2007 International Symposium on Advanced Intelligent Systems
Sep.5-8, 2007, Sokcho, Korea

Learning and Memory in Living Neuronal Networks Connected to Moving Robot

Isao Hayashi
Kansai University
Takatsuki, Japan
Email: ihaya@res.kutc.kansai-u.ac.jp

Takahisa Taguchi
AIST
Ikeda, Japan

Suguru N. Kudoh
AIST
Ikeda, Japan
Email: s.n.kudoh@aist.go.jp

***Abstract*— Dissociated culture system with multi-electrode array is fully useful for elucidation of network dynamics of neurons. The living neuronal network can obtain a kind of "learning and memory, i.e., intelligence" by interactions with outer world. In this paper, we introduce Biologically Inspired Model as a fuzzy computational system for living neuronal networks connected to moving robot, Khepera II robot. The system has a loop procedure, the top-down bio-processing for sending actuator signals to robot from living neuronal network, and the bottom-up robot-processing for electrical stimulation to living neuronal network from robot. By applying the biologically inspired model to the obstacle problem and the tracking problem of robot, we are analyzing the interaction and plasticity of living neuronal network connected to moving robot, and we discuss reconstruction of the neuronal network, which can process "thinking".**

I. Introduction

Dissociated culture system with multi-electrode array is fully useful for elucidation of network dynamics of neurons [1]. Dissociated neurons in vitro begin to elongate neurites array and reconstruct complicated living neuronal networks. The living neuronal network can obtain a kind of "intelligence" by interactions with outer world [2], [3].

In this paper, we developed integration system of living neuronal network and Khepera II robot, using two kinds of fuzzy logic [4]. We call the system as "biomodeling system" [5]–[7], in which the "top-down bio-processing" for sending actuator signals to robot from living neuronal network, and the "bottom-up robot-processing" for electrical stimulation to living neuronal network from robot are connected between neuronal network and robot. We are here analyzing the interaction in biomodeling system, and discuss reconstruction of the neuronal network, which can process "thinking".

II. Living Neuronal Networks Interfaced with Moving Robot

In biomodeling system, we provided a program which generates "premised control rules" for making a robot avoid obstacles. Robot with living neuronal network has two Fuzzy Control Units, FLTD for control of the actuators of the robot in the top-down bio-processing, and FLBU for control of the electrical stimulation to the neuronal network in the bottom-up robot-processing (Figure 1 and Figure 2).

This work was partially supported by the Ministry of Education, Culture, Sports, Science, and Technology of Japan under Grant-in-Aid for Scientific Research 18500181, 19200018 and 18048043.

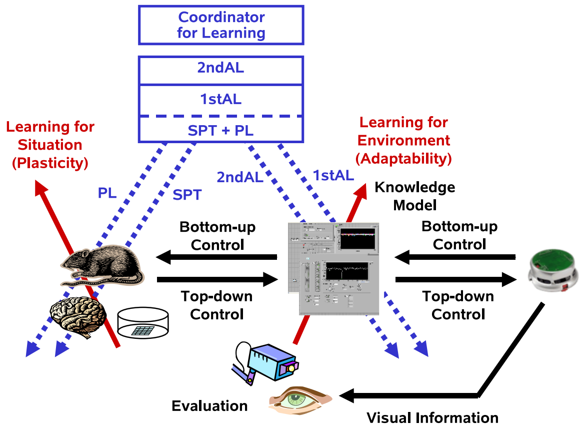

Fig. 1. Biomodeling System

Robot control unit receives 8 inputs from the neuronal network. Stimulation control unit receives outputs of 8 IR sensors of the robot. In FLBU, fuzzy rules are prepared in which the unit applies electrical stimulation to e.g., electrode 1, if obstacles exist near the left side. In FLTD, the 256 fuzzy rules can express the actuators of robot from all the classified patterns of the action potentials in eight inputs (Figure 3).

a In FLTD, setups of the membership function of fuzzy rules were performed as follows. Maximum value frequency of the action potential in all electrodes was made into the maximum of the horizontal axis of a membership function. The maximum of the membership function assigned to the label of high frequency was at three fourths of the points of the maximum frequency, and maximum of the membership function assigned to a low frequency label was conversely was at one fourth of the points of the maximum frequency.

