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A GUI (Graphical User Interface) framework to Introduce H-H Model in Comparison with Kv3.3 Model

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Abstract

The technique of modeling a neuron is mandatory and complex. In this paper, we introduce a simulating window by using graphical user interface (GUI) and it also helps researches in learning Hodgkin-Huxley (H-H) complex mathematical equations. By using such type of simulator, users can build any panel for easy analysis and visualization of results. Therefore, here we discuss this type of panel for H-H model in comparison with Kv3.3 model that motivates to propose a new version of neuron modeling.

Keywords: Neuron; GUI; modeling.

Introduction

From 1939 to 1952, Hodgkin-Huxley (H-H) [1] formulated the existence of ionic current equations across a well developed neuronal circuit by using Kirchhoff's current law. In this paper, we also show the GUI panel for action potential of H-H formulation. This H-H model was the foundation for describing the neural activity with proper mathematics and further researchers mainly work with it. According to H-H model, inactivation of Na^+ ion is purely voltage dependent, and is state independent. But its concept is clearly violated by Kv3.3 model [2] and it verified that the phenomena of inactivation of Na^+ ion is state dependent rather than voltage dependency. Thus, we are approaching for developing our own model from which researchers can simulate and examine various fundamental concepts of neuron modeling by using GUI as other methods could not give the 100% accurate solution of H-H equations as shown in table1. Building small panel also motivates researchers with the opportunity to solve various types of complexities for synaptic

modeling. Therefore, it is an appropriate approach for parametric analogy of mathematical equations in one single panel of GUI.

Parametric analogy

In this paper, we take the values of different parameters of H-H and Kv3.3 models to be plotted in GUI from literature review shown at from table 2.

From Hodgkin and Huxley model, we are going to conclude the basic equation for current flow due to ionic activity in neurons as

Total ionic current,
Tic=Tnac+Tkc+Tlc.....eq:1

Where, T=total current
ic=ionic current
nac =current flow due to sodium ions
kc = current flow due to potassium ions
lc = leakage current flow due to chloride ions

According to previous mechanism, the current flow equation can be given by a balanced format as,

Capacity current + Ionic current =Total neuron membrane current

If, Total neuron membrane current=zero, in steady state condition, then

-Capacity current= Ionic current

Again,
Capacity current= $-c\,Dvt$ ……eq:2

Ionic current=
ina + *ikv3.3* + iklt + il + $i_{ext(t)}$…….....eq:3

If eq:2=eq:3, then

$-c\,Dvt$ = ina + *ikv3.3* + iklt + il + $i_{ext(t)}$……eq:4

Where,
c=capacitace across membrane
Dvt =derivative of voltage w.r.t. time
ina = current due to Na^+ channel
ikv3.3 and iklt = current of Kv3.3 and a Kv1.1-like "low threshold" component of voltage-dependent K^+ channel
il = leak current due to other ions
$i_{ext(t)}$ = step currents (1.0 nA, 0.25 ms) at 200-400Hz
t=time

Table 1: Different methods for solving H-H equations

Eular method	50%	only try to solve the action potential graph
Modified Eular method	60%	
Runga -Kutta	70%	
Predictor Method	80%	
MatlabODE45	90%	

