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Synchronization Phenomena of Four Neurons on FitzHugh-Nagumo Model

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1. Introduction

Some neural oscillator models are studied by many researchers. FitzHugh-Nagumo (FHN) model is one of these models. Periodic solutions on a pair of FHN models have already found[1]. In addition, the periodic solutions have some firing patterns. We propose a system which a neuron is connected to a triangle system. The system has four neurons with inhibitory coupling. We focus on synchronization phenomena of the system. Likewise, we investigate firing patterns.

2. FitzHugh-Nagumo model

In the following, we study the system which is modeled by the excitable FHN models. FHN model is given by the following equations:

$$\frac{du_i}{dt} = u_i(u_i - \alpha)(1 - u_i) - v_i + \frac{K}{N}\sum_{i \neq j}(u_j - u_i) \tag{1}$$

$$\frac{dv_i}{dt} = \tau(u_i - \gamma v_i) \tag{2}$$

where u_{ij} is the activator, v_{ij} is the inhibitor, α, τ and γ are parameters, K is the coupling strength and N is the number of elements. α, τ and γ are fixed at $\alpha = 0.01$, $\tau = 0.001$ and $\gamma = 0.0$ because these values are used in previous study of a pair of excitable FHN elements.

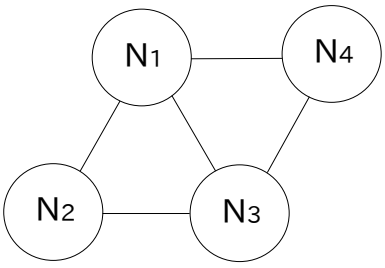

Figure 1: The system of four neurons on FHN model.

3. Simulation results

The simulation model is shown in Fig. 1. We investigate synchronization phenomena by changing the coupling strength K from -1 to 0.

As the results of simulation, in case of $K = -0.035$, the observed time waveforms are shown in Fig. 2. Time waveforms N_1 and N_3 are synchronized at in-phase with N_2 and N_4. Next, we explain two-phase firing pattern in detail. After N_1 and N_3 excite, N_2 and N_4 excite soon. After these successive excitations, all neurons stay quiescent state for a while. On the next successive excitations, N_2 and N_4 excite first. After that, N_1 and N_3 excite soon. These states are repeated.

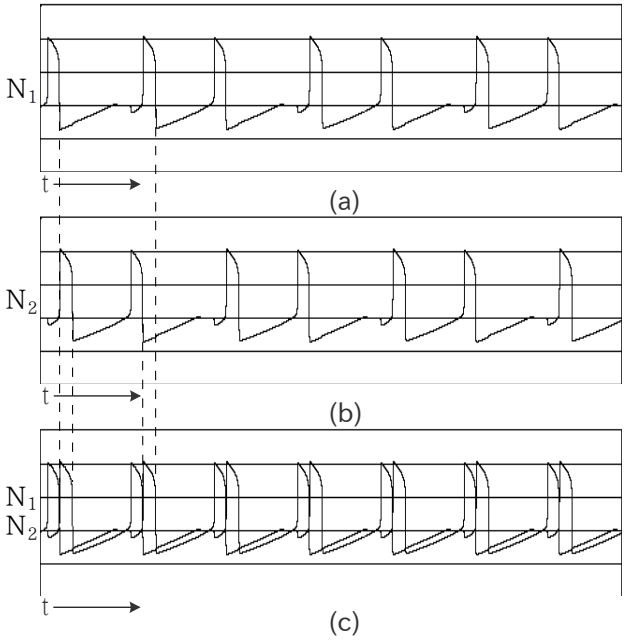

Figure 2: Time evolution of four neurons on FHN model for the coupling strength $K = -0.035$. The solid lines of (a) and (b) correspond to time waveforms of $N_1(N_3)$ and $N_2(N_4)$, respectively. The solid lines of (c) correspond to all neuronal time waveforms.

4. Conclusions

In this study, we proposed a system which a neuron is connected to a triangle system. Periodic solution was observed on the system. Furthermore, we found a simple firing pattern. These facts shed some light on neural activity in the brain and the spinal cord where periodic behavior is often observed.

5. Reference

[1] T. Yanagita, T. Ichinomiya and Y. Oyama, "Pair of excitable FitzHugh-Nagumo elements: Synchronization, multistability, and chaos", Phys. Rev. E 72, 056218, 2005.