Then, the method of setting up fuzzy rules is as follows. The differences of the fuzzy number of each rule assigned to bringing an object close to the left side of the robot and to right side were calculated. We focused on the rules with large differences. The rules with large fuzzy numbers for object at left side correspond to particular patterns evoked by inputs related to left IR sensors. In contrast, the rules with large fuzzy numbers for object at right side correspond to particular patterns related to right IR sensors. So that, for example, consequents of the rules for left IR sensor were configured that speed of left actuator is high.

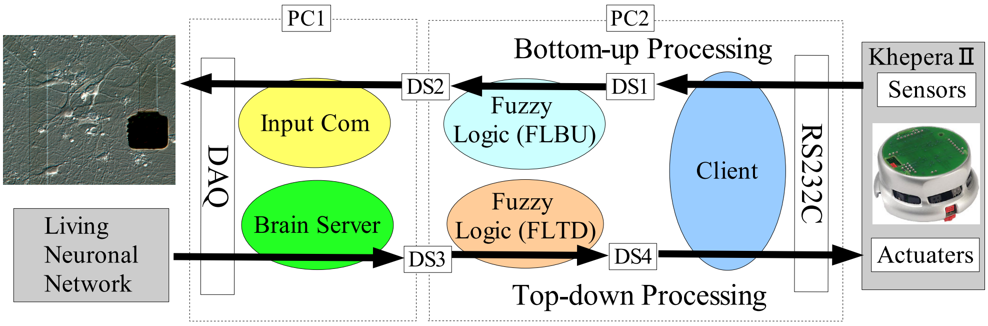

Fig. 2. Living Neuronal Network and Robot

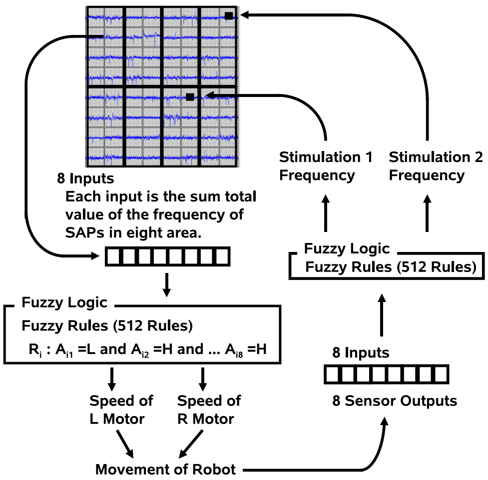

Fig. 3. Robot Control with Living Neuronal Network

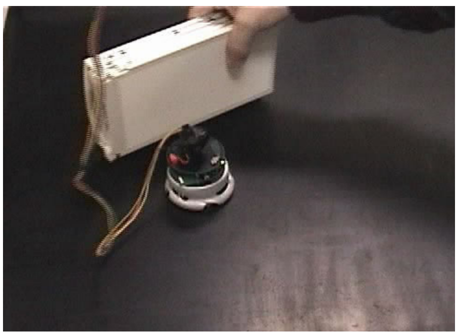

Fig. 4. Collision Avoidance of Robot with Living Neuronal Network

As a result, when Robot control unit detect particular pattern that is evoked by the electrical stimulation to electrode 1, the speed of left actuator is set to be fast, and the robot can avoid the obstacle using fuzzy logic in FLTD (Figure 4). Figure 5 shows an example of trajectory of robot with cultured neuronal network. Orange dots indicate the sensors located at left side of the robot detect objects. Green dots indicate the right sensors detected objects. In the experiments, the robot sometimes ignore the sensor inputs,

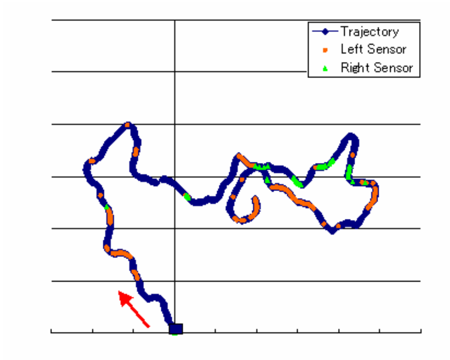

Fig. 5. An Example of Trajectory of Robot

but it feckly avoid collision.