Table 2 : Comparison of parameters of H-H and Kv3.3 model

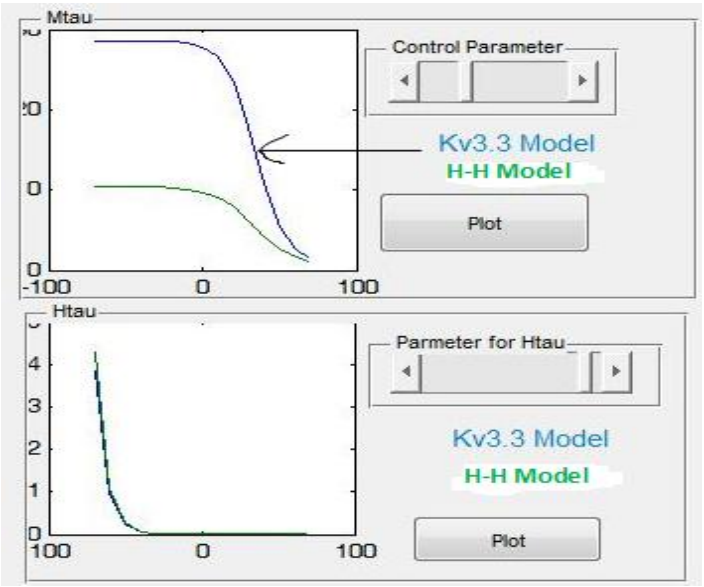
H-H Model	Kv3.3 Model
Minf =1/1+exp((v-35)/-7.3)	Minf =1/1+exp((v-17.81)/-6.95)
Mtau =0.678+27.913/(1+exp(v-22.414)/9.7)	M tau =0.51+9.9/(1+exp(v-17.6)/12.9)
Hinf= 0.25+0.75/(1+exp((v-(-28.294)/29.385))	Hinf= 0.23+0.97/(1+exp((v-(-27.06)/36.1))
Htau= 199.786+(2776.12*exp(-v/7.3))	Htau= 197.98+(3081.46*exp(-v/7.3))

Chronicle review of neuron model

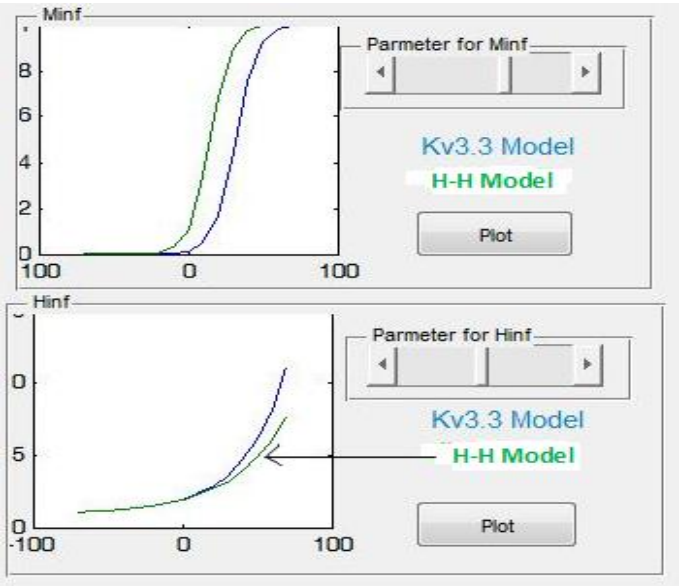
Year	Scientist Name	Work/Research/Model	Draw backs
1902	Bernstein, J. [3]	Resting potential of a nerve cell is due to concentration of potassium ions.	No existence of sodium ions.
1939	Curtis, H. J.& Cole, K. S.[4]	Impedance in the nerve cell is due to large drop in the resistance in parallel with membrane capacity.	This violated the basic structure of the membrane.
1952	Hodgkin, A.L. and Huxley,A.F. [1]	Evolution of an electrical circuit that describes the existence of both Na^+, K^+, Cl^- ions.	unable to give accurate representation of action potential.
1960	Fitzhugh, R. [5]	Involvement of another variable w instead of three variable m, n, h.	not possible to give any circuitry level for modeling of neuron.
1965	Lewis, E.R [6]	Locus model for various activities of synaptic, spontaneous, local potentials, spike initiation.	This model could not give the mathematical solution for neuron modeling.
1966	Harmon, L.D. & Lewis, E.R. [7]	Gave the measure like code that reproduces the details of squid axon membrane conductance.	This circuit was quite complex and expensive to build.
1980	Rinzel, J., & Miller, R.N. [8]	model describes the dynamics of H-H model with proper formulation of waveforms.	Output was not in proper spike format.
1981	Morris, C. & Lecar, H. [9]	Descried the two dimensional system of non-linear differential equations.	Most of the variables were not involved.
1997	Kistler, W.M., et al. [10]	Four differential equations of H-H model were reduced by spike generation method.	Limitations were due to threshold voltage calculation.
2000	Fukai, H., et al. [11]	Described an artificial neural network to identify and model the physiological behavior with proper threshold value.	This model was very much time consuming.
2002	Schaefer, M., et al. [12]	Gave the concept of digital simulation system.	That required improved modeling in which rising phase of action potential can be modified.
2006	Taylor. J and Langlois [13]	Developed general purpose circuit analysis program using PSPICE.	Main problem was that biological components were not easy to simulate.
2008	William, H., et al. [14]	Analysis of H-H equations in matlabODE45 for noise removal.	Biocompatible components were not to be accurately measured.
2010	Xu, J.,et al. [15]	Developed NEUROFET for neuron modeling.	This was not for synapse modeling device.
2012	Vavoulis, D.V.,et al. [16]	Estimated conductance-based neuron models traditionally.	analyzed result was noisy.

