensers x 6 Pressure Sensors x 2 Photoelectric Sensors x 2 Touch Sensors x 8
Internal Sensors	Temperature Battery Voltage Motor Current	Thermometric Sensors x 8 Voltage Sensor Current Sensor
Material		Duralumin, Aluminum
CPU		Pentium III (500MHz) x 2
OS		RT-Linux

these organisms correspond to the control mechanisms of electric power consumption and circuit temperature etc. Table 1 shows the results of the consideration of correspondences between human's autonomic nerve system and the hardware mechanisms. Based on this assumption, we constructed the original hardware architecture in WAMOEBA-2R.

WAMOEBA-2R acquires the voltage of the battery in the motor powered wheel chair directly through the A/D converter and the driving current through the current sensor. Also, using the temperature sensors IC, which are fixed to each body part with silicon, WAMOEBA-2R can measure temperature at eight positions including the motors (the head, the neck, the shoulder, the elbow, and the motor chair) and the electrical circuits (the image processing board and A/D boards etc.).

WAMOEBA-2R can cool these circuit boards by switching the number of driven cooling fans. Moreover, WAMOEBA-2R can control the ON/OFF power supply of the motor powered wheel chair, the neck motor and the arm motor, etc., by itself. WAMOEBA-2R can adjust the entire electric power consumption and the temperature of the motor and the circuit by these functions.

WAMOEBA-2R has two CPU boards which are connected via a LAN, and each CPU connects various I/O boards such as the image processing board and A/D board (ISA and PCI bus). Table 2 shows the hardware specification of WAMOEBA-2R.

3.2 ENDOCRINESYSTEMSOFTWARE

In earlier work [5, 11], the original evaluation method was presented; "evaluation function of self-preservation" using fuzzy set membership function to simulate the endocrine system in robots. In this chapter, the concrete methodology for applying the model to the robot hardware is described.

Each evaluation function converts the sensor input into the evaluation value of durability (breakdown rate) of the robot between 0-1. This function consists of two sigmoid functions with one minimum value which stands for the best state for self-preservation. When this value is close to zero, the state of self-preservation is good, and if this value gets close to one, the state is bad. WAMOEBA-2 has seven kinds of self-preservation evaluation functions which correspond to eleven internal and external sensors. The shape of these functions are decided depending on the basic hardware specs. For example, the evaluation function of the voltage of battery is shown in Fig. 3. In

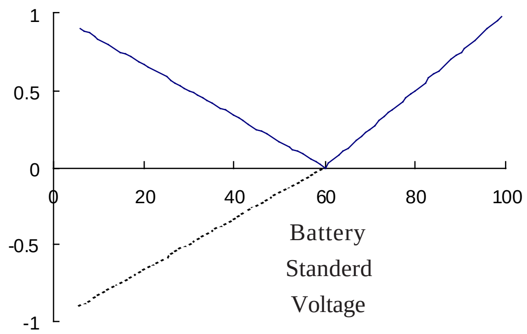

Fig.3 Evaluation Function of Voltage Battery

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-2R calculates the total value *P* of these evaluation functions and outputs four hormone parameters [*H*1 to *H*4] corresponding to four conditions, i.e. whether the evaluation value *P* is good or bad (mood), and whether the *P* changes dynamically or not (arousal), using the four sigmoid functions. These hormone parameters influence many hardware conditions and properties such as the sensor gains, the motor outputs, the temperatures of the circuits and the energy consumption etc. The influences of each hormone are decided by referring to the physiology [6] (Table 3).

The behaviors of WAMOEBA-2R are generated based on the original reflection mechanism called the "motor agent." [12] In the motor agent algorithm, each motor acquires all sensory information and other motor drive conditions through the network with in the robot hardware. Based on this information, each motor decides its own actions autonomously. Based on only the implicit expressions, the "motor agent," which is described as the weight of the network, WAMOEBA-2R can generate the behavior using the whole body, e.g. imitation of the movement area, the sound origin, and avoidance behavior, etc. Fig. 4 shows the structure of the hardware and software of WAMOEBA-2R.

Table 3 Influences of the Hormone Parameters

		H1	H2	H3	H4
Actuator Output		Up	Down	Down	Up
Cooling Fan Output		Down	Up	Up	Down
CCD Camera Viewing Angle		Decrease	Increase	Increase	Decrease
Ultrasonic Sensors Sensing Area		Narrow	Wide	Wide	Narrow
Sound	Volume	Up	Down	Down	Up
	Speed	Up	Down	Down	Up
	Loudness	Down	Down	Up	Up
LCD Color		Red	Blue	Yellow	