To investigate the coordination between the learning type of fuzzy logic and the plasticity learning of neuronal network, we conducted an experiment of robot run in the straight course. The run course assumes full length 120mm, straight line of 90mm in width and we assumes that robot runs along a base line to be located in the center of the run course a control purpose (Figure 6).

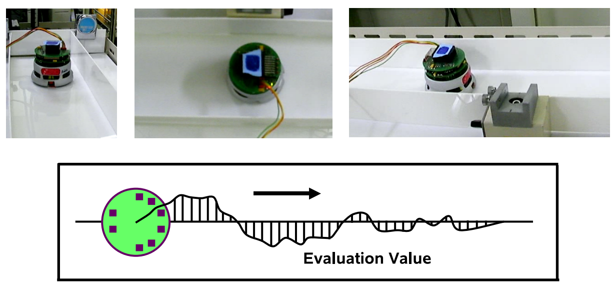

Fig. 6. Experimental Course

At first we adjust a fuzzy rule by the learning type fuzzy logic to realize the adaptability that can support an environmental change. However, the adjustment of the fuzzy rule by the learning type fuzzy logic is two phases, which are the first grade learning type fuzzy logic by the stimulation simulator (the first grade adaptability learning) 鐚 1stAL), and the second grade learning type fuzzy logic in the run road (the second grade adaptability learning) 鏍 2ndAL). In 1stAL, we assume a sensor signal of robot by a stimulation program and give two points of stimulation signals to the neuronal network. Fuzzy rules are adjusted as input with the learning type fuzzy logic of the reaction pattern of the neuronal network and as a supervised signal with the reverse signal of the sensor signal of robot (Figure 7).

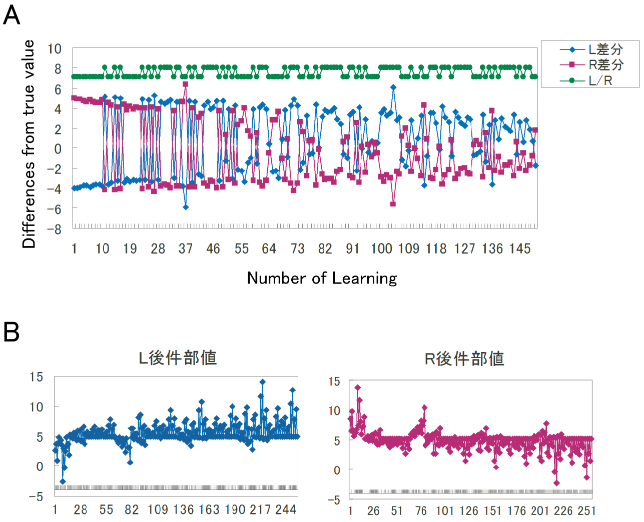

Fig. 7. Learning Process of 1stAL

On the other hand, in 2ndAL, the value of the IR sensor of robot is used as a supervised signal by the web camera which is placed above of the run course and a fuzzy rule is adjusted. An adjusted fuzzy rule is fixed, and robot runs afterwards by plasticity learning, PL of the neuronal network (Figure 8 and Figure 9).

