Neurocomputing 205 (2016) 375–381

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

Multiple modes of electrical activities in a new neuron model under electromagnetic radiation

Mi Lv, Jun Ma*

Department of Physics, Lanzhou University of Technology, Lanzhou 730050 China

ARTICLE INFO

Article history:
Received 20 October 2015
Received in revised form
19 February 2016
Accepted 3 May 2016
Communicated by Grana Manuel
Available online 10 May 2016

Keywords:
Electromagnetic radiation
Electromagnetic induction
Spiking
Bursting
Multiple modes

ABSTRACT

The three-variable Hindmarsh–Rose model is improved to describe the dynamical behaviors of neuronal activities with electromagnetic induction being considered, and the mode transition of electrical activities in neuron are detected when external electromagnetic radiation is imposed on the neuron. The improved neuron model holds more bifurcation parameters and the mode of electric activities can be selected in larger parameter region. It is found that the electromagnetic radiation can excite quiescent neuron but also can suppress the electrical activities in neuron as well. Particularly, it is important to find that multiple modes of electrical activities can emerge alternatively, and these results are consistent with biological experiments.

1. Introduction

The neuronal system is made up of a large number of neurons, and signals are propagated between neurons under complex connection types. The dynamical behavior of electrical activities in neuron and neuronal network has been extensively investigated. For an isolate neuron, its electrical activities can show several of modes such as quiescent, spiking, bursting even chaotic states by applying appropriate external forcing current. Based on the original Hodgkin–Huxley neuron model [1], a variety of simplified neuron modes [2–5] have been established for theoretical and numerical investigation. It is believed that the membrane potential of neuron depends on the changes of transmembrane current, on/off of ion channels and even the regulation induced by astrocyte [6,7]. Based on mean field and properties of nonlinear oscillator, most of the neuron models can describe the dynamical properties in electrical activities. Indeed, the dimensionless Hindmarsh–Rose neuron model is reliable and available for bifurcation analysis [8,9] thus the mode transition in electric activities could be understood. Some researchers argued that more bifurcation parameters should be introduced into the three-variable neuron model so that bifurcation behaviors could be extensively investigated. For example, Refs. [10,11] presented a four-variable Hindmarsh–Rose neuron model by including more controllable bifurcation parameters, and Refs. [12–14] designed a neuron model driven by autapse thus the self-adaption to external forcing could be considered by adding two parameters (time delay and the feedback gain) in the autapse [15]. Gu et al. [16] set up a four-variable biological neuronal model to discern bifurcation behaviors induced by different ion currents. The process of metabolism is often associated with the electrical activities in neuron, and information transition and energy coding should be considered [17–19] during the signal processing and communication. Inspired by Refs. [20], which defined a statistical Hamilton energy by using Helmholtz theorem, the author of this paper confirmed that the mode in electrical activity in neuron is also associated with the energy release [21], for example, the Hamilton energy can be decreased greatly when neuron is under bursting and chaotic states, and it may give some guidance to understand the emergence mechanism for epilepsy. The potential mechanism could be that bursting synchronization induced epilepsy makes energy release explosively. Indeed, the electrical activities in neuron are also dependent on conductance in channels that channels blocking [22] can change the electrical modes of membrane potential for neurons. In fact, it is important to investigate the development and transition of collective behaviors of neurons by setting up different spatial networks [23,24], for example, the pattern selection and change of collective behaviors of neuronal network are changed by blocking [25,26] in ion channels embedded in the membrane of neurons. However, most of the neuronal models should be improved to consider more possible factors such as parameters setting, external forcing, physical evidence and description.

* Corresponding author.
E-mail address: hyperchaos@163.com (J. Ma).

