Periodic Input Leads an Izhikevich Neuron to Induce both Periodic and Irregular Responses

Yota Tsukamoto, Honami Tsushima, and Tohru Ikeguchi

Tokyo University of Science

In the course of neuroscience, not only have real neurons been investigated, but mathematical neuron models of a single neuron have also been analyzed. For example, electrophysiological studies have shown that a real neuron induces chaotic behavior in response to a periodic forcing [1, 2]. A periodically forced Hodgkin–Huxley model [3] can reproduce chaotic responses [4]. The current prominent mathematical neuron model is the Izhikevich neuron model [5], for it is computationally effective and able to reproduce various spike patterns. We have already examined the Izhikevich neuron model with parameter sets for regular spiking, fast spiking, intrinsically bursting, and chattering neurons [6, 7, 8, 9]. However, low-threshold spiking (LTS) neuron have yet to be studied. Thus, focusing on interspike intervals (ISIs), we have evaluated responses of a periodically forced Izhikevich neuron model of an LTS neuron.

The Izhikevich neuron model is two-dimensional ordinary differential equations. In the present study, this model is stimulated by a sinusoidal input defined as $I(t) = I_{DC} + A\sin(2\pi/T)t$, where t is time [ms], I_{DC} is a constant part, and A and T are the amplitude and the period of sinusoidal wave, respectively. We set $I_{DC} = 10$ and changed T and A. We have evaluated the following three quantitative indices. The first index to evaluate responses is the diversity index of ISIs D. It is defined as $D = M/N$, where N represents the total number of ISIs and M represents the number of different values of ISIs [10, 11]. Given a sufficiently long spike sequences, $D \approx 1$ for an irregular response while $D \approx 0$ for a periodic response.

Figure 1 shows the period–amplitude plane of diversity indices of ISIs. There exist two domains: periodic responses and irregular responses. As A increases from zero to 10, diversity indices of ISIs noticeably change. This implies that the phase transition from irregular response to periodic response occurs as A increases.

In this study, we have investigated responses of a periodically forced Izhikevich neuron model of an LTS neuron. Evaluation focusing on ISIs implies that periodic forcing induces both periodic and irregular responses and that change of A and T leads to possible phase transition. The second and third quantitative indices focusing on ISIs are the coefficient of variation (CV) and the local variation (LV) [12, 13]. CV is highly sensitive to local change of firing rate, reflects only distribution of ISIs, and represents the global variability of spike sequences. On the other hand, LV is subject to temporal order of ISIs and represents the intrinsic spiking characteristics independently of local change of firing rate. The results of CV and LV and comparison of the three indices will be discussed in the presentation.

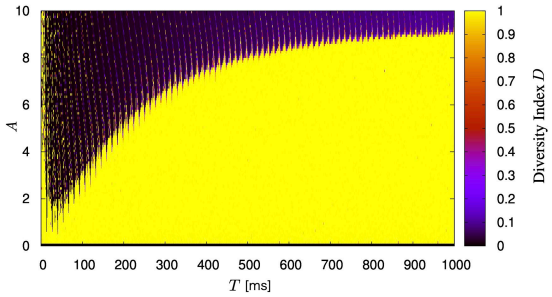

Figure 1: Diversity indices of ISIs for the Izhikevich neuron model of an LTS neuron.

The research of H. T. was partially supported by JSPS KAKENHI Grant Number JP22J12396. The research of T. I. was partially supported by JSPS KAKENHI Grant Numbers JP20H00596, JP21H03514, and JP22K18419.

References

[1] H. Hayashi et al., *Physics Letters A*, 88(8), 435–438, 1982.
[2] K. Aihara et al., *Physics Letters A*, 116(7), 313–317, 1986.
[3] A. L. Hodgkin et al., *Journal of Physiology*, 117(4), 500–544, 1952.
[4] K. Aihara et al., *Journal of Theoretical Biology*, 109(2), 249–269, 1984.
[5] E. M. Izhikevich, *IEEE Transactions on Neural Networks*, 14(6), 1569–1572, 2003.
[6] Y. Tsukamoto et al., *NOLTA, IEICE*, 13(2), 367–372, 2022.
[7] Y. Tsukamoto et al., *Proc. of The 2021 Nonlinear Science Workshop*, NLSW-54, 2021.
[8] Y. Tsukamoto et al., *Proc. of IEICE General Conference*, N-1-16, 2022, in Japanese.
[9] Y. Tsukamoto et al., *Proc. of IEICE NOLTA Society Conference*, A-9, 2022, in Japanese.
[10] N. Sugiura et al., *IEICE Technical Report*, 113(116), 43–48, 2013, in Japanese.
[11] K. Naiki et al., *IEICE TRANSACTIONS on Fundamentals of Electronics, Communications and Computer Sciences*, J100-A(5), 195–204, 2017, in Japanese.
[12] S. Shinomoto et al., *Neural Computation*, 15(12), 2823–2842, 2003.
[13] S. Shinomoto et al., *Journal of Neurophysiology*, 94(1), 567–575, 2005.