Results and Discussion

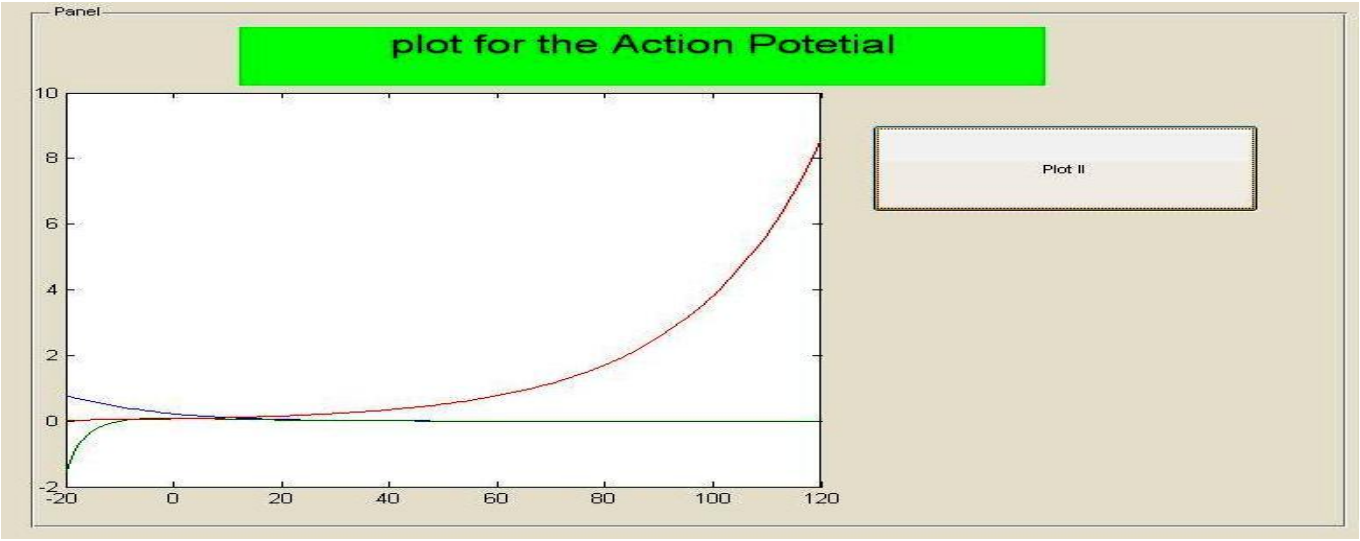
We can discuss from the above chronicle review done on modeling of neuron that all models were developed by using different types of software. Due to drawbacks of the different models, we are using GUI for proper verification of inactivation and activation rates of H-H and kv3.3 model. Various parameters required to build this model are formulated theoretically and reversal potential of an ion channel along with steady state activation and inactivation kinetics are did. Since the equations describing model parameters are often missing from the literature. The digitization process is used to recreate and validate those equations. Figure: 1 below illustrates digitization and plotting of parameters in graphical user interface (GUI) with accuracy and approach to simulate bio components in future.



(a)



(b)



(c)

Figure 1: (a) & (b) Graph of Mtau, Htau, Minf, , Hinf for kv3.3 & H-H model and (c) variation of action potential from H-H model

Here, we are mainly discussing the parameters for activation and inactivation rates of Na^+ (Mtau, Htau, Minf, , Hinf) for Kv3.3 & H-H models respectively [fig:1 (a) & (b)] and also variation of action potential graph is shown [fig:1 (c)]. Actually, the model fails to recreate the current traces observed during the experiment. This problem can be solved with proper approximation to the model parameters. Instead of these limitations, we can use this proposed model for biocompatible NEUROFET designing based on this knowledge and verified the state variable concept of the kv3.3 model.

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