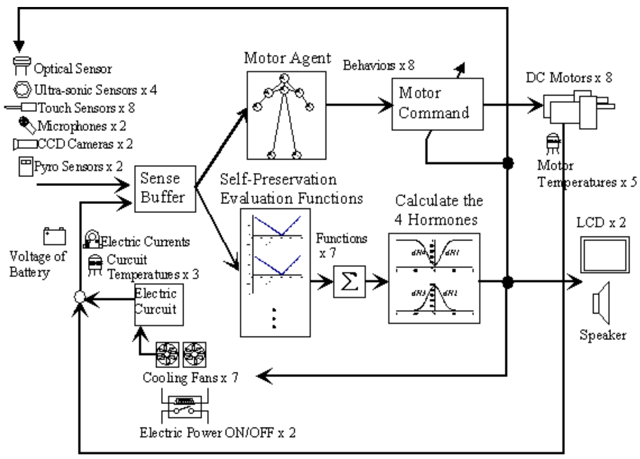

Fig. 4 System Structure of WAMOEBA-2R

4. AFFECTS OF ENDOCRINE SYSTEM

To verify the effects of the presented hardware and software architecture, we performed the experiments using WAMOEBA-2R. The experimental environment was set in an indoor room with a size of 6.0 (L) x 7.4 (W) [m]. There is an obstacle, of which the size is 1200 (L) x 20 (W) x 1080 (T) [mm]. WAMOEBA-2R performed simple collision avoidance behaviors by using the motor agent architecture.

We performed forty sets of experiments with WAMOEBA-2R, first with the presented model and then without the model. Each experiment takes approximately five minutes. In each of the experiments, thirteen kinds of data ,such as the temperature of the motors and the movement distance were sampled every two seconds.

4-1 ADJUSTMENT OF INTERNAL CONDITION

1) Stabilization of Electrical Current Consumption

Fig. 5 shows the history of the motor current value in WAMOEBA-2R in the collision avoidance behavior. When the hormone parameters were not used (No use), it is confirmed that the motor current value changes rapidly according to the mechanical behavior changes of WAMOEBA-2R. These could be regarded as the unstable states. On the other hand, when the parameters were used (Use) , the motor current was stabilized because the behavior changes smoothly by the effects of the hormone

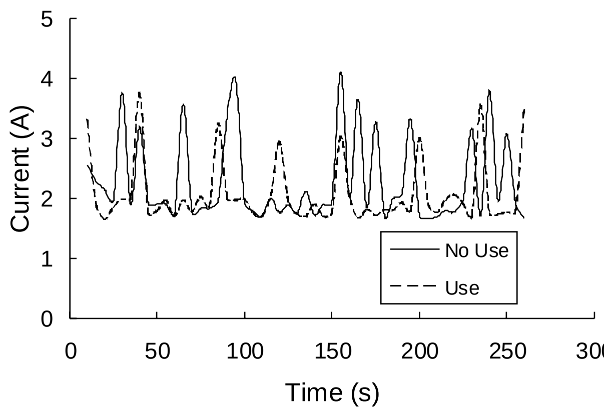

Fig. 5 The Comparison of the Motor Currents

parameters.

Referring to Table 3, if the motor output increases by the hormone parameters *H*1 and *H*4, then the cooling fan output decreases. On the other hand, if the motor output decreases by the hormone parameters *H*2 and *H*3, then the cooling fan output increases. WAMOEBA-2R achieves the stabilization of the current consumption of the entire system not by the suppression of the moving distance or the changing of the behavior form, but by the control adjustment between the motor and the cooling fan.

2) Stabilization of Temperature of Circuit

Based on the above relationship between the stabilization of the motor current and the cooling fan output, we investigated the influences of the temperature adjustment of the cooling fan on the electrical boards.

Fig. 6 shows the cooling fan output and the temperatures of each board. Though the alternation of the motor output influences each cooling fan's output, the H2 hormone parameter is an output due to rising temperature of each board and the output increases of the cooling fan. In this case the temperature of each board tends to converge around just under 26 [℃].

The following statements are the results of the experiments. When the temperatures of circuits are low, the hormone parameters increase the motor output and WAMOEBA-2R can move aggressively. On the contrary, when the temperatures of the electrical circuits are high, the hormone parameters suppress the motor output and increase the output of the cooling fan for the stabilization of the circuits.

From these experiments, it can be said that the proposed model of the endocrine system controls various conditions of WAMOEBA-2R simultaneously. These adjustments are decided not by the rules designed a priori, but by four hormone parameters which constitute the state of excitement or a state of calm for WAMOEBA-2R based on the evaluation value of self-preservation. These can be regarded as results of the realization of a part of the function "homeostasis," which stabilizes the entire system of the living organism.

