Biomodeling System by Living Neuronal Network Connected to Moving Robot

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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. We investigate the spatio-temporal pattern of spontaneous action potentials, and we found that spontaneous activities are enough to construct dynamic functional assemblies of neurons, and synaptic potentiation can induce re-organization of such assemblies of neurons. In addition, the living neuronal network can obtain a kind of "intelligence" by interactions with outer world.

In this paper, we developed integration system of living neuronal network and Khepera II robot, using two kinds of fuzzy logic [2]. We call the system as "biomodeling system" [3,4], 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. Drastic Re-Orgnization of Functional Assembry

The hippocampus neurons were prepared from a Wister rat on embryonic day 17-18 and cultured by the previously described method. We set up the system in which the living neuronal network interacts to feedback stimulator. In the experiment, only one stimulation pulse was applied to an electrode in the cultured neuronal network when action potentials were detected from other both of electrodes. The stimulation activated the network and evoked next synchronized inputs at the two electrodes. The synchronized inputs triggered next stimulation. Thus, bursting-like stimulation pattern was generated by the interaction of network and the real-time feedback system. This result is still preliminary stage, but it certainly suggests that living neuronal network can re-organize their activity pattern depending on environmental I/O interaction.

III. 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).

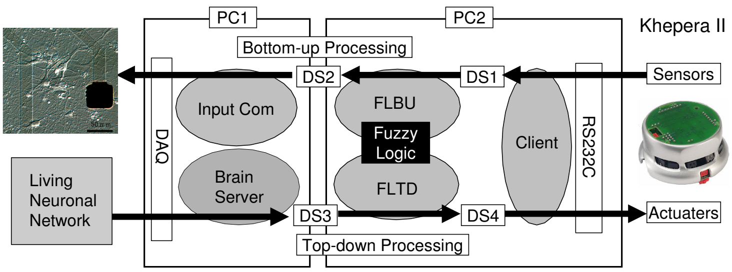

Fig. 1: Biomodeling System

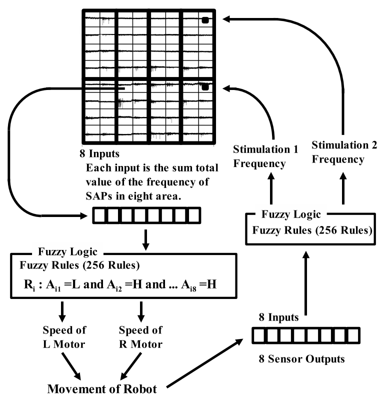

Fig. 2: Robot Control with Living Neuronal Network

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 2).

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.

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 3). Figure 4 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.

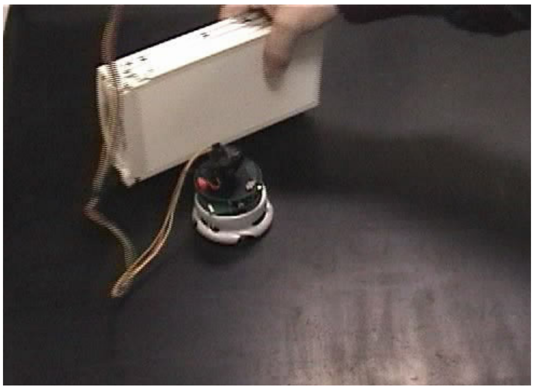

Fig. 3: Collision Avoidance of Robot with Living Neuronal Network

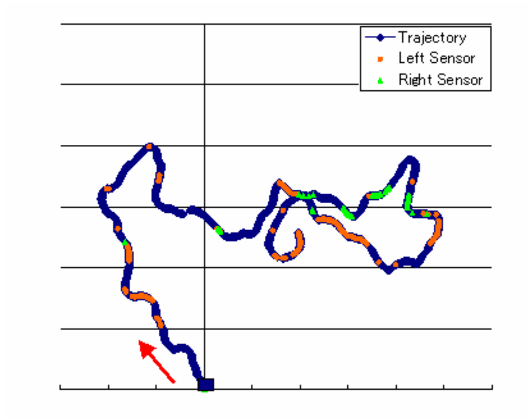

Fig. 4: An Example of Trajectory of Robot

In the experiments, the robot sometimes ignore the sensor inputs, but it feckly avoid collision. In our previous reports [1], the pattern of evoked action potential can be modified by a particular pattern of electrical stimulation. 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

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