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A new photosensitive neuron model and its dynamics

Key words: Photosensitive neuron; Neuron model; Bifurcation; Bursting; Photocell

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Motivation

1. Application of phototube in sensor circuits;

2. Exploring physical processing on optical signals via a phototube in neural circuits;

3. Dynamics of light-dependent neural circuits in the presence of time-varying illumination.

Main idea

1. Phototube is a feasible electronic component, and photocurrent is induced to excite the neural circuit.

2. Photocurrent is dependent on the intrinsic parameters and external illumination.

3. Activated phototubes can be used as current and voltage sources for neural circuits.

4. The firing pattern and mode in neural activities of the functional neural circuit are dependent on the external illumination.

Method

1. A phototube is connected with the simple FitzHugh-Nagumo (FHN) neural circuit.

2. Neural circuit equations are obtained and scale transformation is applied to obtain a functional neuron model.

3. Bifurcation analysis is performed to estimate the dependence of mode selection on the external illumination.

Major results

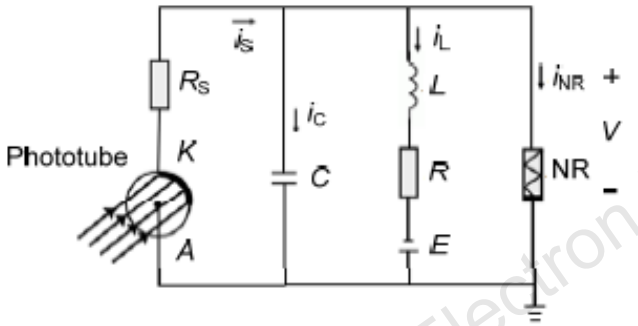

Fig. 1 Implementation of the circuit built for the FitzHugh-Nagumo neuron

A phototube is used to capture external illumination and high-frequency lights, and it activates photocurrents from the phototube and is considered as the voltage source V_s. NR is the nonlinear resistor, C the capacitor, L the induction coil, E the constant voltage source, K the cathode, and A the anode in the phototube

Characteristic of the nonlinear resistor (NR) is estimated by

$$i_{\mathrm{NR}} = -\frac{1}{\rho}\left(V - \frac{1}{3}\frac{V^3}{V_0^2}\right). \qquad (1)$$

Major results (Cont'd)

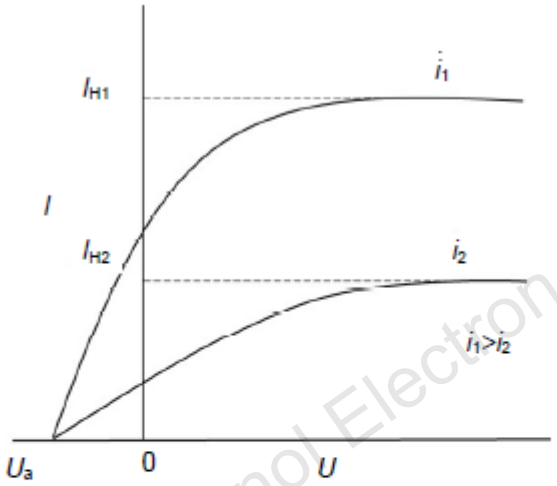

Fig. 2 A plot of the relationship between voltage and photocurrent

U and I represent the voltage and current of the phototube, respectively. I_{H1} and I_{H2} are the maximum currents (saturation currents) emitted from the phototube when the light intensities (i_1 and i_2) are strong enough. U_a denotes the reverse cut-off voltage and is dependent on the material properties of the phototube cathode

Photocurrent across the phototube is approached by

$$I_a = \frac{2I_H}{\pi}\arctan(U - U_a) \ .$$

Major results (Cont'd)

