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A New Approach to Optimal Control of Conductance-based Spiking Neurons*

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Abstract

This paper presents an algorithm for solving the minimum-energy optimal control problem of conductance-based spiking neurons. The basic procedure is (1) to construct a conductance-based spiking neuron oscillator as an affine nonlinear system, (2) to formulate the optimal control problem of the affine nonlinear system as a boundary value problem based on the Pontryagin's maximum principle, and (3) to solve the boundary value problem using the homotopy perturbation method. The construction of the minimum-energy optimal control in the framework of the homotopy perturbation technique is novel and valid for a broad class of nonlinear conductance-based neuron models. The applicability of our method in the FitzHugh-Nagumo and Hindmarsh-Rose models is validated by simulations.

Keywords: Spiking neurons, optimal control, homotopy perturbation method.

1 Introduction

Oscillatory neurons exhibit voltage spikes known as action potentials, which can be controlled by electrical stimulation [1, 2]. The ability to control spiking activities may play an important role in the treatment of many neurological diseases [3, 4]. In recent years, concerning the neuron energy efficiency [5, 6], optimal electrical stimulation in single neuron for different control performances, such as minimum energy and spike times, has received much attention. It is also applicable to the treatment of subthalamic nucleus [7]. In these and many other neurological applications, considerations of optimal electrical stimulation, especially low-power electrical stimuli, are desired, since application of high power stimuli is harmful to the biological tissues and the reduction of power consumption in a neurological implant is essential in order to reduce its size and lengthen its lifetime [8].

In the field of theoretical neuroscience and automatic control, many control methods have been used or developed for minimum-power or minimum-energy controls of spiking

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