http://dx.doi.org/10.1016/j.neucom.2016.05.004

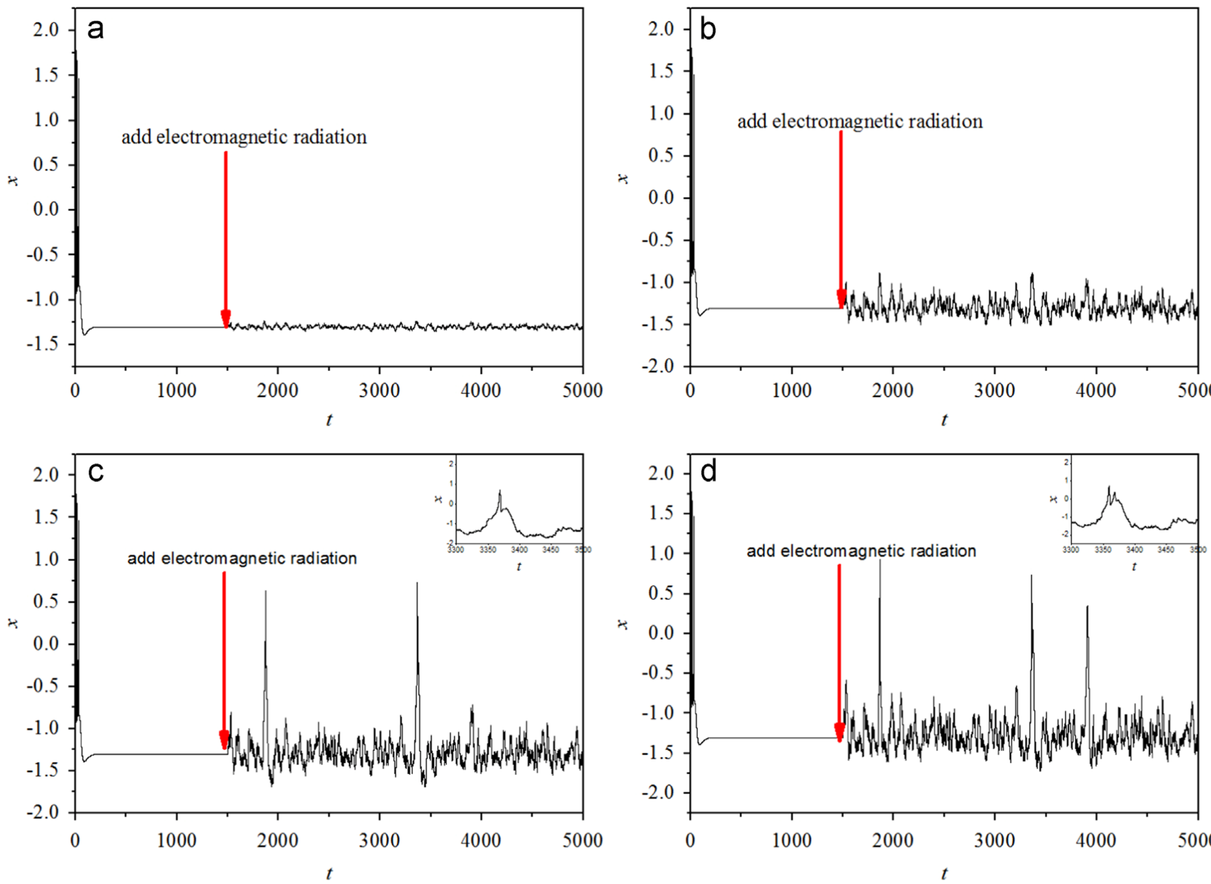

Fig. 1. The transition of electrical activities in an isolate neuron when electrical field radiation is switched on $t=1500$ time units, and external forcing current $I_{ext}=0.8$. For intensity (a) $D=0.1$, (b) $D=0.5$, (c) $D=0.7$, (d) $D=0.9$.

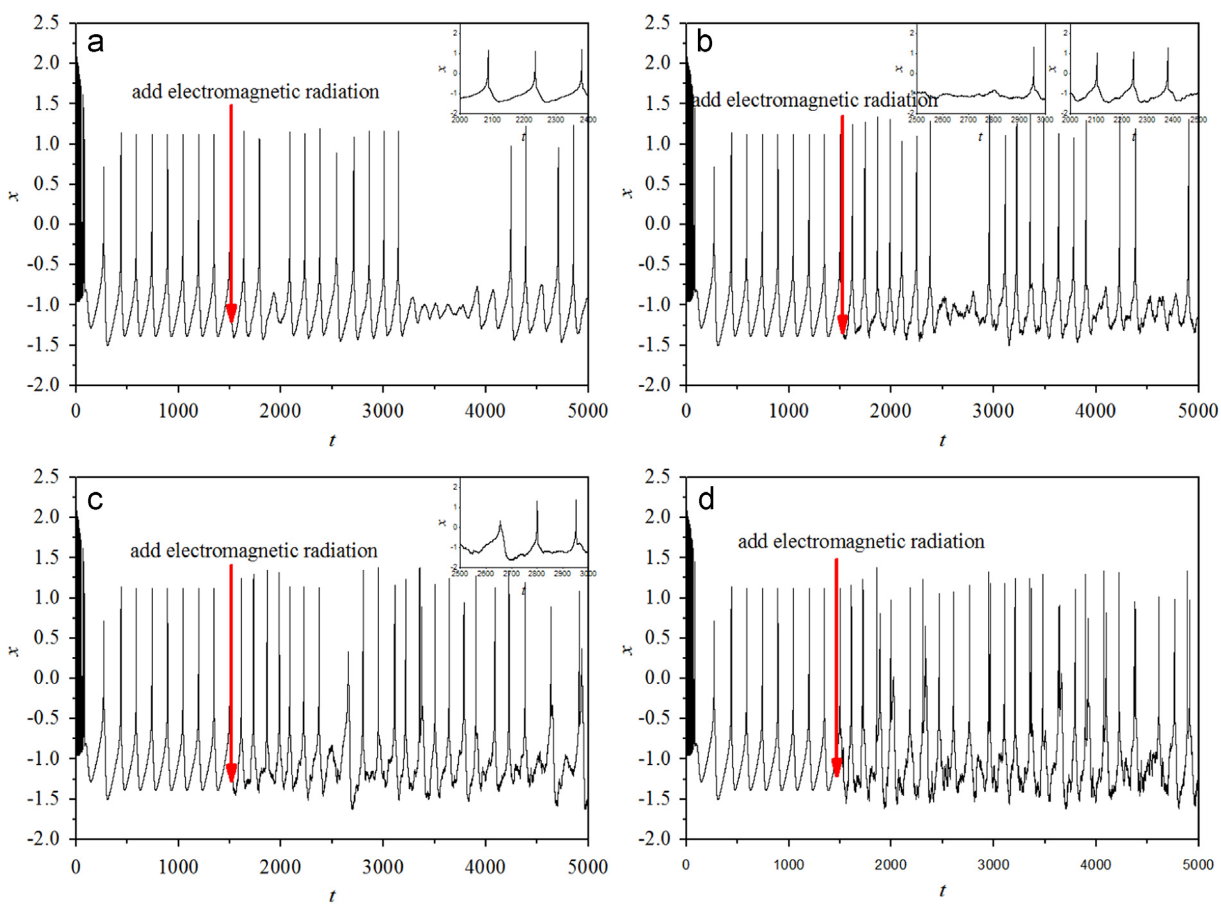

Fig. 2. The transition of electrical activities in an isolate neuron when electrical field radiation is switched on $t=1500$ time units, and external forcing current $I_{ext}=1.84$. For intensity (a) $D=0.1$, (b) $D=0.3$, (c) $D=0.4$, (d) $D=0.7$.