Circuit equation and light-dependent neuron model:

$$\begin{cases} C\dfrac{\mathrm{d}V}{\mathrm{d}t} = \dfrac{V_\mathrm{s} - V}{R_\mathrm{s}} - i_\mathrm{L} - i_\mathrm{NR}, \\ L\dfrac{\mathrm{d}i_\mathrm{L}}{\mathrm{d}t} = V + E - Ri_\mathrm{L}. \end{cases} \tag{4}$$

$$i_\mathrm{s} = \frac{2I_\mathrm{H}}{\pi}\arctan(V_\mathrm{s} - V_\mathrm{a}) = \frac{V_\mathrm{s} - V}{R_\mathrm{s}}. \tag{5}$$

$$\begin{cases} x = \dfrac{V}{V_0}, y = \dfrac{\rho i_\mathrm{L}}{V_0}, \tau = \dfrac{t}{\rho C}, a = \dfrac{E}{V_0}, b = \dfrac{R}{\rho}, \\ c = \dfrac{\rho^2 C}{L}, \xi = \dfrac{\rho}{R_\mathrm{s}}, u_\mathrm{s} = \dfrac{\rho V_\mathrm{s}}{R_\mathrm{s} V_0}. \end{cases} \tag{6}$$

$$\begin{cases} \dfrac{\mathrm{d}x}{\mathrm{d}\tau} = x(1-\xi) - \dfrac{1}{3}x^3 - y + u_\mathrm{s}, \\ \dfrac{\mathrm{d}y}{\mathrm{d}\tau} = c(x + a - by). \end{cases} \tag{7}$$

Major results (Cont'd)

Mode selection on the photocurrent:

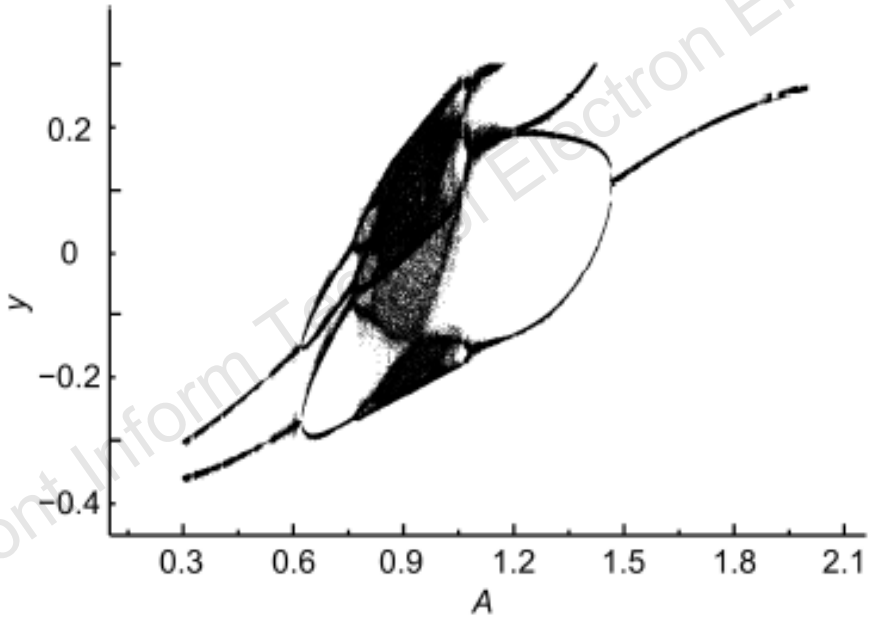

Fig. 3 Bifurcation diagram for a=0.7, b=0.8, c=0.1, ω=1.004, and ξ=0.175

A is the amplitude of the external stimulus

Conclusions

1. Phototube can be coupled to enhance the biophysical function of neural circuits.

2. Photocurrent can be generated to excite the neural circuit.

3. A class of light-dependent neural circuit is proposed and its dynamics is dependent on the external illumination.

4. This functional neural circuit has potential applications in designing artificial eyes.

Prof. Yong LIU, first author of this paper, is a professor of Yancheng Teachers University. He received his PhD degree from Jiangsu University, China, in 2008. His research interests include biological mathematics, neurodynamics, nonlinear dynamics, and pattern formation and control. He has published more than 20 regular articles in the field of nonlinear science.

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