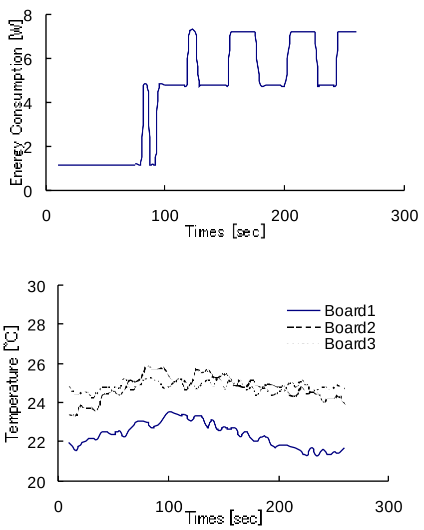

Fig. 6 The Cooling Fans Output and the Temperature of Curcuit Boards (System Used)

4.2 GENERATION OF ADAPTIVE MOTIONS

In this chapter, the adaptability of the arm motion is described. WAMOEBA-2R can detect the moving object by the cameras, and move the arm to the object by the motor agent architecture. Using this properties, we carried out some experiments to confirm the influence of the model of the endocrine system of WAMOEBA-2R. Concretely, we set the obstacle on the trajectory of the arm shown in Fig. 7, and observed the left arm motions according to the output of hormone parameters.

Fig 8 shows one of the results of the motions of WAMOEBA-2R arm without the effects of the endocrine system model. The data were sampled every one second for 485 [sec]. It is confirmed that the end of the arm made the collision with the obstacle, and the motion failed into the "dead lock" loop.

Fig. 9 shows one of the results of the motions of WAMOEBA-2R arm with the effects of the proposed model. It is confirmed that the arm could reach the moving object detected by the cameras. Though the data were sampled for 411 [sec], it took only 172 [sec] of the arm to reach the target. This motion was generated by the following process.

The condition of the hormone parameter was changed according to the output of the self-preservation evaluation function of the joint torques caused by the collisions between the end of the arm and the obstacle. Then WAMOEBA-2R became exciting condition and the mo-

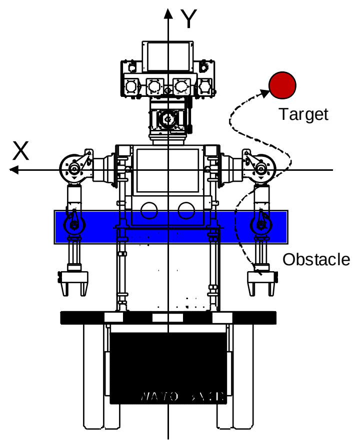

Fig. 7 The Experiment of the Arm Reaching

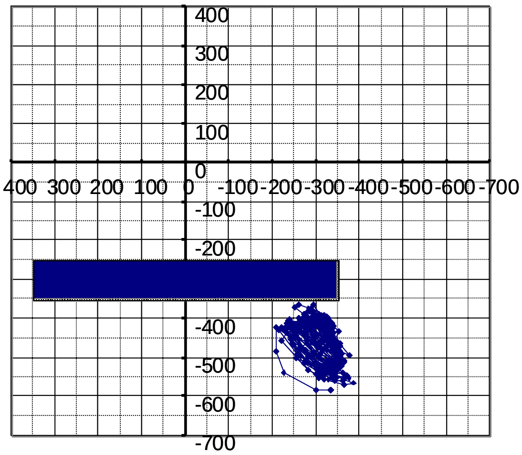

Fig. 8 The trajectory of the arm (without the proposed model)

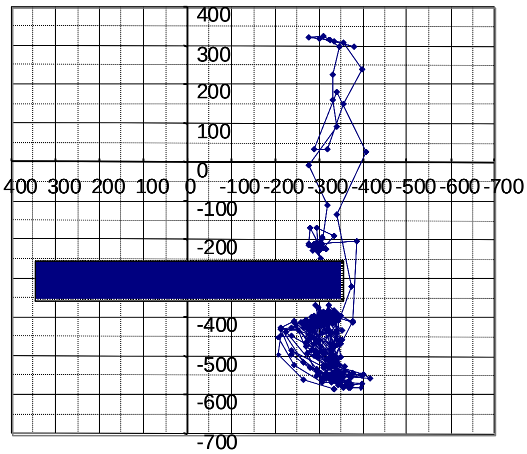

Fig. 9 The trajectory of the arm (with the proposed model)

tion speed and the trajectory of the arm were changed by the effects of the hormone parameters, and the diversity of the motion was generated.

It is thought that the results is one example of the adaptability of the endocrine system.

5. SUMMARY AND FURTHER WORK

In this study, the correlation between a human's endocrine system and the hardware mechanisms were described. Also, we showed the hardware mechanism for modeling the endocrine system in the independent autonomous mobile robot, WAMOEBA-2R developed in this research to realize the emotional communication between humans and robots. WAMOEBA-2R can acquire the internal information such as the voltage of the battery, the consumption current, and the circuit temperature etc. Moreover, WAMOEBA-2R is implemented four kinds of hormone parameters which control the internal conditions by using the cooling fans and electrical switches. These parameters are calculated from the original algorithm "the evaluation function for self-preservation." The parameters influence various parts, such as motor outputs and sensor gains due to the results of these functions. It is found that WAMOEBA-2R can adjust the internal conditions such as the motor current and the temperature of the circuit and produce adaptive behaviors accordingly.

In the future, it would be an interesting study to obtain evaluations concerning the psychological impressions which WAMOEBA-2R gives to humans.

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