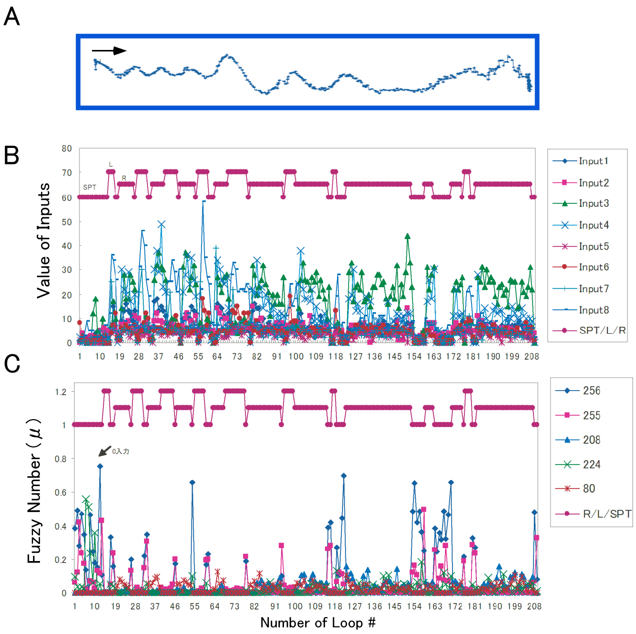

Fig. 8. Trace of Khepera Robot and Membership Grade of Fuzzy Logic

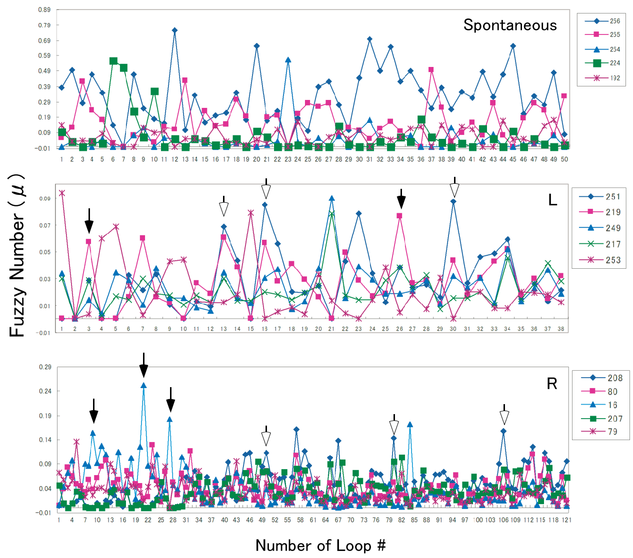

Fig. 9. Membership Grade Classified According to SPT, L, and R

If we observe adequate modification in the behavior of this robot by interaction to outer world, can we define that phenomenon as the intelligence of living neuronal network? Our ultimate goal is to generate intelligence in culture dish and to observe it.

References

[1] S.N.Kudoh and T.Taguchi: Operation of spatiotemporal patterns stored in living neuronal networks cultured on a microelectrode array, *Advanced Computational Intelligence and Intelligent Informatics*, Vol.8, No2, pp.100-107 (2003).

[2] M.A.Lebedev, J.M.Carmera, J.E.O'Doherty, M.Zacksenhouse, C.S.Henriquez, J.C.Principe, and M.A.L.Nicolelis: Cortical ensemble adaptation to represent velocity of an artificial actuator controlled by a brain-machine interface, *Journal of Neuroscience*, Vol.25, No.19, pp.4681-4693 (2005).

[3] D.J.Bakkum, A.C.Shkolnik, G.Ben-Ary, P.Gamblen, T.B.DeMarse, and S.M. Potter: Removing some 'A' from AI: Embodied cultured networks, in *Embodied Artificial Intelligence*, editered by F.Iida, R.Pfeifer, L.Steels, and Y.Kuniyoshi, New York, Springer, pp.130-145 (2004)

[4] I.Hayashi, M.Umano, T.Maeda, and A.Bastian, and L.C.Jain: Acquisition of Fuzzy Knowledge by NN and GA, *Proc. KES98*, pp.69-78 (1998).

[5] S.N.Kudoh, I.Hayashi, and T.Taguchi: Synaptic potentiation reorganized functional connections in a cultured neuronal network connected to a moving robot, *Proc. of the 5th International Meeting on Substrate-Integrated Micro Electrode Arrays (MEA2006)*, pp.51-52, Reutlingen, Germany in July 4-7 (2006).

[6] S.N.Kudoh, T.Taguchi, and I.Hayashi: Interaction and intelligence in living neuronal networks connected to moving robot, *Proc. of 2006 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE2006) in 2006 IEEE World Congress on Computational Intelligence (WCCI2006)*, pp.6271-6275 (No.FUZZ4516), Vancouver, Canada in July 16-21 (2006).

[7] I.Hayashi, T.Taguchi, and S.N.Kudoh: Biomodeling system by living neuronal network connected to moving robot, *Proc. of International Symposium on Artificial Brain with Emotion and Learning (ISABEL2006)*, pp.164-165, Seoul, Korea in August 24-25 (2006).